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Annexure A: Global and Local STI Trends

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GLOBAL TRENDS

for South Africa

Compiled & edited by:

Dr. Ozcan Saritas

National Research University Higher School of Economics

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1. BIO-ECONOMY AND FOOD SECURITY

1.1 Enhancing biodiversity conservation and reducing ecosystem degradation

The management of global nitrogen and nutrient cycles is a foundation for a sustainable bioeconomy, offering opportunities for water, air, greenhouse gas, ecosystem and soil management, while helping with food and energy security. Improving the efficiency of nitrogen and other nutrient use enables to produce more food and energy with less pollution and less resource consumption. Better management of new nutrient sources such as fertilizers, combined with improved collection and reuse of nutrients would save on fertilizer costs, while reducing the environmental impacts and health concerns.[1]

About 2% of global energy use goes to turning atmospheric nitrogen (N2) into reactive nitrogen (Nr) compounds for fertilizers.[2] Losses of N affect all environmental compartments from the stratosphere, through particulate matter in the air we breathe, to terrestrial, freshwater and coastal ecosystems. Nitrous oxide (N2O) - mainly from agriculture is a very powerful greenhouse gas and, now, the main cause of stratospheric ozone depletion, while nitrogen oxides (NOx) are the major cause of tropospheric ozone pollution (threatening health and agricultural productivity). Nitrates (NO3) threaten drinking water quality, and pose risks to human health and biodiversity through harmful algal blooms. Disturbances of the N cycle represent key systemic challenges for modern society. Terrestrial Nr input is now more than double natural levels, while only 20% finds its way to useful products, with 80% being waste contributing to pollution problems.[3]

In addition to nitrogen, there are key challenges for phosphorus (P), potassium (K) and micronutrient management, as these mined resources are non-replaceable. Key challenges for these nutrients include managing available reserves in more sustainable ways, especially given the dominance of global supply from a limited number of countries,[4] and finding ways to motivate better management practices that foster a better circular economy in these nutrients.

There are many ways to improve the nutrient use efficiency for crops (both food and feed crops), and these can be complemented by improved feed conversion efficiency in animals. However, improving economy-wide nutrient use efficiency requires better management of food supply chains, maximizing recycling of manure and wastewater nutrient resources, as well as learning to recycle the huge amount of N_r produced globally (40M tons annually) in the form of NO_x emissions. Optimizing consumption patterns, both regarding food choices and energy consumption will also improve economy-wide nutrient use efficiency. The UN Global Environment Facility and UNEP are preparing the basis for an eventual 'International Nitrogen Management System'.[5]

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[1] Vercruysse, N., Stahel, W.R., Saritas, O. et al. (2015). The Junction of Health, Environment and the Bioeconomy: Foresight and Implications for European Research and Innovation Policies, A report prepared for Directorate-General for Research and Innovation, European Commission, Brussels.

[2] Fowler D., Coyle M., Skiba U. and 15 others (2013). The global nitrogen cycle of the twenty-first century. *Philosophical Transactions of the Royal Society, B.* 368: 2130164. http ://dx.doi.org/10.1098/rstb.2013.0164

[3] M.A. Sutton et al. (eds.) (2011). The European Nitrogen Assessment. Cambridge University Press. http://www.nine-esf.org/ENA-Book

[4] U.S. Geological Survey (2012). Mineral Commodity Summaries 2012, Phosphate Rock, pp 118-119. See also Appendix B, pp 192-195 For definitions of reserve, resource and related terms. See http://minerals.usgs.gov/minerals/pubs/commodity/phosphate_rock/

[5] http://www.inms.international/

By 2030, wider development and implementation of digestion technologies could allow wastewater to be a valuable nutrient resource, while supplying significant amounts of bio-energy. This new thinking could change wastewater treatment plants of the future from generating costs only to becoming profitable facilities.[6] A pilot plant in Zurich has successfully implemented a process to develop a reusable nitrogen fertilizer, a clear liquid.[7] A similar development to recycle P from waste-water was launched as EU research initiative.[8] Wastewater is first concentrated and then treated to create gases that will go to generate electricity and heat. Remnants of the process can then serve as fertilizers.[9]

The principle of recycling N_r rather than "denitrifying" it back to N_2 is also seen in the future potential to develop Nitrogen oxides Capture and Utilization technology (NCU) which offers great opportunities to convert NO_x into fertilizers. Green Economy thinking could stimulate major benefits for health, environment and the bioeconomy**.**

1.2 Building and maintaining resilient ecosystems and communities

The rising force of systemic challenges has raised the importance of resilience as a quality of communities and ecosystems. It is understood that our growing population and our increasingly interconnected complex socio-ecological systems imply greater risks of sudden unforeseen high impact events. Humanity's future will depend on our capacity to maintain and (re-) build resilient ecosystems and communities.

The collective cost of climate change disasters is estimated at US $200 billion every year. Investing in resilience can help to avoid the devastating financial costs of natural disasters, while making day-to-day life better for everyone. It costs 50 percent more to rebuild in the wake of a disaster than to build in a way that can withstand the shock. Building resilience delivers near-term economic benefits and jobs, while making everyone better prepared when a shock hits.[10]

Development of new production systems and intelligent decentralization concepts offer opportunities for increasing resilience. Intelligent decentralization refers to a coordinated system of local endeavors of high diversity and high performance in terms of generating innovative technologies and innovative business models. It is expected that intelligent decentralization will become a significant contributor to local and, eventually, national economies in Europe by 2030. The following signals of technological developments support this expectation:

- In urban farming, innovative technologies make local small-scale production economically viable, open new business opportunities and can contribute to mitigating climate change
- Local treatment of various wastes to avoid transport cost (e.g. urban waste and by products of agriculture)
- Introduction of nanostructured micro reactors in the field of high-purity chemicals. Intelligent parallel working micro-reactors producing chemicals of high purity could take the place of large centralized reactors in the chemical industry. Fine chemicals will no longer need to be produced

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[6] Magid, J. Eilersen, A. M. , Wrisberg , S. and Henze , M. (2006). Possibilities and barriers for recirculation of nutrients and organic matter from urban to rural areas: a technical theoretical framework applied to the medium-sized town Hillerod, Denmark. Ecological Engineering, 28, 44-54.

[7] http://www.bafu.admin.ch/dokumentation/umwelt/13233/13244/index.html?lang=de

[8] http://p-rex.eu/

[9] http://www.vdi-nachrichten.com/Technik-Wirtschaft/Wertschoepfung-Abwasser-gefordert

[10] The Rockefeller Foundation - Building Resilience to the Shocks and Stresses of Climate Change. http://www.rockefellerfoundation.org/our-work/current-work/resilience

at few sites in the world and then shipped to the user but can be produced in the quantities that are needed and where they are needed

- Increasing local production can reduce logistics and commuting distances, which may decrease car use and allow increased commuting by foot and bicycle. Local production therefore reduces unhealthy air pollution emissions and exposures, while increasing physical activity, with both factors contributing to improved health
- Additive manufacturing is widely used today in many areas. These printers sell for less than US$ 3,000, with many available in kit form or preassembled. This technology could be useful to develop local activity, for example locally repairing devices to extend their life. However it must evolve in such a way it does not become another source of plastic wastes. Ethical and liabilities issues should also be addressed (e.g. 3D-printing of harmful substances or guns)
- Innovative business models in finance, such as micro-credit and micro-insurance, have rapidly spread especially in South-East Asia and South America
- Crowd mapping was developed in the U.S. by students, who founded Ushahidi[11], a global organization that empowers people to make a serious impact with open source technologies and cross-sector partnerships. It was first used after the Haiti earthquake in 2010
- Crowd sourcing is used to finance local projects of cultural and commercial nature with a large number of small contributions from global investors
- Precision agriculture can use global positioning systems (GPS) combining it with information from the satellites to provide sustainable agriculture according to local conditions, maximizing yields with minimal chemical input
- Photovoltaic solar and micro-hydro-energy production have opened opportunities for local and municipal small-scale energy networks. “Plus-energy” buildings, producing more energy than it consumes, have gained increasing attention with policymakers for their contribution in developing resilient municipalities (e.g. increased public security and safety during blackouts with no people blocked in elevators and lesser insecurity in the streets)
- In the circular, bio- and blue economy, waste-to-resource innovations, also known as industrial symbiosis, have been developed to increase resource efficiency, lower carbon emissions and increase business competitiveness. Using waste from one company as a resource for another company, or developing local reuse and remarketing networks for second-hand goods, is usually a collaborative process involving social network development

In the circular economy of manufactured capital, regionalization will grow through the reindustrialization of regions linked to an economic reorientation towards the management of existing physical assets. From a systems perspective, activities such as reuse, repair and remanufacturing[12] are best done locally, where the clients and the goods are located, reducing the need for transport and big factories. The same is true for business models of the performance economy, such as renting and sharing goods rather than selling them, such as car sharing. These examples could indicate that the trend of ‘selling performance’ already common among paint manufacturers and other sectors of the manufacturing industry, is spreading to consumer goods, creating local jobs and greatly reducing packaging and (emissions from) transport. In cities, this trend could contribute to the revitalization of non-polluting economic activities.

[11] http://www.ushahidi.com/product/crowdmap/

[12] See for example http://www.product-life.org/en/archive/case-studies/caterpillar-remanufactured-products-group

1.3 From grey tech to green tech

This trend represents a transition from established technologies to newer technologies with higher benefits for health, environment and bio-economy. Among important research directions are:

- Development of bio-based and health-risk-free materials and processed to reduce resource consumption and environmental impact
- Development of tools for better environmental monitoring systems like identification of chemicals and pathogens
- Better health management systems for the investigation of toxicity mechanism, detection of pathogens, and development of treatments
- Better risk assessment systems
- Re-manufacturing systems to preserve existing values for higher resource security and more efficient use of environmental resources
- Recycling end-of-life goods and waste at the end of life of manufactured stock to recover resources in an economically viable way. Up to now, waste management has developed in two directions: energy recovery and the management of dangerous waste. Materials recovery and "closing the loop to the materials market" face a number of obstacles, physical, technological and regulatory
- The circular bioeconomy is a subset of circular economy, which creates value by better exploiting the natural capital (microorganisms, animals and plants). The largest and oldest sectors are agriculture for food production, forestry and fisheries. More recently biotechnologies, agriculture producing methane, hydrogen and bio-plastics have been added to the mix.

Regulations for these new technologies will play an important role. Approaches to facilitate the move towards green technologies can be strong drivers of local job creation, reinforcing social links, reducing the need for transport and reducing waste.

1.4 Food sustainability: Local and global food security

It is estimated that 60% more food will be required to feed 9 billion people on Earth by 2050.[13] Furthermore, changing diets, driven by a growing middle class, will lead to additional demand for more resource-intensive types of food, such as meat. Presently most countries are largely self-supporting with respect to food, but there are major challenges, where war, poor governance and extreme events lead to major humanitarian crises, especially in some African countries. In developing countries population growth is still the most important factor driving the need for food. Yet in many countries demand for food is driven more by affluence than by population growth. Increasing calorific intake and livestock consumption linked to an expanding global middle class is emerging as a future source of increasing demand.[14]

Food and nutritional insecurity will persist in many, predominantly poor, regions.[15] An increasing number of regions will face water scarcity, and the competition for scarce water resources could lead to

[13] OECD (2013), Global Food Security: Challenges for the Food and Agricultural System, OECD Publishing, Paris.

[14] http://ufm.dk/en/publications/2016/files/an-oecd-horizon-scan-of-megatrends-and-technology-trends-in-the-context-of-future-research-policy.pdf

[15] FAO (Food and Agriculture Organization of the United Nations) and WWC (World Water Council) (2015), Towards a Water and Food Secure Future: Critical Perspectives for Policy-makers, FAO/WWC, Rome/Marseille.

internal and international conflict.[16] Soil degradation will affect the amount of land available for productive agriculture: around half of the world's agricultural land is already affected by moderate to severe degradation and around 12 million hectares of productive land become barren annually due to desertification and drought. If no significant improvements are achieved in production practices, the loss of yield may be as high as 50% in some African countries by 2050.[17] The situation in most OECD and BRIICS countries is less severe, as continuing yield improvements will lead to more efficient use of land. Instead of agricultural land expansion, land abandonment is planned in many countries, which will allow ecosystems to partially recover and regenerate.[18]

Food production and consumption have a major impact on both health and environment, including regional planning and land use. If food is need to be made more sustainable, food production (farming systems) and consumption (change in food choices) as well as processing and waste issues need to be addressed. The need for environmental sustainability and food security both globally and locally combined with the patterns of global population growth generates particular sets of future challenges and opportunities the world.

At present, most agricultural resources (land, water and nutrients) go to feed animals rather than humans and the current challenge is as much for 'feed security' as it is 'food security'. The production of meat and dairy, require large inputs of resources like energy, land, nutrients and water, and result in emissions both from animals (greenhouse gases) and manures (nitrogen, phosphorus). Some 80% of global agricultural plant harvest (expressed as nitrogen) goes to feed livestock.[19] Although smaller in their absolute impact, there are also significant environmental effects of vegetables, vegetable oils, coffee, tea and alcoholic beverages.

Rapidly increasing meat and dairy consumption in developing countries is increasing environmental degradation, especially as markets and citizens shift towards western diets. Even small changes in diets can affect resource use and have important environmental and/or health impacts. Different kinds of alternatives to meat emerge in supermarkets (crockets, quorn, tahoe, etc.) or are currently under research. One example of laboratory grown meat is the so-called 'stem cell burger'.[20] The impact of such artificial foods on health and the environment remains to be ascertained.

A major driver for change is the health risks from inappropriate diets, resulting, for example, from excess meat and dairy consumption.[21] Dietary risks represent the largest factor, especially for cardio and circulatory diseases as well as by cancer. Reducing meat and dairy consumption offers the double benefit of improved health and improved environment.

A rapidly developing narrative concerns the opportunity to optimize human diets, to provide appetizing and nutritious food that not only meets calorific needs, but minimizes the health and environmental

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[16] WWAP (United Nations World Water Assessment Programme) (2015), The United Nations World Water Development Report 2015: Water for a Sustainable World, UNESCO, Paris.

[17] UNCCD (United Nations Convention to Combat Desertification) (2014), Desertification: The Invisible Frontline, UNCCD, Bonn.

[18] OECD (2012), Environmental Outlook to 2050: The Consequences of Inaction, OECD Publishing, Paris, http://dx.doi.org/10.1787/9789264122246-en.

[19] Our Nutrient World' (2013): http://www.gpa.unep.org/index.php/global-partnership-on-nutrient-management/publications-and-resources/global-partnership-on-nutrient-management-gpnm/21-nutrient-management-key-messages-for-rio20-summit/file

[20] http://www.bbc.co.uk/news/science-environment-23576143

[21] http://www.forbes.com/sites/alicegwalton/2014/03/04/the-protein-puzzle-meat-and-dairy-may-significantly-increase-cancer-risk/

risks associated with overconsumption, waste and farming practices. There are emerging signals of reducing meat and dairy consumption in developed countries, including rapidly developing narratives on vegan, vegetarian and demitarian (halving meat intake) lifestyles, including the possible health benefits. Changing diets affect the opportunity space for urban farming, with its own opportunities and risks. Reducing excess intake of resource-intensive food types (such as meat and dairy products) also reduces the need to use arable land for the production of livestock feeds. This can potentially free up land for carbon sequestration, supporting climate change mitigation, bio-based products replacing fossil inputs, as well as helping to meet bioenergy goals. Similar challenges apply in fisheries and aquaculture, with rates of fish consumption increasing substantially. Meanwhile, land limitations push for improved methods to conduct agriculture in salt rich environments.

Agriculture and food face global challenges linked to sustainable rural economies, global warming, plant and animal diseases, deforestation, erosion, soil depletion, eutrophication, diversity loss and desertification. Other factors threatening the sustainability of the food system are rising global demand for food, feed and biomass for bio-based products and energy, rapid urbanization, dramatic decreases in rural habitation, and decreasing land available for food production, all pushing system resilience to its limits. There is a growing recognition of the need to optimize food production and consumption in relation to environmental challenges. Direct impacts of agriculture pose environmental threats affecting from water, air and soil quality, to climate, stratospheric ozone and biodiversity. These are caused by a wide range of material flows and their potential environmental load, such as greenhouse gases, nitrogen and phosphorus pollution, as well as heavy metal and pesticide residues.

Around 10% of world’s food production is exported. This figure might increase in the coming decades due to large differences in terms of food supply and demand in various countries. Countries like China and India have not enough agricultural land of sufficient quality to satisfy their increasing demands for both feed and food. This will affect global food transport and might turn some regions into new feed and food exporters. Transportation of food forms additional energy cost and additional environmental impacts from energy supply and use.

1.5 New possibilities for agriculture: urban, saltwater/saline, and fishery

Urban farming is re-emerging as a means of providing local fresh food for own consumption or for sale, including both intensive production facilities and micro-production activities, including as a rewarding past-time with potential health and environmental benefits. One of the main factors contributing to the spread of urban farming is new technologies, such as LED lighting for photosynthetically active radiation (PAR) that lowers the cost of energy and makes new farming techniques efficient at small scale.[22] Vertical (multi-story) farming enables the use of urban space to grow food, especially in specialized niches, where high quality products could be offered at lower costs. Irrigation, fertilizers (e.g. from organic waste) and heating can be obtained from housing nearby, to contribute to the financial viability of urban farming ventures.

With limited amounts of land in urban areas, compared to the huge areas of agricultural land worldwide, it is questionable whether urban farming (especially of plant based foods) could ever be more than a specialty activity. But the benefits of engaging in self-produced food in your “window box” might come just as much from their contribution to personal well-being as their calorific and nutrient value. At larger scale, greening of cities is known to improve citizens’ welfare and supports climate

[22] http://ec.europa.eu/environment/ecoap/about-eco-innovation/policies-matters/eu/243_en.htm

change mitigation. In China, there is currently a rapid increase in sub-urban dairy farming, as livestock feeds are brought into farms with limited land area, to provide fresh milk near to consumers. One can imagine the trend spreading, propelled by the increase in urban consumption of livestock products.

So far little thought has been given to managing the manures from urban farms, while the ammonia emissions to the air from these farms are now recognized as contributing significantly to particulate matter in cities, thereby contributing to the human health risks of air pollution.[23] Similar risks can be expected in relation to water pollution and disease transfer, especially for people in close contact with the animals. Actions to mitigate risks to air and water quality, and biosecurity threats are likely to be a rising concern accompanying the spread of urban farming.

In the coming decades, the land suitable for agriculture is likely to become more limited as rising demand for agricultural products combines with encroaching urbanization and sea level rise. Some of the agricultural soils near the coasts suffer from influx of salt water; this makes them unsuitable so far for most prevailing agricultural crops. Soil salinity also results from irrigation in areas with high evaporation rates. Studies on halophytes (plants that can grow in highly saline water or above saline aquifers) are showing new potential opportunities for agriculture in the sea, coastal areas, salt marshes and deserts with subterranean saline aquifers.[24] Amongst the diverse range of over 10000 halophytes there are plants able to produce food, animal feed and biomass for industrial use and energy.[25] Some halophytes may even be employed to extract salt from the soil and thus restore it for cultivation with less salt tolerant plants. Research is being done on domesticating wild halophytes, on plant selection and breeding as well as on genetic modification. The production of biomass for industrial use and energy from halophytes has so far not been economically feasible, but there are promising signs[26] and enormous potential economic and environmental gains pursued by halophyte pilot projects in Asia, North America, Australia and in the Arab states.

Besides the supply of agricultural products, fish plays an important role in the diets all over the world, and aquaculture has become more significant in fish production than the natural stocks.[27] Various fish farming systems exist. Ocean based, fresh water based to even indoor and recirculation systems, relieve some of the pressure on endangered natural fish populations. However, there are interactions between fish farming and natural stocks as, for example, wild catches are used as feed for some types of fish farming like salmon and shrimp. Fish farming presents opportunities for nutrient recycling, including use of herbivorous fish for remediation of excess algae resulting from eutrophication.

As fish farming increases rapidly in some parts of the world, such as South and East Asia, it needs to be better incorporated into global environmental assessments. Poorly designed systems may exacerbate nutrient pollution and give rise to problems associated with the release of antibiotics and other chemicals in the environment with an increased possibility for human uptake of for example mercury and other chemicals. Direct emissions from fish farming still appear to remain small compared with livestock and arable farming practices, providing an impetus for further growth of the industry through systems that contribute effectively to environmental objectives.

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[23] Gu, Baojing et al. (2014) Agricultural ammonia emissions contribute to China's urban air pollution. *Frontiers in Ecology and Environment* 265-266 doi: http://dx.doi.org/10.1890/14.WB.007 and http://www.esajournals.org/doi/abs/10.1890/14.WB.007

[24] http://www.i-sis.org.uk/SalineAgriculture.php

[25] www.plnatpower.eu

[26] http://cleantechnica.com/2014/01/27/boeing-biofuel-breakthrough-big-deal/

[27] http://www.fao.org/docrep/016/i2727e/i2727e01.pdf

2. CLIMATE CHANGE AND ENERGY

2.1 Ongoing climate change and its adverse effects on human and energy security

Global land and ocean surface temperature data show an averaged combined warming of 0.85°C over the period 1880 to 2012. The greatest warming over the past century has occurred at high latitudes, with a large portion of the Arctic having experienced warming of more than 2°C. The last 30 years were likely the warmest of the last 1,400 years in the northern hemisphere. Anthropogenic greenhouse gas (GHG) emissions are extremely likely to have been the dominant cause of the observed warming since the mid-20th century. Atmospheric concentrations of carbon dioxide (CO_2), methane and nitrous oxide are unprecedented in at least the last 800 000 years.[28] CO_2 emissions account for around 75% of global GHG emissions, with most coming from energy production – fossil fuel combustion represents two-thirds of global CO_2 emissions.[29] Around half of the anthropogenic CO_2 emissions since 1,750 have occurred in the last 40 years. Agriculture is a major emitter of the more powerful greenhouse gases of methane and nitrous oxide.

There is a strong, consistent, almost linear relationship between cumulative CO_2 emissions and projected global temperature change during the 21st century. Further warming over the next few decades is now inevitable, based on recent rises in atmospheric CO_2 levels, and the global mean surface temperature change for the period 2016-35 relative to 1986-2005 will likely be in the range 0.3°C to 0.7°C. Heat waves will likely occur more often and last longer, while extreme precipitation events will become more intense and frequent in many regions. Rainfall will most likely increase in the tropics and higher latitudes, but decrease in drier areas.

The oceans will continue to warm and acidify, strongly affecting marine ecosystems. The global mean sea level will continue to rise at an even higher rate than during the last four decades. The Arctic region will continue to warm more rapidly than the global mean, leading to further glacier melt and permafrost thawing. However, while the Atlantic Meridional Overturning Circulation will most likely weaken over the 21st century, an abrupt transition or collapse is not expected.

Reducing and managing the risks of climate change will require a mixed strategy of mitigation and adaptation. The extent of mitigation efforts will determine levels of future GHG emissions: without additional efforts beyond those already in place today, warming by the end of the 21st century will lead to a high risk of severe, widespread and irreversible impacts globally, even with adaptation. The IEA's New Policies Scenario is consistent with a long-term temperature rise of 4°C.

In many respects, this is already an ambitious scenario that requires significant changes in policy and technologies, but will still lead to dangerous levels of climate change. A more stringent mitigation scenario that leads to CO2-equivalent concentrations of about 450 parts per million in 2100 would meet the 2°C targets agreed at the recent Paris climate conference. This 2°C Scenario (2DS) is characterized by 40-70% reductions in global GHG emissions by 2050 compared with 2010. It will mean increasing the share of low-carbon electricity supply from the current share of approximately 30% to more than 80% by 2050.

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[28] Data from the following reference throughout the section unless otherwise indicated: IPCC (Intergovernmental Panel on Climate Change) (2014), Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, IPCC, Geneva.

[29] OECD (2012), Environmental Outlook to 2050: The Consequences of Inaction, OECD Publishing, Paris, http://dx.doi.org/10.1787/9789264122246-en.

Developing and poorest countries in the world are expected to be much more influenced by climate change, largely due to the lack of financial resources to mitigate the adverse effects.[30] There are greater risks for agriculture and food security as well as increasing pressures for health and social care systems, which may result in hunger and diseases.[31] In the period from 2030 to 2050, climate change may cause 250,000 additional deaths per year, mainly due to malnutrition, malaria and heat stroke.[32] Furthermore, the rises in the sea level and storm surges over the next years to come will have significant impacts on coastal cities, especially in Asia's most densely populated cities.

2.2 Increasing demand for primary energy driven by population and economic growth

Global demand for resources has grown significantly since the beginning of the 20th century, which was a combined result of structural economic change as well as the transition from agricultural to industrial economies. The population of the world has increased fourfold, whereas the production volume went far beyond with 25-fold.[33] Technological advances that led to the economic industrialization provided significantly greater variability in the use of natural resources, particularly to generate energy to run the whole system. Global primary energy demand is set to increase further by 37% between 2012 and 2040. Most of this demand will be due to economic growth in developing countries, which will account for around 60% of global energy consumption. Meanwhile, growth in global demand is expected to slow down from 2% per year in the last two decades to 1% per year after 2025. This is a result of price and policy effects, as well as structural shifts in the global economy towards services and lighter industrial sectors.[34]

Industry will remain the largest consumer of energy in 2040, by which time its energy demand is expected to have risen by about 40%. Manufacturing in the OECD has gradually shifted away from coal and oil over recent decades, a trend that is projected to continue: while in 1990, coal and oil accounted for nearly half of heavy industry's fuel, they are expected to decline to just 15% of the fuel mix by 2040. China's fuel mix will also "lighten-up" by this time. This will lead to a fall in the average amount of industrial energy demand per unit of economic output worldwide. Future energy demand growth varies by industry sub-sector, however, with the chemical sector seeing the largest growth as the demand for plastics and other chemicals increases.[35]

Transportation will be the second largest consumer of energy in 2040. While car numbers are projected to expand with a growing global middle class, fuel efficiency improvements mean energy demand from cars will rise only slightly. Hybrid vehicles could account for nearly 50% of new-car sales by 2040, compared with just 1% in 2010.[36] This effect will be especially noticeable in Europe, where liquid fuels

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[30] Roland Berger (2014) Trend Compendium 2030 //. — 2014. URL: http://www.rolandberger.com/expertise/trend_compendium_2030/Climate_change_and_ecosystem_at_risk.html

[31] World Bank (2014) Climate Change and Poverty: An Analytical Framework. Policy Research Working Paper;No. 7126. World Bank Group, Washington, DC. URL: https://openknowledge.worldbank.org/handle/10986/20639

[32] http://www.who.int/mediacentre/factsheets/fs266/en/

[33] EEA (2016) Global megatrends// European Environment Agency. — 2016. URL: http://www.eea.europa.eu/soer-2015/global/competition http://www.eea.europa.eu/soer-2015/global/competition

[34] Barreneche, A., Keenan, M., Saritas, O. et al. (2016). An OECD Horizon Scan of Megatrends and Technology Trends in the Context of Future Research Policy, A report prepared by the OECD Directorate for Science, Technology and Innovation, commissioned by Danish Agency for Science, Technology and Innovation (DASTI), Copenhagen (Available at: http://ufm.dk/en/publications/2016/files/an-oecd-horizon-scan-of-megatrends-and-technology-trends-in-the-context-of-future-research-policy.pdf)

[35] [35] ExxonMobil (2015), The Outlook for Energy: A View to 2040, Exxon Mobil Corporation, Irving, Texas.

consumption is expected to decline.[37] Commercial transport – including airplanes, shipping, trains and trucks – will account for virtually all of the growth in energy demand from transportation. Most of this demand growth will be met by oil.

The third largest consumer of energy in 2040 will be commercial and residential buildings. Worldwide, households will increasingly shift towards cleaner fuels and will rely more on electricity than primary fuels as domestic appliances and electronics become more widely available. Nearly 1 billion people will newly gain access to electricity by 2040, but more than half a billion will remain without it.[38]

2.3 New technologies and opportunities for energy and environment

A portfolio of low-carbon technologies across all energy sectors will provide great potentials to ensure keeping climate goals achievable while also stimulating the initial development of more complex solutions needed for long-term decarbonization. Some solutions will be broadly applicable, while others will target specific sectors. In the power sector, while onshore wind and solar PV are ready to be mainstreamed in many energy systems, very high levels of deployment will require further innovation in enabling technologies – for example, in energy storage and smart grid infrastructure – to manage their variability and increase the flexibility of power systems.[39] Carbon capture and storage (CCS) technologies are projected to play an important role, though require considerable further technical and market development before they can be extensively implemented. In other energy sectors – including industry, transport and buildings – energy efficiency technologies are expected to play a leading role in achieving the 2DS.

In order to have a better grasp of the energy field can be considered in three sub-domains distinct characteristics, challenges as well as unique research and technology development processes, including:

1. energy generation
2. energy storage, and
3. energy transfer[40]

Energy generation is concerned with the conversion of conventional and renewable energy sources into various forms of energy to be used by vehicles, machinery and other equipment. The next challenge is to store the energy generated to be consumed whenever needed, which may be remote from the sites, where energy is generated. Furthermore, energy storage is particularly crucial for the use of renewables, such as wind, wave and solar, which may not be stable and constant sources of energy. The inherent intermittency of supply of energy generated from renewable sources requires a step-change in energy storage.[41] Finally, energy generated and stored should be transferred for final use. Wide variety of energy transfer technologies are available ranging from pipelines, ships, trains, and trucks for fossil fuels, and power grids as well as more advanced wireless energy transfer technologies, which can supply energy to a particular location, at a particular amount and for a particular duration depending on the demand.

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[37] http://www.eia.gov/outlooks/aeo/pdf/0383(2014).pdf

[38] IEA (2014), World Energy Outlook 2014, OECD/IEA, Paris, http://dx.doi.org/10.1787/weo-2014-en

[39] IEA (2015), Energy Technology Perspectives 2015, OECD Publishing, Paris, http://dx. doi.org/10.1787/energy_tech-2015-en.

[40] Saritas, O. and Burmaoglu, S. (2016). Future of sustainable military operations under emerging energy and security considerations, Technological Forecasting & Social Change, 102, 331-343.

[41] Hall, P.J., and Bain, E.J. (2008). Energy-storage technologies and electricity generation. Energy Policy, 36, 4352-4355.

Generation

Energy generation technologies are researched widely. Besides the conventional energy sources, an increasing focus is observed on renewable sources with less or no negative environmental impact. Among alternative technologies for energy generation are: Wind, Solar, Hydro, Geothermal, Biomass, Nuclear, Coal, Oil, and Gas. Among these the share of renewables is continuously increasing. Comparing different alternatives of renewables, wind can be considered as the highest ranking among other energy generation technologies according to financial, technical, environmental and socio-economic-political criteria.[42] On the global scale, the estimated wind potential is 40.000 TWh/year[43] and wind capacity has been growing at 20-30% per year for decades. In addition, wind technology is widespread because of the ease of setting up power plants for energy production.[44]

Besides wind, solar power is the second highly ranking source of energy. Within solar energy generation, photovoltaic systems appear to be important sources for using abundant energy available from the sun. It is known that Earth intercepts over 170.000 TWh/year from the sun with irradiation varying greatly according to location and season. Among all, Biomass appears to be a widely studied subject. It refers to any plant-derived organic matter available on a renewable basis, including dedicated energy crops, trees, feed crops, agricultural crop wastes and residues, aquatic plants, animal waste, and municipal waste. By harnessing energy without emitting carbon dioxide, the renewable technologies reduce the environmental impact to a minimum level.

One of the key challenges for the widespread use renewable technologies is that they pose storage problems. For instance, despite of the very high potentials of use, photovoltaics are currently limited by storage complications during nights and cloudy days when the sun cannot power the solar cells.[42] Therefore, storage has become an important challenge to address.

Storage

With an increasing share of renewable energy contributions to electrical grids, it is indispensable to invest in storage technologies that allow the adjustment of energy supply to energy demand. Energy storage technology can be defined as a system that absorbs energy and stores it for a period of time before releasing it to supply energy or power services. Breakthroughs are needed in energy storage technology to optimize the performance of energy systems and facilitate the integration of renewable energy resources. Those technologies are implemented on small and large scales in either centralized or decentralized ways throughout the energy system. Wide variety of technologies is available for energy storage with their pros and cons. Six categories for energy technologies can be identified: (1) flywheel technologies, (2) battery storage technologies, (3) supercapacitor storage technologies, (4) hydrogen storage technologies, (5) pneumatic storage technologies, and (6) pumped storage technologies.[45]

Pumped hydro storage (PSH) and Compressed Air Energy Storage (CAES[46]) are used in large energy storage projects, Flywheels (FW) and Electrochemical Double Layer Capacitors (EDLC) are used in small

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[42] Stein, E.W. (2013). A comprehensive multi-criteria model to rank electric energy production technologies. Renewable and Sustainable Energy Reviews, 22, 640-654.
[43] Evans, A., Strezov, V., and Evans, T.J. (2009). Assessment of sustainability for renewable energy technologies. Renewable and Sustainability Energy Reviews, 13, 1082-1088.
[44] Delinea, L.L., and Diesendorf, M. (2013). Is wartime mobilization a suitable policy model for rapid national climate mitigation? Energy Policy, 58, 371-380.
[45] Hadjipaschalis I., Poullikkas, A., and Efthimiou, V. (2009). Overview of current and future energy storage technologies for electric power applications. Renewable and Sustainable Energy Reviews, 13, 1513-1522.
[46] These are called also as pneumatic storage technologies.

energy storage projects, and batteries are used in medium energy storage projects with extensions into the small and large categories. Sodium-sulphur (NaS) and vanadium redox battery (VRB) applications are recommended for battery energy storage technologies to meet specific grid services for a long duration. This finding can be interpreted as an important result for future grid services that are supported by the battery systems. Grid level energy storage systems are considered to be a cornerstone for future power networks and smart grid development.

Transfer

In order to increase efficiency and reduce losses, energy distribution networks must exploit new materials and advanced logistics systems. A more recent option for energy transfer is a wireless energy technology, which appears to be a potentially convenient and increasingly secure delivery option. Although mentioned more frequently recently, the wireless transfer technology can be traced back to Heinrich Hertz[47] and Nikola Tesla (1914) in history. Tesla claimed that electricity can be transferred wirelessly at 95% efficiency. In 2007, long after Tesla`s experiments, Soljajic had a breakthrough in the principle of wireless energy transfer and carried out a middle distance wireless transfer by resonance coupling of electromagnetism, where the level of efficiency was about 40%.[48] By using electrodynamics induction Soljajic successfully powered a 60W bulb wirelessly from a distance of 2 meters. Called by Soljajic as Witricity, this scheme is non-radiative and anti-jamming. The far-field energy transmission issue requires a different concept than Witricity.[49] For instance, energy can be transmitted from energy source to equipment by broadcasting the energy through rectennas. Among the cons of this technology are its health impacts. There are national restrictions regarding this issue.[48]

2.4 New energy mix

In the IEA's New Policies Scenario, demand for fossil fuels will grow by 2040, though their share in the global energy mix is set to decline. This is mainly because of greater use of renewables in the production of electricity. Worldwide, the largest share of growth in renewables-based generation will be from wind power (34%), followed by hydropower (30%) and solar technologies (18%).[50] At the same time, biofuels may provide up to 27% of the world's transportation fuel by 2050, up from the current level of 2%[51], though with uncertain consequences for food security. Nuclear power capacity is set to rise by almost 60% over the same period, but its share in global electricity generation will increase by just one percentage point to 12%. China will account for almost half the expected growth, with India, Korea and Russia collectively making-up a further 30%. Almost 200 operational reactors (out of 434 operating in 2013) will have been decommissioned by 2040, mostly in Europe, the United States, Russia and Japan. The cost of decommissioning is estimated at more than USD 100 billion.[52]

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[47] McSpadden, J.O., Little, F.E., Duke, M.B., and Ignatiev, A. (1996). An in-space wireless energy transmission experiment. IEEE, 468-473.

[48] Kurs, A., Karalis, A., Moffatt, R., Joannopoulos, J.D., Fisher, P., and Soljajic, M. (2007). Wireless power transfer via strongly coupled magnetic resonances. Science, 317, 5834, 83-86.

[49] Visser, H.J., and Vullers, R.J.M. (2013). RF Energy harvesting and transport for wireless sensor network applications: Principles and requirements. Proceedings of the IEEE, 101, 6, 1410-1423

[50] IEA (2015), Energy Technology Perspectives 2015, OECD Publishing, Paris, http://dx.doi.org/10.1787/energy_tech-2015-en.

[51] IEA (2011), Biofuels for Transport, IEA Technology Roadmaps, OECD/IEA, Paris, http://dx.doi.org/10.1787/9789264118461-en

[52] IEA (2015), World Energy Outlook 2015, OECD/IEA, Paris, http://dx.doi.org/10.1787/weo-2015-en

The growth in renewables-based generation will mean oil, gas, coal and low-carbon sources will make up almost-equal parts in the world's energy supply mix by 2040.[53] Without more stringent climate change mitigation policies, fossil fuels will continue to dominate the fuel mix, not least because of the enormous quantity of their reserves. The IEA projects world oil supply to rise to 104 million barrels per day in 2040 and estimates this will require some USD 900 billion per year of investment in upstream oil and gas development by the 2030s.[54] The Middle East and the Russia/Caspian region will likely remain the largest oil exporters over the next decades, while Asia Pacific and Europe will remain the largest importers. The situation in North America is somewhat different, as strong growth in tight oil, oil sands and natural gas liquids could see the region emerge as a net liquids exporter.[55]

Demand for natural gas will grow by more than half, the fastest growth rate of all fossil fuels (IEA, 2014a). A significant proportion of this growth is set to come from unconventional sources, such as shale gas produced in North America.[55] Furthermore, an increasingly flexible global trade in liquefied natural gas will offer some protection against the risk of supply disruptions. Global coal demand will grow by 15% to 2040; around two-thirds of this increase will occur over the next decade, mainly in non-OECD countries like China, after which growth is set to slow considerably.[54]

2.5 Urbanization and megacities: Move towards smarter and sustainable cities

By 2050, the urban population is expected to reach 6 billion up from less than 1 billion in 1950. By 2100, it is likely to reach somewhere around 9 billion, which may represent the 85% of the projected global population. Almost all the growth will occur in the cities of developing countries, with nearly 90% occurring in Asia and Africa. In a few countries like Japan and the Russian Federation, the urban population will decrease in line with falling overall population numbers. The number of "megacities" of 10 million or more inhabitants has almost tripled over the last 25 years, and they now account for 12% of the world's urban population. Forty or so such cities will exist by 2030.[56]

High fertility rates combined with limited job prospects in many rural areas are important drivers of urbanization, as cities typically offer better jobs and educational opportunities. Indeed, urbanization can be an important dynamo of economic growth: cities generally provide easier access to modern and efficient infrastructure – for example, public transportation, housing, electricity, water and sanitation – for large numbers of people in an economically efficient manner[57][58]. In emerging economies such as China, cities have been the main sources of domestic demand, through higher consumption of a growing affluent middle class and very high spending on infrastructure, a dynamic that is expected to continue.[59]

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[53] IEA (2014), World Energy Outlook 2014, OECD/IEA, Paris, http://dx.doi.org/10.1787/weo-2014-en

[54] IEA (2014), World Energy Outlook 2014, OECD/IEA, Paris, http://dx.doi.org/10.1787/weo-2014-en

[55] ExxonMobil (2015), The Outlook for Energy: A View to 2040, Exxon Mobil Corporation, Irving, Texas.

[56] Barreneche, A., Keenan, M., Saritas, O. et al. (2016). An OECD Horizon Scan of Megatrends and Technology Trends in the Context of Future Research Policy, A report prepared by the OECD Directorate for Science, Technology and Innovation, commissioned by Danish Agency for Science, Technology and Innovation (DASTI), Copenhagen (Available at: http://ufm.dk/en/publications/2016/files/an-oecd-horizon-scan-of-megatrends-and-technology-trends-in-the-context-of-future-research-policy.pdf)

[57] OECD (2012b), Environmental Outlook to 2050: The Consequences of Inaction, OECD Publishing, Paris, http://dx.doi.org/10.1787/9789264122246-en.

[58] UN (2014), World Urbanization Prospects: The 2014 Revision, Highlights, UN Department of Economic and Social Affairs, Population Division, New York.

[59] EUISS and ESPAS (2012), Global Trends 2030: Citizens in an Interconnected and Polycentric World, EUISS and ESPAS, Paris.

Building on advances in sensors and their connectivity through high-performance computing – the so-called Internet of Things – urban areas in more advanced economies will increasingly become "smart cities". Various utility and transport networks and systems will become progressively interconnected, thereby supporting more sustainable use and management of resources.[60]

While cities will make it easier to provide modern energy and water infrastructures to a growing number of people, air pollution and unmanaged waste will be major concerns for public health in many urban areas.[61] Climate change will see storm surges and rising sea levels increase over the next decades, which will have major impacts on low-lying coastal cities, especially in Asia, where so much of the world's urban population lives. Extreme weather events will also disrupt complex urban systems and will have major impacts on the insurance industry in developed countries.

The economic benefits of urbanization seen in countries such as China may not materialize in other parts of the world, particularly in sub-Saharan Africa and some parts of Asia. Inadequate education and physical infrastructure, combined with poor governance, have so far constrained the efficient use of productive resources and the industrial development that might have come with it.[62] A growing proportion of low-income groups will become urbanized over the next decades so that in some regions, urban growth will become virtually synonymous with slum formation. Urban slums suffer from substandard housing and inadequate water, sanitation and waste management services, all of which have negative consequences for human health and the environment.[63] Such areas are also more likely prone to conflict and social unrest.[64]

Improving health in cities has emerged as an important issue. In high-income countries, the burden of non-communicable diseases, including cardiovascular and respiratory diseases, cancer is projected to rise from some 86% in 2005 to 89% in 2030 in terms of DALYs.[65] Air pollution, noise and temperature account for a considerable proportion of these non-communicable diseases. Ambient particulate air pollution was ranked ninth as a determinant of disease in the ranking of the Global Burden of Disease estimates in 2010 and is estimated to reduce life expectancy by almost 9 months on average in Europe.[66]

In many cities, there is scope for improvement in environmental quality and health through targeted policies. There is considerable variation in levels of environmental exposures, such as air pollution, noise, temperature and lack of green space within cities, which are associated with a range of preventable adverse health effects. Emerging evidence suggests that multiple factors explain exposure variability. These include: urban and transport planning indicators, such as road network, distance to major roads, and traffic density, household density, industry and natural and green space, personal behaviors and lifestyles. The urban environment is a complex and interlinked system; for instance

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[60] EC (European Commission) (2014a), Preparing the Commission for Future Opportunities: Foresight Network Fiches 2030, working document, https://ec.europa.eu/digital-agenda/en/news/european-commission-foresight-fiches-global-trends-2030.

[61] OECD (2012b), Environmental Outlook to 2050: The Consequences of Inaction, OECD Publishing, Paris, http://dx.doi.org/10.1787/9789264122246-en.

[62] OECD (2015a), The Metropolitan Century: Understanding Urbanisation and Its Consequences, OECD Publishing, Paris, http://dx.doi.org/10.1787/9789264228733-en.

[63] OECD (2012b), Environmental Outlook to 2050: The Consequences of Inaction, OECD Publishing, Paris, http://dx.doi.org/10.1787/9789264122246-en.

[64] UK Ministry of Defence (2014), Global Strategic Trends – Out to 2045, Strategic Trends Programme, Fifth Edition, Ministry of Defence, Swindon.

[65] Busse R., *et al*. (2009). Managing Chronic Disease in Europe, Department of Health Care Management, Berlin University of Technology.

[66] http://www.aphekom.org/web/aphekom.org/home;jsessionid=F72B04D8770C600FD1311ABF499C250D

circular economy, urban farming, the need to reduce worker displacements, favor proximity production, address possible pollution sources in cities pose complex challenges.

These challenges require a holistic approach as social, economic, cultural and political issues are interwoven with urban planning, environmental, transport, energy, food and water issues. **M**aking cities 'green and healthy' goes far beyond simply reducing CO_2 emissions. Environmental interventions at the community level, such as urban and transport planning have been shown to be more cost-effective than interventions at the individual level.[67]

A sustainable and healthy city should have attractive open public spaces and promote sustainable, inclusive and healthy mobility. Some potential policies, such as a reduction of car use by increasing the attractiveness of public and active transportation, combined with more cycling lanes and green spaces may have joint effects in that they may not only reduce environmental exposures such as air pollution, noise, and temperature (i.e. heat islands), but also increase physical activity, UV exposure (Vitamin D), social contacts and thereby reduce stress, morbidity and premature mortality. Moreover, a green and active lifestyle may create co-benefits such as a reduction in CO_2 emissions and traffic congestion. Urban farming may increase biodiversity and quality of life. However, knowledge is still lacking despite a wide variety of experiments taking place in cities. Sharing about such experiments is also necessary as decision-makers need better data to reduce the complexity of factors in urban planning, transport, environmental exposures, social processes and behavior affecting human health: they need enhanced understanding of such issues to know at which level and where to target their actions in an efficient and cost effective way.

New research tools, methods and paradigms are under development. Geographical information systems, smartphones, GPS devices, and remote sensors can be used to produce location-based data and measure environmental exposures and mobility. The Exposome (i.e. totality of environmental exposures)[68], smart cities paradigm, citizen observatories and other related areas of science and technology can provide the information needed. Further action needs to be taken for better visions and concerted research and action involving all stakeholders to provide more holistic solutions. It requires further collaboration between both researchers and practitioners in the field, and more input from many sectors including, urban and transport planning, energy, the bioeconomy, environment, health and well-being and social and behavioral sciences.[69]

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[67] Chokshi DA, Farley TA. Cost-effectiveness of environmental approaches to disease prevention. *New Eng J Med* 2012; 367: 295-7

[68] http://www.mdpi.com/1660-4601/11/8/7805

[69] Vercruysse, N., Stahel, W.R., Saritas, O. et al. (2015). The Junction of Health, Environment and the Bioeconomy: Foresight and Implications for European Research and Innovation Policies, A report prepared for Directorate-General for Research and Innovation, European Commission, Brussels.

3. SOCIAL COHESION, SAFETY AND SECURITY

3.1 Demographic change and the growth of international migration

The world's population is expected to grow during the 21st century, though at a slower rate than in the recent past. According to the UN's 2015 medium-variant projection, the global population will reach 8.5 billion by 2030 and 9.7 billion by 2050. Growth will take place almost entirely in less developed countries – for example, Africa will account for more than half the increase in global population between now and 2050 – while population size in much of the developed world will stabilize or even fall. While today, 60% of the global population lives in Asia (4.4 billion), 16% in Africa (1.2 billion), and 10% in Europe (738 million), by 2050, Asia's share will fall to 54% (5.3 billion), Africa's will increase to 26% (2.5 billion) and Europe's will decline to 7% (707 million). Africa is projected to be the only region still experiencing substantial population growth after 2050, so that by 2100, it is expected to account for 39% (4.4 billion) of the world's population.[70]

Regarding the distribution of the age groups, the number of youth aged 15-24 years is growing rapidly in Africa, increasing 42% by 2030 and more than doubling by 2055.[71] A second group of youthful countries is projected to persist in the Middle East. A high proportion of working-age adults could offer these countries an economic boost; on the other hand, these countries are typically among the poorest and already struggle to provide educational and employment opportunities for their young people. A reservoir of disaffected young people with low education and few job opportunities may lead to greater political and social instability.

Meanwhile, the developed and developing parts of the world experience aging populations. Low fertility rates across much of the developed and, increasingly, developing world will result in population decline in many countries. For some, notably Japan and much of Central and Eastern Europe, populations are expected to fall by more than 15% by 2050. At the same time, life expectancy is projected to reach 83 years in more developed countries by mid-century and 75 years in the less developed regions. The combination of low fertility rates and longer life spans will lead to future ageing in all major regions of the world, so that by 2050, there will be almost complete global parity between the number of over-60s and the number of children. This is a significant change from the past and present: while there are around 900 million over-60s in the world today, their number is projected to increase to 1.4 billion by 2030 and 2.1 billion by 2050, and could rise to 3.2 billion by 2100. Europe has the largest proportion of over-60s (24% in 2015), a share that is projected to reach 34% in 2050. But rapid ageing will occur in other parts of the world as well, particular in Asia, where the over-60s are expected to make up 25% of the population in 2050.[70] Almost 80% of the world's older population will live in less developed regions: China will have about 330 million citizens aged 65 or more, India about 230 million, Brazil and Indonesia over 50 million.[72]

The size of the working-age population (15-64) is currently at an historical peak and will very soon begin to diminish. This means the size of the dependent population (i.e. children under 15 and persons over 65 years of age) relative to the working-age population that provides social and economic support will increase. Without international migration, the working-age population in more developed regions would

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[70] UN (2015), World Population Prospects: The 2015 Revision, Key Findings and Advance Tables, UN Department of Economic and Social Affairs, Population Division, New York.

[71] UN (2015), Youth population trends and sustainable development, Population Facts, No. 2015/1, UN Department of Economic and Social Affairs, Population Division, New York.

[72] UN (2011), World Population Prospects: The 2010 Revision, UN Department of Economic and Social Affairs, Population Division, New York.

decline by 77million or 11% by 2050; the situation in Europe is even more severe, where the size of the working population would decline by 20% (Royal Society, 2012). Old-age dependency ratios are expected to reach very high levels indeed in some OECD countries – 70 per 100 in Japan and over 60 in Italy, Korea, Portugal and Spain by 2050.[73]

Ageing implies changes in lifestyle and consumption patterns, and this will have significant implications for the types of products and services in demand. At the same time, the prevalence of non-communicable diseases and increased disability among the elderly will place considerable burdens on healthcare and other services, where a more-than-proportional increase in demand can be expected. High old-age dependency ratios will lead to fiscal pressures that raise the risks of inter-generational conflict. In response, governments will likely seek to reduce beneficiaries and benefits, increase workers' contributions, and extend the required number of working years.[74]

While the ability of elderly citizens to remain active and continue working beyond official retirement age is set to increase, this alone is expected to be insufficient to meet workforce shortages. The central scenario in the OECD's long-term growth projection assumes that inflows of migrant workers will be an important factor to mitigate ageing in most OECD economies[75], heralding a new age of international migration. It is difficult to measure and estimate reliably future changes in levels of international migration – the movement of people across international boundaries, which is often a response to changing socio-economic, political and environmental forces, is subject to significant volatility.[76] Looking back over the period 1960-2010, international migration stocks grew both in real numbers and as a percentage of the world's population (from 2% in 1960 to 3.1% in 2010). Even if the stock of international migrants is assumed to remain at around 3% of the world's population, this implies a growth to around 250 million by 2030.[77] Other estimates put the flow of international migrants from developing to developed countries at 96 million during 2010-50, with the US, Canada, the UK and Australia the largest net receivers.[78] However, developing Asia, particularly China, could become a major area of destination by 2050, and a growing number of migrants will probably move between and within Asia and Africa as countries in these regions develop economically.

Estimations of future workforce shortages should consider technological change as an important determining factor, particularly the impacts of robotics and artificial intelligence, which may reduce the demand for migrant workers' labor and skills. Technologies such as these and others (e.g. neurotechnologies) may also enhance physical and cognitive capacities, allowing people to work longer in their lives. Nevertheless, on the supply side, youth bulges in some parts of the developing world are creating conditions ripe for outward migration: a likely lack of employment opportunities and growing risks of internal conflict will force many to seek better lives and safety elsewhere. Climate change may

[73] UN (2011), World Population Prospects: The 2010 Revision, UN Department of Economic and Social Affairs, Population Division, New York.

[74] US National Intelligence Council (2012), Global Trends 2030: Alternative Worlds, NIC, Washington, DC.

[75] Westmore, B. (2014), "International Migration: The relationship with economic and policy factors in the home and destination country", OECD Economics Department Working Papers, No. 1140, OECD Publishing, Paris, http://dx.doi.org/10.1787/5jz123h8nd7l-en.

[76] UN (2012), World Urbanization Prospects 2011, UN Department of Economic and Social Affairs, Population Division, New York.

[77] UK Foresight (2011), Migration and Global Environmental Change: Final Project Report, The Government Office for Science, London.

[78] UK Ministry of Defence (2014), Global Strategic Trends – Out to 2045, Strategic Trends Programme, Fifth Edition, Ministry of Defence, Swindon.

also have more of an influence on future international migration flows.[79] And existing diasporas in developed countries will continue to facilitate migration and settlement of friends and family from the less developed world.[80]

International migration, while potentially solving anticipated labor and skills shortages in receiving countries, will see the size and importance of ethnic minority communities grow. Some of these may be poorly integrated and economically disadvantaged, which may lead to tensions and instability.[81] This may make it more difficult for governments to win support for more open and forward-looking immigration policies.[82] Immigration will also be challenged by inequalities: in societies with a shrinking middle class, openness is likely to be perceived as a threat to well-being and job security. Rising populism could also see governments use migrants as scapegoats for existing social problems.[83]

A key, much more significant factor driving globalization is migratory flows. There are roughly 230 million migrants in the world today, moving in search of better lives and better jobs, fleeing from wars and civil strife, and/or reuniting with their families. Migratory movements show no sign of slacking, as the long drawn-out conflicts among other places in North and sub-Saharan Africa and the Middle East drive people to seek safe havens in Europe, and income and wealth disparities across the globe continue to attract people from poorer to more prosperous countries. Many, of course, bring qualifications and skills with them. In the decade to 2010/11, for example, the number of tertiary educated immigrants in the OECD increased by 70%, to reach 27 million.[84] All the signs point to a further strengthening of factors pushing and pulling migratory flows in the decades to come.

3.2 Towards holistic health: Prevention and treatment of diseases and pandemics

The healthcare systems of the future will have to face a growing spectrum of challenges. Progress has been made in the battle against some infectious diseases such as tuberculosis (TB), HIV/AIDS and malaria. HIV/AIDS mortality has fallen quite dramatically in recent years, and deaths from TB (95% of which occur in low- and middle-income countries) are declining, albeit very slowly.[85] Approximately half of the world's population is at risk of malaria (with 90% of malaria deaths occurring in Africa). However, between 2000 and 2013, an expansion of malaria interventions helped to reduce malaria incidence by 30% globally, and by 34% in Africa. During the same period, malaria mortality rates decreased by an estimated 47% worldwide and by 54% in Africa.[86] However, trends are at work in society that suggest that future progress in countering infectious diseases may become harder to achieve. Urbanization is continuing to gather pace in the developing world; climate change is influencing geographic patterns of human and animal infections (e.g. malaria); international tourism is growing; global migration levels are

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[79] European Environment Agency (2015) The European Environment: State and Outlook 2015 – Assessment of Global Megatrends, European Environment Agency, Copenhagen.

[80] EUISS and ESPAS (2012), Global Trends 2030: Citizens in an Interconnected and Polycentric World, EUISS and ESPAS, Paris.

[81] UK Ministry of Defence (2014), Global Strategic Trends – Out to 2045, Strategic Trends Programme, Fifth Edition, Ministry of Defence, Swindon.

[82] ESPAS (European Strategy and Policy Analysis System) (2015), Global Trends to 2030: Can the EU Meet the Challenges Ahead?, ESPAS, Brussels.

[83] EUISS (European Union Institute for Security Studies) (2010), Global Governance 2025: At a Critical Juncture, EUISS, Paris.

[84] OECD (2013), Regions at a Glance 2013, OECD Publishing, Paris, http://dx.doi.org/10.1787/reg_glance-2013-en.

[85] WHO (2014), Global Tuberculosis Report 2014, WHO, Geneva.

[86] WHO (2015), Malaria Fact sheet N°94 Reviewed April 2015, http://www.who.int/mediacentre/factsheets/fs094/en/.

unlikely to abate; and excessive current use of antibiotics is set to reduce the future effectiveness of drugs against some communicable diseases (e.g. TB).

While the annual number of deaths due to infectious disease is projected to decline, the total annual number of deaths from non-communicable diseases (NCDs) is projected to increase from 38 million in 2012 to 52 million by 2030. This epidemic of NCDs is being driven by powerful forces such as demographic ageing, rapid unplanned urbanization, and the globalization of unhealthy lifestyles. While many chronic conditions develop only slowly, changes in lifestyles and behaviors are occurring rapidly and pervasively. The leading causes of NCD deaths in 2012 were cardiovascular diseases, cancers, respiratory diseases and diabetes. These four major NCDs were responsible for 82% of NCD deaths. Going forward, annual cardiovascular disease mortality is projected to increase from 17.5 million in 2012 to 22.2 million in 2030, and annual cancer deaths from 8.2 million to 12.6 million.[87] The prevalence of diabetes has been increasing globally in recent decades, and WHO projects that it will be the seventh-leading cause of death in 2030. NCDs already disproportionately affect low- and middle-income countries, and current projections indicate that by 2020 the largest increases in NCD mortality will occur in Africa and other low- and middle-income countries.[88]

Cases of neurological disease, spurred in particular by rising longevity and the anticipated rapid ageing of societies in the coming decades, are expected to multiply. Alzheimer’s Disease International (ADI), for example, estimates that 46.8 million people worldwide are living with dementia in 2015, and that the number will almost double every 20 years, reaching 74.7 million in 2030 and 131.5 million in 2050.

Fifty-eight percent of all people with dementia live in countries currently classified by the World Bank as low- or middle-income countries. This proportion is estimated to increase to 63% in 2030 and 68% in 2050. Between 2015 and 2050, the number of older people living in high-income countries is forecast to increase by 56%, compared with 138% in upper-middle-income countries, 185% in lower-middle-income countries, and by 239% in low-income countries.[89]

Use of antibacterial drugs has become widespread over several decades (although equitable access to antibacterial drugs is far from being available worldwide). These drugs have been extensively misused in both humans and food-producing animals in ways that favor the selection and spread of resistant bacteria. Consequently, antibacterial drugs have become less effective or even ineffective, resulting in an accelerating global health security emergency that is rapidly outpacing available treatment options.[90]

The global health challenges for the next decades are immense. But the very scale of those challenges across the developing world and the advanced economies offers vast opportunities for established and novel medical procedures, specialized treatments, new medicines and technological solutions, as well as for the development and implementation of innovative systems of health provision and care co-ordination and management. Unfortunately, at the present time the resources devoted to preventing, mitigating and curing disease, as well as to people’s access to those resources, are also unevenly distributed. Evidence to date indicates that access to good health care correlates quite strongly with income level, educational level and access to knowledge.

[87] WHO (2014b), Global Status Report on Noncommunicable Diseases 2014, WHO, Geneva.
[88] WHO (2011), Global Status Report on Noncommunicable Diseases 2010, WHO, Geneva.
[89] ADI (2015), World Alzheimer Report 2015: The Global Impact of Dementia – An Analysis of Prevalence, Incidence, Cost and Trends, ADI, London.
[90] WHO (2014c), Antimicrobial Resistance: Global Report on Surveillance, WHO, Geneva.

On the positive side as incomes and educational levels rise across much of the globe, even in poorer countries, and the middle classes in emerging and developing economies gain ground, the prospects for sustainable health markets in those parts of the world are expected to brighten considerably. The quest for longevity continues at pace, with a great deal of effort being put into finding the substances, interventions and habits that can keep people live longer and healthier lives, for example by revolutionizing the treatment for a massive range of degenerative conditions.[91] For a meaningful long life, the elderly will need to have sufficient mental capital and retain better cognitive abilities and living standards. As people work to an older age, there is a chance that they will *de facto* be mentally stimulated for longer.[92] Quality of life is expected to increase with healthy food, meaningful work, safe workplaces, social security as well as recreational activities in local and global resorts.

Better diets, lower air pollution and chemical exposure levels, healthier living environments and more active lifestyle will lead to a reduction in NCDs (outdoor air pollution is responsible for nearly 500,000 premature deaths in Europe alone.[93] More holistic approaches are needed. Hazard identification and risk assessment require modern approaches taking individual and population characteristics into account. The latter are currently developed in adverse outcome pathway focus in toxicology and creation of follow-up studies of suitable cohorts e.g. family and birth cohorts.

New approaches are needed for health and social care, building both on public engagement and technology, developing and supporting networks within different communities, and engaging people in disease prevention and the provision of healthcare and social services. New social paradigms are emerging, many of which are triggered by contradictions in the urbanization process and new technologies. Social cohesion is an important determinant of health. Social and socio-ecological cohesion, including the urbanization of nature and its socio-environmentally enabling and disabling conditions are key processes in healthy longevity.[94]

Intervention and guidance towards healthy behavior targeting communities as well as individuals are however needed. New cross-cutting methods could help to take cross sectoral approaches including socio-economic and behavioral aspects, the impact of climate change and increased urbanization into account. Human biomonitoring (HBM), sensoring and health surveys can be used as tools for increasing health awareness and promotion, as well as assessing human exposure to environmental agents and their adverse and beneficial effects. Biomarkers are used to measure indicators of changes and events in biological systems with the analysis of specimens of human tissues such as blood, urine, hair, adipose tissue and teeth. Sensors can be used to measure lifestyle, mobility, behavior and exposure patterns in order to suggest and promote healthier patterns.

Thanks in particular to green technologies which allow focusing on safe production and products, we could hope that by 2030, the burden on young generations will be less, resulting in reduction of neurobehavioral and reproductive problems along with improved immune resistance and mental health. The use of nature/green space to treat and relieve diseases such as obesity, COPD (please define), attention deficit hyperactivity disorder (ADHD), allergies, dementia and depression should be considered to ensure sustainable and resilient lifestyles through a balance between humans and nature.

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[91] http://www.gizmag.com/gdf11-protein-aging-mice-harvard/31929/
[92] http://www.pewinternet.org/2014/08/06/future-of-jobs/
[93] Air Quality in Europe – 2014 report http://www.eea.europa.eu/publications/air-quality-in-europe-2014
[94] http://www.sed.manchester.ac.uk/geography/staff/documents/Cities_social_cohesion_and_environment.pdf
http://intl-usj.sagepub.com/content/49/9/1959.abstract

The efficient shift from treatment to prevention, individual participation and responsibility, while ensuring the health of ageing societies and dealing with threats to treatment such as antimicrobial resistance, remain major challenges. The goal is that healthy life expectancy increases as genetic and environmental causes of disease and possible interactions between the two are better understood and as regulation prevent harmful exposure and promote healthy environments. The enhanced use of Information and Communication Technologies increases the amount of health-related information available and could thus continue improving our ability to turn knowledge into increasing life-expectancy and quality of life. The market for diagnostic tools is likely to continue to flourish which could cause dramatic evolutions (positive or negative) in the field of health.

Cheap mapping of the genome has generated an important potential for early 'diagnosis' (or 'prognosis') for every individual. Mapping of the exposome (and all the other 'omes' like the 'virome') as well as other sensor based indicators and human biomonitoring promises to make health and disease, prevention, diagnosis and treatment amenable to analysis through vast amounts of computer power, offering potentially greatly improved health care and health. Yet, considerations of privacy, as well as of cost, e.g. the cost of research, treatment and health insurance, dampen these possibilities and reduce the speed of developments.[95]

3.3 Growing social inequality and instability

Barring major global catastrophes, and despite slowing global growth rates, the world is very likely to be a much richer place by mid-century. World GDP is expected to more than triple by 2060, per capita incomes are also set to rise rapidly, and wealth accumulation is anticipated to continue apace. However, whether this will also be a better world depends very much on how incomes and wealth will be distributed across the globe and within countries.

At present, the prosperity gulf between developed and developing economies is wide. But the future promises convergence. Over the next half century, disparities in GDP per capita are expected to narrow across countries; per capita income levels of the currently poorest economies will more than quadruple (in 2005 purchasing power parity terms), whereas they will only double in the richest economies; China and India will experience more than a sevenfold increase of their income per capita by 2060. Nonetheless, significant gaps in living standards will remain between advanced and emerging economies as well as between them and the least developed countries.

Inequalities within countries will pose major political, social and economic risks in the coming years. Over two-thirds of emerging and poor countries, encompassing 86% of the population of the developing world, will experience growing inequalities. For many, the prospects of long-term help are particularly gloomy: by 2030, some two-thirds of the world's poor could be living in "fragile" states – in other words, in countries where there is no government that could effectively constitute a counterpart for foreign aid agencies.[96]

Rising wealth and income in the developing economies of the world is progressing hand in hand with the emergence of a global middle class. By current projections, the global economy's middle class is

[95] Vercruysse, N., Stahel, W.R., Saritas, O. et al. (2015). The Junction of Health, Environment and the Bioeconomy: Foresight and Implications for European Research and Innovation Policies, A report prepared for Directorate-General for Research and Innovation, European Commission, Brussels.

[96] ESPAS (European Strategy and Policy Analysis System) (2015), Global Trends to 2030: Can the EU Meet the Challenges Ahead?, ESPAS, Brussels.

expected to more than double between 2009 and 2030, from 1.8 billion to almost 5.0 billion, accounting for about 60% of the world population. Some two-thirds of those middle-class citizens are expected to be found in Asia.[97] Of course, the number of people in the middle class does not properly capture its spending power. Given the broad range of expenditures that fall within the middle-class definition, some countries have more affluent middle classes than others. Today's middle class in Europe and North America make up just over half of the global total in terms of number of people, but they account for almost two-thirds of total spending by the world's middle class. This is about to change. Asia's share of global middle-class expenditure is expected to climb from around one-quarter today to almost 60% in 2030, bringing about a huge shift from spending on necessities such as food and clothing to choice-based spending on categories such as household appliances and restaurants.[98]

Growing income and wealth inequalities are not the preserve of the developing world. In the vast majority of advanced countries, the gap between rich and poor has reached its highest level for three decades. Today, the richest 10% of the population in the OECD area earn nearly 10 times the income of the poorest 10%, up from 7 times in the 1980s. However, the ratio does vary widely across OECD countries. In Nordic and many Continental European countries, the ratio is significantly lower than the average, but in Italy, Japan, Korea, Portugal and the United Kingdom it is closer to 10 to 1, between 13 and 16 to 1 in Greece, Israel, Turkey and the United States, and as high as between 27 and 30 to 1 in Mexico and Chile.[99]

Importantly, however, the rise in overall income inequality in OECD countries is not only about the top income bracket. The evidence suggests that what matters most is the gap between low-income households and the rest of the population. Indeed, over the last 30 years, incomes at the low end of the scale often grew much more slowly during the prosperous years and decreased during downturns. Unsurprisingly perhaps, for the vast majority of developed countries for which data are available, poverty rates increased from the mid-1990s to the 2010s, pushing up rates for the OECD area as a whole by 1.5 percentage points. Over the last couple of decades the risk of poverty has shifted markedly away from the elderly towards families with children. Hence, large families with three or more children also tend to have higher levels of poverty risk. Moreover, child poverty is seen to be increasing in almost all OECD and EU countries. On average across the OECD, the child poverty rate increased from 12.2% in 2000 to 13.2% in 2010.[100]

Also at risk are young adults, who make up an increasing share of the poor. The increase in youth poverty is to be found particularly among youngsters not in education, employment or training who run a greater than average chance of unemployment, lower wages, poorer health and therefore a greater risk of long-term "scarring". In many countries, migrant families and their children are also at risk. Within Europe, this is particularly true of non-EU immigrant families and their offspring.[101] And finally, there are those families facing persistent poverty. These are most likely to be older people, single people (especially women both with and without children) and jobless households.

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[97] Gros, D. and C. Alcidi (eds.) (2013), The Global Economy in 2030: Trends and Strategies for Europe, ESPAS, Brussels.

[98] Kharas, H. and G. Gertz (2010), "The new global middle class: A cross-over from west to east", draft version of chapter in China's Emerging Middle Class: Beyond Transformation, C. Li, (ed.), Brookings Institution Press, Washington, DC.

[99] OECD (2013), OECD Science, Technology and Industry Scoreboard 2013: Innovation for Growth, OECD Publishing, Paris, http://dx.doi.org/10.1787/sti_scoreboard-2013-en.

[100] OECD (2013), OECD Income Distribution Database, www.oecd.org/social/income-distribution-database.htm.

[101] Jokinen, K. and M. Kuronen (2011), "Research on families and family policies in Europe: Major trends", in Wellbeing of Families in Future Europe: Challenges for Research and Policy, FAMILYPLATFORM – Families in Europe Volume 1, Uhlendorff, U., M. Rupp and M. Euteneuer (eds.), FAMILYPLATFORM, Brussels.

3.4 Geopolitical instability and changing nature of warfare

The shift from a hegemonic to a multipolar world of economic and political power is of long standing. Indeed, the gradual transition was noted at least as far back as the 1980s.[102] Thirty years on, the dynamics of change are as strong as ever, paving the way for a further significant transformation of the global landscape in the decades ahead.

The next 50 years will see the center of gravity of the world economy shift east and south. By 2030, developing countries are expected to contribute two-thirds of global growth and half of global output, and will be the main destinations of world trade. Simultaneously, considerable changes will take place in the relative size of the world's major economies. Fast growth in China and India will see their combined GDP surpass that of the Group of Seven (G7) economies fairly soon and overtake that of the entire current OECD membership by 2060.[103] The top economies in 2030 are widely expected to be the United States and China, with a race for third place between the European Union and India.[104]

Several new emerging countries will appear on the scene by 2030, since economic progress is accelerating in many states. New large economies in 2030 (measured in total GDP at purchasing power parity [PPP]) will include Mexico, Indonesia, Turkey, Nigeria and Vietnam, their eventual success depending largely on the quality of their governance and of their economic policy, their demographic profile and the level of education they provide to their citizens.[105]

As the new geographic diffusion of power has changed, so too have many of the features of power. A growing list of emerging states will be looking to translate their economic gains into more meaningful global influence. Global governance structures will evolve further as key groupings take on board the growing presence of some of the new vibrant economies, perhaps following the example set by the G7/G8, which scaled up to the G20 as a reflection of those new realities. In so doing, a delicate balance will need to be struck between the necessary engagement of such countries in international economic governance and the challenge of coordinating the growing number and diversity of participants.

Non-state actors such as multinational businesses, non-governmental organizations, sovereign wealth funds, major cities, academic institutions and foundations endowed with global reach are all expected to play increasingly influential roles in the coming decades. In some cases they may even prove instrumental in the creation of new alliances and coalitions that have the wide public support to tackle some of the global challenges facing the planet – poverty, environment, security, etc.[106]

Cities, and in particular megacities, stand out as one of the increasingly powerful subnational actors. Metropolitan areas are the prime engine of growth. In the OECD area, more than half of economic growth and job creation occurred in the 275 metropolitan areas with over 500 000 inhabitants.[107] Megacities (populations over 10 million) in the developed world and in the emerging economies have until now been very much the center of attention for business and policy makers alike – small wonder, since together they account for more than 70% of world GDP. This looks set to change, however, as

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[102] OECD (1987), Interdependence and Co-operation in Tomorrow's World, OECD Publishing, Paris.

[103] Johansson, Å., et al. (2012), "Looking to 2060: Long-term global growth prospects: A Going for Growth report", OECD Economic Policy Papers, No. 3, OECD Publishing, Paris, http://dx.doi.org/10.1787/5k8zxpjsggf0-en.

[104] Gros, D. and C. Alcidi (eds.) (2013), The Global Economy in 2030: Trends and Strategies for Europe, ESPAS, Brussels.

[105] ESPAS (2015), Global Trends to 2030: Can the EU Meet the Challenges Ahead?, ESPAS, Brussels.

[106] NIC (2012), Global Trends 2030: Alternative Worlds, US NIC, Washington, DC.

[107] OECD (2013b), Regions at a Glance 2013, OECD Publishing, Paris, http://dx.doi.org/10.1787/reg_glance-2013-en.

interest switches to the growth of medium-sized cities (below 10 million inhabitants) especially in emerging and developing economies.

All these dynamics will certainly bring about new types of frictions and conflicts on the agenda. Looking back, the last two decades have witnessed a gradual decline in the number (and severity) of internal armed conflicts worldwide – from a peak in 1994 when almost a quarter of the world's countries were embroiled in civil conflict, to less than 15% today. This has been much the result of widespread improvements in factors such as levels of education, economic diversification and more favorable demographic developments.[108] The number of interstate conflicts, while fluctuating somewhat, has also been on a declining trajectory[109], thanks mainly to a rising body of global norms against such warfare and the deepening economic and financial linkages among countries.

When it comes to forecasting the longer-term outlook for armed conflict, views diverge. Forecasts indicate that this downward trend will continue, with the share of countries involved in internal armed struggles falling from 15% now to 12% in 2030, and 10% in 2050, and with conflicts concentrated mainly in sub-Saharan Africa and South Asia.[108] Others are somewhat less sanguine. The US National Intelligence Council states that the risks of interstate conflict are on the rise owing to changes in the international system, but does not foresee conflict on the level of a world war involving all major powers.[110]

New developments might be expected at the crossroads of intra- and interstate armed conflict, as internal tensions spill across frontiers, generating "internationalized" intrastate conflict. Outstanding features of the recent wave of warfare include the extreme fragmentation of armed groups and the decentralized multiplication of fronts and factions engaged in conflict. For Briscoe (2014), three particular risks stand out for the international community: the intractability of conflict, with trouble tending increasingly to re-emerge in territories that have already been affected by warfare; unpredictable suicide attacks on major cities and infrastructures that lead to vulnerable states backing proxy groups and exacerbating cross-border civil war; and doubts about the capacity of current institutional mechanisms to deal with such fragmented and internationalized internal conflicts.

Among the most prominent trends in the evolution of warfare, the following ones can be mentioned[111]:

- Wars are taking place in closer to the habitation areas of civilians, and military operations are increasingly taking place increasingly in residential areas. There is less tolerance for the loss of the military personnel and civilian lives. With the growing role of media and social networking technologies, societies are more exposed to losses. Therefore, increasing number of death tolls overturn social, and thus political support for armies. Lower or no negative impact on human lives and settlements is becoming a key success factor for military operations.
- The security and sustainability of energy sources can be considered as one of the key determinants of success in military operations. Due to the diversity of war environments, concepts and technologies mentioned above, military operations may take place in a wide variety of conditions. This may require military equipment to be suitable for the use of more than one energy source to ensure their viability for an extended period of time.

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[108] Hegre, H. and Nygard, H.M. (2014), "Peace on Earth? The future of internal armed conflict", Conflict Trends, 01-2014, Peace Research Institute, Oslo.

[109] Pettersson, T. and P. Wallensteen (2015), "Armed conflicts, 1946-2014", Journal of Peace Research Vol. 52/4.

[110] NIC (2012), Global Trends 2030: Alternative Worlds, US NIC, Washington, DC.

[111] Burmaoglu, S. and Saritas, O. (2016). Changing characteristics of warfare and the future of military R&D, Technological Forecasting & Social Change, Article in press, available online (http://dx.doi.org/10.1016/j.techfore.2016.10.062).

- The meaning and role of leadership in armies is also changing. In the past, leadership referred to 'power', however, in the current war environment, it refers more to 'common wisdom'. Due to the increasing flow of information from a number of sources and growing complexity, it is difficult, if not impossible, for a single leader to make correct decisions in a limited time. It is expected that satellite and sensor systems, artificial intelligence and advanced data analytics will play a greater role as decision support systems. Therefore, new generation leaders in the army will go beyond sole commanders, but towards becoming 'CEOs of the knowledge economy'. Consequently, creative and flexible thinking, collaborative behaviour, skills collective intelligence and the ability to work with Information and Communication Technologies are becoming crucial qualifications for future military leaders.

There are of course important economic implications for both for the countries involved in conflict and for their trading partners. Armed conflict can impact negatively on openness to trade and investment seems intuitively obvious, and yet the matter has attracted little attention from economic research until fairly recently. Major conflicts can indeed reduce trade flows (by up to two-thirds). The impacts tend to be asymmetrical, affecting the exporter side more than the importer side, and depend to some extent on the nature of the conflict and the number of conflicts a country is involved in.[112] For exporting nations, understanding and anticipating the risks and the nature of these economic impacts will be an important part of conducting business in an increasingly complex geopolitical future.

3.5 Connected world and cybersecurity

Information and Communication Technologies (ICTs) underpin much of the globalization phenomenon. Internet penetration helped by mobile broadband has been growing quickly. For the developing world, it is estimated that over the seven-year period from 2014 to 2020, an additional 1.1 billion new individuals will acquire a mobile phone for the first time, or 155 million per year. Moreover, 3G and 4G penetration is expected to double in the developing markets by 2018, with some operators planning to leapfrog 3G technology and launch 4G networks.[113] However, a new digital divide is looming on the horizon. The next phase of Internet development will be marked by a growing number of connected devices. North America, for example, is likely to have almost 12 devices per capita connected by 2019, Western Europe around 8. This will be in stark contrast to Latin America's 2.9 and Africa's 1.4, suggesting big differences in how societies will be utilizing, and benefiting from, the Internet.[114]

Apart from moves by some governments to limit citizens' access to Internet content through controls (the "walled garden" phenomenon), a further obstacle to the global spread of information technology and its multiple applications and connectivity potential could be the lack of local language in Internet use. While it is true that English serves as a common Internet language for millions of people, the flip side is that millions of people have no access because they speak no English. Around 55% of websites around the world use English as the primary language, yet only 5% of the global population (335 million) speaks English as their first language. Chinese on the other hand (including all dialects) is the first language of over 1.1 billion people (17% of the global population), yet only 3% of websites are written in

[112] Kamin, K. (2015), The Impact of Conflict on Trade – Evidence from Panel Data (work-in-progress draft), University of Kiel, www.etsg.org/ETSG2015/Papers/323.pdf.

[113] GSMA Intelligence (2014), Local World – Content for the Next Wave of Growth, Analysis, GSMA Intelligence, London.

[114] ITU and UNESCO (2015), The State of Broadband 2015: Broadband as Foundation for Sustainable Development, Broadband Commission for Digital Development, Geneva.

Chinese. This trend continues in many non-English-speaking countries throughout the developing world, where very little Internet content exists in languages such as Arabic, Hindi and Bengali.[112]

Whilst providing opportunities for the society, the penetration of ICTs into all spheres of life gives rise to a number of threats. Factors like the transboundary nature of cyberspace, its dependence on sophisticated information technologies, widespread use of sites and services increase the likelihood and strength of threats. Particularly, the protection of sensitive data from the individual to national and international levels has become a major concern for cybersecurity.

Cybercrimes may differ in nature. Broadly three categories can be distinguished:

1. Offences against the confidentiality, integrity and availability of computer systems. These include the following types of crimes: illegal penetration and interference in the computer system, illegal access and use of information, production and distribution of malicious computer programs, breach of confidentiality of personal data
2. Financial cybercrime and crimes causing personal injury. Computer fraud associated with forging signatures, violation of intellectual property rights, carrying out mass mailings, acts causing personal injury
3. Cybercrime associated with the spread of inappropriate content. Actions leading to the incitement of ethnic hatred, production and distribution of child pornography, the acts of international terrorism

The common characteristics of all threats are[115]:

- Cybercrime is widespread in the areas of financial instruments, computer and content in violation of the confidentiality, integrity and availability of computer systems
- Perceptions of the risks vary considerably for the state, business and individuals
- Cybercrime is much more common for individual users than for organized groups of users (organizations, groups, and so on.)
- Individual cybercrime are more common in developing countries and require considerable effort to prevent them
- The share of the global traffic that violates intellectual property rights is 24%
- These criminal tools like botnets have become widespread in 2011 they controlled more than 1 million IP addresses

Around the globe, 82 countries have signed international agreements on the fight against cybercrime. More than 40 countries have become parties to the Convention on Cybercrime of the Council of Europe regulating the most effective tool for the development of regulation in this area.[116] Economic losses from cybercrime in 2014 amounted to more than $ 400 billion.[117] The US is the leading country, which has the highest rank in the Global cybersecurity index (GCI).[118] Whilst the country allocated 0.15% of its GDP for cybersecurity in 2009, the planned amount for 2017 is 0.35% of GDP.[119] This increase

[115] United Nations Office (2013). Comprehensive Study on Cybercrime. http://www.unodc.org/documents/organized-crime/UNODC_CCPCJ_EG.4_2013/CYBERCRIME_STUDY_210213.pdf
[116] United Nations Office (2013). Comprehensive Study on Cybercrime. http://www.unodc.org/documents/organized-crime/UNODC_CCPCJ_EG.4_2013/CYBERCRIME_STUDY_210213.pdf
[117] McAfee Labs (2016). Threats Predictions. http://www.mcafee.com/us/resources/reports/rp-threats-predictions-2016.pdf
[118] ITU (2015). International Telecommunication Union. ABI Research. Global Cybersecurity Index & Cyberwellness. / http://www.itu.int/dms_pub/itu-d/opb/str/D-STR-SECU-2015-PDF-E.pdf
[119] Atlantis (2015). Atlantis Council. Risk Nexus. Overcome by cyber risks? Economic benefits and costs of alternate cyber futures. / http://publications.atlanticcouncil.org/cyberrisks/

investment in information security can be explained, on the one hand, due to the improvement and accessibility of opportunities for cybercrime by hackers, and on the other hand, due to the increase in the share of valuable information to be used in companies and other organizations within networks, which is associated with an increase in the use of ICT technologies in the organizational activities of the companies. Similar to governments, corporations are increasingly investing in cybersecurity in various areas including software and hardware tools, recruitment of staff responsible for information security, special training and staff development programs, the development of professional services, issues on transmission functions on outsourcing.[120]

[120] Frost&Sullivan (2015). Global Information Security Workforce Study. / https://www.isc2cares.org/uploadedFiles/wwwisc2caresorg/Content/GISWS/FrostSullivan-(ISC)%C2%B2-Global-Information-Security-Workforce-Study-2015.pdf

4. SPACE SCIENCES, ENGINEERING AND SECURITY

4.1 Looking up: Exploring wider and deeper space

Humans are driven to explore the unknown, discover new worlds, push the boundaries of our scientific and technical limits, and then push further. The first step in embarking on a long and challenging journey involves laying solid groundwork for a successful endeavor. The International Space Station serves as a national laboratory for human health, biological, and materials research, as a technology test-bed, and as a stepping stone for going further into the solar system. Exploring in translunar space, beyond the protection of the Earth's geomagnetic field, will provide unprecedented experience in deep-space operations.[121] In the bid to explore wider and deeper space, governments and companies around the world continue to work on new space infrastructure. According to the Space foundation, at least 19 countries are involved in developing space infrastructure for orbital and suborbital exploration. In 2015, 86 orbital launches representing the third highest number of launches in 20 years were attempted by countries and organizations around the world.[122] Space agencies are coordinating plans for international collaboration in space exploration to the Moon and Mars. In a report published by the International Space Exploration Sub-Committee (ISS), states that the next important steps for Moon and Mars exploration is to acquire technologies that a capable of landing of exploring the south pole of the moon, technologies such as rendezvous for logistics in deep space as well as habitation technologies.[123]

Meanwhile, a team of scientists at the European Southern Observatory (ESO) have discovered an Earth-like planet that is orbiting the star closest to Earth. The discovery was done using a 3.6-meter telescope at La Silla, in Chile.[124] This Earth-like planet is the closest planet that has been found near our solar system and has the potential of supporting life. According to NASA, the planet is 4.2 light years away from Earth and estimates that, an unmanned spacecraft could reach it by close of the century.[125] The Planet was named Proxima b as it orbits the Proxima Centrauri, the closest star to the Sun. Proxima Centauri is sometimes classified as a Red Dwarf star. Proxima b is about 1.3 times the mass of Earth and appears to be rocky with a potential of hosting liquid water as a result of its warm nature.[126] This discovery opens the possibility that most stars have at least one Earth-like planet. NASA estimates that, there may be as many Earth-like planets as there are stars in our galaxy. The Discovery of the planet was confirmed by a team of astronomers called "The Pale Red Dot Campaign." Currently, no telescopes in space or on the ground can directly photograph Proxima b. Researchers however believe that NASA's James Webb Space Telescope (JWST), which is scheduled to launch in 2018 could be used to view Proxima b in record time.[127]

In order to explore the deeper space better telescope technologies are under development. A recent attempt is the James Webb Space Telescope sometimes called JWST or Webb, which is a large infrared telescope with a 6.5- meter primary mirror. The telescope was designed in a collaboration between NASA, the European Space Agency (ESA) and the Canadian Space Agency (CSA) and expected to be launched the Ariane 5 rocket from the French Guiana in October 2018. The JWST telescope is built on the design and legacy of the Hubble Space Telescope. The telescope will be the primary observatory for the next decade and expected to serve numerous astronomers worldwide. The James Webb telescope

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[121] https://www.nasa.gov/exploration/whyweexplore/why_we_explore_main.html#.WFEBXLKLSUk
[122] https://www.spacefoundation.org/sites/default/files/downloads/The_Space_Report_2016_OVERVIEW.pdf
[123] http://www.ard.jaxa.jp/eng/research/exploration/exploration.html
[124] http://www.jpl.nasa.gov/news/news.php?feature=6600
[125] http://learningenglish.voanews.com/a/possible-earth-like-planet-next-door/3491428.html
[126] http://www.space.com/33834-discovery-of-planet-proxima-b.html
[127]

has been designed to conducts studies on all phases of the history of the universe, spanning the first luminous glows that occurred after the Big Bang theory, the evolution of our solar system, and information about the solar systems of life supporting planets.128

Space missions continue exploring the planets, comets, and other objects in the solar system as well as the characteristics of the interplanetary medium that lies between them. Every day, Voyager 1 extends the reach deeper into space than any other human-made object. The craft launched three decades ago and is now more than a hundred times farther from the sun than our own Earth—over 9 billion miles (15 billion kilometers). Voyager 1 is at the very fringe of our solar system. It is traveling 1 million miles (1.6 million kilometers) a day and, in the next decade, may pass beyond the frontier of the sun's heliosphere and become the first human-made object to reach interstellar space. Voyager 1 and 2 have studied the planets Jupiter, Uranus, Saturn, and Neptune, explored their moons, examined their rings, and revealed much about interplanetary elements such as solar wind. Now, from deep space, the two craft continue to return data. Scientists expect both Voyagers to function until sometime around the year 2020.[129]

4.2 Looking down: Observation, positioning, navigation and communication

Space assets serve as an economic multiplier and enabler for many other sectors, including air, ground and sea transportation, banking, telecommunications and internet services, healthcare, agriculture and energy. Services provided by satellite are essential for much of modern critical infrastructure and scientific activities, such as water management systems (dams), electronic power grids, weather prediction and disaster monitoring/ management, and climate change studies. Space-based systems are crucial for risk prediction and mitigation all around the globe. Developing countries are increasingly seeking space assets in their quest for sustainable economic and social development. In particular, space activities contribute to science, technology, engineering and mathematics (STEM) education and thus to the development of a highly skilled workforce.[130]

Space technologies enabled by satellites for the purpose of looking down the earth can be classified in three categories:

1. Earth observation satellites
2. Global navigation and positioning satellites
3. Communication satellites

Data from EO satellites contributes to many activities, including improving agriculture and water management, tracking refugee populations, predicting weather, monitoring disasters, carrying out relief operations and national defense. EO satellite revenues for sales and value-added services from commercial operators totalled $2.3 billion in 2012, and the sensing market is expected to grow to $6 billion by 2020, as nations use satellites for economic development. Between 2001 and 2010, 140 EO satellites from 26 countries were deployed on orbit; between 2011 and 2020 this number is expected to increase to 298 satellites operated by 43 different countries.[131] An increasing number of these EO satellites are being built and operated by private industry.

[128] http://jwst.nasa.gov/about.html

[129] http://science.nationalgeographic.com/science/space/space-exploration/interplanetary-exploration.html

[130] http://www3.weforum.org/docs/WEF_Bringing_Space_Down_to_Earth.pdf

[131] Khorram, Siamak, Remote Sensing Satellites, Springer Press, 2012.

Space-based technologies have also revolutionized transportation and navigation capabilities, resulting in more efficient routes, improved safety records and lower operating costs. The key enabling technology is the Global Navigation Satellite System (GNSS), Global Positioning System (GPS), Russian GLONASS, Europe's Galileo, China's Beidou, Japan's QZSS and India's IRNSS. These satellites have provided a flexible, accurate and low-cost method to track position, plan routes and more precisely time delivery/arrival schedules in ground, maritime and air transportation. Ground transportation systems (trucking and rail) have long used GPS-based navigation and timing services for fleet management and planning schedules, and the personal use of GPS by motorists for navigation has skyrocketed in recent years. The maritime industry also relies heavily on communications satellites. For railways, GNSS is frequently used in safety-critical devices supporting signaling (high- and low-density lines) and other applications supporting things such as asset management and passenger information. The aviation industry is the latest transportation sector to adopt the technology, prompted by safety concerns. Airlines are embracing satellite navigation services, which promise to cut costs and increase efficiency by improving flight path planning and traffic flow, enhancing the ability to land in bad weather and high terrain, and reducing emissions.[132]

GNSS satellites have also contributed to the development of efficient and cheaper water management systems, for example by providing precise timing for the working of damns and the routing and time management of electric power grids. As a result, such infrastructure has become more affordable for developing countries. The installed base of GNSS devices currently stands at just over 1 billion. This is expected to rise to 7 billion by 2022 – one for almost every person on the planet. Growth rates are most remarkable outside of Europe and North America. The global market for GNSS devices is expected to grow from slightly less than €50 billion in 2012 to €100 billion in 2019. The wider market enabled by GNSS services is expected to grow to €250 billion by 2022.[133][134]

Communications satellites make up the bulk of satellites in orbit, providing television broadcasting, internet services and telephony. They have underpinned the information revolution, enabling long-distance communications in areas where terrain, distance or poor infrastructure make it too difficult to lay cables. The many benefits range from improved banking services to distance education and telemedicine in remote areas. Communications satellites are also bridging the digital divide between developed and developing nations by bringing internet services to remote areas. Satellite communications, the most commercially mature space industry, generate over $100 billion in revenues worldwide, driven primarily by broadcasting services.7 Today, more than 25,000 digital satellite TV channels are available, compared to fewer than 800 analogue channels in 1991,8 and demand continues to grow. By taking advantage of the assets of existing players in space-based telecommunications, new entrants are paying less, and countries are benefitting from having their own satellite to provide domestic telecom services. Countries such as United Arab Emirates, Chile, Laos and Nigeria have applied to the International Telecommunication Union (ITU) to operate geosynchronous communications satellites over their countries, and have started placing contracts for manufacturing and launch services. Many of these countries have also started deregulating their telecommunications sector, boosting business and consumer demand.[135]

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[132] http://www3.weforum.org/docs/WEF_Bringing_Space_Down_to_Earth.pdf
[133] European GNS Agency, GNSS Market Report, Issue 3, 2013, http://www.gsa.europa.eu/node/8748/download/067a7554f8815b9ee528feb737db42c7.
[134] http://www3.weforum.org/docs/WEF_Bringing_Space_Down_to_Earth.pdf
[135] http://www3.weforum.org/docs/WEF_Bringing_Space_Down_to_Earth.pdf

Space-based positioning, navigation and timing (PNT) technologies, such as Global Satellite Navigation Systems (GNSS) provide position, velocity, and timing information to unlimited number of users around the world. In recent years PNT information has become increasingly critical to the security, safety, prosperity, and overall quality of life. As a result, space-based PNT is now widely recognised as an essential element of the global information infrastructure (Space Foundation, 2016).

Nowadays, billions of people are using devices that have satellite-augmented technologies. These devices range from the cheapest tablets to the most upscale smartphone and have satellite positioning, and timing (PNT) functions embedded in them. Space technology, combined with communication networks, is displacing traditional ways of monitoring infrastructure and providing services.[136] On the consumer side,

- There are space-enabled systems to assist with finding prime locations for sport fishing and to help coaches improve the performance of soccer players.
- With the ongoing globalization of food production, space systems are helping the shipping industry better monitor the condition of food in transit across the ocean to ensure that freshness is maintained all the way to the grocery store.
- The abundance of satellite imagery has led to increasing numbers of space data analysis companies that help people understand their surroundings, whether for business or recreational purposes. The number of people who use mobile computers to track a ride, conduct secure banking, locate the tastiest and cheapest food outlets, as a guide to tourist sites has increased. These use are only possible through satellite PNT integrated devices.[137]

The global demand for space data and applications is driving many of the recent investments in space.

4.3 The growth of micro and nano satellites

The satellite industry is seeing rapid growth in the number of small satellites, as vast constellations consisting of hundreds of satellites for Earth observation and telecommunications are being ordered and built. Today, about 60 countries have one or more of their own satellites, up from only 26 countries in 2001. Large satellites are taking advantage of more efficient propulsion systems that may help increase their usable lifespan. The last few years have witnessed the start of a revolution in the design and deployment of satellites. As increasing use is made of small and very small satellites with more capabilities, which will provide valuable contribution for addressing "grand" challenges related to, for example, the environment, climate, water, agriculture and food. The different families of small satellites are distinguished by their weight –less than 500 kg . Nano- and microsatellites weigh between 1 and 50 kg. CubeSats are miniaturized satellites whose original models measured 10x10x10 cm and weighed 1 kg (also known as "1 Unit"). Satellite units can then be combined to create larger CubeSats.

The smaller the satellite, the cheaper it is to build and launch. A nano- or microsatellite can be built for EUR 200-300K. Small satellites are becoming much more affordable, as off-the-shelf components are now commonly used to build satellite platforms and support mass production. Most of the electronics and subsystems required to construct a nano-satellite in-house can be bought online (OECD, 2014d). The main cost barrier remains access to space. Small satellites can be launched as secondary payloads

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[136] https://www.spacefoundation.org/sites/default/files/downloads/The_Space_Report_2015_Overview_TOC_Exhibits.pdf
[137] https://www.spacefoundation.org/sites/default/files/downloads/The_Space_Report_2016_OVERVIEW.pdf

for less than EUR 100K. They can also be deployed from the International Space Station, after having been transported there as cargo.

Small satellites offer vast opportunities in terms of speed and flexibility of construction. Whereas conventional large satellites may take years if not decades to move from drawing board to operational mission, very small satellites can be built very quickly. By way of illustration, it took Planet Labs just nine days to build two CubeSats in early 2015.

Small satellites are finding use across a wide range of applications – from Earth observation and communications to scientific research, technology demonstration and education, as well as defense. The fast deployment of small satellites is taking place as technology for traditional, much larger multifunctional satellites keep evolving. Since the launch of the first CubeSat in 2002, the number of very small satellites in operation has increased at a remarkable rate. In 2014, 158 nano- and microsatellites were launched, i.e. an increase of 72% compared to the previous year.[138] It is expected that between 2014 and 2020 more than 2 000 nano- and microsatellites will require launching worldwide.[139]

The increased use of off-the-shelf components as opposed to more expensive space-qualified products is creating a new world market for space systems and services. Developers are increasingly turning to complex system architectures, to get small satellites to interact in constellations. In 2013, the firm Skybox Imaging launched its first high resolution imagery satellite as part of a planned constellation of 24 small satellites to provide continuously updated and cheaper satellite imagery. Likewise, Planet Labs launched the “Flock 1” constellation with 28 nano-satellites early 2014.

CubeSats are very popular in universities, as technology demonstrators. They emerge as low-cost educational satellite platforms and have gradually become the standard for most university satellites. As of spring 2014, almost a hundred universities worldwide are pursuing CubeSat developments.[140] At the educational level, university small satellites can help students put into practice their engineering and scientific competences much faster.

Although large satellites in geostationary orbits remain key pillars for the telecommunications and meteorological infrastructure, small satellites used in large constellations in lower orbits promise ground-breaking improvements, for example in Earth observation. Microsatellites provide the capacity for around-the-clock observation. A case in point is the monitoring of the health of oceans and inland waters. Satellite constellations can be used for monitoring illegal fishing and improving marine domain awareness to combat criminal activities. Similarly on land, constellations could contribute to monitor agricultural crops, improve crop productivity, and keep track of deforestation.

Small satellites have become very attractive in the past five years, due to their lower development costs and shorter production lead times. Small satellites are thus attracting a lot of interest around the world, and many countries have decided to fund their first space programs with the development of small satellites. Over the last decade, the Ukrainian launcher Dnepr has launched 29% of satellites of 11-50 kgs, ahead of India’s Polar Satellite Launch Vehicle.

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[138] FAA (2015), 2015 Commercial Space Transportation
Forecasts, FAA, Washington, DC.

[139] http://www.sei.aero/eng/papers/uploads/archive/SpaceWorks_Nano_Microsatellite_Market_Assessment_January_2014.pdf.

[140] OECD (2014d), The Space Economy at a Glance 2014, OECD Publishing, Paris, http://dx.doi.org/10.1787/9789264217294-en.

A perennial trade-off between size and functionality: The smaller the satellite, the fewer instruments it can carry and the shorter its life expectancy because of the smaller amount of on-board fuel. Larger satellites still have a major role to play, as they carry more instruments and have longer life-times, which allows important commercial and governmental missions to be carried out. However recent advances, both in miniaturization and satellite integration technologies, have dramatically reduced the scale of the trade-off.[141]

Dealing with high business risk: Increasingly, nano- and microsatellites are being launched in large clusters, and a single failure (at launch or on deployment) can lead to substantial losses. A recent failed Antares rocket launch led to the loss of over 30 satellites.[142]

Debris and collisions: the growing environmental threat: The main environmental concern is that fast deployment of small satellites will heighten the risk of collision in some already crowded orbits, creating a cascading effect as more debris generates ever greater risk of further collisions. According to international guidelines on space debris, most satellites should either move to a 'graveyard' orbit or re-enter the atmosphere when they reach their end-of-life operations. However, by construction, very small satellites do not have the on-board fuel for deorbit maneuvers.

4.4 Resources from the space

Scarcity of resources on the Earth and advancements in space technologies have turned attentions into space for obtaining energy and raw materials beyond the Earth into the space. Among a number of experiments and attempts three appear to be more feasible in the next decades to come, including moon mining, asteroid mining and solar energy from space.

Mining the moon

Over the last decade countries like the US, Russia and China have reiterated their interest for building a based on the Moon. A robotic rover was landed by the Chinese Lunar Exploration Program in December 2013. In January 2014, NASA also announced a programme called Lunar CATALYST -- or 'Lunar Cargo Transportation and Landing by Soft Touchdown' -- that will help commercial companies to develop lunar transportation capabilities. Shortly after in April 2014 Russia launched the Moon 'forever' program.

Besides national governments, private companies like Moon Express and SpaceIL are interested in the Moon. In part, such pioneers are being stimulated on by the Google Lunar X Prize. Launched in September 2007 this program offers $30 million to the first private company to land a robot on the Moon, travel 500 meters, and send two high-definition "Mooncasts" back to the Earth. Thirty-three teams initially registered for this grand challenge, with 16 teams are still on board. Three teams, including SpaceIL, Moon Express and Synergy Moon, have secured a contract to launch their spacecraft. They are now authorized to move forward in the challenge. [143]

Commercial organizations are interested in the Moon as a potential source of raw materials. In particular, our lonely satellite is thought to harbour substantial deposits of cobalt, iron, gold, palladium, platinum, titanium, tungsten and uranium. Since 2009, NASA experiments have also confirmed the presence of water on the Moon, which could prove critical in supporting long-term human occupation.

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[141] https://www.nasa.gov/sites/default/files/atoms/files/small_spacecraft_technology_state_of_the_art_2015_tagged.pdf
[142] https://www.spacefoundation.org/sites/default/files/downloads/The_Space_Report_2015_Overview_TOC_Exhibits.pdf
[143] http://lunar.xprize.org/

However, the most valuable deposit may be a gas called helium-3 that could fuel future nuclear reactors.[144]

Asteroid mining

Asteroid mining is about to be a reality soon. Spacecraft has been deployed to the International Space Station by the Planetary Resources. In the next few years, the Washington-based asteroid mining company is expected to launch a series of ambitious but capable probes. Majority of asteroids orbit in a belt between the planets Mars and Jupiter. These objects are remnants of previous formation of the solar system. Asteroids are composed of a fair amount of trace elements which are economically valuable like Gold, Platinum and Rhoduim. 10 meter (yard) of an S-type asteroid is composed of about 1,433,000 pounds of metal and about 110 pounds of rare metals such as platinum and gold. NASA's spacecraft was scheduled to launch in September 2016 to the asteroid Bennu in October 2018 to carry out studies on it and returning with sample materials for further analysis. The mission is expected to develop important technologies for the exploration of asteroids. These technologies will benefit all interested parties in the exploration and mining of asteroids.[145] The result of the exploration will set the tone for further exploration and possible mining of asteroids in the future. According to NASA, the obstacle to asteroid mining and exploration is the absence of experience in mapping and analysis of the resources in asteroids for extraction.

Space-based solar panels for energy generation

Innovations in solar energy, such as Space-based solar powers (SBSP), have in recent years evolved from a futuristic fantasy into a plausible reality. SBSPs are of importance because energy generated from space overcomes all the problems faced by regular solar power generation (cloudy days, nights and space the panels cover). Placing solar panels into space, would allow the panels to receive constant energy from the sun, no weather changes and about 27% brighter light reaching the panels. Wireless power transmissions have also evolved overtime and have solved the problem associated with transmitting power directly from space. The cost of R&D and capital requirement for SBSP is too great, thereby reducing the possibilities of large scale production. However, private space companies such as SpaceX have made progress by aiming to launch objects into space at a fraction of the current cost. The introduction of disruptive technologies and more investment from governments could go a long way to making SBSP a major source of energy by 2020.

In 2009, renewable energy company SolarEn planned to launch solar panel laden satellite into orbit to capture the rawest forms of radiation from solar from about 22,000 miles above the Earth surface. Rocket technologies can be used to transport the solar technology into space; however, the most intriguing part is transferring the energy collected into power grids on Earth.[146]

Japan's Aero Exploration Agency (JAXA) has in a long time been the world's biggest researcher in space-based solar power technologies. A series of pilot projects have been planned by scientist from the agency with the aim of building a 1-gigawat space-based solar panel generator within the next 25 years. The energy output of the proposed project will be equal to the largest conventional power plants available today. The generator with panels will absorb and also reflect most of the solar energy that falls on the Earth. The design of the project includes two giant mirrors that are programmed to bounce

[144] http://www.explainingthefuture.com/resources_from_space.html
[145] https://www.nasa.gov/content/goddard/new-nasa-mission-to-help-us-learn-how-to-mine-asteroids
[146] http://www.energytrendsinsider.com/2009/04/30/sci-fi-meets-cleantech-space-based-solar-energy-becomes-a-reality/

sunlight onto the space-based solar panels throughout the day. According to estimates, a well-designed space array could generate 40 times the energy from conventional sources.[147]

A paper has been published in the New Space journal by Lewis-Weber based on the earlier work of John C. Mankins with the idea of mounting self-replicating solar panels in space to generate energy. The proposed panels would build canopies of themselves autonomously on the moon's surface. The panels would collect the energy of the sun by entering into the Earth's orbit and wirelessly beamed onto the Earth. The cost of sending a meaningful number of solar panels into space would be astronomical. The idea is to send a single panel with an embedded technology to replicate itself in space. The challenge with the self-replicating solar panels is that self-replicating robots do not yet exist and such a designs is a tough engineering challenge although progress are currently been made by scientist in building simple self-replicating machines.[148]

4.5 Space technology and global/national security

The position of the US as a space power grows less unique as more countries around the world invest in space every year. 58 countries spent over $10 million on space in 2013, compared to 37 in 2003. 22 additional countries have plans for future space investment, bringing the total to 80 countries with space programs and ambitions. This trend indicates that governments see space as a valuable investment in support of social, scientific, economic, and strategic goals. It is also a signal that access to space is becoming easier and more attractive, and the era of space dominance enjoyed by traditional economic powers is rapidly coming to a close. Although the United States remains the world's largest space program, its share of global spending is at its lowest point in history: 54% in 2013 compared to 75 percent in 2000.[149] [150]

The use of space has become a crucial part of national security and international stability. Today the existence of a national space program is symbolic of a nation's standing in the regional security setting and also an integral part of military calculations in international security. The use of space is not only a crucial part of national security but also for a country's economic security. With space technology becoming more widespread, security concerns over dual-use and intent have increased. To mitigate such concerns international cooperation on an agreed legal framework should be developed. While a draft treaty has been presented by China and Russia, there currently is no formal international treaty banning the placement of weapons in space.[151] Modern weapons can be mounted on different platforms and spectacularly complex. The following space technologies can be mentioned with relevance to global and national security, which is expected to become an important issue in the next few years to come.

New air platform technologies: Defense Advanced Research Agency (DARPA) is developing a cluster of high precision and accurate navigation and timing technologies that can function without global positioning system (GPS) while facilitating cooperative and coherent effects from dispersed systems. DARPA has plans to develop and fly prototypes of X-plane to signal the possibilities of new air platform technologies. New approaches are currently under development by DARPA to launch satellites into orbit on short notice. The new approaches are expected to help reduce cost, speed up the time for launching

[147] http://global.jaxa.jp/article/interview/vol53/index_e.html
[148] http://www.popsci.com/for-nearly-infinite-power-build-self-replicating-solar-panels-on-moon
[149] Profiles of Government Space Programs. Rep. 2014 ed. Euroconsult: 43:9.
[150] http://harvardkennedyschoolreview.com/space-technology-trends-and-implications-for-national-security/
[151] http://en.asaninst.org/contents/space-technology-development-effects-on-national-security-and-international-stability/

of satellites and will make use of reusable first stage and space plane systems with the potential of launching satellites from any location within a 24 hour notice at a fraction of the current cost of launching satellites. This is important for the US because, it is relies on space all essential security missions.[152]

Long March-9 Manned Lunar Booster: China's quest to meet its long term space objectives has led it to develop a 3,000 ton takeoff thrust rocket. This vehicle technology will be able to carry up to 5 men to the moon. The technology has been research for a number of years, with scientist visualizing it to be with a diameter of 8 meters and equipped with the ability to carry 100-ton payload into the Earth's orbit.

Wide area surveillance: Wide area surveillance is one application of space technology that has the most to contribute to national security. Countries use this technology to survey its open spaces in large territories e\which has limited access routes to track changes and movements. Canada's Directorate of space Development exploits space-based information which is collected from emerging commercial satellites to contribute to the wide area situational awareness along its cost. The Canadian government is developing capabilities to provide high quality cueing, and classification, motion detection information over its territory where Canadian forces may be deployed.

Radarstat-2: This is a key space technology which functions as a sensor and are been developed to be used by the Canadian government. Through the application of space assets, there is a possibility of regularly monitoring approaches by ships 500 to 1000 km on the ocean. This gives the responsible agencies ample time to respond to intercept questionable vessels.[153]

Integrated Satellite Targeting of Polluters (I-STOP): Environmental treat such as bilge cleaning (illegal fishing), illegal immigration, drug and arms smuggling is of great concern. Timely access to accurate space assets and derived data is of utmost importance. Space technologies offer a cost effective means of tracking changes overtime. Integrated Satellite Targeting Polluters (I-STOP) provides operational monitoring of marine polluters to support environment enforcement activities.[154]

The last, but not the least is the issue of space junk, which may create future environmental and security problem. There are efforts to collect the waste from the space. The Japanese Space Agency has recently launched an experimental space scavenger into orbit with the aim of gathering information about the possibility of getting rid of cosmic junk which are caused by over half a century of space exploration. According to NASA, there are currently, more than 500,000 pieces of "space junk" are circling the Earth. Millions of these junk which are remnants of old rockets and satellites are too tiny to be captured on tracking radar used by NASA. This has led to growing concerns among several companies and space agencies, as the floating objects have a high potential for major collision. There was a need to find ways of getting rid of the unwanted space debris. Researchers at JAXA in collaboration with Nitto Seimo company, a Japanese fishing net company responded by designing and successfully launching the Kounotori 6 (HTV-6) spacecraft in December 2016. The spacecraft is expected to deliver a large magnetic tether made from thin wires of aluminum and stainless steel and has specifically been designed to direct space debris to the Earth's atmosphere. According to JAXA, the success of the experiment will result in another test, where the tether will be attached to a specific debris.[155]

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[152] http://www.darpa.mil/attachments/DARPA2015.pdf
[153] http://www.athenaglobal.com/pdf/space_&_national_security.pdf
[154] http://www.athenaglobal.com/pdf/space_&_national_security.pdf
[155] https://www.rt.com/news/369846-space-junk-collector-japan/

5. WATER RESOURCES AND SUSTAINABILITY

5.1 Growing consumption of water

A growing world population and increasing economic development will enlarge global demand for water along with food and energy with further pressures on the natural environment. Continued degradation and erosion of the natural environment is expected to occur over the coming decades, which, when taken together with climate change, raises the risk of irreversible changes that could endanger two centuries of rising living standards.

Water demand outpaced population growth by a factor of more than two during the twentieth century. Based on continuing socio-economic trends and no new policies to improve water management (a baseline scenario), water demand is projected to increase by 55% globally between 2000 and 2050. Agriculture will remain the largest consumer of water, but sharp increases in demand are expected from manufacturing (+400%), electricity generation (+140%) and domestic use (+130%). This growth is driven by increased demand from OECD non-member economies; by contrast, water demand across the OECD area is expected to fall in line with continuing efficiency improvement in agriculture and investments in wastewater treatment.[156]

Groundwater is being exploited faster than it can be replenished across many parts of the world – the depletion rate more than doubled between 1960 and 2000 – and is also becoming increasingly polluted. By 2050, groundwater depletion may become the greatest threat to agriculture and urban water supplies in several regions. The quality of surface water in many OECD non-member economies is also expected to deteriorate, through nutrient flows from agriculture and poor wastewater treatment. The consequences will be increased eutrophication, biodiversity loss and disease. [157]

Some 3.9 billion people – over 40% of the world's population – are likely to live in river basins under severe water stress by 2050, especially in northern and southern Africa, and South and Central Asia. At the same time, 1.6 billion people – almost 20% of the world's population – are projected to be at risk from floods. The economic value of assets at risk is expected to be around USD 45 trillion by 2050, a growth of over 340% from 2010. [158]

5.2 Climate change, human activity and impacts on water resources

The Earth's water is continually cycled between the reservoirs oceans, atmosphere and land, whereby oceans contain about 96% and only about 3% is fresh water on land.[159] Water remains at the core of the food, environment, climate, health, energy and economy nexus. Freshwater shortages hit agriculture and food production, human and animal health, most industrial sectors, change the environment and have important economic consequences.

Primary production is responsible for 70% of freshwater use. The development of the bioeconomy may pose additional strains on fresh water supplies, which are also challenged by climate change. It is vital to

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[156] OECD (2012b), Environmental Outlook to 2050: The Consequences of Inaction, OECD Publishing, Paris, http://dx.doi.org/10.1787/9789264122246-en.
[157] OECD (2012b), Environmental Outlook to 2050: The Consequences of Inaction, OECD Publishing, Paris, http://dx.doi.org/10.1787/9789264122246-en.
[158] OECD (2012b), Environmental Outlook to 2050: The Consequences of Inaction, OECD Publishing, Paris, http://dx.doi.org/10.1787/9789264122246-en.
[159] http://water.usgs.gov/edu/earthhowmuch.html

develop a better understanding and monitoring capability of the global water cycle covering precipitation, evaporation and evapotranspiration, soil moisture, river discharge, surface and groundwater storage. Drinking water distribution infrastructure should be improved to improve efficiency and reduce loss of water through leakage.

There is an important need to monitor water quality, including combined impacts of chemical pollutants leached to ground and surface waters. There is a real demand for rapid diagnostic tests of water and food quality including biological parameters such as the presence of EHEC, which is a strain of the E. coli bacterium. Emerging technologies for rapid sequencing of nucleic acids with sensors based on nanotechnology can fill a gap here. Also, chemical pollutants (such as pesticide residues), hormone and medicinal drug residues, and their combined impact, require further attention in order to find efficient, proactive procedures to stop the impact of chemicalization.

Marine coastal regions are especially significant because about 70% of the world's population lives near the coast. Wetlands and tidal wetlands (salt marshes) are complex ecosystems continually threatened by factors such as hydrological changes in the water table, urbanization and industrial development, mining, agriculture and marine recreational activities. Exploitation of tar sands for mining is likely to have a serious negative effect on wetland ecosystems due to the destruction of the peat marshes covering the oil sands in wetlands. In addition, mining alters the flow of water in a wider area, thus changing the hydrological balance. Major persisting problems are loss and degradation (especially of biodiversity and water quality) as well as intrusion of saltwater which impacts both the chemistry and microbiology of water supplies. Salt marshes, which play a large role in the aquatic food web, in the delivery of nutrients to coastal waters and in coastal protection are degrading. Such problems require integrated management approaches, for example, controlling water flow, vegetation and sediment accumulation jointly in salt marshes.

More research is required to better monitor and understand wetland processes in order to properly manage economic activities and eliminate health risks. Harmful Algal Blooms (HABs), waterborne and vector-borne diseases can develop under critical environmental conditions, especially in high levels of nitrogen and phosphorus pollution, and threaten human health. Diseases related to wetlands are cyanobacterial toxins in the algal blooms[160] diarrhoea, schistosomiasis[161], Vibrio bacterial infections[162] and mosquito-borne diseases. Actions to reduce HABs have simultaneous environment and health benefits.

In the time span of 2015 to 2030, stress on the water cycle, including on water quality, is likely to increase markedly due to climate change and conflicts in the water-energy-food nexus. Advanced technologies to manage efficient water use for agricultural irrigation and inland aquaculture as part of integrated water management systems are important. A focus on resilience is needed to be able to deal with possibly abrupt changes in environmental, political and economic factors. This requires appropriate indicators of resilience, and improvement of monitoring of essential variables, exploiting all available data and information sources (Earth Observation, in-situ, surveys and citizen networks) and by developing the necessary IT standards to process large heterogeneous data sets**.**

Traditional approaches to solve specific local water issues (e.g. water distribution and wastewater treatment) are complemented by efforts to improve systemic understanding of the water-food-energy-

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[160] http://www.who.int/water_sanitation_health/diseases/cyanobacteria/en/
[161] http://www.who.int/schistosomiasis/en/
[162] http://www.who.int/schistosomiasis/en/

climate and also health nexus. It is expected that water monitoring will improve under the impetus of concerns of the United Nations to measure progress towards the Sustainable Development Goals.

5.3 Transboundary aspects of water

On a global scale, pressures from human activities have weakened the ability of aquatic ecosystems to perform essential functions, which is compromising human well-being and sustainable development. The complex interactions between mankind and aquatic resources can be considered within several major concerns, including: freshwater shortage; pollution; overfishing and other threats to aquatic living resources; and habitat and community modification.[163]

Transboundary pollution has a more severe effect than any other concern, and also has by far the gravest impact on human health. Pollution is mainly concentrated in inland and nearshore systems. The most critical transboundary pollution issue is suspended solids, causing the greatest impact in Latin America, Southeast Asia and Sub-Saharan Africa. Large-scale land-use changes, including infrastructure development, deforestation and agriculture, have increased the sediment load of international waters. Eutrophication has its most severe transboundary impacts in Europe & Central Asia and Northeast Asia. Agricultural run-off was identified as the primary cause, but the tremendous growth of aquaculture in several East Asian regions has also become a factor. Oxygen-depleted zones, an extreme result of eutrophication, are now present not only in enclosed seas, such as the Baltic Sea and the Black Sea, but also in large coastal areas which have internationally important fisheries. Globally, harmful algal blooms are considerably more widespread and frequent than they were a decade ago, a situation that is expected to further deteriorate due to the increased application of agricultural fertilizers, especially in Asia and Africa.

Microbial pollution is of particular concern in the freshwater ecosystems of tropical developing countries, but is also widespread in Large Marine Ecosystems (LMEs) with densely populated coasts. Microbial pollution is projected to increase due to population growth and urbanization outpacing the provision of sewage treatment facilities. Chemical pollution is also an issue of global importance, inflicting moderate to severe impacts in more than half of the regions assessed. Overall, pollution is slight to moderate in most of the LMEs, with severe pollution limited to localized hotspots usually found in close proximity to point sources of pollution, such as sewage and industrial effluent outfalls and river mouths, as well as in areas with limited water circulation, such as semi-enclosed bays. Sea-based pollution is most prevalent in LMEs with a high concentration of oil and gas industries, and shipping activities.

The over abstraction of water resources is resulting in the drying up of rivers, lakes and aquifers, leading to water shortages in many regions. For Sub-Saharan Africa, it is undoubtedly the top priority. In arid regions, in particular, water diversions lead to significant reductions in crucial low flow periods. These changes adversely affect the productivity of downstream wetland ecosystems and subsequently the provision of their goods and services. The overexploitation of water resources and changes in river basin hydrodynamics are largely attributed to the agricultural sector, principally as a result of water impoundment by dams and groundwater abstraction for irrigation, deforestation and drainage of wetlands to expand agricultural areas and inappropriate agricultural land-use practices. About 70% of all abstracted water is utilized by irrigated agriculture, and since many developing countries expect

[163] http://www.unep.org/dewa/giwa/publications/finalreport/executive_summary.pdf

agriculture to be the main sector driving economic growth, water scarcity is likely to become an even greater problem in the future.

Salinization was revealed by the regional assessments to be more widespread and severe than is generally perceived. Reduced stream flow, inappropriate irrigation practices and over abstraction of groundwater have increased the salinity of freshwater throughout the world. As a result, agricultural land is becoming too saline to support important crops, and salinization has made many aquifers unsuitable as a source of water for drinking and certain economic purposes.

With more than 200 million people relying on fisheries for their livelihood and over 1 billion people depending on fisheries for their protein supply, the world cannot achieve the goal for hunger eradication without improving fisheries management. Overexploitation of living resources is assessed as severe. On a transboundary scale, large commercial fishing fleets are the major contributors to the problem, exploiting specific transboundary straddling and migratory stocks. A common environmental impact from overfishing is 'fishing down the food web', whereby fishers exhaust large predator populations, distorting the food web and forcing fishers to target smaller, less valuable species. Aquaculture, which has been expanding rapidly for more than a decade, will supply an ever-increasing share of the global fish market. The question remains whether aquaculture will be undertaken in a sustainable manner.

Water infrastructure itself is one of the largest drivers of habitat modification in the world's rivers and a major factor affecting lake habitats. Besides that direct conversion of habitats for urban and industrial development, mariculture, dredging, unsustainable harvesting, poor land use practices in adjacent drainage basins, and pollution are among the major causes of coastal and marine habitat modification.

All these factors increase stress on the limited water resources and bring political conflict on the agenda as a serious concern for transboundary waters. A total of 145 nations include territory within international basins, and 21 countries lie entirely within international basins. While most basins are shared between just two countries, there are many basins where this number is much higher. There are 13 basins worldwide that are shared between 5 and 8 riparian nations. Five basins, the Congo, Niger, Nile, Rhine and Zambezi, are shared between 9 and 11 countries. The river that flows through the most nations is the Danube, which travels within the territory of 18 nations.[164] Among the three large international water conflicts are between China and India on the Brahmaputra River; between Egypt, Ethiopia and Sudan on the Nile River; and between Turkey and Iraq on the Tigris River.[165] The broad spectrum of water disputes makes them difficult to address. International organizations play the largest role in mediating water disputes and improving water management.

5.4 New technologies for sustainable water use

A number of technologies are being developed, which provide opportunities for the sustainable use of water resources. They aim at addressing the most important challenges including water filtration,

[164] http://www.un.org/waterforlifedecade/transboundary_waters.shtml
[165] https://www.geopoliticalmonitor.com/three-international-water-conflicts-watch/

purification, desalination, monitoring, irrigation and processing. Some of the most prominent examples are given below.[166] [167] [168]

Nanotechnology filtration: According to the World Health Organization, 1.6 million people die each year from diarrheal diseases attributable to lack of safe drinking water as well as basic sanitation. Recent water purification systems using nanotechnology remove microbes, bacteria and other matter from water using composite nanoparticles, which emit silver ions that destroy contaminants. It is a sign that low-cost water purification may finally be round the corner – and be commercially scaleable.

Membrane chemistry: Membranes, through which water passes to be filtered and purified, are integral to modern water treatment processing. The pores of membranes used in ultrafiltration can be just 10 or 20 nanometres across – 3,000 times finer than a human hair. Recent breakthroughs have been credited with forcing down the cost of desalinated water from $1 per cubic meter to between $0.80 and $0.50 over five years. New ceramic membranes are helping to make treatment more affordable.

Seawater desalination: seawater desalination is still extremely expensive, with reverse osmosis technology consuming a vast amount of energy: around 4 kilowatt hours of energy for every cubic meter of water. One solution is biomimicry - mimicking the biological processes by which mangrove plants and euryhaline fish (fish that can live in fresh briny or salt water) extract seawater using minimal energy. Another new approach is to use biomimetic membranes enhanced with aquaporin: proteins embedded in cell membranes that selectively shuttle water in and out of cells while blocking out salts.

Smart monitoring: In developing countries alone, it is estimated that 45m cubic meters are lost every day in distribution networks. Leaks are not only costly for companies, but increase pressure on stretched water resources and raise the likelihood of pollutants infiltrating supplies. New monitoring technologies help companies to ensure the integrity of their vast water supply networks. Electronic instruments, such as pressure and acoustic sensors, connected wirelessly in real time to centralized and cloud-based monitoring systems will allow companies to detect and pinpoint leaks much quicker.

Intelligent irrigation: Considering that approximately 70% of the world's freshwater is used by the agricultural industry, innovation in irrigation is considered to be crucial for sustainable water systems. Applying a more intelligent approach to water management by deploying precision irrigation systems and computer algorithms and modelling is already beginning to bring benefits to farmers.

Wastewater processing: Engineering still has its place, however. Many people living in urban areas, even in advanced economies, still do not have their sewage adequately treated and wastewater is often discharged, untreated, into rivers and estuaries or used as irrigation water. New technologies are promising to transform wastewater into a resource for energy generation and a source of drinking water. Modular hybrid activated sludge digesters, for instance, are now removing nutrients to be used as fertilizers and are, in turn, driving down the energy required for treatment by up to half.[169]

5.5 Towards a circular economy: Water

The circular economy, which is a concept that has a lot in common with green economy and industrial ecology models, is seen by many as a huge opportunity for innovation, job creation and economic

[166] https://www.theguardian.com/sustainable-business/new-water-technologies-save-planet
[167] http://www.oecd.org/sti/nano/47601818.pdf
[168] https://www.oecd.org/sti/ind/oecd-shipbuilding-workshop-kokubun.pdf
[169] http://www.oecd.org/env/resources/42349741.pdf

development: estimates indicate a trillion dollar opportunity in this area encompassing a technosphere (reuse and service life extension of manufactured stock, material recycling) and a biosphere (organic materials including those in manure, mining waste).

A circular economy of manufactured stock (infrastructure, buildings, equipment and goods, materials), builds on local or regional reuse and on repair and remanufacturing strategies, including retrofitting existing structures. Compared with standard manufacturing, these activities have a high potential for both local job creation and waste prevention, using small amounts of material, energy and water. Among the main impacts of a circular economy are improved health through reduced transport needs, massive annual GHG emission reductions, and the creation of a diversity of local jobs. The gains from an environmental and societal perspective of reuse and service-life extension are a higher resource efficiency and resource security, combined with substantial reductions in waste and contamination. Doubling the service-life of goods reduces resource consumption (energy, water, material) and waste volumes by half; remanufacturing, compared to manufacturing, prevents up to 90% emissions and is 40% more cost effective, even if it is much more labor intensive. In addition; keeping people in meaningful jobs or activities has health benefits, as unemployment is known to have repercussions for people's physical and mental health.[170]

Water, which is at the heart of a circular economy, can be used more efficiently by closing loops in industrial applications as well as by sufficiency approaches (e.g. drip irrigation in agriculture). But some water cycles have biophysical limits, e.g. through accumulation effects of toxic substances or salt.

Key challenges in the circular, bio and blue economy include: reducing the accumulation of toxic substances and the release of pathogenic agents, promoting the high efficiency recovery of materials from alloys or mixtures (e.g. precious elements used in nanotechnology applications, recovery of components), and reducing the dissipative usage of materials**.** Particularly important are the operation and maintenance of infrastructure, including the remanufacturing / upgrading of ageing infrastructure; upgrading the stock of existing buildings to high energy efficiency (retrofitting), recycling materials; and the low-emission deconstruction of tall buildings and infrastructure. A circular economy also builds on the intelligent management of stocks (capital) at an appropriate scale (local to global), based on functionality, with a strong focus on using existing resources. Stewardship and an attitude of caring also apply to managing natural capital, cultural capital (both physical and intangible) and human capital (e.g. through education, health).

The shift to a circular economy in order to exploit its potential for jobs and dematerialized growth demands a shift in the mind-set of policymakers. Sustainable taxation, for instance, has cross-cutting implications, also for developing better materials and recycling processes. By taxing non-renewable resources (fuel, material) instead of labor, labor-intensive activities (including recycling) can become more competitive in comparison with resource intensive ones.[171]

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[170] http://www.oecd.org/employment/mental-health-and-work-sweden-9789264188730-en.htm
[171] Stahel, W.R. (2013). Policy for material efficiency—sustainable taxation as a departure from the throwaway society; Published 28 January 2013 doi: http://dx.doi.org/10.1098/rsta.2011.0567 Phil. Trans. R. Soc, 13 March 2013 vol. 371 no. 1986 20110567.

Global and Local STI Trends

A desk scan for the South Africa Foresight Exercise for Science, Technology and Innovation 2030

March 2017

Contents

1 Introduction

This document presents the output of a limited desk scan of global and local science, technology and innovation (STI) trends, conducted in early 2017, to serve as an input to the national STI Foresight initiative which is being undertaken by the National Advisory Council on Innovation (NACI).

The desk scan did not review comprehensively all possibly relevant STIs. Nevertheless, it is believed that the information contained herein will be of value to the Foresight exercise.

The document consists of a range of extracts from other published material, collated into a single document in a coherent sequence and with an organising structure. Where necessary, the extracts were lightly edited to improve the flow. In general, new content has not been written.

The bibliography which is provided at the end of the document consists of two parts:

- A primary bibliography, which lists references from which extracts have been used directly to produce the present document.
- A secondary bibliography, which lists references which are referred to by the extracts which make up the content of the present document.

2 Digital

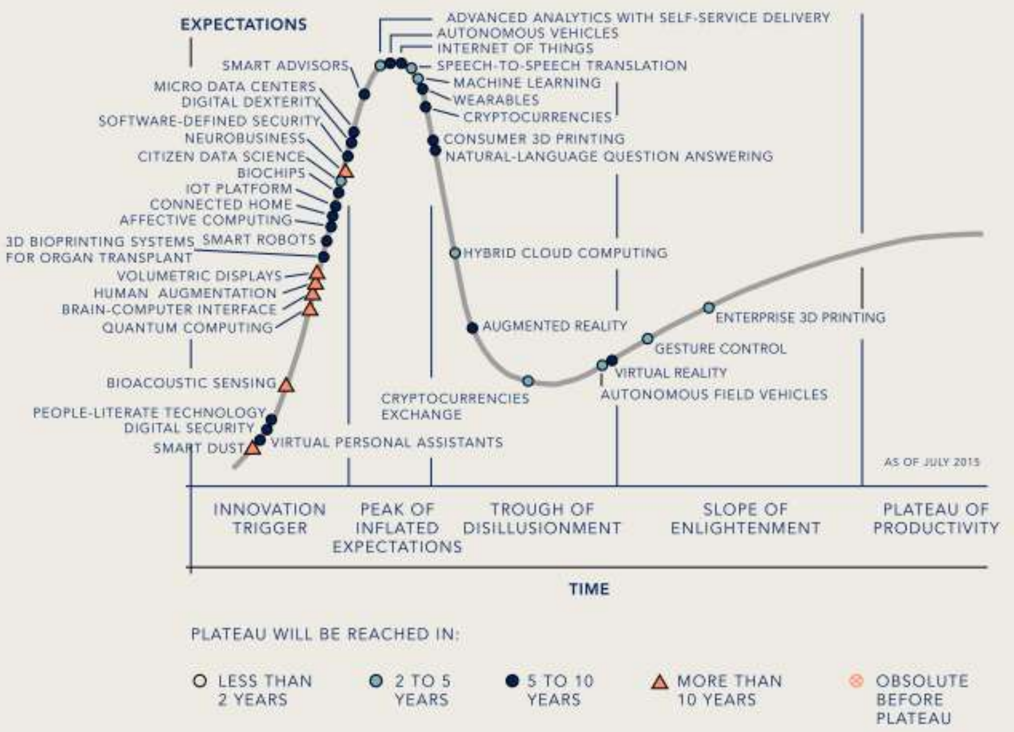
2.1 General

2.1.1 Digital technologies hold great promise

[Extracts from [1], pp 34-39]

The growing maturity and convergence of digital technologies are likely to have far-reaching impacts on productivity, income distribution, well-being and the environment by 2030. These impacts will vary across industries, countries and sections of the workforce. Given how ICTs are in different stages of maturity and evolve at different paces and with different uncertainties, it is difficult to forecast with precision when and how impacts will come. Expectations of technologies often tend to be exaggerated well in advance of their eventual adoption and dissemination (Figure 19 below). In fact, the impacts of digital technologies on productivity gains so far fall short of those seen in earlier industrial revolutions (Gordon, 2012; Cowen, 2011). But this is likely to change over the next 10 to 15 years, as big data and processing power improve real-time measurement of business activities, lower equipment costs, bring faster and cheaper business experimentation, and digitalisation enables innovations to be replicated with greater speed and fidelity (Brynjolfsson and McAfee, 2011).

FIGURE 19: Hype cycle for emerging technologies.
Source: Gartner, 2015.



By 2030, firms will be predominantly digitalised, enabling product design, manufacturing and delivery processes to be highly integrated and efficient. Additive manufacturing technologies will allow certain products to be tailored to specific user needs using computer-assisted drawing software. Placing an order will be a matter of uploading a file providing the desired specifications, which will trigger automated manufacturing and delivery processes, possibly involving different companies that can more easily coordinate thanks to digital technologies. The Internet of Things, big data analytics, artificial intelligence and machine learning tools will enable the emergence of smart machines that will be increasingly adjustable through sensor technologies, cheap computing power and the real-time use of algorithms (OECD, 2015ca). Some of these digital technologies are described in more detail in the Technology Trends section.

The costs of equipment and computing will continue to fall, while the rise of open source development practices will create further communities of developers, not only in software but also in hardware and “wetware”, e.g. in do-it-yourself synthetic biology. There will be greater opportunity for entrants – including individuals, outsider firms and entrepreneurs – to succeed in new markets. Pattern-recognition technologies, such as big data and machine learning, will enhance capabilities for assessing user needs and overall demand for innovation. The risks and time-spans in product development and market launch are expected to decrease, spurring additional developments. Innovation-related production costs will fall in key industries, with cloud computing and 3D printing services providing platforms for new firms. Product distribution costs will continue to fall, reducing the cost of launching new products and services (OECD, 2015d). These developments could also provide emerging economies with opportunities to accelerate technological catch-up, possibly allowing them to leapfrog to productivity levels closer to those observed in OECD countries.

The services sector has already become a dynamic part of the economy, enabled by digital technologies that have helped to create new and more efficient businesses, boosted productivity growth, and facilitated international trade in services. Manufacturing in OECD economies increasingly thrives on services inputs for value creation, and the differences between manufacturing and services have become increasingly blurred. A large part of future growth in production is expected to come from so-called “manu-services”, which involve combining advanced manufacturing with a range of different services. The growing and complex interactions between manufacturing and services will call for a more integrated view on manufacturing and services in company strategies, as well as in policy discussions (OECD, 2015c).

Without digital technologies, the increasing international fragmentation of production in “global value chains” (GVCs) would not have been possible: manufacturing GVCs cannot function as efficiently without digitally-enabled logistics, telecommunications, and business services. Within these GVCs, more labour-intensive activities have typically been offshored from OECD economies to economies with low cost labour. But the extent to which this will continue in the future is uncertain. Wage increases, e.g. in Eastern China, are quickly eroding the labour cost advantage of emerging economies, while long and complex GVCs have exposed companies to a growing degree of supply risk in case of adverse shocks. In addition, management, logistical and operational problems, including the protection of IPR, resulted often in significant ‘hidden’ costs (i.e. costs that were not taken into account in the decision to offshore) and have in some cases made offshoring less or not profitable (OECD, 2015c). Taken together, these supply-side factors may motivate some companies in some industries to “re-shore” activities closer to their main markets in OECD countries.

Still, in addition to their lower labour costs, emerging economies such as China and India are the world’s most populous countries and have high GDP growth, which make them increasingly important markets for firms in many industries. A new middle class is fast-emerging that will lead to a rise in consumption of basic consumer products and other product categories. These demand-side factors mean emerging economies are likely to remain favoured locations for production activities, reducing the likelihood of widespread re-shoring to OECD economies (OECD, 2015c). Furthermore, income gains and changing consumption patterns mean that manufacturing exports from China, India and other Asian economies are expected to climb up the global value-added ladder, while significant shifts towards services will see China and other emerging economies gain large shares in services trade at the expense of OECD economies in the long-run (Johansson and Olaberria, 2014).

The decreasing cost of computing power and other advances in digital technologies are already disrupting labour markets and making workers redundant (see Brynjolfsson and McAfee, 2011). Computers have begun displacing labour when it comes to explicit (codifiable) routine tasks that follow precise and well-understood procedures such as clerical work (e.g. accounting) and some physical operations in production lines. For the time being, tasks that are hard to describe as a set of steps and are bounded to particular circumstances remain impervious to automation (Autor, 2015). These tasks are more abstract in nature and often involve problem-solving capabilities, intuition, creativity and persuasion. However, advances in machine learning and artificial intelligence are expected to expand the capabilities of task automation. Recent research suggests that almost half of total employment could be at high risk (with a probability of more than 70%) of becoming automated over the next two decades (Frey and Osborne, 2013). This probability is based on the degree to which the job requires social intelligence, creativity, and perception and manipulation skills.

If these predictions prove correct, then a large portion of the workforce will need to be retrained. Depending on how quickly economies are able to create new jobs to replace those that have been lost, there may still be too few jobs, perhaps on a permanent basis (technological unemployment). Greater work-sharing and a reduced working week could help distribute work more evenly, but would need to guarantee a living wage (Skidelsky, 2013). Work may also become more fragmented, with an increasing number of workers doing lots of different part-time jobs – the rise of the so-called “gig economy”. The growth of online platforms that link a vast pool of freelancers, who are physically based in different parts of the world, with companies inviting them to bid to work on a wide variety of tasks, is enabling this trend. While such platforms offer flexibility to workers and companies, they raise some difficult questions about workplace protections and what a good job will look like in the future (Sundararajan, 2015). Furthermore, two of the biggest markets for these platforms are India and the Philippines, where lower costs of living allow workers there to undercut their peers in OECD economies. This could trigger a “race to the bottom”, driving down real wages and increasing inequality in OECD countries (Fox and O’Connor, 2015).

OECD countries have experienced an upwards trend in the value-added share of the financial sector in GDP over the past half-century, which has coincided with the sector’s growing influence on the overall economy and society (Mukunda, 2014). The sector’s rising profit share is considerably higher compared with the rest of the economy and its high wages have attracted some of the best talent, possibly at the expense of sectors with greater potential for productive innovation (Cournède et al, 2015; Cecchetti and Kharroubi, 2015). Banks and other lenders represent the largest component of the financial sector and have expanded at broadly similar rates. Intermediated credit and stock market capitalisation have also increased. While these trends may hold over the next 10 to 15 years, if not intensify as financial services further develop in emerging economies, digitalisation promises to disrupt the sector considerably. For instance, banks’ lending role will be increasingly challenged by digitally-enabled peer-to-peer lending platforms, while equity crowdfunding is also expected to grow (OECD, 2015e). Online payment systems (such as PayPal) and cryptocurrencies (such as bitcoin) are also forecast to proliferate. Other innovations leveraging the blockchain will lower transaction costs and provide computationally inexpensive methods for securely transferring value. This is expected to disrupt those institutions, like banks, whose raison-d’être lies in the centralised provision of trust behind transactions.

Long-term investment plays a key role in promoting innovation-based growth and job creation. Yet high-frequency computer trading and a disproportionate focus on quarterly earnings will likely continue to bias capital markets towards short-termism. A key policy challenge will therefore be to establish long-term investment incentives that offset tendencies in the financial system to measure profit margins on a short-term basis (WEF, 2011). Institutional investors with a longer-term return horizon, such as pension funds, sovereign wealth funds, or foundations, could help counterbalance this trend, particularly if a larger proportion of their investment portfolios could be targeted at financing innovative young firms.

2.1.2 Education and learning, and the digital divide

[Extracts from [1], pp 45, 46]

As digital technologies make ever-deeper inroads into education, and in particular at university level, learning methods and strategies will change. The scope for personalisation is already expanding, as the capabilities and the willingness to use digital resources help create bespoke pathways for learning, for example by breaking the courses into modules and enabling students and instructors to re-configure the modules to suit the learning situation. Then there is analysis and use of “big data”, which offers more nuanced and timely insights into all kinds of learning processes and tailoring of content to specific learning contexts. Nonetheless, far from placing the technology and the IT infrastructure in the foreground, the focus is expected to continue to shift toward conceiving it as a digital learning environment (Brown, 2015).

Access to education, of course, is not necessarily access to knowledge. The future is on a course that will increasingly thrive on ubiquitous access to ever-growing volumes of information and data in contexts other than those of a structured learning/teaching environment. The keys are the growing penetration of the Internet and mobile technology. According to the latest data from the International Telecommunication Union (ITU), 43% of the world's population is now online with some form of regular access to the Internet, and the figure is growing by the day. However, the digital divide is proving stubbornly persistent in terms of access to broadband Internet, including the challenge of extending last-mile access to infrastructure to remote and rural communities. There are as yet 4.2 billion or 57% of the world's people who still do not enjoy regular access to the Internet (ITU, 2015). For some observers, however, the digital divide may soon be bridged, namely by mobile technology (ITU, 2015). The total number of unique mobile subscribers is between 3.7 billion and 5 billion people (depending on source). According to Ericsson (2015), mobile broadband subscriptions will reach 7.7 billion globally by 2020. They already account for an overwhelming share of all broadband subscriptions, and it is expected that while mobile broadband will only complement fixed broadband in some segments, it will become the dominant form of access in others (Ericsson, 2015).

But other digital divides may be waiting around the corner. It is not just the humans who are getting connected. Many analysts agree that the Internet of Things (IoT) is now coming of age, and foresee strong growth in the IoT in their predictions. There are currently five connected devices for every person connected with the Internet. How-ever, looking forward, machine-to-machine is expected to show strong growth driven by new use cases, e.g. in cars, machines and utility metering. Paradoxically perhaps, the growth of the IoT may even introduce a new form of the digital divide, in terms of who has access to which connected devices (ITU and UNESCO, 2015).

2.1.3 SME growth and ICT uptake in Africa

[Extracts from [2], pp 42, 43]

Information and communication technologies (ICTs) are transforming Africa. Across the continent, new start-up digital enterprises are emerging, while existing small and medium enterprises (SMEs) are increasingly leveraging ICTs to expand. Intensified use of ICTs presents Africa's SMEs with opportunities in virtually every sector as well as room to create jobs.

The pace of transformation across Africa, however, is slow and one of the major barriers is poor ICT infrastructure. A number of countries are reaping the benefits of greater digital penetration but others are watching from the sidelines. In Kenya for example, the M-Pesa mobile money disruption has enabled many SMEs to be more efficient.

According to the 2016 Global Systems for Mobile Association (GSMA) report, however, the rest of Africa is still the world's most under-penetrated region in terms of mobile connectivity in spite of the fact that it recorded an annual subscriber growth over the same period of more than 13 percent. Improved universal infrastructure that is affordable and a flexible policy and regulatory environment would go a long way in realizing Africa's digital potential. With improved access to the internet and a more open policy environment, African enterprises could be better equipped to leapfrog and create innovative solutions.

At the same time, the adoption of 4G in sub-Saharan Africa is dismal owing to the fact that the relevant spectrum is still tied up in analogue broadcast. Implementation of digital migration in some countries is slow. As a result, many countries in the region have allocated far less spectrum to mobile services than their counterparts in other parts of the world, even though the region is heavily dependent on mobile networks for internet access. This trend undermines SME expansion, especially those that operate in remote areas.

Right now, Africa's youth should be a catalyst for creating digital jobs in virtually every sector including business processing outsourcing (BPO) both from external and internal sources. They have a fairly good education and can take advantage of the fibre connectivity in major urban centres. SMEs that have ventured into the BPO industry and other digital-dependent enterprises experience many challenges including excessive taxation on both ICT equipment and broadband use. Capacity building, too, is a problem in many countries as governments are often reluctant to spend in ICT especially on areas where they have no understanding. Just like other digital jobs destinations in India and the Philippines, there is need for a deliberate policy and effective implementation to support this emerging sector to provide much-needed employment.

In the future, the Internet of Things (IoT) and Big Data analytics will bring new digital jobs to the continent's young job seekers. African governments should, therefore, prepare by modernizing the education and training system to better prepare the workforce for the influx of these new types of jobs.

Further, as we look ahead, global dynamics indicate that China is losing its competitiveness in low-end manufacturing of ICT hardware. India is stepping into this one-trillion-dollar industry, but there is an opportunity for African countries to take advantage too. Perhaps there are lessons to be learned from Ethiopia, the African country already competing with India in this emerging space. This will require massive, practical capacity building in Africa's SMEs through makerspaces or incubation centres.

For SMEs to succeed and exploit emerging opportunities that create jobs for Africa's youth bulge, governments—in 2017 and beyond—must adopt supportive policies—such as targeted tax incentives and updated laws—that realize practical capacity building and flexible regulatory frameworks to enable innovation.

2.1.4 Digital jobs and smart urbanisation

[Extracts from [2], p 58-60]

Given Africa's demographic boom and Africa's drive to play a more competitive role in the global economy, the question is not if digital jobs will play a role in Africa's future job market, but whether or not these jobs can be successfully used to catalyze growth, support innovation, and foster sustainable and resilient communities. The worldwide model of digital jobs has been configured largely to utilize low-cost, but tech-savvy, labour in developing countries to augment the staff of international ICT businesses rather than to supply a steady stream of jobs for its burgeoning population. While this trend can help foster the emergence and growth of a middle class in these countries, it also creates an inherent instability as other developing nations vie for (and can ultimately take away) those commodity-based digital jobs.

With all indications that urbanization trends will continue for decades in Africa, national governments should strive to create policy frameworks that help ensure endogenous and sustainable growth of digital jobs that are not solely outsourced to Africa from without. Further, policymakers should include digital jobs in an economic system that promotes productivity across the analogue-digital spectrum. For example, technological innovations in agriculture can increase farming outputs, which affects jobs along the entire supply chain. Similarly, technological innovations in medicine can help ensure a healthy and therefore productive population. The overall effect is one where the preponderant application of technology at both the local and national economic levels significantly impacts the number of digital jobs generated from within the African economy.

One way to support digital jobs, especially in the wake of Habitat III resolutions in Quito, is through urban centres: In Africa, a higher proportion of the youth population will reside in urban centres by the year 2040. When these centres serve as hubs for technology and innovation, all sectors of the economy, as well as all segments of the community, can benefit in a more meaningful way. Urban centres in Africa should strive to attract international technology businesses, which will contribute to an overall system that promotes science, technology, engineering, and mathematics (STEM) education, entrepreneurship, inclusion and accessibility, and ultimately more jobs for all sectors of the economy.

Given its position as the youngest and fastest-growing population in the world, Africa no doubt needs more digital jobs to support its population. But that those digital jobs should shore up an African-based technology economy is much more significant. Africa is in a unique position, and significantly so, to prepare its youth for more STEM-based jobs (including digital jobs) while building both urban and rural communities that promote productivity and innovation.

This will not happen by wishful thinking. It will happen through the deliberate and systematic strategies of progressive African governments with a long-term vision and the wherewithal to implement appropriate policies in technology and to provide and facilitate the necessary funding to create resilient, sustainable, innovative, and productive (let's just call it "smart") urban communities as well as efficient agricultural systems. As the concept of smart cities emerges in the world, Africa has a unique opportunity to take a new look at what the word "smart city" really means in the context of African urbanization in the digital age. Africa needs successful urbanization models that incorporate technology into the community fabric in a way that provides greater access to and benefits from technology across the socio-economic spectrum. Kenya is looking to do just that with its new smart city.

Konza Technology City (KTC) of Kenya is a new smart city being planned, designed, and built from the ground up. It is striving to be a model for combining urban master planning, technology, policy, and the rule of law to create a place that takes the word "smart" in its truest sense. While KTC is currently going through the steps of building a city—and all of the concrete, steel, and human resources that this entails—it is also asking, and endeavouring to answer, hard questions about how to make smart choices about the nexus of technology, jobs, creation, and urban planning. Smart cities like Konza, and those in other parts of the world such as the Smart Cities Mission in India, must strive to play a major role in ensuring that technology and digital jobs help to bring people out of poverty and increase their physical and digital mobility. This is especially important in Africa where urbanization trends have not been contributing to the goal of transitioning people out of poverty to the degree that can and should be expected. When cities like KTC serve as innovation hubs—where people live, work, and play—the community extends well beyond the physical borders of the city. When smart cities create digital jobs by way of innovative technology, especially in life sciences and agriculture, it creates jobs across all sectors of the economy, which ensures that digital jobs are part of the solution—not the solution itself.

2.2 Artificial Intelligence

[Extracts from [1], p 54-56]

Artificial intelligence (AI) is defined as the ability of machines and systems to acquire and apply knowledge and to simulate intelligent behaviour. This means performing a broad variety of human tasks, e.g. sensing, processing oral language, reasoning, learning, making decisions, and demonstrating ability to move and manipulate objects accordingly. Intelligent systems use a combination of big data analytics, cloud computing, machine-to-machine communication, and the Internet of Things (IoT) to operate and learn (OECD, 2015h).

It is only a matter of time before machines become as smart as humans (Helbing, 2015). AI abilities are likely to reach those of the human brain within the next few decades. Robotics will be one of the technological fields that benefits most from AI developments, as AI will enable robots to adapt to new working environments with no reprogramming (OECD, 2015c). Advanced robots could generate substantial savings on labour costs and productivity gains. AI also holds great promises for safety, by physically replacing humans, reducing work accidents and enhancing decision-making in hazardous and dangerous situations.

All economic sectors will be affected by AI developments, some more than others. AI and advanced robots will become increasingly central to manufacturing. Sectors that are likely to experience a new production revolution and full transformation include agriculture, chemicals, oil and coal, rubber and plastics, shoe and textile, transport, construction, defence, and surveillance and security (López Pelaez and Kyriakou, 2008; ITF, 2015; Roland Berger, 2014b; ESPAS, 2015; MGI, 2013; UK Government Office for Science, 2012).

AI opens new business opportunities in robotics manufacturing, whose current global market is estimated at USD 26 billion (Goldin and Pitt, 2014). China is expected to account for more than one-third of the industrial robots installed worldwide in 2018 (IFR, 2015) and should be one of the fastest-growing markets for advanced robotics as domestic salaries increase, global quality standards rise and new technologies alter industrial processes at the core of China's economy (e.g. electronics, ICTs, etc.).

AI-enhanced systems are expected to form an integral part of everyday life by 2030. Services robots may change households and personal assistance services (ESPAS, 2015; MGI, 2013). In sectors where interpersonal skills are key (e.g. tourism and restaurants) robots could act like humans (López Pelaez and Kyriakou, 2008). AI will be increasingly deployed in education, medicine, law, marketing, and finance. In the health sector, for instance, surgery robots are already in use and further automation of health-related tasks are highly probable (López Pelaez and Kyriakou, 2008). Diagnostics could also evolve with AI-enabled analysis of medical databases (MGI, 2013). As their performance improves, especially their anthropomorphist capacity, AI may increasingly perform social tasks. "Social robots" may help address the needs of ageing society by assisting humans physically and psychologically, artificially acting as companions and diminishing social isolation of the elderly (IERC, 2015).

AI will have high impact on employment although its scale and nature are still uncertain. It is estimated that up to 47% of US jobs and 36% of UK jobs may disappear due to future technology advances (Brynjolfsson and McAffee, 2014). In France, it is estimated that 42% of jobs are likely to be automated in the next 20 years (Roland Berger, 2014b). Humans will most likely be substituted by AI-enabled robots in "dirty, dangerous, and demanding" jobs, as well as in those that are repetitive and labour-intensive. But advances in smart systems will also enable automation of some knowledge work. For the first time, automation will no longer depend on a differentiation between manual and intellectual tasks but on some routine features of the jobs. Middle income classes may be under particular pressure, as an increasing number of administrative, cognitive and analytical jobs may be performed by data- and AI-empowered applications.

As smart machines replace human workers in jobs, reproducible goods and services could be produced at lower marginal cost and become almost free. Productivity gains and economic growth could thus be disconnected from job creation and well-being. However, a no-job growth jeopardises public budgets and social safety net systems. A drop in employment would be echoed by a proportional drop in the tax base and government revenues. Social contributions and personal tax income accounted for an average 18% of OECD GDP in 2013 (OECD, 2015j). Likewise, employment-based pension systems are threatened. As workers may be left without salary, income redistribution policies will become more central to future social cohesion. The challenge could be of an unprecedented scale to avoid growing inequality.

An essential factor for reaping the benefits of AI is the provision of reliable transport, energy and communication networks, including the IoT (OECD, 2015h). AI can make mistakes, resulting in possibly serious damages (e.g. wrong patient diagnosis). AI decisions may also be subject to misunderstanding, criticism or rejection (e.g. loan refusal). AI may ultimately become uncontrollable. The imperfect and unpredictable nature of AI questions the principles of legal responsibility and how liability should be shared among AI itself, AI constructors, programmers, owners, etc. Another legal dimension of AI is related to the intellectual property (IP) of inventions enabled by AI, and how IP rights and revenues should be shared. Legal considerations will have major consequences on insurance markets and IP systems.

New skills needs are expected to emerge. Demand for knowledge workers who are able to develop AI or to perform AI-enabled tasks will increase. Creative or tacit-knowledge, which are less codifiable, or skills requiring social interactions or physical dexterity, which are less easily automatable, are likely to remain in human hands over the next few decades (López Pelaez and Kyriakou, 2008; Brynjolfsson and McAffee, 2015). Today's education systems should ensure that young people are equipped with the right skills to perform in tomorrow's AI-enhanced environment. Training systems will help smooth the transition and ensure people can follow the unpredictable learning curve of AI.

The integration of smart robots into the private sphere will increase emotional attachment in relation to AI machines and alter human behaviours. Some argue that behavioural differentiation between AI and non-AI machines may justify providing social robots with legal rights and that their protection could serve as a guide to broader regulation of socially desirable behaviours (Darling, 2012). Others consider that social relationships between humans and robots should be reflected in moral obligation (Coeckelbergh, 2010). More broadly, the use of AI for all human purposes raises several ethical and philosophical issues around human life, the possible dehumanisation of society, the role humans may play in a new AI-enhanced society, and a new human relation to time, for instance through a rebalancing of work and free time.

Impact on employment

[Extracts from [12], pp 1, 2]

Emerging technologies like industrial robots, artificial intelligence, and machine learning are advancing at a rapid pace, but there has been little attention to their impact on employment and public policy. Darrell West addresses this topic in a new paper titled What Happens If Robots Take the Jobs? The Impact of Emerging Technologies on Employment and Public Policy. It examines what happens if robots end up taking jobs from humans and how this will affect public policy.

While emerging technologies can improve the speed, quality, and cost of available goods and services, they may also displace large numbers of workers. This possibility challenges the traditional benefits model of tying health care and retirement savings to jobs. In an economy that employs dramatically fewer workers, we need to think about how to deliver benefits to displaced workers.

The impacts of automation technologies are already being felt throughout the economy. The worldwide number of industrial robots has increased rapidly over the past few years. The falling prices of robots, which can operate all day without interruption, make them cost-competitive with human workers. In the service sector, computer algorithms can execute stock trades in a fraction of a second, much faster than any human. As these technologies become cheaper, more capable, and more widespread, they will find even more applications in an economy.

The recent trend towards increased automation stems in part from the Great Recession, which forced many businesses to operate with fewer workers. After growth resumed, many businesses continued automating their operations rather than hiring additional workers. This echoes a trend among technology companies that receive massive valuations with relatively few workers. For example, in 2014 Google was valued at $370 billion with only 55,000 employees, a tenth the size of AT&T's workforce in the 1960s.

Experts disagree on the size of the impact that automation technologies will have on the workforce. While some warn of staggering unemployment, others point out that technology may create new job categories that will employ displaced workers. A third group argues that the computers will have little effect on employment in the future. Any policy measures that address the future of employment must account for the uncertainty of outcomes on employment.

If automation technologies like robots and artificial intelligence make jobs less secure in the future, there needs to be a way to deliver benefits outside of employment. “Flexicurity,” or flexible security, is one idea for providing healthcare, education, and housing assistance whether or not someone is formally employed.

Perhaps the most provocative question raised is how people will choose to spend their time outside of traditional jobs. “Activity accounts” could finance lifelong education or volunteering for worthy causes. Working fewer hours will enable some to spend more time with friends and family, or on creative pursuits. No matter how people choose to spend time, “there needs to be ways for people to live fulfilling lives even if society needs relatively few workers.”

2.3 Big data analytics

[Extracts from [1], pp 52, 53]

Big data analytics is defined as a set of techniques and tools used to process and interpret big data that are generated by the increasing digitisation of content, greater monitoring of human activities and the spread of the Internet of Things (IoT) (OECD, 2015i). Big data analytics is associated with data mining, profiling, business intelligence, machine or statistical learning and visual analytics. It can be used to infer relationships, establish dependencies, and perform predictions of outcomes and behaviours (Helbing, 2015; Kuusi and Vasamo, 2014).

Big data analytics offers opportunities to boost productivity, foster a more inclusive growth, and contribute to citizens' wellbeing (OECD, 2015i). Big data analytics should help firms, governments and consumers/citizens access an unprecedented amount of data (volume), increasingly inform their decision-making with real-time data (velocity) and combine a new range of information from structured and unstructured sources (variety), generating disruptive impacts on all human activities (value). The IoT and the acceleration in both the volume and velocity of open data that are accessible and exploitable will further increase the needs for big data analytics and enhance the strategic value of big data.

The exploitation of big data will become a key determinant of innovation and a competition factor for individual firms (MGI, 2011c). Data-driven governance offers significant room for improving public administration efficiency (MGI, 2011c). Big data analytics represents a key opportunity to rebuild public trust through greater openness, transparency, responsiveness and accountability of the public sector (Ubaldi, 2013).

Consumers and citizens could be better informed and participate more closely in public affairs; they will enjoy and expect more personalised products and service.

Increasing access to public science has the potential to make the entire research system more effective and productive by reducing duplication and the costs of creating, transferring, and reusing data; by allowing the same data to generate more research, including in the business sector; and by multiplying opportunities for domestic and global participation in the research process (OECD, 2014b). The rise of open data and open access policies and infrastructures is already making isolated scientific datasets and results part of big data. The number of stakeholders involved in research practices and policy design will continue to increase, making science a citizen endeavour, reinforcing a more entrepreneurial approach to research and encouraging more responsible research policies.

Big data analytics may trigger some substantial changes in healthcare systems by enabling a shift from a reactive setup that focuses on disease to a preventive setup that focuses on quality of life and wellbeing (OECD, 2013d). Sharing health data, through electronic health record systems, for example, can increase efficient access to healthcare and provide novel insights into innovative health products and services (OECD 2013e). Diagnosis, treatment and monitoring of patients may become a joint venture of analytical software and physicians. Clinical care may even become preventive in nature as big data analytics help discover pathologies before symptoms occur. On top of open research data, the connection of smart applications through the IoT will enable the gathering of a wealth of health-related records, being self-reported or automatically tracked, on both sick and healthy people. New potential clinical trial participants will be more easily in reach. Broad data on exposures, outcomes and healthcare utilisation could be put together with deep clinical and biological data, opening new avenues to advance common knowledge, for instance on ageing-related diseases, or to support interdisciplinary research, for instance on combined effects of cure and care (Anderson and Oderkirk, 2015).

The rise of big data analytics poses major challenges to skills and employment policies (OECD, 2015i). The demand for data specialist skills will exceed the current supply of the labour market and the current capacity of education and training systems, requiring rapid adjustments in curricula and the skill sets of teachers and on-the-job workers. Big data is also expected to increase the need for a fast, widespread and open Internet (including the IoT), new supercomputing powers and large storage facilities, which current IT infrastructures cannot fully support. Legal institutions must also evolve to better promote a seamless flow of data across nations, sectors and organisations. There are growing concerns about how to define and appropriate open access rights, while maintaining publishers' and researchers' incentives to keep publishing and performing research. International cooperation will be key in that respect.

Growing social inequalities will result not only from job destruction and employment polarisation that will inevitably come along with the structural shift in skills, but also from weaker social mobility and a persisting digital divide. Discrimination enabled by data analytics may result in greater efficiencies, but may also limit an individual's ability to modify path-dependent trajectories and escape socioeconomic lock-ins. In addition, a new digital divide is arising from growing information asymmetries and related power shifts from individuals to organisations, from traditional businesses to data-driven businesses, and from government to data-driven businesses (OECD, 2015i). Social cohesion and economic resilience could be undermined, especially in developing economies.

Big data analytics may enable a massive brewing of personal data that become accessible to a large number of actors (everyone?) in a way that is unpredictable and could become uncontrollable, as the volume, velocity and variety of data increase. For instance, patients sharing sensitive health data may support medical research and benefit from preferential medical treatment. Yet medical data made accessible to business interests (e.g. insurance companies and employers) raises a major issue of privacy and equity. Privacy is also endangered if these data are not well protected and if hacking or misuse could result from breaches in security.

Big data analytics offers a unique possibility to combine personal data with pattern recognition programmes, enabling the generation of new information and knowledge about people (ITF, 2014). However, the same data and same programmes could serve to manipulate people, distort their perception of reality and influence their choices (Glancy, 2012; Helbing, 2015; IERC, 2015; Piniewski et al., 2011). Individual autonomy, free thinking and free will would be challenged, potentially undermining the foundations of modern democratic societies.

Big data and the global food chain

[Extracts from [14], pp 1, 2]

The way digital technologies are reshaping the relationship between consumers and brands has been hotly debated over the past few years, with much discussion of the reshaping of consumer decision journeys, the advent of multichannel marketing and sales, and the impact of smart phones and the mobile Internet on customer behaviour. Yet an even bigger opportunity has been largely overlooked. By taking advantage of big data and advanced analytics at every link in the value chain from field to fork, food companies can harness digital's enormous potential for sustainable value creation. Digital can help them use resources in a more environmentally responsible manner, improve their sourcing decisions, and implement circular-economy solutions in the food chain.

So far, most of the excitement about digital's potential in the consumer-packaged-goods industry has centred on marketing and sales. But for food producers, the opportunities begin higher upstream and end lower downstream. At the upstream end, the agricultural practices followed by dairy farmers, cacao and coffee producers, wheat and barley producers, cattle farmers, and so on result in enormous variations in commodity costs in an industry where raw materials represent easily 60 percent of the cost of goods sold (COGS).

Manufacturing and packaging also represent a substantial share of COGS, as well as contributing to companies' environmental and social footprints and food-safety risks. At the other end of the food chain, big data and advanced analytics can be used to optimize downstream activities such as waste management. Food waste causes economic losses, harms natural resources, and exacerbates food-security issues. About a third of food produced for human consumption is lost or wasted every year in a world where 795 million people—a ninth of the population—go hungry.

Cutting postharvest losses in half would produce enough food to feed a billion more people. Global food waste and loss cost $940 billion a year, have a carbon footprint of 4.4 Gt CO2-equivalent (more than 8 percent of global greenhouse-gas emissions), and a blue-water footprint of about 250 cubic km (3.6 times the annual consumption of the US). In 2007, the amount of food wasted globally equated to 1.4 billion hectares—an area bigger than Canada—of agricultural production.

Using technology to improve areas such as climate forecasting, demand planning, and the management of end-of-life products could bring enormous social, economic, and environmental benefits. For example, the French start-up Phenix runs a web-based marketplace to connect supermarkets with end-of-life food stocks to NGOs and consumers who could use them. The platform enables the supermarkets to save the costs of disposal, gives consumable products a second life, and alleviates some of the social and environmental burden of waste.

The opportunities for digital innovation in the food chain are enormous and vary by context, with some well suited to emerging markets and others more appropriate to mature economies.

Big data and infectious disease research

[Extracts from [29], p 52]

Data are the critical currency for improving global health capabilities and preparedness for epidemic and pandemic threats. Big data and the associated analytics will have a paradigm-changing impact on how global systems will monitor infectious disease dynamics—including resurgent antibiotic resistance, the more rapid spread of new threats arising from global connectivities, potential bioterrorism threats, and the development of synthetic organisms. More importantly, big data will provide a better understanding of the instabilities and complex adaptive responses of microorganisms that trigger emergent threats. Big data, which is already enabling the holistic, systems-based analysis of human, animal, and ecosystem interdependencies that make zoonotic diseases such a threat to human health, is also being overlaid onto the domains of molecular epidemiology, pathogen biology, and the development of diagnostics, drugs, and vaccines.

One key challenge will be dealing with not just the rapid proliferation of data but the growing diversity of data classes. Other challenges will include determining how to integrate, analyze, and curate the massive, heterogeneous datasets being generated; accounting for the variable reliability of the data; and generating actionable guidance. In the end the ultimate value of big data will come down to its utility for the public health practitioner and policy maker.

Competing in a data-driven world

[Extracts from [13], p vii]

Data and analytics capabilities have made a leap forward in recent years. The volume of available data has grown exponentially, more sophisticated algorithms have been developed, and computational power and storage have steadily improved. The convergence of these trends is fuelling rapid technology advances and business disruptions.

- Most companies are capturing only a fraction of the potential value from data and analytics. Our 2011 report estimated this potential in five domains; revisiting them today shows a great deal of value still on the table. The greatest progress has occurred in location-based services and in retail, both areas with digital native competitors. In contrast, manufacturing, the public sector, and health care have captured less than 30 percent of the potential value we highlighted five years ago. Further, new opportunities have arisen since 2011, making the gap between the leaders and laggards even bigger.
- The biggest barriers companies face in extracting value from data and analytics are organizational; many struggle to incorporate data-driven insights into day-to-day business processes. Another challenge is attracting and retaining the right talent—not only data scientists but business translators who combine data savvy with industry and functional expertise.

- Data and analytics are changing the basis of competition. Leading companies are using their capabilities not only to improve their core operations but to launch entirely new business models. The network effects of digital platforms are creating a winner-take-most dynamic in some markets.
- Data is now a critical corporate asset. It comes from the web, billions of phones, sensors, payment systems, cameras, and a huge array of other sources—and its value is tied to its ultimate use. While data itself will become increasingly commoditized, value is likely to accrue to the owners of scarce data, to players that aggregate data in unique ways, and especially to providers of valuable analytics.
- Data and analytics underpin several disruptive models. Introducing new types of data sets ("orthogonal data") can disrupt industries, and massive data integration capabilities can break through organizational and technological silos, enabling new insights and models. Hyperscale digital platforms can match buyers and sellers in real time, transforming inefficient markets. Granular data can be used to personalize products and services—and, most intriguingly, health care. New analytical techniques can fuel discovery and innovation. Above all, data and analytics can enable faster and more evidence-based decision making.
- Recent advances in machine learning can be used to solve a tremendous variety of problems—and deep learning is pushing the boundaries even further. Systems enabled by machine learning can provide customer service, manage logistics, analyze medical records, or even write news stories. The value potential is everywhere, even in industries that have been slow to digitize. These technologies could generate productivity gains and an improved quality of life—along with job losses and other disruptions. Previous MGI research found that 45 percent of work activities could potentially be automated by currently demonstrated technologies; machine learning can be an enabling technology for the automation of 80 percent of those activities. Breakthroughs in natural language processing could expand that impact even further.

Data and analytics are already shaking up multiple industries, and the effects will only become more pronounced as adoption reaches critical mass. An even bigger wave of change is looming on the horizon as deep learning reaches maturity, giving machines unprecedented capabilities to think, problem-solve, and understand language. Organizations that are able to harness these capabilities effectively will be able to create significant value and differentiate themselves, while others will find themselves increasingly at a disadvantage.

2.4 Blockchain

[Extracts from [1], pp 70-72]

Blockchain is a database that allows transferring value within computer networks. This technology is expected to disrupt several markets by ensuring trustworthy transactions without the necessity of a third party. The proliferation of this technology is, however, threatened by technical aspects that remain to be resolved.

Internet applications such as web browsers and email programs use protocols that define how software on connected devices can communicate with each other. Whereas the purpose of most traditional protocols is information exchange, blockchain enables protocols for value exchange. This new technology empowers a shared understanding of value attached to specific data and thus allows transactions to be carried out. In itself, blockchain is a distributed database that acts as an open, shared and trusted public ledger that nobody can tamper with and that everyone can inspect. Protocols built on blockchain (e.g. bitcoin) specify how participants in a network can maintain and update the ledger using cryptography and through general consensus. The combination of transparency, strict rules and constant oversight that can potentially characterise a blockchain-based network provides sufficient conditions for its users to trust the transactions conducted within, without the necessity of a central institution. As such, the technology offers the potential for lower transaction costs by removing the necessity of trustworthy intermediaries to conduct sufficiently secure value transfers. It could disrupt markets and public institutions whose business model or raison-d'être lies in the provision of trust behind transactions.

Blockchain technology was originally conceived for bitcoin, a digital currency that is not regulated nor backed by any central bank. Instead, the technology aims to be trustworthy by itself (i.e. it makes a trusted third party unnecessary) by preventing double-spending and constantly keeping track of currency ownership and transactions (OECD, 2015l). The supply of bitcoins is limited and regulated by a mathematical algorithm that defines the rate at which currency will be created. The procedure for updating the ledger rewards users who devote computing resources to encrypt transactions (called miners) with new bitcoins that enter the network's monetary base. Once a set of transactions has been encrypted, the entire network (including non-miners) verifies its validity by a 51% majority consensus. As in regular currency trade, bitcoin exchange rates with traditional currencies are determined through a double-auction system. This setup incentivises scrutiny and thus secures the network: if bitcoin is increasingly adopted and its value increases relative to other currencies, there will be additional incentive to devote computational power for rewards.

While the experience of bitcoin is already forcing a rethink of currencies, expected impacts of the underlying blockchain technology go beyond digital money. This technology could destabilise incumbents in asset management businesses, but also government authorities, and could transform the way many services are provided. Potential applications can be clustered into three categories:

2.4.1 Financial transactions

Financial applications of blockchain technology go beyond bitcoin and digital money. For example, the technology provides opportunities for cross-border remittance payments, which often represent high transaction costs in proportion to the remittance amount. Equity crowdfunding provides another opportunity, as it often involves large amounts of administration efforts relative to the size of individual investments (Collins and Baeck, 2015). In view of potential applications, clearing houses (e.g. the New York Stock Exchange and Nasdaq), banks (e.g. Goldman Sachs), credit card companies (e.g. Master Card) and insurance companies (e.g. New York Life Insurance Company) have already invested around USD 1 billion in start-ups using blockchain technologies (Pagliery, 2015; de Filippi, 2015).

2.4.2 Record and verification systems

This technology can also be used for creating and maintaining trustworthy registries. The blockchain distributed ledger provides a robust, transparent and easily accessible historical record. It can be used for storing any kind of data, including asset ownership. Possible uses include the registration and proof of ownership of land titles and pensions, and verifying authenticity of works of art, luxury goods and expensive drugs (The Economist, 2015; Thomson, 2015). A key difference of this category of applications is that blockchain relies on a central institution for updating and storing the ledger. Already Honduras has plans to build a land title registration system using blockchain (Chavez-Dreyfuss, 2015), which could radically change the way notary offices manage real estate. The shared blockchain ledger could also bring significant improvements to resource allocation in the public sector by consolidating accounting, increasing transparency and facilitating auditing to prevent corruption and boost efficiencies. A shared ledger within the different levels of government could ensure that transactions are consistent and error free. Also, given that key public and private institutions in emerging countries are less developed and trusted for financial markets to flourish and for public services to be efficient, blockchain could offer a “fast track” for the development of financial services and public registry keeping.

2.4.3 Smart contracts

Blockchain technology offers the opportunity to append additional data to value transactions. These data could specify that certain rules are required to be met before the transfer takes place. In this way, a transaction would work as an invoice that would be cleared automatically upon fulfilment of certain conditions. Such “smart contracts” based on blockchain are also referred to as programmable money (Bheemaiah, 2015). The conditions specified in the transfer as programming code could be used to express the provision of services such as cloud storage of data (e.g. Dropbox), marketplaces (e.g. eBay), and platforms for the sharing economy such as Uber and AirBnB (de Filippi, 2015). Microsoft is setting up a joint venture in this field to power its services renting out computer servers (Pagliery, 2015).

A critical uncertainty for “institution-less” applications is that their security depends greatly on the number of users. This means applications have to sufficiently scale before becoming trustworthy. Moreover, the standard mathematical algorithm that ensures a tamper-resistant ledger (currently employed by bitcoin) becomes more computationally intensive as the network becomes more scrutinised. This translates into vast amounts of electricity required to process and verify transactions conducted within the network. Less computationally-intensive alternatives for reaching a secure consensus are currently being developed and tested. An additional uncertainty specific to smart contracts lies in the extent to which complex services can be sufficiently programmed into rules. In order for such networks to completely run by themselves (i.e. without a firm backing the service), instructions embedded in transfers should provide an exhaustive definition of the service. While this is likely possible for a great amount of routine services (e.g. computing), it is questionable whether this could be achieved with more complicated applications such as marketplaces and the sharing economy of Uber and AirBnB. These often require mechanisms of dispute resolution that are difficult to codify and delimit.

The pseudo-anonymity of transactions raises several concerns around the technology’s potential exploitation for illegal activities. While all transfers conducted through blockchain are permanently recorded and immutable, it contains information only relative to agents’ Internet identity, which may not necessarily lead to their real identity. Some users of virtual currencies have already been involved in improper use and illegal activities, including money laundering and transfer of value for illegal goods. More effective methods of identification could lead to more effective law enforcement in digital currencies compared with the use of cash (OECD, 2015l). However, smart contract applications could also allow the creation and operation of illegal markets that would operate without a responsible firm or institution subject to regulatory compliance.

2.5 Digital by default: Transforming government

[Extracts from [4], pp 3, 4]

By digitizing processes and making organizational changes, governments can enhance services, save money, and improve citizens’ quality of life.

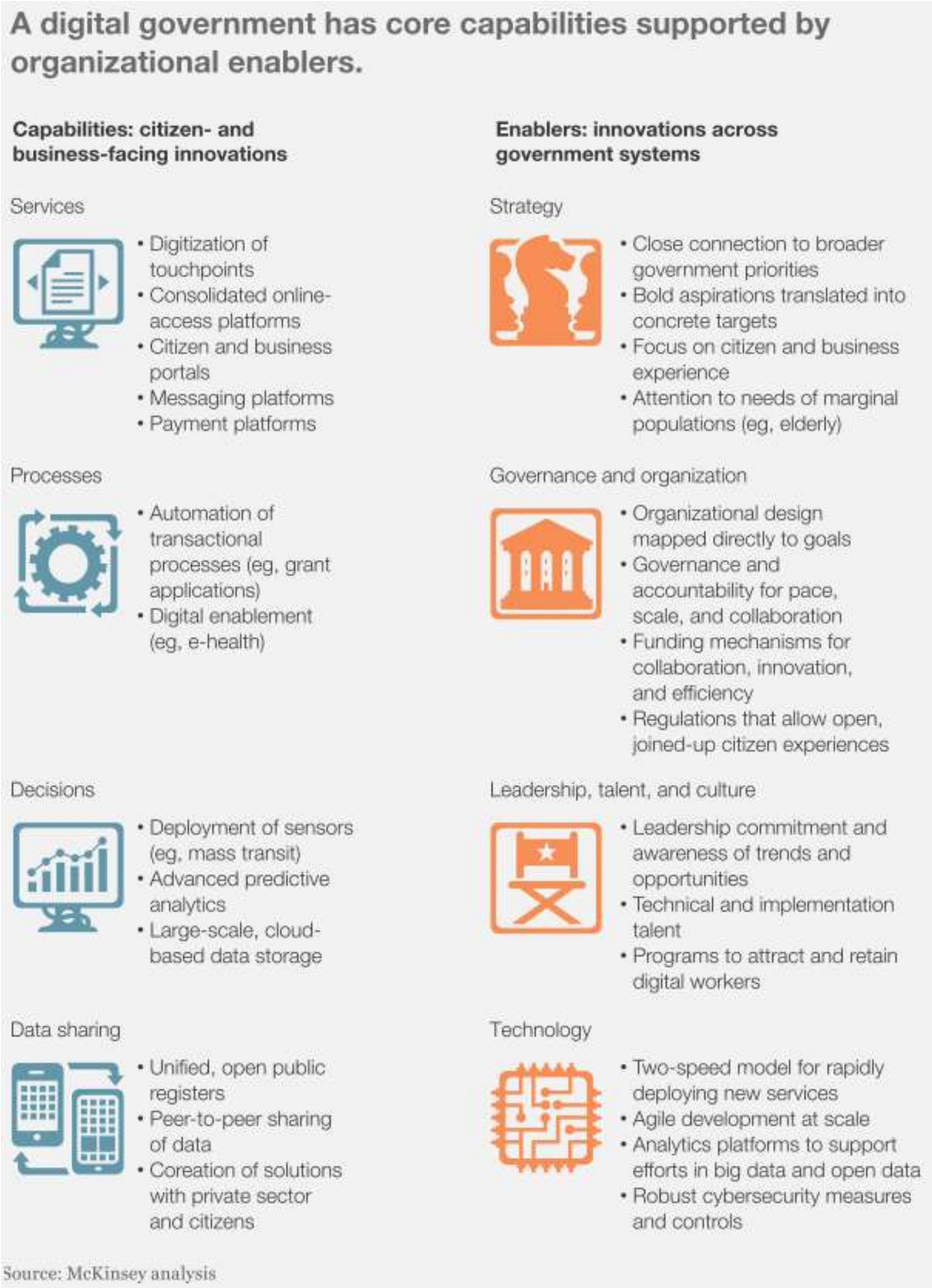
As companies have transformed themselves with digital technologies, people are calling on governments to follow suit. The stakes are high: our estimates suggest that government digitization could generate over $1 trillion annually worldwide.

Few if any governments face the same type of competitive pressure that compels businesses and even social-sector organizations to digitize. After all, there's little risk that a government will be displaced by a digital challenger. But that shouldn't give governments an excuse for complacency. The dynamics of globalization mean that countries and municipalities must vie for investment, workers, and knowledge—resources for which digital technology can be a magnet.

By digitizing, governments can provide services that meet the evolving expectations of citizens and businesses, even in a period of tight budgets and complex challenges such as income inequality, geopolitical instability, and aging populations. Not only do citizens prefer digital services and interactions with governments, but digital services can also empower citizens and broaden their engagement with government. For businesses, too, digital government services are convenient and efficient. Government digitization efforts can also compel businesses to digitize more quickly.

Governments have few, if any, models for public-sector institutions that have been digital from day one, and some governments' initial attempts to digitize have come up short. But governments have begun borrowing approaches from digital business start-ups, established companies that are digitizing, and other governments that are farther along in their digital transformations. And regardless of how digitally sophisticated a government might be—whether it is just beginning to develop digital capabilities or it is rolling out digital services that rival those of the hottest start-up—it can always take another step forward.

Digitizing a government requires attention to two major considerations. The first is the core capabilities that governments use to engage citizens and businesses and carry out their work: the methods and tools they use to provide services, the processes they implement, their approach to making decisions, and their sharing and publishing of useful data. The other consideration is the organizational enablers that support governments in delivering these capabilities: strategy; governance and organization; leadership, talent, and culture; and technology (Figure below).



These elements make up a framework that governments can use to set their priorities for a comprehensive digital transformation that boosts the efficiency, responsiveness, and quality of government activity and helps improve quality of life. In this article, we offer a detailed look at the capabilities and enablers in this digital-government framework, along with guidelines and real-world examples drawn from our experience helping government leaders seize the opportunities that digitization has to offer.

The core capabilities of a digital government

Governments typically begin their digitization efforts by rebuilding a few fundamental capabilities around advanced technologies. With experience, they can broaden their digitization programs, working toward providing world-class digital experiences to citizens, businesses, and other users of government services. We have grouped government capabilities into four categories—services, processes, decisions, and data sharing—and proposed, for each one, a progression from quick digital wins to transformative efforts that can generate substantial benefits for users.

2.6 Digital finance for all

[Extracts from [5], p 1]

Two billion individuals and 200 million businesses in emerging economies today lack access to savings and credit, and even those with access can pay dearly for a limited range of products. Rapidly spreading digital technologies now offer an opportunity to provide financial services at much lower cost, and therefore profitably, boosting financial inclusion and enabling large productivity gains across the economy. While the benefits of digital finance—financial services delivered via mobile phones, the internet or cards—have been widely noted, in this report we seek to quantify just how large the economic impact could be.

- Digital finance has the potential to provide access to financial services for 1.6 billion people in emerging economies, more than half of them women. It could increase the volume of loans extended to individuals and businesses by $2.1 trillion and allow governments to save $110 billion per year by reducing leakage in spending and tax revenue. Financial-services providers would benefit too, saving $400 billion annually in direct costs while sustainably increasing their balance sheets by as much as $4.2 trillion.

- Overall, we calculate that widespread use of digital finance could boost annual GDP of all emerging economies by $3.7 trillion by 2025, a 6 percent increase versus a business-as-usual scenario. Nearly two-thirds of the increase would come from raised productivity of financial and non-financial businesses and governments as a result of digital payments. One-third would be from the additional investment that broader financial inclusion of people and micro, small, and medium-sized businesses would bring. The small remainder would come from time savings by individuals enabling more hours of work. This additional GDP could lead to the creation of up to 95 million jobs across all sectors.

- The potential economic impact varies significantly depending on a country's starting position. We conducted field research in seven countries that span geographies and income levels: Brazil, China, Ethiopia, India, Mexico, Nigeria, and Pakistan. Lower-income countries such as Ethiopia, India, and Nigeria have the largest potential, with the opportunity to add 10 to 12 percent to their GDP, given low levels of financial inclusion and digital payments today. In comparison, middle-income countries such as China and Brazil could add 4 to 5 percent to GDP—still a substantial boost.

- The rapid spread of mobile phones is the game changer that makes this opportunity possible. In 2014, nearly 80 percent of adults in emerging economies had a mobile phone, while only 55 percent had financial accounts—and mobile phone penetration is growing quickly. Mobile payments can lower the cost of providing financial services by 80 to 90 percent, enabling providers to serve lower-income customers profitably. The data trail these technologies leave can enable lenders to assess the creditworthiness of borrowers, and can help businesses better manage their finances.

- Businesses and government leaders will need to make a concerted effort to secure these potential benefits. Three building blocks are required: widespread mobile and digital infrastructure, a dynamic business environment for financial services, and digital finance products that meet the needs of individuals and small businesses in ways that are superior to the informal financial tools they use today.

Broadening access to finance through digital means can unlock productivity and investment, reduce poverty, empower women, and help build stronger institutions with less corruption—all while providing a profitable, sustainable business opportunity for financial service providers. The benefits for individuals, businesses, and governments can transform the economic prospects of emerging economies.

2.7 Digital globalisation

[Extracts from [7], p viii]

The rapidly growing flows of international trade and finance that characterized the 20th century have flattened or declined since 2008. Yet globalization is not moving into reverse. Instead digital flows are soaring—transmitting information, ideas, and innovation around the world and broadening participation in the global economy.

- The world is more interconnected than ever. For the first time in history, emerging economies are counterparts on more than half of global trade flows, and South-South trade is the fastest-growing type of connection.
- While flows of goods and finance have lost momentum, used cross-border bandwidth has grown 45 times larger since 2005. It is projected to grow by another nine times in the next five years as digital flows of commerce, information, searches, video, communication, and intracompany traffic continue to surge.
- Digital platforms change the economics of doing business across borders, bringing down the cost of international interactions and transactions. They create markets and user communities with global scale, providing businesses with a huge base of potential customers and effective ways to reach them.
- Small businesses worldwide are becoming "micro-multinationals" by using digital platforms such as eBay, Amazon, Facebook, and Alibaba to connect with customers and suppliers in other countries. Even the smallest enterprises can be born global: 86 percent of tech-based start-ups we surveyed report some type of cross-border activity. The ability of small businesses to reach new markets supports economic growth everywhere.
- Individuals are participating in globalization directly, using digital platforms to learn, find work, showcase their talent, and build personal networks. Some 900 million people have international connections on social media, and 360 million take part in cross-border e-commerce.
- Over a decade, global flows have raised world GDP by at least 10 percent; this value totalled $7.8 trillion in 2014 alone. Data flows now account for a larger share of this impact than global trade in goods. Global flows generate economic growth primarily by raising productivity, and countries benefit from both inflows and outflows.
- Although more nations are participating, global flows remain concentrated among a small set of leading countries. The gaps between the leaders and the rest of the world are closing very slowly, but catch-up growth represents a major opportunity for lagging countries. Some economies could grow by 50 percent or more over the long term by accelerating participation.
- Many companies grew more complex and inefficient as they expanded across borders. But digital technologies can tame complexity and create leaner models

for going global. This is a moment for companies to rethink their organizational structures, products, assets, and competitors.

Countries cannot afford to shut themselves off from global flows, but narrow export strategies miss the real value of globalization: the flow of ideas, talent, and inputs that spur innovation and productivity. Digital globalization makes policy choices even more complex. Value chains are shifting, new hubs are emerging, and economic activity is being transformed. This transition creates new openings for countries to carve out profitable roles in the global economy. Those opportunities will favor locations that build the infrastructure, institutions, and business environments that their companies and citizens need to participate fully.

2.8 Internet of Things

[Extracts from [1], pp 50, 51]

The Internet of Things (IoT) is defined as the connection over time of almost any object and device to the Internet's network of networks (OECD, 2015h). In the public space, at the workplace and at home all kinds of objects and sensors will gather data and exchange these with one another and with humans. The IoT is really an Internet of everything, since in addition to connecting things, it also enables digital connections among other elements in the physical world, such as humans, animals, air and water. The networked sensors and actuators in the IoT allow monitoring of the environment, status reporting, receiving of instructions, and sometimes even automated actions (MGI, 2013).

The number of connected devices in and around people's homes in OECD member countries will probably increase from 1 billion today to 14 billion by 2022 (OECD, 2015h). By 2030, it is estimated that 8 billion people and maybe 25 billion active "smart" devices will be interconnected and interwoven by one single huge information network (OECD 2015i). Other estimates indicate a number of 50 to 100 billion connected devices in and outside people's homes by 2020 (Evans, 2011; MGI, 2013; Perera et al., 2015). The result is the emergence of a gigantic, powerful "superorganism", in which the Internet represents the "global digital nervous system" (OECD, 2015i).

The IoT is set to enable a hyper-connected and ultra-digitally responsive society. Its economic impact is estimated between USD 2.7 trillion and USD 6.2 trillion annually by 2025 (MGI, 2013). While the IoT has profound implications for all aspects and sectors of the economy, the largest impacts are expected in the healthcare sector, network industries and the manufacturing sector.

2.8.1 Health and healthcare

The IoT provides opportunities to improve people's health and provide better healthcare by connecting inner and outer bodily sensors to both personal health monitoring devices and professional health care systems. An Internet of bio-nano things monitoring and managing internal and external health hazards may be emerging (Akyldiz et al., 2015). The treatment of chronically ill patients in particular is expected to become more efficient (MGI, 2013).

2.8.2 Energy systems

IoT-enabled smart grids with smart energy meters allow for two-way communication between homes/organisations and the energy grid (OECD, 2015h). Consumer awareness about energy consumption will rise, potentially reducing energy consumption as a result. In addition, smart grids help cut utility operating costs and reduce power outages and electricity waste by providing real-time information about the state of the grid (MGI, 2013).

2.8.3 Transport systems

The IoT holds great promises for the improvement of transport management and road safety. Sensors attached to vehicles and elements of the road infrastructure may become interconnected, thereby generating information on traffic flows, the technical status of vehicles and the status of the road infrastructure itself. Traffic lights and road toll systems may be adapted to the actual road usage, emergency services can be triggered automatically, and car theft protection may be enhanced (OECD, 2015h).

2.8.4 Smart cities and urban infrastructures

The IoT also holds promise for other efficiency gains in the functioning of cities. Embedded sensors in waste containers and water infrastructure management enable the streamlining of garbage collection and may improve water management (MGI, 2013). Furthermore, location-based services that citizens may use on their mobile phones can give city planners new insights into the usage of the public road infrastructure (OECD, 2015h).

2.8.5 Smart manufacturing

The IoT will also impact manufacturing by improving factory operations and managing risk in the supply chain (OECD, 2015h). Existing business processes, such as product logistics, inventory management and maintenance of machines will change radically. Waste and loss could be significantly reduced by using sensors and circuit breakers. The IoT offers data and tools to create comprehensive supply-chain intelligence.

How fast and how effectively the IoT will evolve over the next 15 years depends to a large extent on the roll-out of fixed and mobile broadband and the decreasing cost of devices (OECD, 2015h). In addition, in order to optimise the potential of the IoT, business and governments will have to build capacity to process the large amounts and variety of data that are produced. Skills for data analysis are a key asset for the future, and inequity is likely to enlarge as the gap between those who can and cannot keep up with IoT developments widens as well (Policy Horizons Canada, 2013).

Intertwined developments in the areas of big data, the cloud, machine-to-machine communication and sensors underpin the rise of the IoT. The impact of the IoT depends in particular on new and emerging technological developments in two key areas: big data analytics and artificial intelligence. In addition, the interoperability among sensors, computers, and actuators is an important issue for the IoT to succeed (MGI, 2013).

Security and privacy are considered the most important risks relating to the IoT. Hackers may be able to remotely take over connected objects such as the electricity grid and driverless cars or manipulate IoT-generated data. The reliability of the network is a major issue, since human lives may depend on successful, sometimes real-time transfers of data. The key issue of consent and perhaps the notion of privacy itself are also challenged by the near-continuous flow of sensitive data that the billions of ubiquitous sensors will produce (OECD, 2015h). Furthermore, artefacts in the IoT can become extensions of the human body and mind. Human autonomy and agency may be shifted or delegated to the IoT, with potential risks for users' privacy and security (IERC, 2015).

Conflicts with existing regulation and regulatory uncertainty may act as bottlenecks when rolling out IoT services nationwide (OECD, 2015h). The international dimension of the IoT adds further to the complexity, since objects and artefacts could be controlled remotely from abroad while litigation is treated under national legal frameworks.

2.9 Computer architecture

[Extracts from [18], p 1]

Application trends, device technologies and the architecture of systems drive progress in information technologies. However, the former engines of such progress – Moore's Law and Dennard Scaling – are rapidly reaching the point of diminishing returns. The time has come for the computing community to boldly confront a new challenge: how to secure a foundational future for information technology's continued progress.

This report stems from an effort to reach out to the applications and devices/circuits communities, and understand their trends and vision. We aim to identify opportunities where architecture research can bridge the gap between the application and device domains.

There are significant trends:

- We now have a clear specialization gap — a gap between off-the-shelf hardware trends and application needs. Some applications, like virtual reality and autonomous systems, cannot be implemented without specialized hardware, yet hardware design remains expensive and difficult.
- Cloud computing, now truly ubiquitous, provides a clear "innovation abstraction;" the Cloud creates economies of scale that make ingenious, cross-layer optimizations cost-effective, yet offers these innovations, often transparently, to even the smallest of new ventures and startups.
- Going vertical with 3D integration, both with die stacking and monolithic fabrication, is enabling silicon substrates to grow vertically, significantly reducing latency, increasing bandwidth, and delivering efficiencies in energy consumption.
- Getting closer to physics: device and circuit researchers are exploring the use of innovative materials that can provide more efficient switching, denser arrangements, or new computing models, e.g., mixed-signal, carbon nanotubes, quantum mechanical phenomena, and biopolymers.
- And finally, machine learning has emerged as a key workload; in many respects, machine learning techniques, such as deep learning, caught system designers "by surprise" as an enabler for diverse applications, such as user preference prediction, computer vision, or autonomous navigation.

2.10 Open data in developing countries

[Extracts from [3], pp 1-3]

How can developing countries secure the full benefits of open data? What barriers are blocking greater impacts? And how can open data be implemented in ways that respond to local context, and that build on existing policy and practice foundations. To address questions like these, the Exploring the Emerging Impacts of Open Data in Developing Countries (ODDC) research network has been gathering information on open data activities across 13 different countries on three continents. Using a mixed-methods case study research, 17 local research partners have developed in-depth accounts on the supply, mediation and use of open data in diverse settings: from budget scrutiny to oversight of judicial systems. This briefing offers 15 initial insights generated from a preliminary synthesis of this research, offered as a basis for further conversations.

1. **There are many gaps to overcome before open data availability, can lead to widespread effective use and impact.** Open data can lead to change through a 'domino effect', or by creating ripples of change that gradually spread out. However, often many of the key 'domino pieces' are missing, and local political contexts limit the reach of ripples. Poor data quality, low connectivity, scarce technical skills, weak legal frameworks and political barriers may all prevent open data triggering sustainable change. Attentiveness to all the components of open data impact is needed when designing interventions.
2. **There is a frequent mismatch between open data supply and demand in developing countries.** Counting datasets is a poor way of assessing the quality of an open data initiative. The datasets published on portals are often the datasets easiest to publish, not the datasets most in demand. Politically sensitive datasets are particularly unlikely to be published without civil society pressure. Sometimes the gap is on the demand side – as potential open data users often do not articulate demands for key datasets.
3. **Open data initiatives can create new spaces for civil society to pursue government accountability and effectiveness.** The conversation around transparency and accountability that ideas of open data can support is as important as the datasets in some developing countries.
4. **Working on open data projects can change how government creates, prepares and uses its own data.** The motivations behind an open data initiative shape how government uses the data itself. Civil society and entrepreneurs interacting with government through open data projects can help shape government data practices. This makes it important to consider which intermediaries gain insider roles shaping data supply.
5. **Intermediaries are vital to both the supply and the use of open data.** Not all data needed for governance in developing countries comes from government. Intermediaries can create data, articulate demands for data, and help translate open data visions from political leaders into effective implementations. Traditional local intermediaries are an important source of information, in particular because they are trusted parties.
6. **Digital divides create data divides in both the supply and use of data.** In some developing countries key data is not digitised, or a lack of technical staff has left data management patchy and inconsistent. Where Internet access is scarce, few citizens can have direct access to data or services built with it. Full access is needed for full empowerment, but offline intermediaries, including journalists and community radio stations, also play a vital role in bridging the gaps between data and citizens.
7. **Where information is already available and used, the shift to open data involves data evolution rather than data revolution**. Many NGOs and intermediaries already access the information which is now becoming available as data. Capacity building should start from existing information and data practices in organisations, and should look for the step-by-step gains to be made from a data-driven approach.
8. **Officials' fears about the integrity of data are a barrier to more machine-readable data being made available**. The publication of data as PDF or in scanned copies is often down to a misunderstanding of how open data works. Only copies can be changed, and originals can be kept authoritative. Helping officials understand this may help increase the supply of data.

9. **Very few datasets are clearly openly licensed, and there is low understanding of what open licenses entail.** There are mixed opinions on the importance of a focus on licensing in different contexts. Clear licenses are important to building a global commons of interoperable data, but may be less relevant to particular uses of data on the ground. In many countries wider conversation about licensing are yet to take place.
10. **Privacy issues are not on the radar of most developing country open data projects, although commercial confidentiality does arise as a reason preventing greater data transparency**. Much state held data is collected either from citizens or from companies. Few countries in the ODDC study have weak or absent privacy laws and frameworks, yet participants in the studies raised few personal privacy considerations. By contrast, a lack of clarity, and officials' concerns, about potential breaches of commercial confidentiality when sharing data gathered from firms was a barrier to opening data.
11. **There is more to open data than policies and portals**. Whilst central open data portals act as a visible symbol of open data initiatives, a focus on portal building can distract attention from wider reforms. Open data elements can also be built on existing data sharing practices, and data made available through the locations where citizens, NGOs are businesses already go to access information.
12. **Open data advocacy should be aware of, and build upon, existing policy foundations in specific countries and sectors.** Sectoral transparency policies for local government, budget and energy industry regulation, amongst others, could all have open data requirements and standards attached, drawing on existing mechanisms to secure sustainable supplies of relevant open data in developing countries. In addition, open data conversations could help make existing data collection and disclosure requirements fit better with the information and data demands of citizens.
13. **Open data is not just a central government issue: local government data, city data, and data from the judicial and legislative branches are all important.** Many open data projects focus on the national level, and only on the executive branch. However, local government is closer to citizens, urban areas bring together many of the key ingredients for successful open data initiatives, and transparency in other branches of government is important to secure citizens democratic rights.
14. **Flexibility is needed in the application of definitions of open data to allow locally relevant and effective open data debates and advocacy to emerge.** Open data is made up of various elements, including proactive publication, machine-readability and permissions to re-use. Countries at different stages of open data development may choose to focus on one or more of these, but recognising that adopting all elements at once could hinder progress. It is important to find ways to both define open data clearly, and to avoid a reductive debate that does not recognise progressive steps towards greater openness.
15. **There are many different models for an open data initiative: including top-down, bottom-up and sector-specific.** Initiatives may also be state-led, civil society-led and entrepreneur-led in their goals and how they are implemented – with consequences for the resources and models required to make them sustainable. There is no one-size-fits-all approach to open data. More experimentation, evaluation and shared learning on the components, partners and processes for putting open data ideas into practice must be a priority for all who want to see a world where open-by-default data drives real social, political and economic change.

A more detailed version of this synthesis, along with available partner case study reports can be found at http://www.opendataresearch.org/emergingimpacts/.

2.11 Compressed sensing

[Extracts from [25], pp 3-6]

In the last two decades, two separate revolutions have brought digital media out of the pre-Internet age. Both revolutions were deeply grounded in the mathematical sciences. One of them is now mature, and you benefit whenever you go to a movie with computer-generated animation. The other revolution has just begun but is already redefining the limits of feasibility in some areas of biological imaging, communication, remote sensing, and other fields of science.

The first could be called the "***wavelet revolution***." Wavelets are a mathematical method for isolating the most relevant pieces of information in an image or in a signal of any kind (acoustic, seismic, infrared, etc.). There are coarse wavelets for identifying general features and fine wavelets for identifying particular details. Prior to wavelets, information was represented in long, cumbersome strings of bits that did not distinguish importance.

The central idea of wavelets is that for most real-world images, we don't need all the details (bytes) in order to learn something useful. In a 10-megapixel image of a face, for instance, the vast majority of the pixels do not give us any useful information. The human eye sees the general features that connote a face—a nose, two eyes, a mouth—and then focuses on the places that convey the most information, which tend to be edges of features. We don't look at every hair in the eyebrow, but we do look at its overall shape. We don't look at every pixel in the skin, because most of the pixels will be very much like their neighbours. We do focus on a patch of pixels that contrast with their neighbours—which might be a freckle or a birthmark or an edge.

Now much of this information can be represented much more compactly as the overlapping of a set of wavelets, each with a different coefficient to capture its weight or importance. In any typical picture, the weighting amplitude of most of the wavelets will be near zero, reflecting the absence of features at that particular scale. If the model in the photograph doesn't have a blemish on a particular part of her skin, you won't need the wavelet that would capture such a blemish. Thus you can compress the image by ignoring all of the wavelets with small weighting coefficients and keeping only the others. Instead of storing 10 million pixels, you may only need to store 100,000 or a million coefficients. The picture reconstructed from those coefficients will be indistinguishable from the original to the human eye.

Curiously, wavelets were discovered and rediscovered more than a dozen times in the 20th century—for example, by physicists trying to localize waves in time and frequency and by geologists trying to interpret Earth movements from seismograms. In 1984, it was discovered that all of these disparate, ad hoc techniques for decomposing a signal into its most informative pieces were really the same. This is typical of the role of the mathematical sciences in science and engineering: Because they are independent of a particular scientific context, the mathematical sciences can bridge disciplines.

Once the mathematical foundation was laid, stronger versions of wavelets were developed and an explosion of applications occurred. Some computer images could be compressed more effectively. Fingerprints could be digitized. The process could also be reversed: Animated movie characters could be built up out of wavelets.

In 2004, the central premise of the wavelet revolution was turned on its head with some simple questions: Why do we even bother acquiring 10 million pixels of information if, as is commonly the case, we are going to discard 90 percent or 99 percent of it with a compression algorithm? Why don't we acquire only the most relevant 1 percent of the information to start with? This realization helped to start a second revolution, called ***compressed sensing***.

Answering these questions might appear almost impossible. After all, how can we know which 1 percent of information is the most relevant until we have acquired it all? A key insight came from the interesting application of how to reconstruct a magnetic resonance image (MRI) from insufficient data. MRI scanners are too slow to allow them to capture dynamic images (videos) at a decent resolution, and they are not ideal for imaging patients such as children, who are unable to hold still and might not be good candidates for sedation. These challenges led to the discovery that MRI test images could, under certain conditions, be reconstructed perfectly—not approximately, but *perfectly*—from a too-short scan by a mathematical method called L1 (read as "ell-one") minimization. Essentially, random measurements of the image are taken, with each measurement being a randomly weighted average of many randomly selected pixels. Imagine replacing your camera lens with a kaleidoscope. If you do this again and again, a million times, you can get a better image than you can from a camera that takes a 10-megapixel photo through a perfect lens.

The magic lies, of course, in the mathematical sciences. Even though there may be millions of scenes that would reproduce the million pictures you took with your kaleidoscopic camera, it is highly likely that there will be only one sparse scene that does. Therefore, if you know the scene you photographed is information-sparse (e.g., it contains a heart and a kidney and nothing else) and measurement noise is controlled, you can reconstruct it perfectly. L1 minimization happens to be a good technique for zeroing in on that one sparse solution. Compressed sensing actually built on, and helped make coherent, ideas that had been applied or developed in particular scientific contexts, such as geophysical imaging and theoretical computer science, and even in mathematics itself (e.g., geometric functional analysis). Lots of other reconstruction algorithms are possible, and a hot area for current research is to find the ones that work best when the scene is not quite so sparse.

As with wavelets, seeing is believing. Compressed sensing has the potential to cut down imaging time with an MRI from 2 minutes to 40 seconds. Other researchers have used compressed sensing in wireless sensor networks that monitor a patient's heartbeat without tethering him or her to an electrocardiograph. The sensors strap to the patient's limbs and transmit their measurements to a remote receiver. Because a heartbeat is information-sparse (it's flat most of the time, with a few spikes whose size and timing are the most important information), it can be reconstructed perfectly from the sensors' sporadic measurements.

Compressed sensing is already changing the way that scientists and engineers think about signal acquisition in areas ranging from analogue-to-digital conversion to digital optics and seismology. For instance, the country's intelligence services have struggled with the problem of eavesdropping on enemy transmissions that hop from one frequency to another. When the frequency range is large, no analogue-to-digital converter is fast enough to scan the full range in a reasonable time. However, compressed sensing ideas demonstrate that such signals can be acquired quickly enough to allow such scanning, and this has led to new analogue-to-digital converter architectures.

Ironically, the one place where you aren't likely to find compressed sensing used, now or ever, is digital photography. The reason is that optical sensors are so cheap; they can be packed by the millions onto a computer chip. Even though this may be a waste of sensors, it costs essentially nothing. However, as soon as you start acquiring data at other wavelengths (such as radio or infrared) or in other forms (as in MRI scans), the savings in cost and time offered by compressed sensing take on much greater importance. Thus compressed sensing is likely to continue to be fertile ground for dialogue between mathematicians and all kinds of scientists and engineers.

2.12 Cognitive computing and neuromorphic computing

[Extracts from [16], pp 5, 6]

Cognitive computing is making important strides, with important contributions from industry and academia, but further advances will require the development of new science in both hardware and software development. As an example, more work is needed to measure the entropy of data sets to determine the quality, richness, and diversity of a data set and whether it is complete enough to enable cognitive computing applications, such as anomaly detection, with context and behavioral analysis that ensures privacy. New science could also enable applications in the areas of risk-based capacity planning for infrastructure development, control of viral propagation, and computational creativity.

While new processor technologies using field-programmable gate arrays, for example, and advanced graphical processing units are producing multiple-fold improvements over traditional computing with regard to machine learning, those kind of incremental advances will not change the game. Neuromorphic computing, inspired by the architecture and operations of the brain, has already improved processing time on selected video tasks by three orders of magnitude, but highly speculative technology still being investigated could increase the speed for training neural networks by four to five orders of magnitude. The timeline for turning these proof-of-concept demonstrations into implemented technologies will be longer than most companies can support, however, so this is a place where [national public science institution] could play a role through its centres by bringing researchers from academia and industry together to shorten that timeline. The benefit should be on the order of trillions of dollars.

2.13 Mathematical simulations

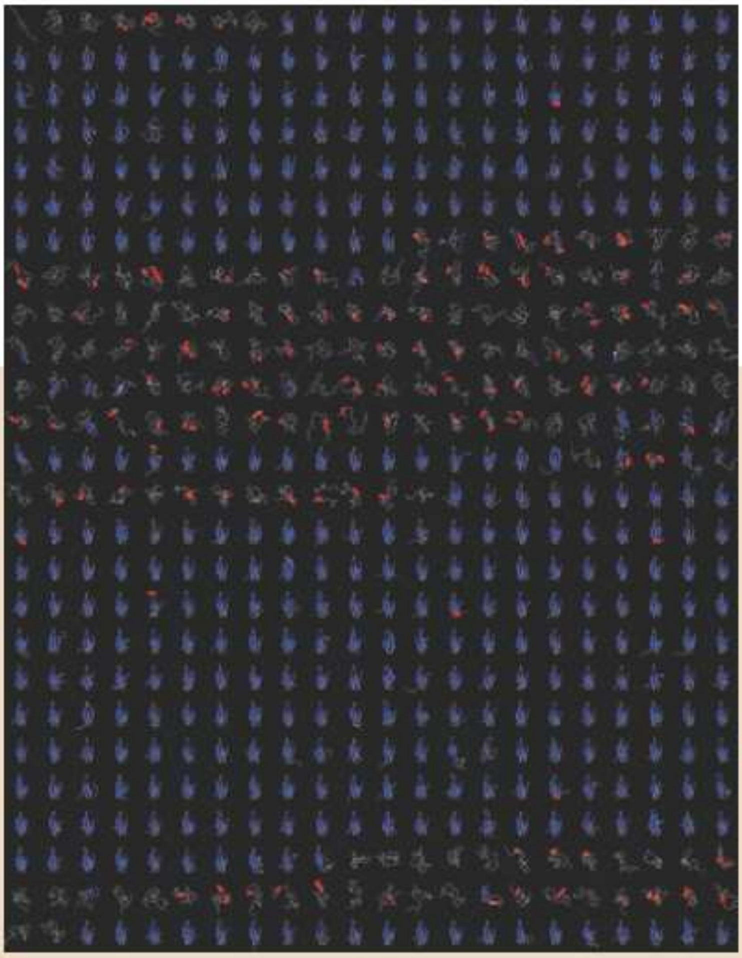
[Extracts from [25], pp 11-17]

Computer simulations, which are built on mathematical modelling, are used daily in scientific research of all types, for informing decision making in business and government, including national defence, and for designing and controlling complex systems such as those for transportation, utilities, and supply chains, and so on. Simulations are used to gain insight into the expected quality and operation of those systems and to carry out what-if evaluations of systems that may not yet exist or are not amenable to experimentation.

In scores of applications, from physics to biology to chemistry to engineering, scientists use computer models—whose construction requires the formulation of mathematical and statistical models, the development of algorithms, and the creation of software—to study phenomena that are too big, too small, too fast, too slow, too rare, or too dangerous to study in a laboratory.

While scientists and engineers have long been able to write down equations to describe physical systems, before the computer age they could only solve the equations in certain highly simplified cases, literally using a pen and paper or chalk and a blackboard. Now, however, the scientific universe has changed.

While many are aware of the amazing gains in raw speed from Moore's law—the approximate doubling of computer hardware capabilities every two years—successful simulation on this scale also depends to an equal degree on new algorithms that perform the needed computations. For example, the transition from two to three dimensions invariably increases (usually by an enormous factor) the difficulty of a problem, requiring mathematical advances in representing reality as well as problem solving. Three-dimensional simulations on this scale are possible only through a combination of massive computing power and smart mathematical algorithms. The transition from a two- to a three-dimensional model requires more than simply running the same code with more data points. Often, new mathematical representations must be incorporated to capture new phenomenology, and new comparisons against theory must be made to assess the validity of the resulting three-dimensional model. More generally, advances in mathematics and statistics and improved algorithms provide leapfrog advances in computational capabilities. Scholarly studies have estimated that at least half of the improvement in high-performance computing capabilities over the past 50 years can be traced to advances in mathematical sciences algorithms and numerical methods rather than to hardware developments alone.



5 / Snapshots of the folding and unfolding of a protein, obtained from a simulation of unprecedented length performed on the special-purpose supercomputer Anton. Multiple transitions are observed between a disordered "unfolded state" (red and gray) and an ordered "folded" state (blue). Printed with permission from D.E. Shaw Research. /

The value of simulation is not limited to real-world problems of huge scale: It is just as useful for tiny problems such as understanding processes within our cells. Many of the cell's functions are carried out by proteins—large molecules that fold into a precise shape to accomplish a particular task. At present, nobody knows how to take the chemical formula for a protein and predict the shape it will fold into. The shape is determined by the forces between the many atoms within the protein and between those atoms and their surroundings. Calculating the net result of all those forces is a daunting computational challenge, but simulations are getting close to that goal. Recently a special-purpose supercomputer managed to simulate the motion of a relatively small protein called FiP35 over a period of 200 microseconds (one five-thousandth of a second), during which time it folded and unfolded 15 times (see Figure 5 above). Again, while part of this capability was made possible by the special-purpose hardware, it also depends on mathematical advances. First, the precise but computationally intractable force field must be replaced by a good approximation based on empirical data and on simpler systems, and mathematical analysis is necessary to characterize the adequacy of the approximation. Second, computational algorithms have been developed to speed the computation of the interactions between atoms.

These success stories illustrate the kinds of problems that scientists now routinely ask computer simulations to solve. For decades, biology had only two modes of research—*in vivo* (experiments with living organisms) and *in vitro* (experiments with chemicals in a test tube). Now, there is a third paradigm, *in silico* (experiments on a computer). And the results of this kind of experiment are taken just as seriously.

Nevertheless, simulations face major challenges, which will be the focus of ongoing research over the next 20 years.

- ***Real-world processes*** often require simulation over a wide range of scales, both in space and in time. For instance, the core collapse of a supernova takes milliseconds, while the crucial convection step takes place over a span of seconds and the aftermath of the explosion lasts for centuries. Spatially, the thermonuclear flame of the supernova varies from millimetres to hundreds of meters during the explosion.
- In ***biology***, the range of scales is just as daunting. Subcellular processes are linked to events at the scale of a cell. These effects cascade upward, affecting heart tissues, then the heart, and finally (in the event of a heart attack) the health of the whole body. Likewise, the timescales also span a vast range: microseconds for the folding of a protein, fractions of a second for the choreography of a single heartbeat, minutes for a heart attack, weeks or months for the body's recovery. It is very difficult to incorporate all these scales into a single mathematical model.
- Related to the multiscale problem is the ***multiphysics problem***. Often the types of models used at different scales are incompatible with one another. Events at a subcellular level are often chemical and random, influenced by the presence or absence of a few molecules. In the heart, these events translate into electrical currents and mechanical motions that are governed by differential equations, which are usually deterministic. Multiphysics can also characterize a single scale: The heart is simultaneously an electric circuit and a hydraulic pump. It's not easy to reconcile and simultaneously model those two identities. Progress in such cases often depends on a combination of insights from the domain science and the mathematical sciences.
- Given the complexity of simulations, ***model validation*** also becomes an important challenge. First the modeller has to make sure that the individual parts of the program are working as expected; for a complex simulation, this can be very difficult. Then he or she will test it to see if it reproduces the behaviour of simple real-world systems and matches existing data. Finally, the model will be used to make predictions about genuinely new phenomena.
- Scientist who do simulations would like ***more computing power***. Three-dimensional simulations are just barely feasible today, but some researchers would really like to go up to six dimensions!
- But raw computing power is not the only solution. At the cutting edge of research, the importance of ***new and better algorithms*** cannot be overstated. To put it simply, you can wait 2 years for Moore's law to hand you a computer that is twice as fast—or you can get the same speedup today by developing better algorithms.

Apparent advances in raw computation speed do not translate directly, and perhaps not even indirectly, to simulations that are faster or more accurate. Today's expectation is that the high-end computers of the future will have huge numbers of very fast "cores"—processing units operating individually at extremely high speed—but that communication between cores will be relatively slow. Hence, software written for computers with a single core (or a small number of cores) will not be efficient, and standard computations, such as those for linear algebra, will need serious reworking by mathematical and computer scientists.

2.14 Models of real-world systems

[Extracts from [23], p 13]

The notion of building models of real-world systems has a long history. Among the first predictable, recurring phenomena humans tried to model were astronomical in nature, including the diurnal cycle, the passing of the seasons, and the movement of planets in the night sky. Early astronomers, including Aryabhata (born in India in 476) and Tycho Brahe (born in Denmark in 1546), carried out the immensely complex computations by hand. The advent of digital computing in the mid-20th century offered a way to perform massive computations based on mathematical formulas, and revolutionized modelling capabilities. Weather and climate modelling is a classic example of how digital computing transformed an entire field.

The current situation in social system modelling is not unlike weather forecasting 35 years ago, when computational methods first began surpassing expert judgement (Edwards, 2010). For example, the Federal Reserve Board now relies on both experts (board members) and models (e.g., FRB/US) to estimate the near-term prospects for the U.S. economy, which are then used to decide on policy. The performance of both the experts and the models has been checkered. In the 2007–2009 financial crisis, the FRB/US model correctly predicted the steep drop in housing prices, but substantially underestimated the rise in unemployment. Expert predictions of unemployment were also too optimistic, even while the crisis was unfolding. A variety of computationally sophisticated social system modelling efforts are now under way in economics (e.g., Delli Gatti et al., 2011), finance (e.g. Geanakoplos et al., 2012), and other policy realms (e.g. state stability and epidemics). Consequently, prospects for these domains to follow the trajectory of weather model development are strong.

2.15 The convergence of automotive and technology

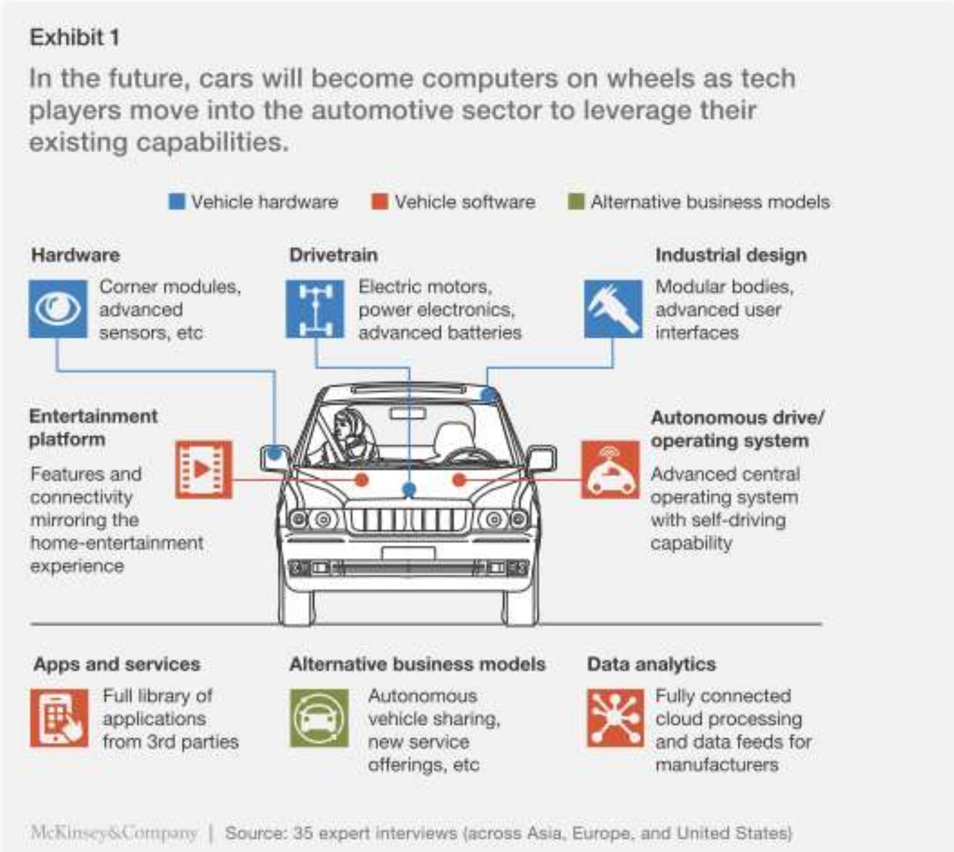
[Extracts from [10], pp 1-7]

As four technology trends reshape the global automotive sector, customer preferences are moving away from its traditional strongholds, such as chassis and engine development. This shift in customer preferences and the sheer size of the automotive sector have attracted new players: a potent mix of large high-tech companies and start-ups. Both differ from the automotive incumbents on virtually every level.

The fortunes of players in the automotive sector have always depended on what customers see as valuable. Most of this value has resided in the hardware of vehicles and in the automakers' brands. However, future innovations will probably focus on disruptive technology trends, so the customers' perceptions of value will shift, increasingly putting incumbents in danger. The four trends that will favour the newcomers are these:

- **Electrification**. Drivetrains will shift toward hybrid-electric, electric, and fuel-cell technologies as they mature and become cheaper.
- **Autonomous driving.** The operation of automated cars will move from advanced driver-assistance systems to fully autonomous driving as the technology matures.
- **Diverse mobility.** As the sharing economy expands and consumer preferences change, the standard model will continue to evolve from outright purchase or lease to rentals and car sharing.
- **Connectivity.** The possibilities for "infotainment" innovations, novel traffic services, and new business models and services will increase as cars get connected to each other, to the wider infrastructure, and to people.

Attracted by the shift in customer preferences, the importance of the new trends, and the global automotive market's massive size and value-creation potential, technology players are making their way into the sector. As they develop new software options, cars are evolving into computers on wheels, a change similar to events in the computer industry 20 years ago and the cellphone industry 10 years ago. As a result, we anticipate that a complex ecosystem will emerge in the automotive sector (Exhibit 1).



Although the sector adheres to a vertically integrated business model, with OEMs in full control of their supplier networks, the new tech players are more focused on horizontal moves:

- A number of high-tech players are developing autonomous-driving systems that are quite likely to merge into what the computer industry calls an operating system (the central system that makes a unit run).
- Disruptors from the taxi and ride-sharing industries are developing innovative new business models.
- Two leading online and technology companies are focusing on in-car entertainment platforms, which they hope will become the standard for applications.

No single player is likely to dominate any part of such a horizontally organized, complex value chain by itself. But many of the new tech entrants are well positioned to take the lead in the software-focused parts. For each part of the ecosystem, there might be room for only a few winners, since few players will be able to invest the resources necessary to reach scale (Exhibit 2).

The automakers have invested billions in car hardware, from engine plants to stamping facilities and beyond, so they have the best position to dominate the hardware-focused areas. In software, the tech players enjoy significant advantages, including leading-edge capabilities, agile operating models, and the financial muscle required to pursue exploratory investments aggressively. For the automakers and tech players, success in tomorrow's mobility sector will depend on how well they build on these natural advantages.

Exhibit 2

A couple of specialized players will probably dominate each niche of the future automotive ecosystem.

Future scenario as a horizontal move for players

• Mechanical hardware	Subassemblies get standardized, and players merge to benefit from scaling up—ie, chassis components, body substructures shared across models/brands
• Drivetrain	3–5 players with competitive advantage scale up production—ie, batteries for electric vehicles, fuel cells, drive units for modular cars
• Industrial design • Branding	Vehicle interiors and exteriors remain a key differentiator, and importance of brand value rises in an increasingly commoditized sector
• Operating system	2–3 standard operating systems for autonomous drive (and potential other systems—eg, onboard communication architecture) as a plug-and-play solution
• In-car entertainment	2–3 large-scale multimedia ecosystems present attractive opportunity for 3rd-party development, probably established mobile platforms (iOS, Android)
• Cloud • Data analytics	Analytics skills and server technology are leveraged to create services that facilitate the usage of big data for commercialization and customer satisfaction
• Apps and services	Built-in navigation and media get replaced by apps provided by 3rd-party developers, curated via app store and more widely connected via online services
• Alternative business models	Vehicle provided to consumer just for duration of ride and specific to trip purpose, making mobility the actual product, beyond vehicle

McKinsey&Company | Source: Expert interviews

Automakers not uncommonly spend up to 75 percent of their overall capital-expenditure distributions on traditional product-development and manufacturing assets. Tech players instead allocate a similar ratio to software development and the customer experience. The largest technology entrants also spend more on R&D than automakers do—over 10 percent compared with less than 5 percent of their revenues, respectively—and allocate more of this spending to disruptive technologies.

The convergence of the automotive and high-tech sectors will rewrite the rules of competition and lessen the chances of survival for traditional players that fail to act. The competitive space remains fluid at this point, but that could change quickly as incumbents move to position themselves advantageously and tech companies solidify their investment strategies.

3 Biotechnologies

3.1 Neurotechnologies

[Extracts from [1], pp 57, 58]

Neurotechnology is defined as any artificial means to interact with the brain and nervous system in order to investigate, assess, access and manipulate the structure and function of neural systems (Giordano, 2012). This encompasses brain research itself, surgical interventions in the brain to implant electronic devices that can repair or substitute brain functions, the treatment of brain diseases and conditions through methods such as external brain stimulation, and the use of neuro-prostheses through brain-computer interfaces.

Neurotechnologies promise to help better understand the natural processes of the brain, to study and treat neurological disorders and injuries, and to enhance neural capabilities, resulting in increased human intelligence and efficiency. Advances in neurotechnology are expected to impact many different fields, including medicine, defence and intelligence agency operations, the justice system, advertising, business, communications, and even politics (Potomac Institute, 2015).

Neurotechnologies bring together and combine expertise from neuroscience, microsystems engineering, computer science, clinical neurology and neurosurgery. The field is converging with other fields in order to advance. The synergistic nature of these advances means that new paradigms and technologies for enhancing humans are likely to develop rapidly. The way ahead will be transformed by advances in nanotechnologies, big data analytics and neuroscience, among others.

Neurotechnologies could provide effective treatments for many serious neurological and mental health disorders. For example, they could be used to retard disease progression and potentially cure those suffering from Parkinson's disease; and they could improve the quality of life for people suffering from depression, migraines and other psychiatric conditions (Nuffield Council on Bioethics, 2013). The best-known novel neurotechnologies in the medical field are as follows:

Transcranial brain stimulation is a non-invasive procedure used to stimulate the brain. While it is regularly used as a research tool, therapeutic applications are being increasingly explored, specifically in treating drug-resistant depression.

- Deep brain stimulation is an invasive procedure requiring brain surgery to place electrodes in a specific region deep within the brain. Its therapeutic uses include treating movement disorders (such as those associated with Parkinson's disease) and neuropathic pain. There is also considerable research activity exploring its use to treat a wide range of psychiatric disorders such as epilepsy, dystonia, Tourette's syndrome, depression, obsessive-compulsive disorder and cluster headaches (Nuffield Council on Bioethics, 2013; OECD, 2014c).
- Brain-computer interfaces (BCIs) may or may not be invasive and work by acquiring brain signals, analysing them, and translating them into commands that are relayed to output devices (e.g. computers and robotics) that carry out desired actions (Shih et al, 2012). Such applications can be further enhanced by incorporating artificial sensory systems that provide environmental feedback to the brain. BCIs have vast implications for those who have neurological disabilities. For example, they can be used to replace or restore useful function to people disabled by neuromuscular disorders, to improve cognitive functions, and to communicate thoughts and intentions when normal capabilities are impaired (Wolpaw and Wolpaw, 2012; Policy Horizons Canada, 2013).

Beyond clinical applications, BCIs could be widely applied in fields such as entertainment, defence, finance, human computer interaction, education and home automation; the most promising areas are assistive technologies and gaming. BCIs are also being used for reaction and evaluation monitoring in fields such as marketing and ergonomics. BCIs can also enable hands-free device control and user-state monitoring, which can be useful for automobile drivers, pilots, astronauts and others engaged in focus-demanding tasks (Potomac Institute, 2015).

More speculatively, BCIs could be used to enhance baseline intelligence, allowing multiple brains to cooperate on tasks and enhance performance. They could also be used to develop new senses for human beings, such as the ability to sense magnetic fields or infrared or radio waves. Neuroimaging could be used to document and share dreams, ideas, and abstract concepts. Users would be able not only to control machines with their minds but also to mentally share thoughts (Potomac Institute, 2015).

Beyond the clinical applications, the automobile, advertising and defence industries have invested in neurotechnology and will likely increase investments as the potential of such technologies grows. Innovation in the field is booming, with the number of patents filed at the United States Patent and Trademark Office doubling from around 800 in 2010 to more than 1 600 in 2014. There are currently over 8 000 active patents and more than 1 500 pending applications (Potomac Institute, 2015). Patents have been awarded to firms well beyond those in the medical field, such as those working on video game control systems based on brain waves.

Invasive neurotechnologies requiring neurosurgery risk potential unintended physiological and functional changes in the brain resulting from the implanted electrodes or stem cells, as well as infection and bleeding associated with surgery itself. Non-invasive neurotechnologies pose fewer risks, although their long-term use may lead to negative consequences on brain structure and functioning (Mak and Wolpaw, 2009; Wolpaw, 2010; Nuffield Council on Bioethics, 2013) and may also be associated with complex unintended effects on mood, cognition and behaviour (Nijboer et al, 2013).

There are ethical considerations for BCI technologies that relate to its potential to change some central concepts and categories used to understand and observe the set of values, norms and rules that involve the human moral status. The blurring distinction between man and machine makes it more difficult to assess the limits of the human body and raises questions concerning free will and moral responsibility (Schermer, 2009).

3.2 Transforming neuroscience clinical trials with technology

[Extracts from [26], pp 37-42]

New technologies are disrupting all industries, including health care and drug development. Although they have yet to make a major impact in clinical trials, technological innovations offer the potential to improve efficiency and productivity through the use of novel outcomes, increased patient engagement, reduced patient burden, and improved trial management. It is argued that technology can enable the field's ethical duty to conduct efficient next-generation clinical trials. Yet the expanded use of new technologies also raises regulatory and operational concerns as well as barriers to implementation. Moreover, some caution against replacing the entire human element of clinical trials with technology. Although there are some aspects of trial design where efficiencies can be gained by more rapidly enrolling and prequalifying large numbers of participants and gathering data that show whether a treatment works or not, humans are better at developing research objectives and analyzing data.

There are other technologies that are likely to disrupt the drug development enterprise such as synthetic biology—so-called exponential technologies because they are developing at an exponential rate. Virtual reality and the Internet of Things are another two emerging paradigms that are transforming consumer-based technology development.

Novel assessment tools

Continuous measurement of activity and behaviour is one approach that enables collection of precise and frequent information at a relatively low cost, as well as new types of information that could not be measured in the past. Smaller and more sophisticated sensors are driving the increasing use of these technologies beyond the consumer market. Thus, they could be used to develop digital signatures that characterize how different populations behave, such as people with schizophrenia or bipolar disease. Continuous data capture of an individual enrolled in a trial can provide insight into that person's mental well-being and the stability of daily routines. Such measures could allow the reframing of behaviours beyond those included in the DSM-5 [the standard classification of mental disorders in the USA] and could also enable the implementation of just-in-time interventions.

Major challenges with regard to these devices include how to make sense of the enormous amounts of data that can be acquired, and how to leverage that data, including data about how an individual uses technology, to learn more about the disease itself and its progression. Differentiating the signal from the noise presents yet another challenge, although some suggest that digital measures allow investigators to embrace the noise by identifying interesting signals embedded in noisy measures. However, while continuous monitoring such as this may be more objective than patient self-report measures, others emphasise that conscious experience is an important component of psychiatric disease; this requires active measures such as self-report, in addition to more objective passive measures.

Other challenges for those hoping to use data from wearables and in-home monitoring devices are the standardization and normalization of data from many different types of devices and applications. Standardization of measures is also very important. An association of large consumer technology companies has established a standards committee that is tasked with creating standards for consumer devices that assess activity, sleep, electroencephalogram (EEG), and other measures. The underlying technology for these devices is often very similar, which should make standardization somewhat easier. There is also a trend toward "make-your-own" devices, however. For example, Biogen has publicly stated it is developing a device with enhanced sensitivity to the multiple sclerosis patient experience.

However, it should be noted that although implementation of Clinical Data Interchange Standards Consortium (CDISC) standards reduces the time from start-up to finish of a study by 60 percent, adoption of CDISC standards has been slow and has not penetrated the entire research ecosystem of stakeholders.

Integrating these data, along with physiologic, genotypic, and phenotypic data from other sources, presents an additional challenge. However, it is argued that integrated disease models will enable creation of interesting multivariate models in neuroscience and other disease areas, and thus will become a preferred type of model.

Wearables and other types of sensors may also be useful as tools to assess compliance with a study protocol. Models can be developed through machine learning to identify fraudulent sites and participants. In addition, objective data such as how many steps a person takes a day, or how many times he or she interacts with others, could provide good objective indicators of depression and other psychiatric conditions. Whatever novel treatment targets, endpoints, and trial designs are used, what regulators are most interested in is clinical meaningfulness. To what extent does the treatment affect how the patient feels, functions or survives; how do you measure this?

3.3 Organoid technology

[Extracts from [11], pp 1, 6]

Organoids are stem cell–derived structures generated in vitro that display the three-dimensional architecture and physiology of intact organs. They offer unique possibilities for modelling and studying normal development and disease processes and open up innovative approaches to medical research, drug discovery, and toxicology testing. Together with reprogramming technology and gene editing methods, organoids hold the promise to influence the innovation cycle in biomedical research, including fields that historically have been the subject of intense ethical debate.

Organoids hold great potential for investigating human development and disease. Organoid technology can reduce animal experimentation and may potentially close the gap between preclinical drug development and human trials. We predict that organoids will become model systems that are complementary to existing animal in vivo and cell-based in vitro models. It is very unlikely, however, that organoid technology will entirely replace animal experiments or experiments on human embryos and fetuses.

Organoids face several layers of complexity, not only technologically but also with regard to their ethical introduction in research, clinical care, and society. Only by engaging in constructive interdisciplinary dialog around these issues, involving not only scientists but also patients, policy-makers, clinicians, ethicists, and the public, can we ensure responsible innovation and long-term acceptance of this exciting technology.

3.4 Diffusion tensor imaging: a new view of the brain

[Extracts from [25], pp 24-28]

On battlefields and playing fields, from Iraq to Cowboys Stadium, one of the signature injuries of the past decade has been concussion. More than 300,000 soldiers suffered suspected concussions between 2001 and 2007. Nevertheless, it remains a difficult condition to diagnose because the damage to the brain is hard to see with conventional imaging techniques. The brain may look completely normal on magnetic resonance imaging (MRI) or on a computed axial tomography (CAT) scan, yet patients report ongoing effects, such as memory loss, headaches, sensitivity to light or noise, and depression.

A new imaging technique—a variant of MRI called ***diffusion tensor imaging***—has revealed that the damage to concussed brains may lie not in the gray matter but in the *white matter*. For decades, neurologists considered the white matter (consisting of axons and glial cells) to be less important than the gray matter (which consists of neurons). They saw the white matter as a passive scaffolding for the brain's architecture. However, this view has changed dramatically in the last decade. If the brain is like a computer, then the gray matter can be compared to the processors, while the white matter can be compared to the communications grid that links those processors. Even the most powerful processors cannot work correctly if the pathways are destroyed or disrupted.

Besides concussion, a whole host of other brain functions and malfunctions are now linked to the white matter. Patients with schizophrenia, Alzheimer's disease, or deterioration due to a stroke, autism, and attention deficit disorder all have detectable changes in diffusion tensor imaging images of their white matter. Even during normal development and learning, the diffusion tensor imaging changes in intriguing ways.

The revolution in our understanding of white matter—which has only just begun—would never have been possible without diffusion tensor imaging. And diffusion tensor imaging, in turn, would never have been possible without the mathematical sciences. The mathematics is hidden in plain sight: in that mysterious word "tensor" in diffusion tensor imaging. A tensor is a mathematical concept, developed in the 19th century, that generalizes the notion of vectors. Tensors have proved useful in a number of areas of physics.

To explain what a tensor has to do with white matter in the brain, it helps to start with how MRI works. An MRI machine creates a strong magnetic field, which causes the protons in the body to rotate and line up in a predictable way. Most of these protons are actually hydrogen atoms in water molecules; thus MRI is especially sensitive to the water (or fluids) in your body. It is an excellent complement to traditional x-rays, which see the dense, hard structures in your body but are relatively blind to the soft tissues. One of the most informative parts of the body to image with MRI is the brain, because it is squishy and it uses a lot of blood.

By modulating or pulsing the magnetic field in various ways, doctors can tune the MRI scan to detect different kinds of tissue in the body. In particular, one technique allows them to measure the displacement of water molecules over a short period of time—displacements that are due not to blood flow but to random jitters of the molecules, called *Brownian motion*. Because Brownian motion underlies the process of diffusion, this technique measures what is called the “apparent diffusion coefficient” in a tiny cubic region of the brain.

Beginning in the early 1990s, researchers noticed a puzzling fact: In the white matter, the apparent diffusion coefficient of a sample seemed to depend on its orientation with respect to the magnetic field. Tilt the sample and you would get a different diffusion coefficient. In 1991, a biomedical engineer had a eureka! moment: The dependence of the apparent diffusion coefficient on orientation wasn’t a problem, it opened a path toward a solution.

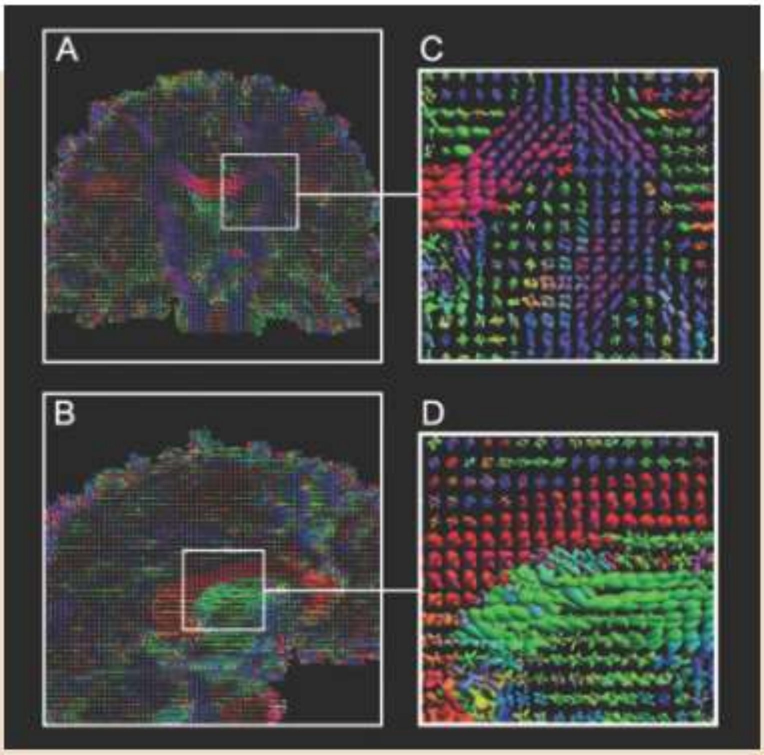
This engineer knew something that most doctors didn’t. In an anisotropic material—a material that is directionally dependent, such as a wood with a grain going in a particular direction or brain tissue that consists of layers or fibres—water doesn’t diffuse equally rapidly in all directions. Water molecules move faster along the fibres and more slowly perpendicular to them. Over time, a tiny blob of water molecules will diffuse into an ellipsoid (or football) shape, with the long axis of the ellipsoid pointing along the fibres. The diffusion tensor contains all the mathematical information needed to graph this ellipsoid. It is not just a single number (like the apparent diffusion coefficient) but a 3×3 array of numbers. Starting with pork loins and working up to living human tissue, the experimental and mathematical procedures were developed for measuring the diffusion tensor from point to point within a sample and putting it into a three-dimensional image.

9 / Diffusion tensor imaging used to reconstruct network connections in the brain (tractography). Similarly oriented fibers are shown in the same color. Reprinted from Moriah E. Thomason and Paul M. Thompson, 2011, Diffusion imaging, white matter, and psychopathology, Annual Review of Clinical Psychology *7:63-85, with permission from Annual Reviews, Inc. /*

Diffusion tensor imaging was made to order for visualizing white matter, which consists mostly of axons, elongated cells that convey electrical impulses. Water diffuses rapidly along the length of an axon but slowly across the width. In addition, many but not all axons have a fatty sheath, called a myelin layer, which impedes the diffusion of water. (The myelin sheath is also what gives white matter its colour.) Thus diffusion tensor imaging can both map out the direction of the brain's electric fibres (this is called "tractography" and is illustrated in Figure 9 above) and also detect the extent of myelination in various parts of the brain.

Already this imaging capability has led to fundamental insights about normal and abnormal brains. For example, biologists have known for a long time that the human brain starts out with little myelin, and that the axons gradually myelinate over childhood and adolescence. The myelination process seems to be associated with learning. With diffusion tensor imaging, researchers can now see this process in living humans. For example, they can see which parts of the brain are associated with reading and language acquisition. The fibre integrity (or "fractional anisotropy") seems to peak in the early 30s and gradually decreases thereafter; this may explain why memory and other cognitive processes decline gradually with age.

Likewise, diffusion tensor imaging points out areas of the white matter that are compromised in particular diseases, including schizophrenia, autism, and attention deficit hyperactivity disorder. And in concussion injuries, the fibre integrity is reduced near the site of the injury. This finding could be useful as both an objective criterion for diagnosis and a way of predicting which patients will suffer more serious long-term symptoms.



10 / High angular resolution diffusion imaging data used to show diffusion surfaces in three dimensions in the brain. This allows for a higher-resolution image than conventional diffusion tensor imaging but generates a great deal more data, making data mining and analysis more complex. Reprinted from Moriah E. Thomason and Paul M. Thompson, 2011, Diffusion imaging, white matter, and psychopathology, Annual Review of Clinical Psychology *7:63-85, with permission from* Annual Reviews, Inc. /

In the decade of the 2000s, research on diffusion tensor imaging took off, with the number of research papers doubling roughly every 2 years. Probably the most fundamental problem that remains is to distinguish when two fibres cross within a single cube (or "voxel," the three-dimensional analogue of a pixel) of the image. It has been estimated that as many as 30 percent of the voxels in a diffusion tensor imaging scan have more than one fibre passing through them. Unfortunately, the standard diffusion tensor cannot detect this fact.

One way to address the problem of crossing fibres would be to improve the resolution of the scans, so that each voxel is smaller. This would require MRI scanners with stronger magnetic fields—a trend that has continued throughout the past decade. But a less expensive alternative is to develop mathematical methods that would replace ellipsoids with more complicated diffusion surfaces. For example, a method called ***high angular resolution diffusion imaging*** (as shown in Figure 10 above) combines magnetic resonance data with the principles of tomography, and it produces spectacular detailed images of crossing fibres that would confuse an ordinary diffusion tensor imaging scan.

However, it generates a great deal more data, necessitating advances in data mining and analysis. It is safe to say that much work remains to be done, from both the experimental and analytical sides.

4 Manufacturing and advanced materials

4.1 Additive manufacturing

[Extracts from [1], pp 63, 64]

Manufacturing today is primarily subtractive (i.e. products are built by using material and removing unnecessary excess), or formative (i.e. material is forced to take shape using a forming tool). Additive manufacturing – also commonly known as 3D printing – encompasses different techniques that build products by adding material in layers, often using computer-aided design software (OECD, 2015c; VDI Technologiezentrum GmbH, 2015). 3D printing processes use plastics, metals and ceramics and have three main applications. Rapid prototyping is used industrially in R&D for model and prototype production. The application at later stages of product development is known as rapid tooling. Rapid manufacturing refers to the production of end-use parts using layer-manufacturing techniques directly without the need for any tooling (Hague and Reeves, 2000).

The global additive manufacturing market is estimated to grow at a compound annual growth rate of around 20% from 2014 to 2020 (MarketsandMarkets, 2014). As 3D printing processes continue to mature and grow, they can potentially address many important needs. In intensely competitive consumer product markets, 3D printing can meet rising expectations for quality design and personalisation. It allows much room for design flexibility and high complexity of samples and components. In general, additive manufacturing technologies become profitable where small quantities meet highly complex and increasingly customised products.

Originally, additive manufacturing was primarily used to create visualisation models of prototypes, thereby shortening product design processes. As materials, accuracy and the overall quality of the output improved, 3D printing started to widen its scope of application. Today, 3D printed prototypes for fit and assembly as well as presentation models are widespread and are expected to become even cheaper and faster to produce by 2030. Rapid prototyping is used by engineers, architects, designers and medical professionals, and in education and research (Gibson et al., 2015).

3D printing technologies are set to bring about new products in health, medicine and biotechnology. Dental applications represent the largest share in the medical field to benefit from 3D printing technologies. Printed dental prostheses, hip implants and prosthetic hands (bioprinting or bioengineering), as well as prototypes of exoskeletons are already in use. DNA printers and printing of body parts and organs from the patient's own cells are in the process of development. Bioprinted biological systems not only resemble humans genetically, but they also respond to external stress as if they are living organs (Kuusi and Vasamo, 2014). Bioengineering experts estimate that animal testing could be replaced by 3D printed human cells by 2018 (Faulkner-Jones, 2014). In the future, people with particular dietary requirements could print their own fortified or functional food. Bio-printed meat made from living cells could also be a future field of application (VDI Technologiezentrum GmbH, 2015).

Metal processing through the use of 3D printing processes such as selective laser melting and electron beam melting is common in the automotive, defence, and aerospace industries. Many components have already been produced for space applications; their number will continue to grow, as will their complexity. Further research in metal alloys can have long-term impacts on space exploration, as future generations of astronauts may be able to print equipment they need based on material that takes less mass at launch (OECD, 2014d). In energy technologies additive manufacturing is increasingly used for service and maintenance of highly complex replacement parts (VDI Technologiezentrum GmbH, 2015).

The digitisation of 3D printing technologies will allow product design, manufacturing and delivery processes to become more integrated and efficient. As 3D printing will drive digital transportation, storage, creation and replication of products, it has the potential to change work patterns and to spark a production revolution. Companies will sell designs instead of physical products. Placing an order will be a matter of uploading the resulting file that will trigger automated manufacture and delivery processes, possibly involving different companies that can easily coordinate (OECD, 2015c).

3D printing could also offset the environmental impacts of traditional manufacturing processes and supply chains due to lower waste production. Direct product manufacturing using printing technologies can reduce the number of steps required for parts production, transportation, assembly and distribution, reducing the amount of material wasted in comparison with subtractive methods (OECD, 2015c). On the other hand, printers using powdered or molten polymers still leave behind certain amounts of raw materials in the print bed that are typically not reused (Olson, 2013). The most commonly used plastic for home use printing, acrylonitrile butadiene styrene (ABS), is recyclable. Other feedstocks (such as polylactic acid [PLA]) are bio-degradable. However, a recent study has shown that emission rates of ultrafine particles of printers using ABS and PLA are particularly high and could pose health risks (Stephens, 2013). Information on health and environmental effects of newer materials such as fine metal powders, used in selective laser sintering, is still scarce. Likewise, research on the embedded energy of materials, their carbon footprint, and the tendency to overprint objects caused by simplicity and ubiquity will need further attention (Olson, 2013).

The range of materials used in 3D printing is still limited, and their use is subordinate to printing methods and devices. Surface quality and detail are often not sufficient and require cost-intensive post-processing. Conventional printing devices work slowly and quality monitoring (even though the first print heads with integrated sensors have been developed) is difficult during the printing process. Another obstacle to overcome is the price of the printing devices. Over the last few years, simple 3D printers have appeared on the electronic consumer market at very affordable prices (below USD 1 000), while at the same time more sophisticated 3D printers (for example for metal processing) often sell for more than USD 1 million (EC, 2014a; MGI, 2013). Costs are expected to decline rapidly in coming years as production volumes grow (MGI, 2013). It remains difficult to predict precisely how fast this technology will be deployed, but it will likely eventually permeate the production processes of different types of products in larger numbers (OECD, 2015c).

The abilities of additive manufacturing can also be abused. Debates on private printing of firearms and product piracy accompany the evolution of this technology. As 3D printing becomes more and more accessible, the risk of illegal reproduction of jewellery and works of art rises.

4.2 Nanomaterials

[Extracts from [1], pp 61, 62]

Nanomaterials are defined as a material with any external dimensions in the nano-scale (10-9 metre) or having internal structure or surface structure in the nanoscale that represents a range from approximately 1 nanometre (nm) to 100 nm (ISO, 2012). Nanomaterials can be either natural, incidental or artificially manufactured / engineered. Nanomaterials include carbon based products; nanostructured metals, alloys, and semiconductors; ceramic nanoparticles; polymers; nanocomposites; and sintering and bio-based materials (VDI Technologiezentrum GmbH, 2015). Among carbon based materials, nanotube technologies and graphene are of particular interest for industry and research purposes. Among other materials that currently attract most attention are nano-titanium dioxide, nano-zinc oxide, graphite, aerogels and nano-silver (EC, 2014a).

Nanomaterials are expected to have considerable impact on materials science due to their unique mechanical, magnetic and electric characteristics that cannot be generated at milli- or microscale. This is because nanomaterials, in contrast to macroscopic materials, show a high ratio of surface atoms to core atoms. Their behaviour is mainly dominated by surface chemistry. The higher surface proportion increases the surface energy of the particles, causing the melting point to sink and the chemical reactivity to increase. Unique optical, magnetic, electrical and other properties emerge at this scale by exploiting quantum effects.

The current market value of nanomaterials is around EUR 20 billion (EC, 2014a) and the spectrum of commercially viable applications is expected to increase over the next few years. Although marketed in small quantities in absolute figures, applications such as carbon black and amorphous silica have reached a level of maturity and already represent high volumes of the nanomaterials market. Areas of application already encompass medicine, imaging, energy and hydrogen storage, catalysis, lightweight construction, and UV protection (VDI Technologiezentrum GmbH, 2015; Tsuzuki, 2009).

One of the most promising application areas for nanomaterials is in medicine, which currently accounts for the highest share of applied nanoproducts (Vance et al., 2015). Nanomaterials are expected to enhance diagnostics in several ways, e.g. increases in sensitivity of diagnostics chips (lab-on-a-chip) will enable earlier diagnosis of cancer; robust fluorescent markers using nanomaterials are likely to increase reliability of in-vitro diagnostics (VDI Technologiezentrum GmbH, 2015); and tagged gold nanoparticles will boost the development of molecular imaging and can also be used for rapid screening of cancer drugs that require less special equipment than traditional methods (University of Massachusetts Amherst, 2014). Nanomaterials are also expected to enhance medical treatment, e.g. biocompatible nanocellulose could be applied in treating burns.

Outside of the medical field, nanomaterials will be increasingly used in everyday items. For example, nanofibres have enabled development of textiles that are water-, wrinkle-, and stain-resistant or, if intended, selectively permeable. Combined with e-textiles, they could contribute to the development of smart fabrics / functional textiles (VDI Technologiezentrum GmbH, 2015; EC, 2014), which may also be used in military and emergency response applications to increase the safety of individuals. Nanomaterials are also likely to facilitate development of functional building materials such as self-cleaning concretes. In the energy and environment area, smart polymeric nanomaterials have expected uses in biodegradable packaging and hydrogels, while silicon nanocrystals are used already in photovoltaic cells (OECD, 2011c).

Industrial research on nanomaterials is dominated by multinational enterprises from a variety of sectors. BASF is one of the leading companies in the fields of chemical nanotechnology, nanostructured materials, nanoparticles, and safety of nanomaterials. For instance, the company is a global leader in research on metallic organic frameworks applied in energy and environment industries (BASF, 2015). L'Oréal is among the largest nanotechnology patent holders in the United States, and has used polymer nanocapsules to deliver active ingredients into deeper layers of the skin (Nanowerk, 2015). Beyond the multinationals, an increasing number of technology start-ups are exploiting nanomaterials in specific niche areas. For example, a promising application area for nanomaterials is waste-water treatment by individuals in less-developed parts of the world. One start-up has developed a cost-effective water filtration membrane based on titanium dioxide nanoparticles that are able to filter dirt and bacteria (Nanowerk, 2014), while another has designed an open-source 3D-printable water filter prototype that uses activated carbon and nanomembrane technology and that can be integrated into a water bottle cap (Faircap, 2014).

Nanomaterials face several challenges if they are to find widespread commercial applications. On a technical level, signal transmission between the nanoscale and the macroscopic world remains problematic, as does controlling mechanical responses at the nanoscale (Fahlman, 2011). These technical restrictions continue to hinder development of cost-effective, large-scale commercial applications of nanomaterials.

There are also questions around unintended hazards (toxic effects) to humans and the environment. While particle size alone is insufficient to account for toxicity (SCENIHR, 2009), using nanomaterials in some specific environments may need to be regulated (OECD, 2015k). For example, due to their small size, nanoparticles can permeate cell membranes (via skin absorption, ingestion, inhalation) and travel to places in the body where larger particles cannot physically reach (Suran, 2014). The same risk has to be considered for the use of nanoparticles in agriculture (Das et al, 2015). Risk assessment is still confronted with a considerable lack of data on exposure of nanomaterials to the environment, requiring further research (EC, 2014a; OECD, 2011c; Fahlman, 2011).

4.3 Biomanufacturing

[Extracts from [24], pp 2-3]

Biomanufacturing is a specific area in which advanced manufacturing can change the world. Success in biomanufacturing means learning from and improving on the incredible capabilities already found in nature. The biosphere can create everything from the small molecules required for the functioning of cells to single organisms (the fungal mycelia) more than a mile across.

A 787 jet and a cell have about the same number of parts, but biologists still have vast gaps in their knowledge of how cells operate. Nevertheless, people have been learning how to adapt biological processes to human purposes since our distant ancestors began fermenting liquids and drinking them. Biological processes are used to produce fructose, antibiotics, biofuels, industrial chemicals such as acrylamide and isoprenes, and many other products. Furthermore, the discipline known as synthetic biology, through essentially a modular plug-and-play technology analogous to apps for a mobile phone, offers the hope of creating biological factories for a virtually unlimited number of products.

There are three emerging opportunities in particular: bionanotechnology, safe biopharmaceuticals, and personalized medicine.

- ***Bionanotechnology*** brings together nanotechnology, biotechnology, robotic technologies, microscale systems, and nanoscale systems to form hybrid systems with very specific functions. It offers the hope of developing nanoscale science and engineering to produce biomolecular and chemical building blocks and assembling them in a variety of forms. It may, for example, yield scaffolds for tissue regeneration, tiny sensors to monitor what happens in the human body, or agents effective against drug-resistant human pathogens.

- ***Safe biopharmaceuticals*** represent one of the fastest growing segments of the pharmaceutical market. These are complex molecules designed to be safe and effective for the treatment of diseases such as cancer, arthritis, or multiple sclerosis. For example, [researchers] have been working on a process to manufacture the coagulant heparin, which is extracted from pig intestines, that would offer many advantages over the traditional source.
- ***Personalized medicine*** takes this idea farther by investigating the need for drugs on demand that are tailored to each individual. In cancer treatment, the results of a tumor biopsy can point to a specific treatment that is likely to be more effective than others for a particular patient. As researchers learn more about the mechanisms that cause disease, this approach could yield very specific treatments that are customized to the specific form of an individual's disease.

The major barrier to these technologies is the lack of a business model that can drive them. Developing a single drug can cost well over $1 billion, but in the future drugs will treat smaller and smaller groups of people. Developing a drug for each of these small groups, using current approaches, will be prohibitively expensive.

Transforming the pharmaceutical industry from large volumes of a relatively small number of products to small volumes of a very large number of products will require fundamental changes. Safety testing will need to become quicker and cheaper while delivering safer drugs. Because complete safety can never be guaranteed, people will need to understand the risks and benefits of any new drug or diagnostic. Close links between R&D and manufacturing will be critical to make pharmaceuticals efficiently and safely. No business plan currently exists for personalized medicine, despite rapid advances in science and manufacturing techniques.

4.4 Nanomedicine manufacturing

[Extracts from [28], pp 56-60]

Many biological structures and processes are inherently nanoscale, and nanotechnology research related to medicine and health applications is starting to bear fruit. For example, some drugs, including cancer-fighting drugs such as Docetaxel, are more soluble and move through cell walls and membranes to disease sites more easily if they are nanoscale. Nanomedical breakthroughs include increasing success in gene therapy and development of new antiviral vaccines (hepatitis C, pneumonia). Most of these novel disease-fighting solutions are still in early stages; in 2015, there were more than 250 nanomedicine projects in clinical trials.

Now is the time to expand the study of nanomedicine manufacturing. Although many scale up and manufacturing hurdles for a new nanomedicine are similar to those of any new therapeutic, manufacturing nanomedicines poses special issues. Perhaps the most prevalent is the need for nanoscale characterization at all stages of discovery, development, and commercialization. In addition, nanomaterials that meet medical-grade requirements for purity and reproducibility can be difficult to obtain. It is not uncommon for expensive nanomedicines, produced under Food and Drug Administration (FDA) current Good Manufacturing Practices (cGMPs), to not meet specifications or give poor efficacy reproducibility. Safety extends not only to dosage and clinical results, but also to manufacturing and the need to avoid contamination and toxicological factors.

The United States currently leads the world in nanomedicine. In 2012, the United States accounted for 53 percent of nanomedicine patent applications, followed by Europe (25 percent) and Asia (12 percent). Drug delivery represented the largest segment in nanomedicine, accounting for 76 percent of publications and 59 percent of nanomedicine patents. The second-largest segment was in vitro diagnostics (11 percent of publications and 14 percent of patent filings). In addition to the obvious health benefits, nanomedicine is a sizable "industry" that is projected to grow to over $130 billion in 2016, compared to $63.8 billion in 2010.

A sustainable medical nanomanufacturing infrastructure is needed to move innovative medical research, including in cell and gene therapies, into commercial use. For instance, there are few contract manufacturing organizations with capabilities for cGMP[1] manufacturing of nanomedicines, quality assurance/quality control testing protocols are inadequate, and there are few services with the ability to incorporate small molecule drugs in FDA-approved, bio-compatible nanoparticle-based formulations.

Especially vital to the translation of research toward application is the Nanotechnology Characterization Laboratory (NCL). By developing and performing a standard set of appropriate tests for nanomaterials proposed for cancer diagnosis or treatment, NCL has greatly expedited the development, trial, and regulatory review process. The obvious strengths of NCL notwithstanding, there is a serious "opportunity gap" with respect to the ability of developers to move beyond sub-gram quantities of material that are readily produced in an individual laboratory, to the kilogram quantities required for preclinical safety assessments and Phase I clinical trials.

The updated NIH/NCI Nanotechnology Cancer Plan released in 2015 includes a section on Commercialization of Nano-Products for Cancer and Manufacturing Challenges of Nano-Products. The plan focuses only on the manufacture of nanoparticles, not nanoscale devices or other medical applications of nanotechnology. It notes that "perhaps the most frequent shortcoming manufacturers encounter in the advancement of therapeutic nanoparticles is a lack of thorough characterization of the product and the identification, to the extent possible, of the critical quality attributes. This requires, among other things, an early emphasis on the appropriate analytical methods, which is something that is frequently neglected." While the plan does a good job of outlining the challenges related to manufacturing nanoparticles for medical use, the alliance (and NIH in general) is not set up to support manufacturing research.

The Translation of Nanotechnology in Cancer (TONIC) Consortium was established in 2011 to bring together Alliance-funded research centres, pharmaceutical and biotechnology companies, and patient advocacy groups to promote collaboration between academia and industry and share knowledge about best practices in translating nanotechnology from the laboratory to the marketplace. The consortium has formed a working group on nanodrugs to develop clinical protocols for testing nanoparticle drugs in patients, while in the process addressing limitations and gaps specific to nanoparticle therapeutics.

The Nano-Bio Manufacturing Consortium (NBMC) is funded by the Air Force Research Laboratory. The mission of NBMC is to mature an integrated suite of nano-bio manufacturing technologies and transition it to industry. The program envisions the convergence of nanotechnology, biotechnology, advanced (additive) manufacturing, and flexible electronics enabling real-time, remote physiological and health/medical monitoring. Early research is focused on developing a technology platform for human performance monitors for military and civilian personnel in high stress situations such as pilots, special operations personnel, firefighters, and trauma care providers.

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[1] Refers to the Current Good Manufacturing Practice regulations enforced by the U.S. Food and Drug Administration.

4.5 Manufacturing for sustainability

[Extracts from [24], pp 32-33]

Sustainability has a direct link to manufacturing, since many sustainability issues involve the design and making of things. There are six drivers of sustainability issues.

- The first is the growth in world population, from 7 billion people today to a projection of more than 9 billion in the year 2050 and more than 10 billion by 2100. Approximately 37 percent of the world's population lives in China and India, and by 2021 India will overtake China as the most populous country in the world.
- The second driving force is the rapid urbanization of the world's population. In 2010 the world's urban population surpassed the rural population, and by 2050 it is projected to be twice as large as the rural population. Over the next two generations, the equivalent of a thousand great cities with populations of more than five million will be built—an average of 20 each year.
- The third driver is the expansion of the middle class—from less than one-third of the world's population to more than one-half. As incomes grow, people will consume more and place greater demands on the world's resources.
- The extraction of resources is the fourth driver. The consumption of biomass, minerals, metals, and fossil fuels are all projected to rise in future decades. One consequence of this projected increase, is a rapid rise in international land acquisitions by foreign parties. "The equivalent of half of Western Europe has been acquired in Africa alone since 2000."
- The fifth driver consists of governmental laws and regulations to promote sustainability. For example, US Executive Order 13514 requires that 95 percent of all applicable new contract actions for products and services advance sustainable acquisition. Similar provisions are appearing in countries around the world to quantify and reduce resource impacts.
- Finally, the private sector realizes that it needs to address sustainability issues as part of the issues associated with the goods and services it sells.

Sustainability Indexes

A variety of efforts are under way to measure and report on the sustainability of products. For example, Nike has led the development of a Materials Sustainability Index that encompasses about 40,000 different materials. International teams of researchers have done technical reviews of quantification methods to evaluate the sustainability of products throughout the supply chain. Innovators and designers can use this information to build sustainability into products throughout their life cycle. This information also can be used to evaluate suppliers of products no matter where they are located. It is a common language, a common set of metrics and indicators, which everybody has to aspire to.

5 Energy

5.1 General

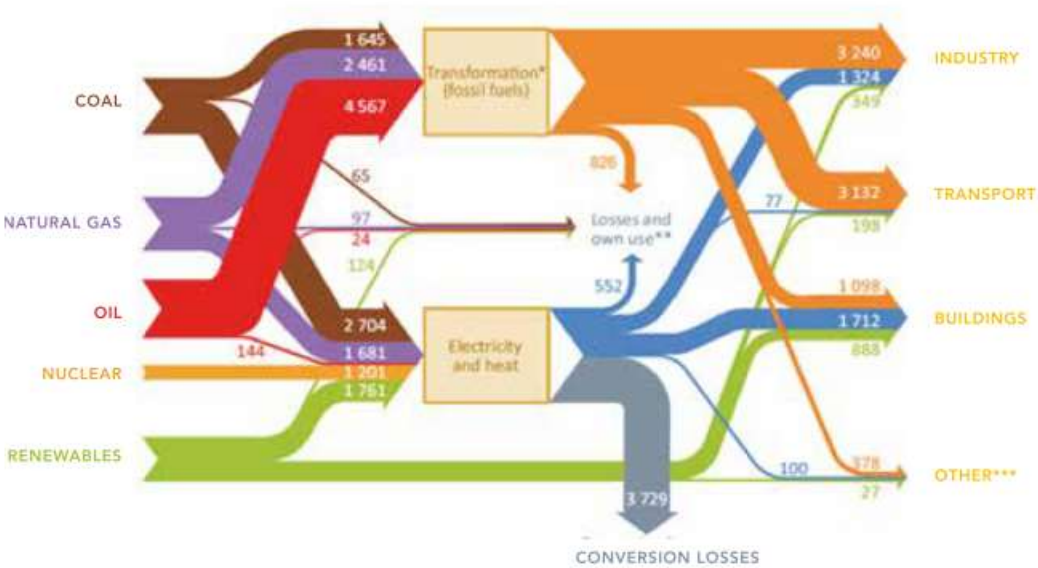
5.1.1 Energy futures

[Extracts from [1], pp 18-21]

Based on existing and planned government policies (the International Energy Agency's [IEA] so-called "New Policies Scenario"), global primary energy demand is set to increase by 37% between 2012 and 2040. Most of this increased demand can be ascribed to economic growth in non-OECD countries, particularly in Asia, which will account for around 60% of global energy consumption. Under this scenario, growth in global demand is expected to slow down from over 2% per year in the last two decades to 1% per year after 2025. This is a result of price and policy effects, as well as structural shifts in the global economy towards services and lighter industrial sectors (IEA, 2014a).

Industry will remain the largest consumer of energy in 2040 (Figure 9), by which time its energy demand is expected to have risen by about 40%. Manufacturing in the OECD has gradually shifted away from coal and oil over recent decades, a trend that is projected to continue: while in 1990, coal and oil accounted for nearly half of heavy industry's fuel, they are expected to decline to just 15% of the fuel mix by 2040. China's fuel mix will also "lighten-up" by this time. This will lead to a fall in the average amount of industrial energy demand per unit of economic output worldwide. Future energy demand growth varies by industry sub-sector, however, with the chemical sector seeing the largest growth as the demand for plastics and other chemicals increases (ExxonMobil, 2015).

FIGURE 9: World energy demand by fuel and sector in the IEA's New Policies Scenario, 2040 (Million Tonnes of Oil Equivalent). Source: IEA, 2015a.



Transportation will be the second largest consumer of energy in 2040. While car numbers are projected to expand with a growing global middle class, fuel efficiency improvements mean energy demand from cars will rise only slightly. Hybrid vehicles could account for nearly 50% of new-car sales by 2040, compared with just 1% in 2010 (ExxonMobil, 2015). This effect will be especially noticeable in Europe, where liquid fuels consumption is expected to decline (EIA, 2014). Commercial transport – including airplanes, shipping, trains and trucks – will account for virtually all of the growth in energy demand from transportation. Most of this demand growth will be met by oil (ExxonMobil, 2015).

The third largest consumer of energy in 2040 will be commercial and residential buildings. Worldwide, households will increasingly shift towards cleaner fuels and will rely more on electricity than primary fuels as domestic appliances and electronics become more widely available (ExxonMobil, 2015). Nearly 1 billion people will newly gain access to electricity by 2040, but more than half a billion will remain without it (IEA, 2014a).

In the IEA's New Policies Scenario, demand for fossil fuels will grow by 2040, though their share in the global energy mix is set to decline. This is mainly because of greater use of renewables in the production of electricity (Figure 10). Worldwide, the largest share of growth in renewables-based generation will be from wind power (34%), followed by hydropower (30%) and solar technologies (18%) (IEA, 2014a). At the same time, biofuels may provide up to 27% of the world's transportation fuel by 2050, up from the current level of 2% (IEA, 2011), though with uncertain consequences for food security. Nuclear power capacity is set to rise by almost 60% over the same period, but its share in global electricity generation will increase by just one percentage point to 12%. China will account for almost half the expected growth, with India, Korea and Russia collectively making-up a further 30%. Almost 200 operational reactors (out of 434 operating in 2013) will have been decommissioned by 2040, mostly in Europe, the United States, Russia and Japan. The cost of decommissioning is estimated at more than USD 100 billion (IEA, 2014a).

The growth in renewables-based generation will mean oil, gas, coal and low-carbon sources will make up almost-equal parts in the world's energy supply mix by 2040 (IEA, 2014a). Without more stringent climate change mitigation policies, fossil fuels will continue to dominate the fuel mix, not least because of the enormous quantity of their reserves (Figure 11). The IEA (2014) projects world oil supply to rise to 104 million barrels per day in 2040 and estimates this will require some USD 900 billion per year of investment in upstream oil and gas development by the 2030s. The Middle East and the Russia/Caspian region will likely remain the largest oil exporters over the next decades, while Asia Pacific and Europe will remain the largest importers. The situation in North America is somewhat different, as strong growth in tight oil, oil sands and natural gas liquids could see the region emerge as a net liquids exporter (ExxonMobil, 2015).

Demand for natural gas will grow by more than half, the fastest growth rate of all fossil fuels (IEA, 2014a). A significant proportion of this growth is set to come from unconventional sources, such as shale gas produced in North America (ExxonMobil, 2015). Furthermore, an increasingly flexible global trade in liquefied natural gas will offer some protection against the risk of supply disruptions. Global coal demand will grow by 15% to 2040; around two-thirds of this increase will occur over the next decade, mainly in non-OECD countries like China, after which growth is set to slow considerably (IEA, 2014a).

5.1.2 Climate change and energy technology innovation

[Extracts from [1], pp 21-23]

Global land and ocean surface temperature data show an averaged combined warming of 0.85°C over the period 1880 to 2012. The greatest warming over the past century has occurred at high latitudes, with a large portion of the Arctic having experienced warming of more than 2oC. The last 30 years were likely the warmest of the last 1 400 years in the northern hemisphere (IPCC, 2014). Anthropogenic greenhouse gas (GHG) emissions are extremely likely to have been the dominant cause of the observed warming since the mid-20th century. Atmospheric concentrations of carbon dioxide (CO2), methane and nitrous oxide are unprecedented in at least the last 800 000 years (IPCC, 2014). CO2 emissions account for around 75% of global GHG emissions, with most coming from energy production – fossil fuel combustion represents two-thirds of global CO2 emissions (OECD, 2012b). Around half of the anthropogenic CO2 emissions since 1750 have occurred in the last 40 years (IPCC, 2014). Agriculture is a major emitter of the more powerful greenhouse gases of methane and nitrous oxide.

There is a strong, consistent, almost linear relationship between cumulative CO2 emissions and projected global temperature change during the 21st century (IPCC, 2014). Further warming over the next few decades is now inevitable, based on recent rises in atmospheric CO2 levels, and the global mean surface temperature change for the period 2016-35 relative to 1986-2005 will likely be in the range 0.3°C to 0.7°C. Heat waves will likely occur more often and last longer, while extreme precipitation events will become more intense and frequent in many regions. Rainfall will most likely increase in the tropics and higher latitudes, but decrease in drier areas. The oceans will continue to warm and acidify, strongly affecting marine ecosystems. The global mean sea level will continue to rise at an even higher rate than during the last four decades. The Arctic region will continue to warm more rapidly than the global mean, leading to further glacier melt and permafrost thawing. However, while the Atlantic Meridional Overturning Circulation will most likely weaken over the 21st century, an abrupt transition or collapse is not expected (IPCC, 2014).

Reducing and managing the risks of climate change will require a mixed strategy of mitigation and adaptation. The extent of mitigation efforts will determine levels of future GHG emissions: without additional efforts beyond those already in place today, warming by the end of the 21st century will lead to a high risk of severe, widespread and irreversible impacts globally, even with adaptation (IPCC, 2014). The IEA's New Policies Scenario, discussed above, is consistent with a long-term temperature rise of 4°C. In many respects, this is already an ambitious scenario that requires significant changes in policy and technologies, but will still lead to dangerous levels of climate change. A more stringent mitigation scenario that leads to CO2-equivalent concentrations of about 450 parts per million in 2100 would meet the 2°C targets agreed at the recent Paris climate conference. This 2°C Scenario (2DS) is characterised by 40-70% reductions in global GHG emissions by 2050 compared with 2010. It will mean increasing the share of low-carbon electricity supply from the current share of approximately 30% to more than 80% by 2050 (IPCC, 2014).

Energy technology innovation will be key in achieving the 2DS. Support for a portfolio of low-carbon technologies across all energy sectors (Figure 12) will provide the greatest potential to ensure uptake of immediately available solutions that keep climate goals achievable while also stimulating the initial development of more complex solutions needed for long-term deep decarbonisation (IEA, 2015b). Some solutions will be broadly applicable, while others will target specific sectors. In the power sector, while onshore wind and solar PV are ready to be mainstreamed in many energy systems, very high levels of deployment will require further innovation in enabling technologies – for example, in energy storage and smart grid infrastructure – to manage their variability and increase the flexibility of power systems (IEA, 2015b). Carbon capture and storage (CCS) technologies are projected to play an important role, though require considerable further technical and market development before they can be extensively implemented. In other energy sectors – including industry, transport and buildings – energy efficiency technologies are expected to play a leading role in achieving the 2DS.

Emerging economies are projected to account for most of the increase in GHG emissions over the coming decades. Their uptake of innovative low-carbon technologies accounts for almost three-quarters of worldwide CO2 emissions reduction in 2050 in the 2DS. While rapid economic development holds significant potential to deploy the latest low-carbon technologies across all energy sectors, this will depend on international cooperation that supports technology and knowledge transfer. Furthermore, emerging economies will need to accumulate the necessary domestic skills and organisational capabilities if technology adoption, adaptation and development are to succeed (IEA, 2015b).

5.1.3 Energy 2050

[Extracts from [8], pp 1-3]

When it comes to energy, there is one matter everyone agrees on. For the near future, at least, the world will need more of it—and how it is produced and used will be a critical factor in the future of the global economy, geopolitics, and the environment. With that in mind, McKinsey took a hard look at the data, modelling energy demand from the bottom up, by country, sector, and fuel mix, with an analysis of current conditions, historical data, and country-level assessments. On this basis, McKinsey's Global Energy Insights team has put together a description of the global energy landscape to 2050.

It is important to remember that this is a business-as-usual scenario. That is, it does not anticipate big disruptions in either the production or use of energy. And, of course, predicting the future of anything is perilous. With those caveats in mind, here are four of the most interesting insights from this research.

Global energy demand will continue to grow. But growth will be slower—an average of about 0.7 percent a year through 2050 (versus an average of more than 2 percent from 2000 to 2015). The decline in the rate of growth is due to digitization, slower population and economic growth, greater efficiency, a decline in European and North American demand, and the global economic shift toward services, which use less energy than the production of goods. For example, in India, the percentage of GDP derived from services is expected to rise from 54 to 64 percent by 2035. And efficiency is a forthright good-news story. By 2035, McKinsey research expects that it will take almost 40 percent less fuel to propel a fossil-fuelled car a mile than it does now. By 2050, global "energy intensity"—that is, how much energy is used to produce each unit of GDP—will be half what it was in 2013. That may sound optimistic, but it is based on recent history. From 1990 to 2015, global energy intensity improved by almost a third, and it is reasonable to expect the rate of progress to accelerate.

Demand for electricity will grow twice as fast as that for transport. China and India will account for 71 percent of new capacity. By 2050, electricity will account for a quarter of all energy demand, compared with 18 percent now. How will that additional power be generated? More than three-quarters of new capacity (77 percent), according to the McKinsey research, will come from wind and solar, 13 percent from natural gas, and the rest from everything else. The share of nuclear and hydro is also expected to grow, albeit modestly.

What that means is that by 2050, non-hydro renewables will account for more than a third of global power generation—a huge increase from the 2014 level of 6 percent. To put it another way, between now and 2050, wind and solar are expected to grow four to five times faster than every other source of power.

Fossil fuels will dominate energy use through 2050. This is because of the massive investments that have already been made and because of the superior energy intensity and reliability of fossil fuels. The mix, however, will change. Gas will continue to grow quickly, but the global demand for coal will likely peak around 2025. Growth in the use of oil, which is predominantly used for transport, will slow down as vehicles get more efficient and more electric; here, peak demand could come as soon as 2030. By 2050, the research estimates that coal will be down to just 16 percent of global power generation (from 41 percent now) and fossil fuels to 38 percent (from 66 percent now). Overall, though, coal, oil, and, gas will continue to be 74 percent of primary energy demand, down from 82 percent now. After that, the rate of decline is likely to accelerate.

Energy-related greenhouse-gas emissions will rise 14 percent in the next 20 years. That is not what needs to happen to keep the planet from warming another two degrees, the goal of the 2015 Paris climate conference. Around 2035, though, emissions will flatten and then fall, for two main reasons. First, cars and trucks will be cleaner, due to more efficient engines and the deployment of electric vehicles. Second, there is the shift in the power industry toward gas and renewables discussed above. The countervailing trends are that there are likely to be some 1.5 billion more people by 2035, and global GDP will rise by about half over that period. All those people will need to eat and work, and that means more energy.

The world is full of unpredictable and sometimes wonderful surprises, so I accept that these numbers are unlikely to be perfect. As with any forecast, they are based on assumptions—about China and India, for example—as well as about oil prices and economic growth. Other sources see different outlooks. Concerted global action to reduce greenhouse-gas emissions, for example, could change the arc of these trends. Technological disruptions could also bend the curve.

For business and political leaders, though, the implications are clear. Given that global energy demand will grow, it is likely that prices will continue to be volatile. Better energy efficiency, then, is an important way to reduce related risks. Technology development is critical to ensuring that the world gets the energy it needs while mitigating environmental harm. This will require substantial new investments. Finally, to encourage the creation of the clean and reliable energy infrastructure that the world needs, energy producers will need to work with local, regional, national, and international regulators. Getting things right the first time is essential; there is extensive evidence to show that dramatic changes in policy act as a powerful deterrent to energy investments by producers. Given the scale of the new investments needed, this will be a factor of growing importance.

5.2 Solar energy

[Extracts from [17], pp 1-2]

Last year, China and the United States installed a record 15 and 7.5 gigawatts (GW) of solar, respectively. This year, the world could install as much as 66 GW. In 2015, investors poured $161 billion of capital into solar, the largest amount for any single power source. In China, 43 GW of capacity have been installed, more than in any other nation; India aspires to build 100 GW of solar capacity by 2017. Across the sun-drenched Middle East, investment rose from $160 million in 2010 to about $3.5 billion in 2015.

The world is building more solar-power plants because they are getting cheaper. Since 2009, the total installed costs of solar have fallen by as much as 70 percent around the world. New power-purchase agreements frequently fall below $100 per megawatt-hour, with some reaching less than $30. That price puts solar at or below the cost of a new natural-gas plant.

Regulatory measures, such as the Investment Tax Credit in the United States, further support the economics of solar. In many instances, solar is often “in the money”—that is, less costly than the next cheapest alternative. A number of leading multinationals are signing solar deals not only to gain green credentials but also to lower their energy costs and diversify their sources of supply.

Given these trends, we believe that 2,000 to 3,000 GW of solar capacity—or almost half of total electric-power capacity in the world today— will be economic by 2025. Of course, solar can’t fully meet the need for electricity on its own because (among other reasons) the sun doesn’t always shine, so not all of this will be built. But a significant portion will. And that growth will transform energy markets around the world.

Although the future is bright, many solar companies are struggling. Downstream providers—the developers and builders of solar-power plants—have pursued growth and market share but struggled to deliver profits. In the United States, valuations of some companies fell drastically in 2015 and 2016, and there have been a number of high-profile restructurings and bankruptcies, possibly with more to come.

Macro factors also play a role. Low oil and gas prices have tested solar’s competitive position. The threat—though perhaps now more distant—of higher interest rates is another negative factor because the economics of solar projects are sensitive to the cost of capital.

In spite of these issues, we believe opportunities for growth and profit exist throughout the solar value chain.

5.3 Advanced energy storage technologies

[Extracts from [1], pp 65, 66]

Energy storage technology can be defined as a system that absorbs energy and stores it for a period of time before releasing it to supply energy or power services. Breakthroughs are needed in energy storage technology to optimise the performance of energy systems and facilitate the integration of renewable energy resources.

With an increasing share of renewable energy contributions to electrical grids, it is indispensable to invest in storage technologies that allow the adjustment of energy supply to energy demand. Those technologies are implemented on small and large scales in either centralised or decentralised ways throughout the energy system. Large-scale systems (grid energy storage), of which 97% capacity is accounted for by pumped hydro storage (IEA, 2015b), can balance power fluctuations. Battery systems are suitable for decentralised but shorter-term balancing due to limited storage capacity, long charging time and self-discharge (VDI Technologiezentrum GmbH, 2015; MGI, 2013). In general, new energy storage technology could change where, when, and how energy is used.

There has been a sharp increase in the deployment of large-scale batteries and thermal energy storage over the last decade (IEA, 2015b). Batteries in particular have experienced major technological acceleration, as reflected in patent “bursts” (OECD, 2014b; Dernis et al., 2015). However, most energy storage technologies are still in the early stages of development. The economic viability of energy storage and advanced batteries will likely be driven by the development of three primary applications: electric and hybrid vehicles, distributed energy, and utility grid storage (MGI, 2013).

Electrochemical energy storage still represents the technological state-of-the-art in batteries and encompasses lead acid batteries, nickel-based systems, high-temperature redox flow and lithium-ion batteries. The majority of portable consumer electronics devices and passenger hybrid and electric vehicles (EVs) are powered by lithium-ion batteries which have seen consistent reductions in price and increases in performance in recent years. For example, there was a 40% price decline for a lithium-ion battery pack in an EV between 2009 and 2013 (MGI, 2013), which saw sales of EVs grow to 665 000 in 2014 compared with virtually none on the road in 2009 (IEA, 2015b). Some car manufacturers have started to sell vehicle-to-home systems, enabling customers to use vehicles to charge homes and vice versa. In the future, supercapacitors (high-capacity electrochemical capacitors) that store kinetic energy in pendulum movements and charge nearly without time delay, could also allow cars to charge during normal stops in traffic, e.g. at traffic lights (Kuusi and Vasamo, 2014).

Other new battery systems encompass for example the metal-air battery that is at an early level of research. Metal-air batteries typically use lithium or zinc (zinc-air batteries or fuel cells) for the anode, and oxygen, which is drawn in from the environment, as the cathode. This makes the battery lightweight with a long-lasting regenerative cathode. Over the coming decade, energy density could increase to a level that battery-powered vehicles could become cost-competitive with vehicles powered by internal combustion engines. Two routes are being pursued to improve energy density: developing electrode materials with higher capacity and developing cells using higher voltage chemistry (Element Energy, 2012). Marketable products could be available by 2020 (VDI Technologiezentrum GmbH, 2015).

Power outages cause billions of dollars’ worth of damage every year worldwide. Over-generation also remains a major issue (IEA, 2015b). Large-scale energy storage systems have the possibility to balance power fluctuations and to decentralise them. These systems include hydroelectric energy storage such as pumped-storage hydroelectricity, compressed air energy storage, and hydrogen and battery systems. Battery systems will be suitable for short- and medium-term load balancing in particular, but their limited storage capacity and self-discharge makes them less suitable for long-term load balancing (VDI Technologiezentrum GmbH, 2015).

Energy storage technologies are expected to contribute to meeting the 2oC Scenario (2DS) targets by providing flexibility to the electricity system and reducing wasted thermal energy (IEA, 2015b). In fact, more energy could be sourced from renewable sources if energy output could be controlled through storage solutions (Elsässer, 2013). At the same time, as deployment of renewables continues to rise, the demand for energy storage technologies is also expected to grow (IEA, 2015b). Smart storage systems and smart grids may also encourage the production of renewable energy by local cooperative structures (ESPAS, 2014); cost-effective solar, wind and battery technologies are key building blocks for decentralised energy systems (Policy Horizons Canada, 2013). In developing economies, storage systems have the potential to bring reliable power to remote areas and places it has never before reached (US Department of Energy, 2014).

Technology breakthroughs are needed in high-temperature thermal storage systems and scalable battery technologies, as well as in storage systems that optimise the performance of energy systems and facilitate the integration of renewable energies (IEA, 2015b). R&D activities on storage solutions are also underway with a view to realising technology cost reductions (IEA, 2014b). The high capital costs of storage technologies remain a barrier to wide deployment (IEA, 2015b).

As the materials, technologies and deployment applications for storing energy are created, new techniques and protocols must be developed to validate their safety and ensure that the risk of failure and loss is minimised (US Department of Energy, 2014). For instance, the benefits of lithium batteries should be evaluated as they relate to global environmental and health impacts of lithium extraction and handling.

5.4 Battery storage

[Extracts from [19], pp 4, 5]

Battery technology, particularly in the form of lithium ion, is getting the most attention and has progressed the furthest. Lithium-ion technologies accounted for more than 95 percent of new energy-storage deployments in 2015. They are also widely used in consumer electronics and have shown promise in automotive applications, such as plug-in hybrids and electric vehicles. Prices for lithium-ion batteries have been falling and safety has improved; moreover, they can work both in applications that require a lot of energy for a short period (known as power applications) and those requiring lower amounts of energy for longer periods (energy applications). Collectively, these characteristics make lithium-ion batteries suitable for stationary energy storage across the grid, from large utility-scale installations to transmission-and-distribution infrastructure, as well as to individual commercial, industrial, and residential systems.

Our model confirms the centrality of lithium-ion batteries to utility-scale energy storage, but with two important caveats. First, it is critical to match the performance characteristics of different types of lithium-ion batteries to the application. For example, we looked at two major lithium-ion-battery providers that were competing to serve a specific industrial application. The model found that one company's products were more economic than the other's in 86 percent of the sites because of the product's ability to charge and discharge more quickly, with an average increased profitability of almost $25 per kilowatt-hour of energy storage installed per year.

Second, in some specific applications, non-lithium-ion technologies appear to work better. For demand-charge management and residential solar-plus storage, certain lead-acid products are more profitable than lithium-ion cells. For large-scale firming of wind power, our model shows that flow cells can be more economic than lithium-ion cells for all but the shortest periods (less than an hour) and are projected to continue to lead on cost through 2020.

Policy and market limits

Our model suggests that there is money to be made from energy storage even today; the introduction of supportive policies could make the market much bigger, faster. In markets that do provide regulatory support, such as the PJM and California markets in the United States, energy storage is more likely to be adopted than in those that do not. In most markets, policies and incentives fail to optimize energy-storage deployment. For example, the output from intermittent renewable-energy sources can change by megawatts per minute, but there are few significant incentives to pair renewable energy with storage to smooth power output.

Another issue is that tariffs are varied and not consistently applied in a way that encourages energy-storage deployment. Thus, customers with similar load profiles are often billed differently; some of these tariffs provide incentive for the adoption of storage to the benefit of the electrical-power system, while others do not. Pairing load profiles with appropriate tariffs and ensuring that tariffs are stable could help build the economic business case for energy storage.

Finally, the inability to bring together detailed modelling, customer data, and battery performance (due in part to policy choices and rules limiting data access) makes it difficult to identify and capture existing opportunities.

What the future of energy storage may hold

Our work points to several important findings.

First, energy storage already makes economic sense for certain applications. This point is sometimes overlooked given the emphasis on mandates, subsidies for some storage projects, and noneconomic or tough-to-measure economic rationales for storage (such as resilience and insurance against power outages).

Second, market participants need to access the detailed data that could allow them to identify and prioritize those customers for whom storage is profitable. Given the complexity of energy storage, deployment is more likely to follow a push versus a pull sales model, favouring entrepreneurial companies that find creative ways to access and use these data.

Third, storage providers must be open-minded in their design of energy-storage systems, deciding whether lithium-ion, lead-acid, flow-cell, or some other technology will provide the best value. A strategy that employs multiple technologies may carry incremental costs, but it may also protect against sudden price rises.

Fourth, healthy margins are likely to accrue to companies that make use of battery and load-profile data. The unique characteristics of individual customers will favour tailored approaches, including the development of algorithms that find and extract the greatest value. Strong customer relationships are required to access relevant data and to deliver the most economical solution as regulations and technologies evolve.

Fifth, how to use storage to reduce system-wide costs will require some thought. Examples might include price signals that are correlated with significant deviations in power generation and consumption, rules that reward the provision of storage to serve multiple sites in close proximity, and tariffs that favour self consumption (or load shifting) of renewable electricity.

The most important implication is this: the large-scale deployment of energy storage could overturn business as usual for many electricity markets. In developed countries, for example, central or bulk generation traditionally has been used to satisfy instantaneous demand, with ancillary services helping to smooth out discrepancies between generation and load. Energy storage is well suited to provide such ancillary services. Eventually, as costs fall, it could move beyond that role, providing more and more power to the grid, displacing plants. That moment is not imminent. But it is important to recognize that energy storage has the potential to upend the industry structures, both physical and economic, that have defined power markets for the last century or more. And it is even more important to be ready.

5.5 Synthetic biology

[Extracts from [1], pp 67-69]

Synthetic biology is the design and construction of new biological parts and the re-design of natural biological systems for useful purposes. It is a new field of research in biotechnology that emphasises standardisation, modularisation and interoperability in genetic engineering. Following these principles, scientists are creating a catalogue of functional bio-components that are expected to have a wide range of applications in health, agriculture, industry and energy.

While humans have been involved in genetic manipulation by selective breeding for 10 000 years, it was only in the 1970s that direct manipulation of DNA in organisms became possible through genetic engineering. Synthetic biology is a recent field of research that has introduced an engineering approach to genetic manipulation. It is defined as the design and construction of new biological parts, devices, and systems, and the redesign of existing, natural biological systems for useful purposes (Royal Academy of Engineering, 2009).

While traditional genetic engineering generally uses trial-and-error approaches to produce new biological designs, synthetic biology attempts to reshape living systems on the basis of a rational blueprint (de Lorenzo and Danchin, 2008). To achieve this, synthetic biology utilises engineering principles such as standardisation, modularisation and interoperability. For instance, synthetic biologists create and catalogue functional components called “bio-bricks” based on DNA sequences that may or may not be found in nature. Bio-bricks perform certain functions that can be combined to produce innovations in a wide range of sectors including health, agriculture, industry and energy.

As a technology platform, synthetic biology has the potential to offer significant socio-economic benefits, create new businesses and bring greater efficiency to existing ones (OECD, 2014e). It may be leveraged by several key market sectors such as energy (e.g. relatively low-cost transport fuels), medicine (e.g. vaccine development), agriculture (e.g. engineered plants) and chemicals. The latter has a wide range of applications through bio-based production of new materials including environmentally friendly bio-plastics and cosmetics (e.g. synthetically designed natural fragrances). Within the field of marine biotechnology, several applications are envisaged for diatoms (plankton) that could have positive environmental effects, serve as gene-editing machines and produce biofuels (Daboussi et al., 2014). Synthetic biology may also help meet bio-economy objectives, i.e. reduction of greenhouse gas emissions and attaining food and energy security. As global population continues to grow and threats to water and soil quality increase, synthetic biology offers far-reaching agricultural applications that promise to increase productivity and efficiency. Examples include not only crops that are resistant to drought and diseases and increase yields, but also plants that produce their own fertilisers.

Currently, two trends in synthetic biology stand out. Gene editing uses the natural immune defences of bacteria to create "molecular scissors" that cut out and replace strands of DNA with great precision (Sample, 2015). This technique is helping scientists further understand the roles of genes in health and how several diseases could be treated by modifying tissues and organs. Patients' immune cells could be reprogrammed to make them attack cancer cells; immune cells could be made resistant to the HIV virus; and genetic disorders could be stopped from being passed on to offspring. Do-it-yourself (DIY) biology or bio-hacking refers to a growing community of individuals and small organisations that study and practise biology and life science outside of professional settings. Lower costs of equipment, instruments and computing coupled with the rise of open source development practices have fuelled this movement, democratising science and giving people access to their own biological data. Since 2003, the cost of gene sequencing has dropped by at least one million-fold (OECD, 2014e). Cost-effectiveness has also improved for gene synthesis as well (at a much slower pace), yet price declines in both synthesis and sequencing have recently stagnated (Carlson, 2014). DIY biology represents a potential engine of innovation similar to Silicon Valley, with a large number of individuals discovering and finding applications for bio-bricks. In the future, innovation in this field could be further democratised, allowing users to tinker and improve products and services from large firms, as has already occurred in manufacturing sectors (von Hippel, 2005).

The development of this technology poses a number of risks for biosafety and biosecurity. Biosafety covers the range of policies and practices designed to protect workers and the environment from unintentional misapplications or accidental release of hazardous laboratory agents or materials. Biosecurity is usually associated with the control of critical biological materials and information, to prevent unauthorised possession, misuse or intentional release (OECD, 2014e). Risks are difficult to assess given the unbounded amount of emergent properties of products and genetically engineered systems (SCHER, SCENIHR and SCCS, 2015).

The open source practices in synthetic biology also give rise to both biosafety and biosecurity concerns. Compared to many other types of science, experimentation in this field may be exposed to additional hazards (e.g. dealing with pathogens) given the self-replicating and transmissible nature of organisms (Wolinsky, 2009). As for biosecurity, DIY biology could be directed towards illegal activities, some which could threaten public safety (e.g. biological weapons). As the technology becomes globally adopted, uses for bio-bricks will become difficult to track, regulate or mitigate (NIC, 2012). For gene editing, although much additional expertise would be needed to produce infectious agents, authorities need to ensure sufficient oversight and review.

While gene therapy (i.e. altering the body's ordinary tissues) is an accepted medical technique, this is not the case for modifications that would alter a person's reproduction cells. The later type of genome editing (referred to as germline editing) could, in principle, alter the nature of the human species. Representatives from the National Academies of Science of the United States, the United Kingdom and China gathered recently to agree on a moratorium on permanent alterations to the human genome (Wade, 2015). The group called scientists around the world to abstain from germline editing research until risks are better assessed and a broad societal consensus about the appropriateness of these techniques is reached.

The future of synthetic biology depends on reliable, accurate and inexpensive DNA synthesis. While the cost of DNA sequencing is now negligible, costs for writing genetic code need to tumble by similar orders of magnitude. The technical difficulties involved in reaching parity with sequencing are considerable and create high financial risks for the typically small, high-technology companies working to develop synthetic biology. Major hurdles must also be overcome in bioinformatics and software infrastructure, though the relevant software will likely be available to a mass audience long before DNA synthesis. This can be good for synthetic biology (e.g. by creating interest among school pupils) but it increases the need for biosecurity vigilance, as sequence designs could be easily sent to other countries for manufacture without appropriate controls. At the same time, the large number of regulations that need to be followed to legally produce transgenic organisms (particularly to prevent harm in humans and their escape from controlled environments) is likely to restrict applications (OECD, 2014e; Travis, 2015).

5.6 Bioenergy in Europe

[Extracts from [20], p 1]

Bioenergy in Europe still offers one of the most capital-efficient transitions from coal to renewables, as well as a scalable opportunity for European utilities to take part in the second wave of renewable-energy-source growth. With carbon capture and storage still far from happening, bioenergy offers a way for big utilities to comply with renewable targets while using their existing assets.

How can that happen? We believe the levelized cost of bioenergy—its cost per kilowatt-hour— has the potential to be reduced by almost half by 2025, making bio-based electricity close to competitive with coal depending on the type of plant (exhibit). While there's no denying this would require significant effort, it doesn't require technological breakthroughs but rather simply making better use of the opportunities already at hand.

For instance, boiler efficiency in biomass plants today is often as low as 30 percent. Increasing steam parameters such as pressure, temperature, and energy efficiency would reduce the volume of feedstock required and lower costs. Further gains could be made by standardizing plant designs, adopting boiler and plant modularization, and applying design to value. And fuel costs could be lowered by driving greater efficiency in the biomass supply chain, whether by applying lean techniques to remove stumbling blocks, moving to long-term contracts, or improving fuel-treatment technology.

5.7 The future of second-generation biomass

[Extracts from [9], pp 1-5]

The promise of the second-generation (2G) bio-conversion industry is that it will transform cellulose-based, nonedible biomass and agricultural waste into clean and affordable high-value fuels or chemicals. (The first-generation, or 1G, technology converts edible biomass.) In this way, 2G could offer an alternative source both of energy and of chemical-industry inputs, which other renewable technologies cannot provide.

That is 2G's potential, but the industry failed to deliver on this promise for almost a decade. However, there has been progress in recent years. Since the inauguration of the first commercial-scale 2G plant, in 2013, eight more have opened around the world, of which some, not surprisingly, are failing, while others are progressing. Most are in North America, two are in Brazil, and one is in Europe—all markets with mature 1G biomass industries and governments that support cellulosic ethanol.

Second-generation projects have also begun attracting interest in China, India, Indonesia, and Malaysia in the form of government initiatives to coordinate action and to facilitate the establishment of a 2G ethanol market. As these trends suggest, the technology could be approaching the acceleration phase that marked the development trajectory of other industries, such as wind power, solar energy, and shale gas. In each case, growth was modest at first and then took off (exhibit).

Drawing on more than 100 interviews with executives and experts and on our work with key industry players, we have identified seven critical enablers in three challenging areas—resources, management, and the market—that the 2G industry must address to ensure continued progress.

Resources

Every business needs money, inputs, and processes that work. The second-generation biofuels industry faces challenges on each count—but these can all be addressed.

Reliable, commercial-scale conversion technology

Commercial 2G plants must demonstrate that they can deliver high-yield products at a competitive price, but conversion technology is taking longer than hoped to reach the necessary scale. One problem is that these plants must process the equivalent of up to 400 truckloads1 of biomass a day. The semisolid nature of (wet) biomass, which is often mixed with dirt and other impurities, complicates the processing. Biomass must be mechanically pretreated—for example, by extrusion, milling, or grinding—and fed continuously in preparation for hydrolysis.

What's next. The design, reliability, and processes of 2G equipment are all improving. Meanwhile, engineering is rightsizing specifications, increasing levels of process automation, and eliminating costly process aids. The race is on to become the first player to operate a stable, cost-competitive commercial-scale plant. For front-running facilities, the question is not whether their processes work but rather the strength of their operational performance—uptime, throughput, yield, and cost—and how quickly they will cut costs while improving their operations.

Given the need for energy and chemicals that are not derived from fossil fuels, as well as the benefits of renewables—reducing pollution and diversifying domestic energy sources—there's a case for developing 2G bioconversion into a full-fledged industry.

How big a piece of the renewables pie is 2G likely to capture? This will depend on two things: the speed of adoption and whether 2G can address the enablers discussed above and improve relative to alternative fuels. The future is unknown. What is clear, however, is that even after the problems of the past decade, the 2G industry now has an opportunity to industrialize its technology—and thus to improve its chances of success.

5.8 The resource revolution

[Extracts from [6], pp 1-4]

A few years ago, resource strains were everywhere: prices of oil, gas, coal, copper, iron ore, and other commodities had risen sharply on the back of high and rising demand from China. The overall picture looks quite different today. Technological break-throughs such as hydraulic fracturing for natural gas have eased resource strains, and slowing growth in China and elsewhere has dampened demand. Since mid-2014, oil and other commodity prices have fallen dramatically, and global spending on many commodities dropped by 50 percent in 2015 alone.

Even though the hurricane-like "supercycle" of double-digit annual price increases that prevailed from the early 2000s until recently has hit land and abated, companies in all sectors need to brace for a new gale of disruption. This time, the forces at work are often less visible and may seem smaller-scale than vertiginous cyclical adjustments or discovery breakthroughs. Taken together, though, they are far-reaching in their impact. Technologies, many having little on the surface to do with resources, are combining in new ways to transform the supply-and-demand equation for commodities. Autonomous vehicles, new-generation batteries, drones and sensors that can carry out predictive maintenance, Internet of Things (IoT) connectivity, increased automation, and the growing use of data analytics throughout the corporate world all have significant implications for the future of commodities. At the same time, developed economies, in particular, are becoming ever more oriented toward services that have less need for resources; and in general, the global economy is using resources less intensively.

These trends will not have an impact overnight, and some will take longer than others. But understanding the forces at work can help executives seize emerging opportunities and avoid being blindsided.

A technology-driven revolution

To understand what is going on, consider the way transportation is being roiled by technological change. Vehicle electrification, ride sharing, driverless cars, vehicle-to-vehicle communications, and the use of lightweight materials such as carbon and aluminum are beginning to ripple through the automotive sector. Any of them individually could materially change the demand and supply for oil—and for cars. Together, their first- and second-order effects could be substantial. McKinsey's latest automotive forecast estimates that by 2030, electric vehicles could represent about 30 percent of all new cars sold globally, and close to 50 percent of those sold in China, the European Union, and the United States.

That's just the start, since vehicles for ride-sharing on local roads in urban areas can be engineered to weigh less than half of today's conventional vehicles, much of whose weight results from the demands of highway driving and the potential for high-speed collisions. Lighter vehicles are more fuel efficient, use less steel, and will require less spending on new roads or upkeep of existing ones. More short-haul driving may accelerate the pace of vehicle electrification. And we haven't even mentioned the growth of autonomous vehicles, which would further enhance the operating efficiency of vehicles, as well as increasing road capacity utilization as cars travel more closely together. Several million fewer cars could be in the global car population by 2035 as a result of these factors, with annual car sales by then roughly 10 percent lower—reflecting a combination of reduced need as a result of sharing but also higher utilization and therefore faster turnover in vehicles and fleets.

The upshot of all this isn't just massive change for the automotive sector, it's a shift in the resource intensity of transportation, which today accounts for almost half of global oil consumption and more than 20 percent of greenhouse-gas emissions. Oil demand from light vehicles in 2035 could be three million barrels below a business-as-usual case. If you include the accelerated adoption of lighter materials, oil demand could drop by six million barrels. We may see "peak" oil—with respect to demand, not supply—around 2030.

Many other commodities face similar challenges. Natural-gas demand has been growing strongly as a source of power generation, especially in the United States and emerging economies. We see no signs of electricity demand abating—on the contrary, we expect demand for electricity to outpace the demand for other energy sources by more than two to one. But the electricity-generation mix is changing as solar- and wind-power technology improve and prices fall; wind could become competitive with fossil fuels in 2030, while solar power could become competitive with the marginal cost of natural-gas and coal production by 2025. Fossil fuels will continue to dominate the total energy mix, but renewables will account for about four-fifths of future electricity-generation growth.

Metals will be affected, too. Iron ore, a key raw material for steel production, may already be in structural decline as steel demand in China and elsewhere cools, and as recycling gathers pace. Lighter cars on roads that require less maintenance would only hasten that decline. We estimate that a smaller carfleet alone would potentially reduce global steel consumption by about 5 percent by 2035, compared with a business-as-usual scenario. Copper, on the other hand, is used in many electronics and consumer goods and could see a steady growth spurt—unless substitutes such as aluminium become more competitive in a wider set of applications. Electric vehicles, for example, require four times as much copper as those that use internal-combustion engines.

Some of the biggest impact on resource consumption could come from analytics, automation, and Internet of Things advances. These technologies have the potential to improve the efficiency of resource extraction—already, underwater robots on the Norwegian shelf are fixing gas pipelines at a depth of more than 1,000 metres, and some utilities are using drones to inspect wind turbines. Using IoT sensors, oil companies can increase the safety, reliability, and yield in real time of thousands of wells around the globe. These technologies will also reduce the resource intensity of buildings and industry. Cement-grinding plants can cut energy consumption by 5 percent or more with customized controls that predict peak demand. Algorithms that optimize robotic movements in advanced manufacturing can reduce a plant’s energy consumption by as much as 30 percent. At home, smart thermostats and lighting controls are already cutting electricity usage.

In the future, the pace of economic growth in emerging economies, the rate at which they seek to industrialize, and the vintage of the technology they adopt will continue to influence resource demand heavily. A key question is, how quickly will these economies adopt the new technology-driven advances? The challenge in part is from regulation and in part a question of access to capital, for example with solar energy in Africa. But the innovations provide new approaches to address age-old issues about resource intensity and the dependency on growth. Above all, they create the potential for dramatic reductions in natural-resource consumption everywhere. And that means there are substantial business opportunities for those with the foresight to seize them.

6 Other STI areas

6.1 Agricultural sustainability in USA and Africa

[Extracts from [27], pp 1-14]

US agriculture has had an impressive history of productivity that has resulted in relatively affordable food, feed, and fibre for domestic purposes and increases in agricultural exports. Fewer farmers are producing more food and fibre on about the same acreage, while input and energy use per unit output has decreased over the last 50 years. Despite these tremendous advances, U.S. farmers are facing the daunting challenges of meeting the food, feed, and fibre needs of the nation and of a growing global population and of contributing to U.S. biofuel production, under the constraints of rising production costs, increasingly scarce natural resources, and climate change. Agriculture is at a pivotal stage in terms of meeting societal demands for products while improving sustainability.

Defining agricultural sustainability

Improving sustainability is a process that moves farming systems along a trajectory toward meeting various socially determined sustainability goals as opposed to achieving any particular end state. Agricultural sustainability is defined by four generally agreed-upon goals:

- Satisfy human food, feed, and fibre needs, and contribute to biofuel needs.
- Enhance environmental quality and the resource base.
- Sustain the economic viability of agriculture.
- Enhance the quality of life for farmers, farm workers, and society as a whole.

To be sustainable, a farming system needs to be sufficiently productive, robust (that is, be able to continue to meet the goals in the face of stresses and fluctuating conditions), use resources efficiently, and balance the four goals.

Towards agricultural sustainability in the 21st century

All farms have the potential and responsibility to contribute to different aspects of sustainability. However, the scale, organization, enterprise diversity, and forms of market integration associated with individual farms provide unique opportunities or barriers to improving their ability to contribute to global or local food production, ecosystem integrity, economic viability, and social well-being. Dramatic and continuous improvement in agricultural sustainability will require long-term research, education, outreach, and experimentation by the public and private sectors in partnership with farmers.

Research has to address multiple dimensions of sustainability and explore agro-ecosystems properties if systemic changes in farming systems are to be pursued. Therefore, the incremental approach to improving agricultural sustainability needs to be complemented by a transformative approach that would dramatically increase integrative research by bringing together multiple disciplines to address key dimensions of sustainability simultaneously beyond the agro-ecological dimension. The transformative approach would apply a systems perspective to agricultural research to identify and understand the significance of the linkages between farming components and how their interconnectedness and interactions with the environment make systems robust and resilient over time.

Scientific foundation for improving sustainability

Science—including biophysical and social sciences—is essential for understanding agricultural sustainability. Science generates the knowledge needed to predict the likely outcomes of different management systems and expands the range of alternatives that can be considered by farmers, policy makers, and consumers.

The transformative approach aims for major improvement in sustainability performance by approaching 21st century agriculture from a systems perspective that considers a multiplicity of interacting factors. It would involve:

- Developing collaborative efforts between disciplinary experts and civil society to construct a collective and integrated vision for a future of U.S. agriculture that balances and enhances the four sustainability goals.
- Encouraging and accelerating the development of new markets and legal frameworks that embody and pursue the collective vision of the sustainable future of U.S. agriculture.
- Pursuing research and extension that integrate multiple disciplines relevant to all four goals of agricultural sustainability.
- Identifying and researching the potential of new forms of production systems that represent a dramatic departure from (rather than incremental improvement of) the dominant systems of present-day American agriculture.
- Identifying and researching system characteristics that increase resilience and adaptability in the face of changing conditions.
- Adjusting the mix of farming system types and the practices used in them at the landscape level to address major regional problems such as water overdraft and environmental contamination.

Application of a systems approach to agriculture is not limited to the farm level. The collective and potentially synergistic effects of agricultural systems at a landscape or community scale have gained recognition. However, the scientific foundation for and data needed to develop a landscape approach for improving sustainability of agriculture is sparse. Although a landscape approach to agricultural research could inform the design of agro-ecosystems to maximize synergies, enhance resilience, and inform what policies would be useful in influencing collective actions, programs to encourage such research do not exist.

Examples of transformative landscape-scale research include:

- Develop systems type mixes, patterns, and technologies for landscape diversity that maintain economic output while reducing overall water use.
- Develop systems type mixes and technologies to reduce nitrogen, phosphorus, and pesticide losses to downstream fragile water bodies, particularly in source regions responsible for hypoxia.
- Develop tools for modelling of systems and patterns for multipurpose economic, aesthetic, and environmental impacts to enhance community well-being and assist in planning, local policy, market identification, and farmer decision making.
- Develop policies and legal frameworks that encourage cooperative watershed landscape and ground water management across field and farm boundaries.
- Generate landscape design options to increase resilience and adaptability to changing conditions using a combination of the above approaches.

Returns on research investments could be increased by incorporating farmer knowledge. Much of the technical and managerial innovation in sustainable agriculture has occurred through on-farm innovation and experimentation. Engaging farmers as partners with scientists in innovation, development, extension, and outreach processes could produce effective and long-lasting technology adaptation and adoption. In addition, farmers' networks and farmer-to-farmer mentoring programs can help spread knowledge gained from research and help adapt such knowledge to farmers' local conditions.

Relevance of lessons learned to sub-Saharan Africa

When considering the relevance of lessons learned in the United States to sub-Saharan Africa, it is important to recognize key differences between the two regions. African farmers produce a wide variety of crops using diverse farming systems across a range of agro-ecological zones. Most systems are rain-fed, and many soils are severely depleted of nutrients. External inputs are expensive. High transportation costs and lack of infrastructure often inhibit access to outside resources and markets. Specific management approaches need to be developed in that context. Nonetheless, the concepts of sustainability and many of the broad approaches presented in this report are relevant and concur with conclusions from some recent international reports. They include:

- An interdisciplinary systems approach is essential to address the improvement and sustainability of African agriculture that recognizes the social, economic, and policy contexts within which farming systems operate. Evolving systems would need to address all four sustainability goals and be adapted to local conditions.
- Research programs need to actively seek input and collaboration from farmers to ensure research being conducted and technologies tested are relevant to their needs.

- Women, who play a pivotal role in African agriculture, need to be provided with educational and training opportunities and be involved in the development of research agendas.
- Technologies are needed to address soil, water, and biotic constraints, but they have to be integrated with local ecological and socioeconomic processes. Use of locally available resources would have to be maximized and combined with judicious use of external inputs when necessary.
- Promising technologies and approaches include soil organic matter management, reduced tillage, integrated fertility management, water harvesting, drip irrigation, stress-resistant crop varieties, improved animal breeds, integration of crops and livestock, and use of global information systems for landscape and regional analysis and planning.
- Expanding market access will be essential to increase productivity and enhance livelihoods in rural Africa. Investing in rural infrastructure could improve access to local, regional, and international markets.

6.2 Science and the farm in Africa

[Extracts from [2], p 32]

Africa's youth employment issue is fundamentally one of agricultural modernization and investment in science. Farming remains the dominant occupation of most young Africans; this despite the fact that few respond "I want to be a farmer" when asked about their aspirations. More youths remain on farms than leave, although the movement away is very visible and has raised concern about food security, aging of the countryside, and excessive dependence on food imports. Concerns would be best directed toward understanding the needs of young people who stay on farms, already a large group that will grow as the global slowdown and attenuation of the commodity boom affect the continent. The agriculture that will allow young farmers to prosper will have to draw on the best of modern agricultural science—and at present it does not.

Current levels of investment in Africa's agricultural science cannot support modernization. The prevailing paradigm of "closing yield gaps" has created the erroneous view that known science can be applied to great effect without investing in new science. Across the subcontinent, although investment in agricultural research has grown in real terms since 2000, it has declined as a share of agricultural GDP. Spending on agricultural research in Africa south of the Sahara in proportion to the size of the agricultural sector is about half that in Latin America and the Caribbean. At a time when social media vastly improves the capacity of young people to communicate even in remote rural areas, the absence of vibrant scientific communities weakens the attitudinal foundation supporting innovation. Even the improved varieties that advanced farmers seek may be a decade or more old. Today's pests and diseases and erratic weather patterns overtake yesterday's new varieties. Science that does not keep up falls behind.

Science that does keep up can deliver. Over 200 new bean varieties have been developed and released through the PanAfrican Bean Research Alliance (PABRA), a consortium of 29 bean-producing countries in Africa led by the International Centre for Tropical Agriculture (CIAT). These new varieties are helping to transform beans from a subsistence food to a marketed crop that boosts nutrition. Over 60 new varieties of orange sweet potato with enhanced vitamin A have been released in 15 countries of Africa over the past decade and a half, reducing the vitamin A deficiency of millions. A new program on African Chicken Genetic Gains (ACGG) led by the International Livestock Research Institute (ILRI) in partnerships with the governments of Ethiopia, Nigeria, and Tanzania is producing a better backyard chicken for smallholder farmers. These and other efforts to strengthen the scientific foundations of Africa's agriculture are essential for creating the jobs that will employ ambitious and hopeful young people. Some entrants to the labor force should become scientists, and millions of others should be beneficiaries of science through advances in soil management, greenhouse gas mitigation, better breeds and seeds, improved management of pests and diseases, rapid response to biotic shocks, and the myriad other ways in which advanced science serves agriculture.

The challenges of youth employment and agricultural modernization are often seen and addressed in isolation. In fact, they are inseparable—either mutually reinforcing problems that jeopardize the future of an entire continent, or mutually reinforcing solutions, each to the problem of the other. Investment in agricultural science determines which.

6.3 Micro and nano satellites

[Extracts from [1], pp 59, 60]

The last few years have witnessed the start of a revolution in the design and deployment of satellites. Small satellites have become very popular. The different families of small satellites are distinguished by their weight –less than 500 kg . Nano- and microsatellites weigh between 1 and 50 kg. CubeSats are miniaturised satellites whose original models measured 10x10x10 cm and weighed 1 kg (also known as "1 Unit"). Satellite units can then be combined to create larger CubeSats.

The smaller the satellite, the cheaper it is to build and launch. A nano- or microsatellite can be built for EUR 200-300K. Small satellites are becoming much more affordable, as off-the-shelf components are now commonly used to build satellite platforms and support mass production. Most of the electronics and subsystems required to construct a nanosatellite in-house can be bought online (OECD, 2014d). The main cost barrier remains access to space. Small satellites can be launched as secondary payloads for less than EUR 100K. They can also be deployed from the International Space Station, after having been transported there as cargo. It is expected that between 2014 and 2020 more than 2 000 nano- and microsatellites will require launching worldwide (SpaceWorks, 2014).

Small satellites offer vast opportunities in terms of speed and flexibility of construction. Whereas conventional large satellites may take years if not decades to move from drawing board to operational mission, very small satellites can be built very quickly. By way of illustration, it took Planet Labs just nine days to build two CubeSats in early 2015.

Small satellites are finding use across a wide range of applications – from Earth observation and communications to scientific research, technology demonstration and education, as well as defence. The fast deployment of small satellites is taking place as technology for traditional, much larger multifunctional satellites keep evolving. Since the launch of the first CubeSat in 2002, the number of very small satellites in operation has increased at a remarkable rate. In 2014, 158 nano- and microsatellites were launched, i.e. an increase of 72% compared to the previous year (FAA, 2015).

6.3.1 Creating new commercial ventures

The increased use of off-the-shelf components as opposed to more expensive space-qualified products is creating a new world market for space systems and services. Developers are increasingly turning to complex system architectures, to get small satellites to interact in constellations. In 2013, the firm Skybox Imaging launched its first high resolution imagery satellite as part of a planned constellation of 24 small satellites to provide continuously updated and cheaper satellite imagery. Likewise, Planet Labs launched the "Flock 1" constellation with 28 nanosatellites early 2014.

6.3.2 Pushing knowledge frontiers

CubeSats are very popular in universities, as technology demonstrators. They emerge as lowcost educational satellite platforms and have gradually become the standard for most university satellites. As of spring 2014, almost a hundred universities worldwide are pursuing CubeSat developments (OECD, 2014d). At the educational level, university small satellites can help students put into practice their engineering and scientific competences much faster.

6.3.3 Monitoring lands and oceans

Although large satellites in geostationary orbits remain key pillars for the telecommunications and meteorological infrastructure, small satellites used in large constellations in lower orbits promise ground-breaking improvements, for example in Earth observation. Microsatellites provide the capacity for around-the-clock observation. A case in point is the monitoring of the health of oceans and inland waters. Satellite constellations can be used for monitoring illegal fishing and improving marine domain awareness to combat criminal activities. Similarly on land, constellations could contribute to monitor agricultural crops, improve crop productivity, and keep track of deforestation.

6.3.4 Opening space to all

Small satellites have become very attractive in the past five years, due to their lower development costs and shorter production lead times. Small satellites are thus attracting a lot of interest around the world, and many countries have decided to fund their first space programmes with the development of small satellites. Over the last decade, the Ukrainian launcher Dnepr has launched 29% of satellites of 11-50 kgs, ahead of India's Polar Satellite Launch Vehicle.

A perennial trade-off between size and functionality: The smaller the satellite, the fewer instruments it can carry and the shorter its life expectancy because of the smaller amount of on-board fuel. Larger satellites still have a major role to play, as they carry more instruments and have longer lifetimes, which allows important commercial and governmental missions to be carried out. However recent advances, both in miniaturisation and satellite integration technologies, have dramatically reduced the scale of the trade-off (NASA, 2014).

Dealing with high business risk: Increasingly, nano- and microsatellites are being launched in large clusters, and a single failure (at launch or on deployment) can lead to substantial losses. A recent failed Antares rocket launch led to the loss of over 30 satellites (SpaceWorks, 2015).

Debris and collisions: the growing environmental threat: The main environmental concern is that fast deployment of small satellites will heighten the risk of collision in some already crowded orbits, creating a cascading effect as more debris generates ever greater risk of further collisions. According to international guidelines on space debris, most satellites should either move to a 'graveyard' orbit or re-enter the atmosphere when they reach their end-of-life operations. However, by construction, very small satellites do not have the onboard fuel for deorbit manoeuvres.

6.4 Smart cities and smart communities

[Extracts from [21], p 1]

Smart cities are going to be amazing community hubs that will be more sustainable, efficient, and supportive of citizens. The concept of smart communities is based on intelligent infrastructure such as broadband (FttH) and smart grids, so that connected and sustainable communities can be developed. However, they cannot be built within the silo structure that currently dominates our thinking; a holistic approach is needed one that includes environmental issues such as self-sufficient energy buildings, exchanges for renewable energy and e-cars, delivery of e-health, e-education and e-government services, as well as digital media and internet services.

To date, the easiest path to incorporating these concepts into a smart community has been with the development of Greenfield' residential communities. These projects essentially start with no existing legacy utility infrastructure, and involve the construction of new dwellings capable of incorporating a range of new technologies. Greenfield development sites can be used as test beds and lead the way for other existing communities to follow suit.

How data and information is processed and utilised will be a key to the success of smart cities, which is why developments regarding Big Data management, M2M communication and Cloud Computing are of particular importance to smart city developments.

The home automation market has certainly caught the interest of some of the industry heavyweights with Qualcomm, Samsung and Apple all developing their own smart home automation solutions. Reportedly, Google acquired Nest in order to develop home automation offerings too.

The global smart city and smart home markets are expected to escalate in the coming years. In China, all three leading mobile operators have major smart city projects. Stockholm came first in Ericsson's Networked Society City Index 2014. The United Arab Emirates are building an ambitious smart city from scratch Masdar City in Abu Dhabi aims to be the world's first zero carbon, zero waste city powered entirely by renewable energy sources.

The connected city

[Extracts from [22], p 1]

In 1995 George Gilder, futurist, predicted the death of cities, which he called “leftover baggage from the industrial era.” No prediction could have been more wrong. Cities have been thriving over the past few decades, and by 2030 there may be 5 billion people living in cities. Digital has not killed physical space. Instead, digital and physical are recombining. The internet has entered physical space—becoming the Internet of Things—and it is changing the way we interface with the space around us. Through networks and sensors we can understand the city in a different way and respond to that information. By 2020, the number of connected devices is expected to grow to 50 billion; this will include not only phones and iPads but also sensors. Growth in these devices is producing a massive amount of data in our cities, and we can learn a great deal from big data in urban space.

6.5 Bayesian inference

[Extracts from [25], pp 20-23]

Over the last 30 years, Bayesian analysis has become a central tool in statistics and science. Its primary advantage is that it answers the types of questions that scientists are most likely to ask, in a direct and intuitive way. And it may be the best technique for extracting information out of very large and heterogeneous databases.

The number of applications of Bayesian inference has been growing rapidly and will probably continue so over the next 20 years. For example, it is now widely used in astrophysics. Certain theories of cosmology contain fundamental parameters—the curvature of space, density of visible matter, density of dark matter, and dark energy—that are constrained by experiments. Bayesian inference can pin down these quantities in several different ways. If you subscribe to a particular model, you can work out the most likely parameter values given your prior belief. If you are not sure which model to believe, Bayes's rule allows you to compute odds ratios on which one is more likely. Finally, if you don't think the evidence is conclusive for any one model, you can average the probability distributions over all the candidate models and estimate the parameters that way.

Bayesian inference is also becoming popular in biology. For instance, genes in a cell interact in complicated networks called pathways. Using microarrays, biologists can see which pathways are active in a breast cancer cell. Many pathways are known already, but the databases are far from perfect. Bayesian inference gives biologists a way to move from prior hypotheses (this set of genes is likely to work together) to posterior ones (that set of genes is likely to be involved in breast cancer).

In economics, a Bayesian analysis of consumer surveys may allow companies to better predict the response to a new product offering. Bayesian methods can burrow into survey data and figure out what makes customers different (for instance, some like anchovies on their pizza, while others hate them).

Bayesian inference has proved to be effective in machine learning—for example, to teach spam filters to recognize junk e-mail. The probability distribution of all e-mail messages is so vast as to be unknowable; yet Bayesian inference can take the filter automatically from a prior state of not knowing anything about spam, to a posterior state where it recognizes that a message about "V1agra" is very likely to be spam.

While Bayesian inference has a variety of real-world applications, many of the advances in Bayesian statistics have depended and will depend on research that is not application-specific. Markov chain Monte Carlo, for example, arose out of a completely different field of science. One important area of research is the old problem of prior distributions. In many cases there is a unique prior distribution that allows an experimenter to avoid making an initial estimate of the values of the parameters that enter into a statistical model, while making full use of his or her knowledge of the geometry of the parameter space. For example, an experimenter might know that a parameter will be negative without knowing anything about the specific value of the parameter.

Basic research in these areas will complement the application-specific research on problems like finding breast cancer genes or building robots and will therefore ensure that Bayesian inference continues to find a wealth of new applications.

7 The innovation environment

7.1 Multi-interdisciplinary Centres – a new trend in NSIs

[Extracts from [16], pp 25, 26]

When the National Science Foundation (NSF) Engineering Research Centers (ERC) programme was established [in the USA] in 1984, its focus was on multidisciplinary engineering, research, education, and workforce development in partnership between academia and industry. Today, that focus needs clarifying and updating to reflect the current state of science and engineering research. For example, multidisciplinary engineering research now needs to include not only diverse engineering disciplines but also the physical, life, and social sciences. Multidisciplinary also needs to be augmented by interdisciplinary, which means having some individuals who are trained to communicate across disciplinary boundaries and to integrate across disciplinary boundaries. The partnership aspect of the ERCs also needs to be expanded beyond those between industry and academia to include government at various levels and civil society as funders, facilitators, and representatives of the user communities who stand to benefit from innovation.

To reflect this new focus, these new enterprises should be called **multi-interdisciplinary centres (MIDs)**, and a number of grand challenges requiring MID solutions include the following:

- Ensuring abundant, safe, sustainable food, water, and energy;
- Minimizing harm from changes in climate that are no longer avoidable;
- Engineering materials from abundant elements to substitute for current uses of scarce ones;
- Understanding the brain;
- Combating infectious and vector-borne diseases;
- Defeating cancer;
- Facilitating graceful aging;
- Defending the planet from killer asteroids; and
- Sending humans into space not just to visit but to stay.

The American Innovation Strategy (updated in October 2015) is built on three pillars. The first, investing in the fundamental building blocks of innovation, includes:

- educating Americans with 21st century skills,
- strengthening leadership in fundamental research through research funding and nurturing research institutions,
- building a leading physical infrastructure to support innovation, and
- developing an advanced information technology ecosystem.

The second pillar calls for:

- promoting market-based innovation by accelerating business innovation using tax credits,
- encouraging innovation-based entrepreneurship,
- growing investment in ingenuity with effective policy on intellectual property rights, and
- promoting innovative, open, and competitive markets.

The third pillar of the innovation strategy aims to catalyze breakthroughs for national priorities, including:

- unleashing a clean-energy revolution;
- accelerating biotechnology, nanotechnology, and advanced manufacturing;
- developing breakthroughs in space applications;
- driving breakthroughs in health care technology, and
- creating a leap forward in educational technologies.

The [Obama] administration has already established some MIDs, including five Energy Innovation Hubs and the eight centres of the National Network for Manufacturing Innovation, the latter of which have already brought together more than 800 company, university, and non-profit partners and leveraged a $600 million investment to attract over $1.2 billion in non-federal investment.

7.2 Africa's innovation environment

[Extracts from [15], pp 6-7]

Despite African economies diverging in their growth paths from 2010 to 2015, the continent's overall outlook remains promising. Africa's collective GDP is still expanding faster than the world average, and it is forecast to accelerate over the next five years to become the world's second-fastest-growing region once again. In the longer term, four factors could have a transformative effect on the continent's economies and their pace of growth.

- **The world's fastest urbanization**. Africa is the world's fastest urbanizing region. Over the next decade, an additional 187 million Africans will live in cities—equivalent to ten cities the size of Cairo, Africa's largest metropolitan area (1). Between 2015 and 2045, an average of 24 million additional people are projected to live in cities each year, compared with 11 million in India and nine million in China (Exhibit E4 above). Urbanization has a strong correlation with the rate of real GDP growth, because productivity in cities is more than double that in the countryside: Africa's urban GDP per person was $8,200 in 2015, compared with $3,300 in rural areas[2]. Higher productivity translates into higher incomes, and cities offer better access to infrastructure, education, and new markets, resulting in more rapid growth in consumption by households and businesses. The challenge will be to cope with the stresses of rapid urban expansion, including provision of housing and services.
- **A workforce larger than those of either China or India by 2034.** Africa has a young population and a growing labour force—a highly valuable asset in an aging world. The challenge for Africa will be to ensure that its economies continue to create sufficient jobs for the many millions of young people entering the workforce—thus far the signs are positive with the rate at which stable jobs have been created outpacing growth in the workforce—and to help develop their skills. By 2034, the working-age population is expected to be 1.1 billion, larger than that of either China or India. Roughly 60 percent of the world's population lives in countries with fertility rates below replacement rates and, for the first time in human history, demographic change could mean that the planet's population plateaus. In some countries, one-third of the workforce could retire in the period to 2025, with a potentially negative impact on economic growth prospects. However, Africa's demographics are still working in its economic favour: an expanding working-age population is associated with strong rates of GDP growth.
- **Huge potential from accelerating technological change.** The accelerating scope, scale, and economic impact of technology is a major transformative force around the world (2). Faster penetration of the internet and mobile phones offers Africa a huge opportunity to enhance growth and productivity; Africa's penetration of smart phones is expected to reach 50 percent by 2020, from only 18 percent in 2015[3]. Previous MGI research estimated that the internet could drive 10 percent of Africa's GDP by 2025 (3). This trend is already transforming a

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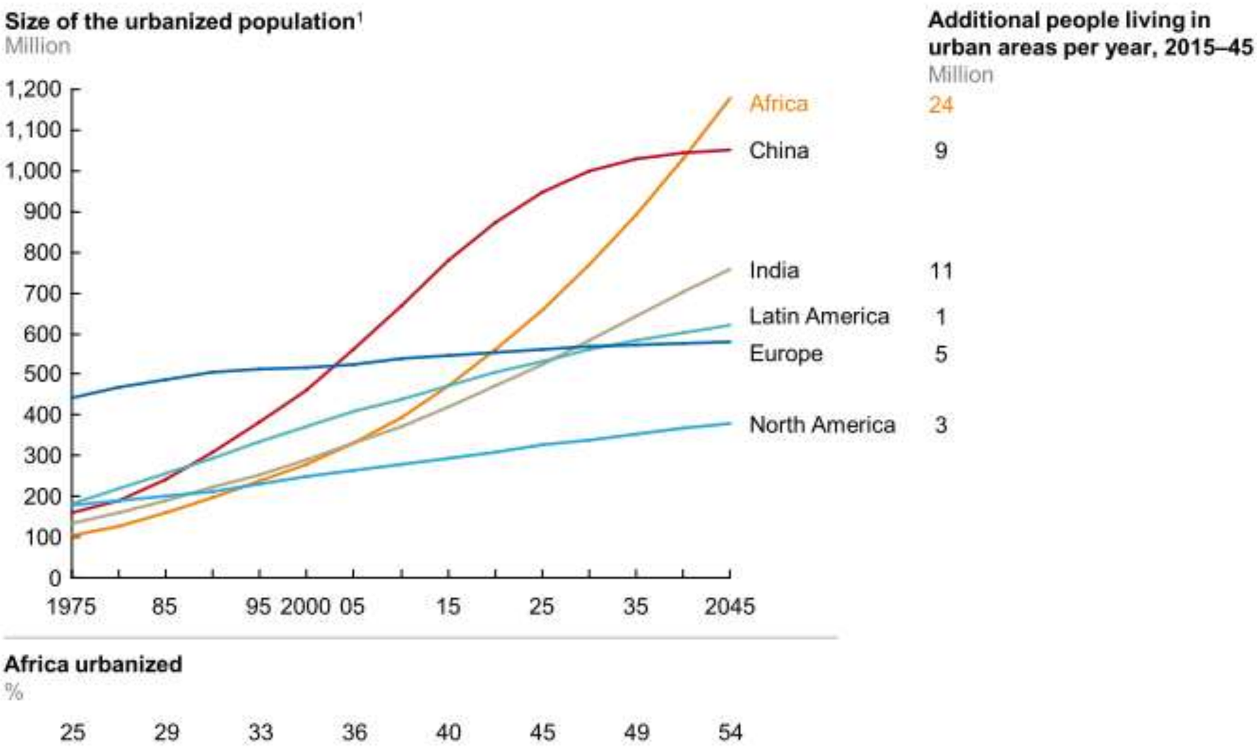
1. MGI estimated this figure by splitting into rural and urban activities sectoral data from the International Labour Organization, World economic outlook, IMF, April 016; United Nations Statistics Division; national statistical offices; and Lars Christian Moller, Ethiopia's great run: The growth acceleration and how to pace it, World Bank working paper number 99399, November 2015.

2. Estimated by MGI using forecasts from The mobile economy: Sub-Saharan Africa 2015, GSMA, 2015; UN Population Division.

number of sectors, including banking, retail, power, health care, and education. Electronic payments are sweeping across the region and changing the business landscape. East Africa is already a global leader in mobile payments. E-commerce in Africa is growing quickly—revenue has doubled in Nigeria each year since 2010. In South Africa, smart metering is taking off and is expected to modernize consumer payments in the power sector, while ambulance services are using mobile application technology to improve response times greatly. The African Leadership University, launched in Mauritius in 2015, is using technology to reduce teaching costs and deliver e-learning, creating a replicable model for expansion across the continent.

Exhibit E4

Africa is urbanizing faster than any other region; its cities are expected to gain 24 million people each year until 2045



1 Population living in urban areas. UN forecasts last adjusted in 2014.

SOURCE: World urbanization prospects, June 2014 revision, United Nations population division; McKinsey Global Institute analysis

- **Continued abundance of resources.** Africa contains 60 percent of the world's unutilized but potentially available cropland, as well as the world's largest reserves of vanadium, diamonds, manganese, phosphate, platinum-group metals, cobalt, aluminium, chromium, and gold. It is responsible for 10 percent of global exports of oil and gas, 9 percent of copper, and 5 percent of iron ore. Even at recent low prices for such commodities, a significant share of African production continues to be cost-competitive, putting the resources sector in a strong position for when demand—and, eventually investment—recover[4]. Capturing these opportunities will be challenging. Governments will need to improve their investment attractiveness in a weaker environment, while companies must review their approach to community engagement so that they

3. When taking into account only the technical costs or equivalent, before royalties and taxes.

have the support of local communities as well as their “license to operate” from regulators.

7.3 Regulatory environment and technological innovation in Africa

[Extracts from [2], pp 48, 49, 53-57]

Why is regulating technology important? Are regulations and the regulatory environment likely to stifle innovation in Africa? What regulations are appropriate and even helpful for innovation? How can governments balance out regulations and entrepreneurship? Is there tension between the regulators and innovators in Africa?

So far, nothing can elaborate on these questions better than the development, success, and spread of digital financial services (DFS) in Africa. In particular, Kenya’s M-Pesa (as well as similar products in Kenya and Tanzania), a mobile phone-based banking product and later a technological platform, has pushed the frontier of innovation and financial inclusion without compromising financial stability. Kenya’s combination of a supporting policy environment with a sound regulatory and supervisory framework allowed space for innovators and entrepreneurs to introduce financial innovations and a diversification of products into the market. Regulators agreed with the innovators on prudent risk management, and the policy environment ensured a stable macroeconomic environment. These combined factors ensured Kenya’s success. These are major outcomes that form a strong base for lessons for 2017 in the African continent as well as for Kenya to sustain the frontier and move to the next level.

Indeed, countries that have embraced DFS and created a regulatory yet innovation-friendly environment have provided the guidelines to proactively shape market outcomes. This lesson has allowed innovators to successfully introduce new products into the market with new delivery channels and methods. Those countries have raised their financial inclusion profiles and created vibrancy in the financial market and the totality of their economies. Thus, different countries in Africa that have provided better regulatory environments even at extremes—such as the Kenyan case of “test-and-learn” approach—have found great success. The case is different for those countries that have not embraced the digital financial revolution; often their constraints can be traced to their prevailing regulatory environment, but not their prevailing legal frameworks.

The M-Pesa revolution and resulting technological platform developed in four innovative and virtuous stages, spurred by a conducive regulatory environment. First, the mobile phone platform was used for money transfer between users and later for payments and settlement—these uses were made easier and a rollout more possible in 2006 when the Kenyan government amended the communication law to recognize electronic units of money. The practicality of transforming cash into electronic units of cash, storing it on a SIM card, and simultaneously loading it into a bank account led to the development of a transactions platform in the absence of a national payments and settlement law. Second, encouraged by regulators, virtual savings accounts were developed using the same M-Pesa technological platform—impacting the banking intermediation process.

Third, the development and application of information capital (credit scores) for participants in this technological platform arose as companies started using the M-Pesa payment data including travel and communication patterns to determine the risk profile of customers and offer them loans at affordable rates, eliminating information asymmetry inhibiting the development of credit markets in Africa. This development was supported by already-existing credit information bureaus and amendments on information sharing to the Banking Act. Finally, cross-border payments and international remittances based on the M-Pesa technological platform have become possible aided by the National Payments Act, which allowed for standalone payments and settlement units including foreign exchange remittances. Now, the M-Pesa technological platform has revolutionized financial inclusion in Kenya to reach over 75 percent of the population and increase financial access touch points: 76.7 percent of the population are within five kilometres of a touch point, and there are 161.9 financial access touch points per 100,000 Kenyans compared to 63.1 in Uganda, 48.9 in Tanzania, and 11.4 in Nigeria.

Products like M-Pesa cannot thrive if the regulators on both sides do not understand the potential of the innovations taking place to the totality of the economy as well as the risks, and provide risk mitigation processes upfront—thus avoiding stifling emerging innovative products. Other countries in Africa that have followed similar paths even with different legal frameworks have been successful. Rules and guidelines should encourage prudent behaviour by both the financial institutions and market participants. Regulators should manage the orderly entry and exit of financial institutions in the market, minimizing the potential for major disruptions in the financial system. This did not change when other regulators, like telecommunication (telco) regulators in Kenya, came to the scene; in that example, it strengthened the case for DFS and provided credibility with regulators working as a team.

So far, this pattern has worked well, but DFS platforms have brought other actors that are regulated differently into the marketplace, such as the fintechs and the telecommunication companies partnering with banks to provide access to financial services. What happens now, when such partnerships require different regulators and regulatory technology? In this case, regulatory technology must develop further, cope, and align with these new product designs and market actors. In the Kenyan case, M-Pesa is like a joint product between commercial banks and a telco (Safaricom), and other similar products have been developed and rolled out to the market in a similar way. These types of products sit in a commercial bank as a transactions platform and the telcos provide the technological transmissions of transactions to this platform. The regulators of banks and telcos then concentrate their efforts and guidelines along these shared responsibilities.

For further progress and faster financial inclusion in Africa in 2017—as well as increased uptake of other transformative innovations—what is required is further improvement in the regulatory environment, regulatory reforms as well as leveraging on successful cases to make the financial market more accessible, efficient, safe, and reliable to boost confidence and endogenously move financial inclusion to the next level. It is emerging in this way for example in East Africa.

The lessons are clear that a poor regulatory environment can be a major obstacle to innovations in the market and will constrain the speed of financial inclusion. In this regard, we can scheme out the role of regulations and what we may regard as a good regulatory environment. First, regulatory changes are needed to enable successful adoption and adaptation of innovations. In successful cases of DFS, regulators in telecos, central banks, and even competition encouraged adoption and use by steering a favorable environment for new products and enhancing their credibility. Second, the regulatory environment as well as frontier regulatory technology being adapted in the financial sector improved financial inclusion. The success of financial inclusion and accessibility to the financial market is compatible with the developmental role of regulators in Africa. Finally, related policies must open and even encourage and incentivize the consumer base to take up the new technology. In the Kenyan case, by bringing the financially excluded into the banking system, it has enhanced consumer protection and has created a better environment for monitoring anti-money laundering (AML) and combating the financing of terrorism (CFT). More importantly, it has created a better environment for monetary policy.

From this example, we can also provide a more global picture of the urgency of such innovations and their potential for transforming the lives of millions. A McKinsey Global

Institute Report (2016), Digital Finance for All: Powering Inclusive Growth in Emerging Economies, [5] recently recounted some of the achievements of this new technology:

- Digital finance has the potential to provide access to financial services for 1.6 billion people—more than half of whom are women-—in emerging and developing economies.
- It can increase the volumes of loans extended to individuals and businesses by $2.1 trillion and allow governments to save $110billion per year by reducing leakage in spending and tax revenues.
- Financial service providers can benefit by serving $400 billion annually in direct costs while sustainably increasing their balance sheets by as much as $4.2 trillion.
- The overall boost to GDP in these economies can be $2.7 trillion by 2025, a 6 percent increase. The contribution would come from raised productivity of financial and non-financial businesses and governments with DFS.

However, the fears of regulatory arbitrage, risks, and misunderstanding of how innovations are taking place continues to prevent so many African regulators from embracing DFS as well as creating an environment for other innovations in the market to thrive. The tension of regulation and innovation perhaps reigns even into 2017. What should be done? Going forward, how is the balance to be achieved? Nothing seems to explain this better than the words of the late Sir Andrew Crockett after the global financial crisis:

But whatever the underlying causes [of the global financial crisis], public opinion rightly expects the regulatory environment to be reformed to prevent a repetition of the economic and human costs of the crisis. There is a natural desire in such circumstances for "more regulation." What is needed, however, is "better regulation," a regime that can more readily identify emerging vulnerabilities, that can properly price risks, and that strengthens incentives for prudent behaviour. In some cases, this will require additional regulation; in others, a better-targeted use of powers that regulators already have.

What results can we look for or showcase where the balance of regulation and innovation has been seen to work? Do we assume that in 2017 the regulators, especially in Africa, will acquire and adapt the frontier regulatory technology that will balance out and encourage innovation, innovative products, and entrepreneurship? The Kenyan case demonstrates that entrepreneurs and innovations will thrive with a supporting policy and regulatory environment. Its successes would not have been possible without the strong regulatory institutions as institutions have two important functions: First, they define the rules of the game, generating a set of dynamic principles to guide the market of dynamic innovators and entrepreneurs. Second, they define the appropriate incentives (as well as penalties). A combination of rules, dynamic guidelines, and appropriate incentives will encourage prudent behaviour in the market and will support market development. In this regard, innovators and entrepreneurs will find it easy and rewarding to operate and thrive in such a market and a regulatory environment.

This synergy is what will support innovation in the market and attract new entrepreneurs. But there are two important caveats to watch for in 2017. Financial stability—like so many other important drivers of growth—cannot be sustained by regulations alone. Other internal and external factors, such as an unstable macroeconomic environment and threats of recession, can threaten success. Economic recession robs the economy of the supply of investment opportunities and the financial sector thrives on this dynamism to allocate financial resources to affect the investments. In addition, capping interest rates destroys the instrument that is used worldwide to price risk. In this case, domestic de-risking is bad for financial stability as well as encouraging innovation and entrepreneurs in the market. A regulatory approach and a regulatory environment that will encourage innovation and entrepreneurship is what African economies should strive to achieve in 2017 but also work on the pitfalls that can disrupt the process that will kill innovativeness and broad-based growth across sectors.

8 Technology, automation and employment

A key issue to address concerning technological development, and especially the advancement of digitally-based automation technology, is that of the potential loss of existing jobs, and the potential creation of new employment opportunities. This matter is discussed in different ways in a number of subsections above (see subsections 2.1, 2.2, 2.7, 2.15, 4.1, 4.5, 5.8, 6.2, 7.1 and 7.2).

A recent report, entitled A Future that Works: Automation, Employment and Productivity (January 2017, McKinsey Global Institute), provides an excellent explanation and analysis of the issue. The Executive Summary of the report is provided below, along with extracts from a range of other relevant reports. It is strongly recommended that the full McKinsey report be consulted.

8.1 Jobs and automation

[Extracts from [2], p38]

The automation of jobs has been a historical challenge in the developed world and is becoming a growing one in the developing world. Both in Africa and elsewhere, two-thirds of all jobs are susceptible to automation due to advancing technology. The situation, though, is not necessarily dire, as slow adoption of advanced technology and lower wages are likely to stave off automation and its resulting job displacement in developing countries. In a majority of cases developing-country jobs are safer than they would otherwise be in the short term owing to lags in technology adoption.

8.2 Automation, employment and productivity

In brief

[Extracts from [30], pp vii-viii]

Advances in robotics, artificial intelligence, and machine learning are ushering in a new age of automation, as machines match or outperform human performance in a range of work activities, including ones requiring cognitive capabilities. In this report, part of our ongoing research into the future of work, we analyze the automation potential of the global economy, the factors that will determine the pace and extent of workplace adoption, and the economic impact associated with its potential.

- Automation of activities can enable businesses to improve performance, by reducing errors and improving quality and speed, and in some cases achieving outcomes that go beyond human capabilities. Automation also contributes to productivity, as it has done historically. At a time of lackluster productivity growth, this would give a needed boost to economic growth and prosperity and help offset the impact of a declining share of the working-age population in many countries. Based on our scenario modelling, we estimate automation could raise productivity growth globally by 0.8 to 1.4 percent annually.
- About half the activities people are paid almost $15 trillion in wages to do in the global economy have the potential to be automated by adapting currently demonstrated technology, according to our analysis of more than 2,000 work activities across 800 occupations. While less than 5 percent of all occupations can be automated entirely using demonstrated technologies, about 60 percent of

all occupations have at least 30 percent of constituent activities that could be automated. More occupations will change than will be automated away.

- Activities most susceptible to automation involve physical activities in highly structured and predictable environments, as well as the collection and processing of data. In the United States, these activities make up 51 percent of activities in the economy accounting for almost $2.7 trillion in wages. They are most prevalent in manufacturing, accommodation and food service, and retail trade, and include some middle-skill jobs. Technical, economic, and social factors will determine the pace and extent of automation. Continued technical progress, for example in areas such as natural language processing, is a key factor. Beyond technical feasibility, the cost of technology, competition with labour including skills and supply and demand dynamics, performance benefits including and beyond labour cost savings, and social and regulatory acceptance will affect the pace and scope of automation. Our scenarios suggest that half of today's work activities could be automated by 2055, but this could happen up to 20 years earlier or later depending on the various factors, in addition to other wider economic conditions.
- People will need to continue working alongside machines to produce the growth in per capita GDP to which countries around the world aspire. Our productivity estimates assume that people displaced by automation will find other employment. The anticipated shift in the activities in the labour force is of a similar order of magnitude as the long-term shift away from agriculture and decreases in manufacturing share of employment in the United States, both of which were accompanied by the creation of new types of work not foreseen at the time.
- For business, the performance benefits of automation are relatively clear, but the issues are more complicated for policy-makers. They should embrace the opportunity for their economies to benefit from the productivity growth potential and put in place policies to encourage investment and market incentives to encourage continued progress and innovation. At the same time, they must evolve and innovate policies that help workers and institutions adapt to the impact on employment. This will likely include rethinking education and training, income support and safety nets, as well as transition support for those dislocated. Individuals in the workplace will need to engage more comprehensively with machines as part of their everyday activities, and acquire new skills that will be in demand in the new automation age.

Executive summary

[Extracts from [30], pp 1-19]

Automation is not a new phenomenon, and questions about its promise and effects have long accompanied its advances. More than a half century ago, US President Lyndon B. Johnson established a national commission to examine the impact of technology on the economy and employment, declaring that automation did not have to destroy jobs but "can be the ally of our prosperity if we will just look ahead." Many of the same questions have come to the fore again today, as a result of remarkable recent advances in technologies including robotics, artificial intelligence (AI), and machine learning. Automation now has the potential to change the daily work activities of everyone, from miners and landscape gardeners to commercial bankers, fashion designers, welders—and CEOs. But how quickly will these technologies become a reality in the workplace? And what will their impact be on employment and on productivity in the global economy?

Over the past two years, we have been conducting a research program on automation technologies and their potential effects. Some of our key findings include the following.

- We are living in a new automation age in which robots and computers can not only perform a range of routine physical work activities better and more cheaply than humans, but are also increasingly capable of accomplishing activities that include cognitive capabilities. These include making tacit judgments, sensing emotion, or even driving—activities that used to be considered too difficult to automate successfully.
- The automation of activities can enable productivity growth and other benefits at both the level of individual process and businesses, as well as at the level of entire economies, where productivity acceleration is sorely needed, especially as the share of the working-age population declines in many countries. At a microeconomic level, businesses everywhere will have an opportunity to capture benefits and achieve competitive advantage from automation technologies, not just from labour cost reductions, but also from performance benefits such as increased throughput, higher quality, and decreased downtime. At a macroeconomic level, based on our scenario modelling, we estimate automation could raise productivity growth on a global basis by as much as 0.8 to 1.4 percent annually.
- Our approach to analyzing the potential impact of automation is through a focus on individual activities rather than entire occupations. Given currently demonstrated technologies, very few occupations—less than 5 percent—are candidates for full automation today, meaning that every activity constituting these occupations is automated. However, almost every occupation has partial automation potential, as a significant percentage of its activities could be automated. We estimate that about half of all the activities people are paid to do in the world's workforce could potentially be automated by adapting currently demonstrated technologies.
- The pace and extent of automation, and thus its impact on workers, will vary across different activities, occupations, and wage and skill levels. Many workers will continue to work alongside machines as various activities are automated. Activities that are likely to be automated earlier include predictable physical activities, especially prevalent in manufacturing and retail trade, as well as collecting and processing data, which are activities that exist across the entire spectrum of sectors, skills and wages. Some forms of automation will be skill-biased, tending to raise the productivity of high-skill workers even as they reduce the demand for lower-skill and routine-intensive occupations, such as filing clerks or assembly-line workers. Other automation has disproportionately affected middle-skill workers. As technology development makes the activities of both low-skill and high-skill workers more susceptible to automation, these polarization effects could be reduced.
- Automation will have wide-ranging effects, across geographies and sectors. Although automation is a global phenomenon, four economies—China, India, Japan, and the United States—account for just over half of the total wages and almost two-thirds the number of employees associated with activities that are technically automatable by adapting currently demonstrated technologies. Within countries, automation potential will be affected by their sector mix, and the mix of activities within sectors. For example, industries such as manufacturing and agriculture include predictable physical activities that have a high technical potential to be automated, but lower wage rates in some developing countries could constrain adoption.

- Automation will not happen overnight, and five key factors will influence the pace and extent of its adoption. First is technical feasibility, since the technology has to be invented, integrated and adapted into solutions that automate specific activities. Second is the cost of developing and deploying solutions, which affects the business case for adoption. Third are labour market dynamics, including the supply, demand, and costs of human labour as an alternative to automation. Fourth are economic benefits, which could include higher throughput and increased quality, as well as labour cost savings. Finally, regulatory and social acceptance can affect the rate of adoption even when deployment makes business sense. Taking all of these factors into account, we estimate it will take decades for automation's effect on current work activities to play out fully. While the effects of automation might be slow at a macro level within entire sectors or economies, they could be quite fast at a micro level, for an individual worker whose activities are automated, or a company whose industry is disrupted by competitors using automation.
- While much of the current debate about automation has focused on the potential for mass unemployment, predicated on a surplus of human labour, the world's economy will actually need every erg of human labour working, in addition to the robots, to overcome demographic aging trends in both developed and developing economies. In other words, a surplus of human labour is much less likely to occur than a deficit of human labour, unless automation is deployed widely. However, the nature of work will change. As processes are transformed by the automation of individual activities, people will perform activities that are complementary to the work that machines do (and vice versa). These shifts will change the organization of companies, the structure and bases of competition of industries, and business models.
- For business, the performance benefits of automation are relatively clear, but the issues are more complicated for policy makers. They should embrace the opportunity for their economies to benefit from the productivity growth potential and put in place policies to encourage investment and market incentives to encourage continued progress and innovation. At the same time, they must evolve and innovate policies that help workers and institutions adapt to the impact on employment. This will likely include rethinking education and training, income support, and safety nets, as well as transition support for those dislocated. Individuals in the workplace will need to engage more comprehensively with machines as part of their everyday activities, and acquire new skills that will be in demand in the new automation age.

The scale of shifts in the labour force over many decades that automation technologies can unleash is of a similar order of magnitude to the long-term technology-enabled shifts in the developed countries' workforces away from agriculture in the 20th century. Those shifts did not result in long-term mass unemployment because they were accompanied by the creation of new types of work not foreseen at the time. We cannot definitively say whether historical precedent will be upheld this time. But our analysis shows that humans will still be needed in the workforce: the total productivity gains we estimate will come about only if people work alongside machines.

GAUGING AUTOMATION POTENTIAL IN THE GLOBAL WORKPLACE TODAY

The Czech writer Karel Capek coined the word "robot" almost a century ago, in a 1920 play about factory androids that each do the work of two-and-a-half humans at a fraction of the cost. Science fiction has since become business fact. Robots are commonplace in manufacturing, and algorithms are playing an ever-larger role in companies from UPS to Amazon. With recent developments in robotics, artificial intelligence, and machine learning, technologies not only do things that we thought only humans could do, but also can increasingly do them at superhuman levels of performance. Some robots that are far more flexible—and a fraction of the cost—of those used in manufacturing environments today can be "trained" by frontline staff to perform tasks that were previously thought to be too difficult for machines, and are even starting to take over service activities, from cooking hamburgers to dispensing drugs in hospital pharmacies. Artificial intelligence is also making major strides: in one recent test, computers were able to read lips with 95 percent accuracy, outperforming professional human lip readers who tested at 52 percent accuracy.

We used the state of technology in respect to 18 performance capabilities to estimate the technical automation potential of more than 2,000 work activities from more than 800 occupations across the US economy, and then broadened our analysis across the global economy (see Box E1, "How we established the technical automation potential of the global economy").

Only a small percentage of occupations can be fully automated by adapting current technologies, but some work activities of almost all occupations could be automated

Unlike some other studies, the core of our analysis focuses on work activities rather than whole occupations. We consider work activities a more relevant and useful measure since occupations are made up of a range of activities with different potential for automation. For example, a retail salesperson will spend some time interacting with customers, stocking shelves, or ringing up sales. Each of these activities is distinct and requires different capabilities to perform successfully.

Overall, we estimate that 50 percent of the activities that people are paid to do in the global economy have the potential to be automated by adapting currently demonstrated technology. While less than 5 percent of occupations can be fully automated, about 60 percent have at least 30 percent of activities that can technically be automated (Exhibit E2). While certain categories of activity, such as processing or collecting data, or performing physical activities and operating machinery in a predictable environment, have a high technical potential for automation, the susceptibility is significantly lower for other activities including interfacing with stakeholders, applying expertise to decision making, planning, and creative tasks, or managing and developing people (Exhibit E3).

The degree of automation potential varies considerably among sectors and countries

A significant degree of variation among sectors of the economy, and among the occupations within those sectors, emerges from this analysis. For example, almost one-fifth of the time spent in US workplaces involves predictable physical activity and is prevalent in such sectors as manufacturing and retail trade. Accordingly, these sectors have a relatively high technical potential for automation using today's technology. Exhibit E4 shows a range of sectors in the US economy broken down into different categories of work activity.

Within sectors, too, there is considerable variation. In manufacturing, for example, occupations that have a large proportion of physical activities in predictable environments such as factory welders, cutters, and solderers have a technical automation potential above 90 percent based on adapting currently developed technologies, whereas for customer service representatives that susceptibility is less than 30 percent.

Box E1. How we established the technical automation potential of the global economy

To assess the technical automation potential of the global economy, we used a disaggregation of occupations into constituent activities that people are paid to do in the global workplace. Each of these activities requires some combination of 18 performance capabilities, which we list in Exhibit E1. They are in five groups: sensory perception, cognitive capabilities, natural language processing, social and emotional capabilities, and physical capabilities.

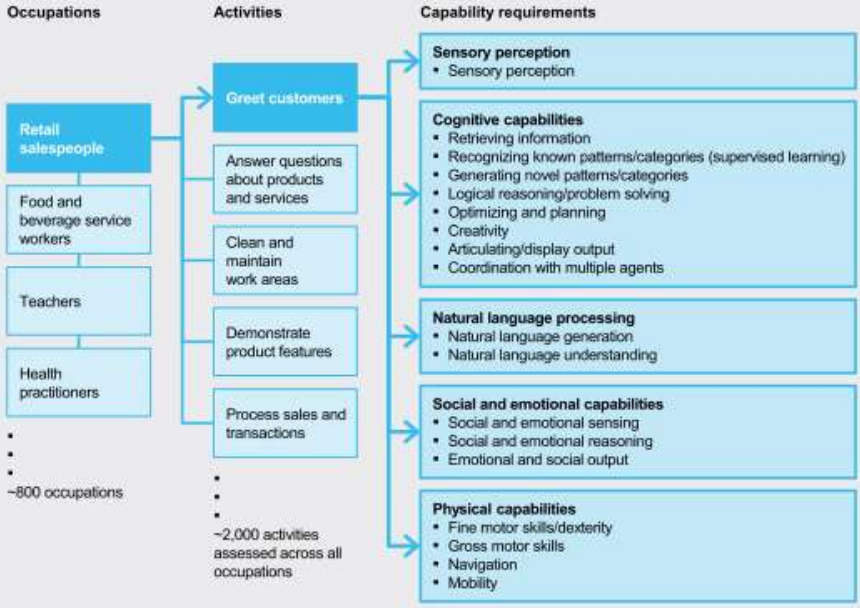
We estimated the level of performance for each of these capabilities that is required to perform each work activity successfully, based on the way humans currently perform activities—that is, whether the capability is required at all, and if so, whether the required level of performance was at roughly a median human level, below median human level, or at a high human level of performance (for example, top 25th percentile). We then assessed the performance of existing technologies today based on the same criteria.

This analysis enabled us to estimate the technical automation potential of more than 2,000 work activities in more than 800 occupations across the economy, based on data from the US Department of Labor. By estimating the amount of time spent on each of these work activities, we were able to estimate the automation potential of occupations in sectors across the economy, comparing them with hourly wage levels. Drawing on industry experts, we also developed scenarios for how rapidly the performance of automation technologies could improve in each of these capabilities.

The analysis we conducted for the United States provided us with a template for estimating the automation potential and creating adoption timing scenarios for 45 other economies representing about 80 percent of the global workforce. For details of our methodology, see the technical appendix.

Exhibit E1

To assess the technical potential of automation, we structure our analysis around 2,000 distinct work activities



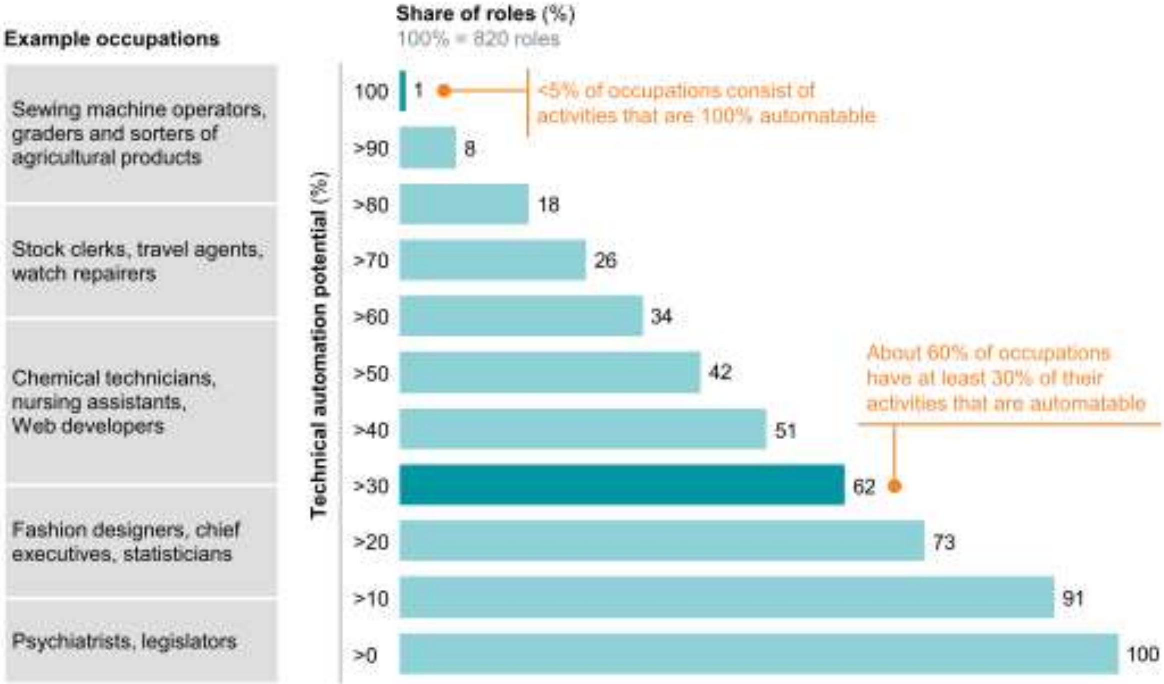
SOURCE: McKinsey Global Institute analysis

While wage and skill levels are negatively correlated with technical automation potential (on average, occupations with higher wages and skill requirements have lower automation potential, reflecting some skill bias), a large amount of variation underlies the averages. Essentially all occupations, whether high skill or low skill, have some technical automation potential, including CEOs; we estimate about 25 percent of their work could potentially be automated, primarily such tasks as analyzing reports and data to inform decisions, reviewing status reports, preparing staff assignments, and so on.

Exhibit E2

While few occupations are fully automatable, 60 percent of all occupations have at least 30 percent technically automatable activities

Automation potential based on demonstrated technology of occupation titles in the United States (cumulative)[1]



1 We define automation potential according to the work activities that can be automated by adapting currently demonstrated technology.

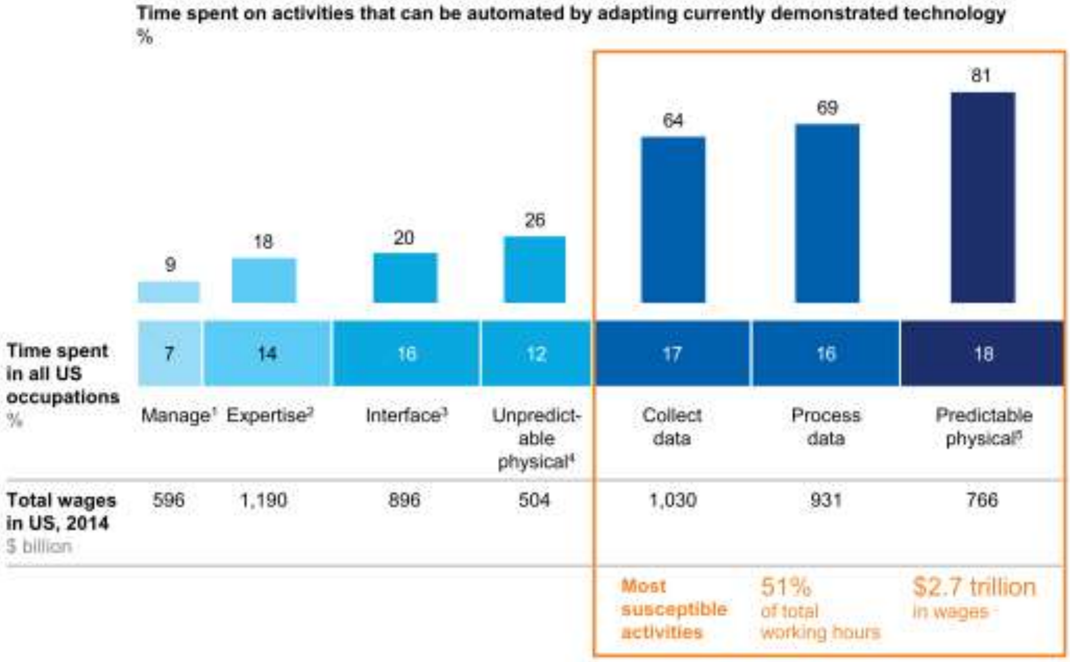
SOURCE: US Bureau of Labor Statistics; McKinsey Global Institute analysis

At a global level, technically automatable activities touch the equivalent of 1.2 billion employees and $14.6 trillion in wages (Exhibit E5). Four economies—China, India, Japan, and the United States—account for just over half of these total wages and employees; China and India together account for the largest technically automatable employment potential—more than 700 million full-time equivalents between them—because of the relative size of their labour forces. The potential is also large in Europe: according to our analysis, 62 million full-time employee equivalents and more than $1.9 trillion in wages are associated with technically automatable activities in the five largest economies—France, Germany, Italy, Spain, and the United Kingdom.

Our analysis of the technical automation potential of the global economy shows that there is a range among countries of about 15 percentage points. Two factors explain this range. The first is the sectoral makeup of each economy, that is, the proportion of a national economy that is in sectors such as manufacturing or accommodation and food services, both of which have relatively high automation potential, compared with the proportion in sectors with lower automation potential such as education. The second factor is the occupational makeup of sectors in different countries, in other words, the extent to which workers in these sectors are engaged in job titles with high automation potential, such as manufacturing production, and those in job titles with lower automation potential such as management and administration. A detailed look at all 46 countries we have examined is available online.

Exhibit E3

Three categories of work activities have significantly higher technical automation potential



1 Managing and developing people.
2 Applying expertise to decision making, planning, and creative tasks.
3 Interfacing with stakeholders.
4 Performing physical activities and operating machinery in unpredictable environments.
5 Performing physical activities and operating machinery in predictable environments.
NOTE: Numbers may not sum due to rounding.

SOURCE: US Bureau of Labor Statistics; McKinsey Global Institute analysis

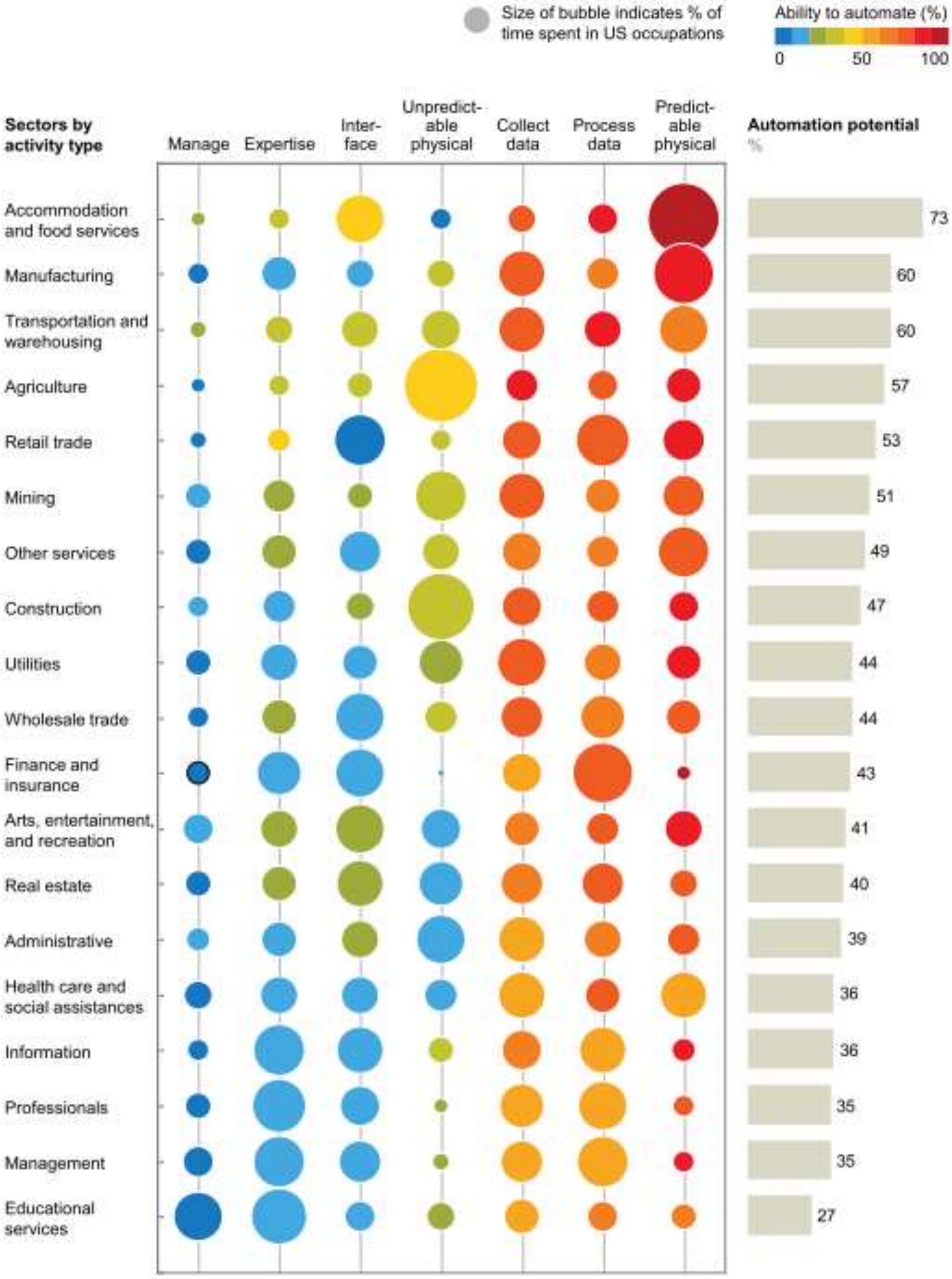
FACTORS AFFECTING PACE AND EXTENT OF AUTOMATION

While the technology is advancing, the journey from technical automation potential to full adoption is nonetheless likely to take decades. The timing is affected by five sets of factors:

- **Technical feasibility.** Technology has to be invented, integrated and adapted into solutions that automate specific activities. Deployment in the workplace can begin only when machines have reached the required level of performance in the capabilities required to carry out particular activities. While machines can already match or outperform humans on some of the 18 capabilities in our framework, including information retrieval, gross motor skills, and optimization and planning, many other capabilities require more technological development. In particular, advancements in natural language understanding could unlock significantly more technical automation potential. Emotional and social reasoning capabilities will also need to become more sophisticated for many work activities. For typical work activities, multiple capabilities, such as sensory perception and mobility, will be needed simultaneously, and thus solutions that integrate specific capabilities in context must be engineered.

Exhibit E4

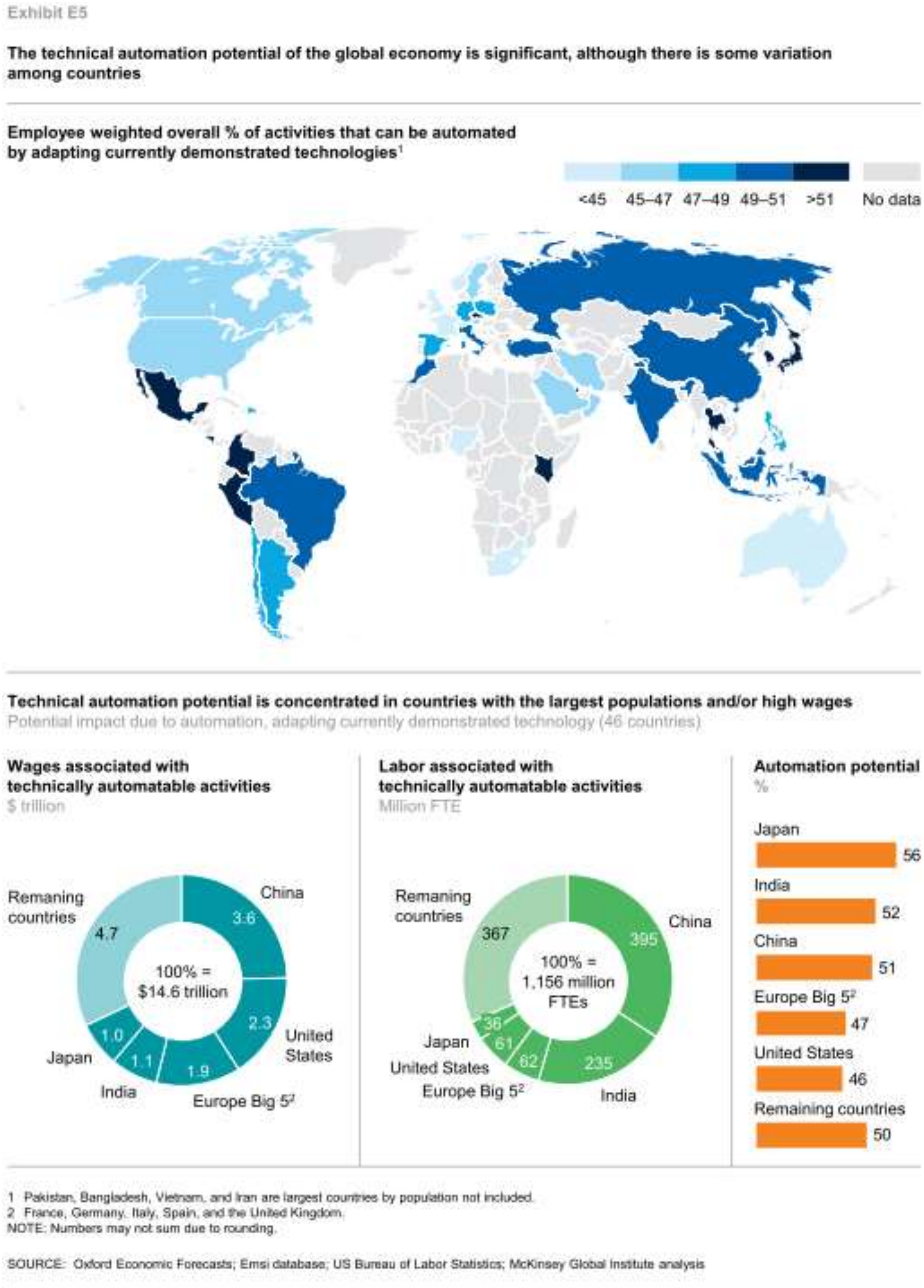
Technical potential for automation across sectors varies depending on mix of activity types



SOURCE: US Bureau of Labor Statistics; McKinsey Global Institute analysis

- **Cost of developing and deploying solutions.** The cost of automation affects the business case for adoption. Developing and engineering automation technologies takes capital. Hardware solutions range from standard computers to highly designed, application-specific hardware such as robots with arms and other moving parts requiring dexterity. Cameras and sensors are needed for any activity requiring sensory perception capabilities, while mobility requires wheels or other hardware that enable machines to move. Such attributes increase costs relative to a general-purpose hardware platform. Even "virtual" solutions that are based on software require real investments in engineering to create solutions.

For deployment, hardware requires significant capital spending, and thus automation that requires it has high initial costs compared to wages. Software solutions, by comparison, tend to have a minimal marginal cost, which usually makes them less expensive than wages and thus they tend to be adopted earlier. Over time, both hardware and software costs decline, making solutions competitive with human labour for an increasing number of activities.



- **Labour market dynamics.** The quality (for instance, skills), quantity, as well as supply, demand, and costs of human labour as an alternative affect which activities will be automated. For example, restaurant cooking has high automation potential, more than 75 percent, based on currently demonstrated technologies, but the decision to deploy the technology will need to take into account the wage costs of cooks, who earn $11 per hour on average in the United States, and the abundance of people willing to working as cooks at that wage. Labour market dynamics also differ by geography, not only in terms of how different and evolving demographics affect the base supply of labour, but also different wage rates. Manufacturing automation is more likely to be adopted sooner in countries with high manufacturing wages, such as North America and Western Europe, than in developing countries with lower wages. Furthermore, the effects of automation can interact with labour market skills and supply. For example, if middle-income workers such as clerks and factory workers are displaced by the automation of data collection and processing and predictable physical activities, they could find themselves moving into lower paid occupations, increasing supply, and potentially putting downward pressure on wages. Conversely, they might take time to retrain into other high-skill positions, delaying their re-entry into the labour force, and temporarily reducing labour supply.

- **Economic benefits.** In addition to labour cost savings, a business case for automation could include performance gains such as increased profit, increased throughput and productivity, improved safety, and higher quality, which sometimes exceed the benefits of labour substitution (see Box E2, "Automation technologies could provide significant performance benefits for companies beyond labour substitution"). For example, the benefits of increased production and lower overall maintenance costs by automating the control room of an oil and gas production facility dwarf those associated with reduced labour costs in the control room. Automated driving of cars and trucks could not only reduce the labour costs associated with drivers; it could also potentially improve safety (the vast majority of accidents are the result of driver errors) and fuel efficiency.
- **Regulatory and social acceptance.** Even when deploying automation makes business sense, the rate of adoption can be affected by contextual factors such as regulatory approval and the reaction of users. There are multiple reasons that technology adoption does not happen overnight. The shift of capital investment into these new technologies takes time (in aggregate), as does changing organizational processes and practices to adapt to new technologies. Reconfiguring supply chains and ecosystems can be labourious, and regulations sometimes need to change. Government policy can slow adoption, and different businesses adopt technologies at different rates. Changing the activities that workers do also requires dedicated effort, even if they are not actively resisting. And especially in the case of automation, individuals may feel uncomfortable about a new world where machines replace human interaction in some intimate life settings, such as a hospital, or in places where machines are expected to make life-and-death decisions, such as when driving.

Automation adoption will take decades, across a wide range of possible scenarios

To analyze a range of potential scenarios for the pace at which automation will affect activities across the global economy, we constructed a model that simplifies the effects of these five factors into four timing stages: capability development, solution development, economic feasibility, and final adoption. The S-curve in Exhibit E6 indicates the potential time range that emerges from our scenario analyses, with the dark blue line representing an "earliest adoption" scenario and the light blue line a "latest adoption" scenario, aggregating across all of the activities that account for about 80 percent of the world's workforce. For example, we estimate that adapting currently demonstrated technology has the technical potential to automate roughly 50 percent of the world's current work activities. While the date at which this could happen could be around 2055, assuming all the factors are in place for successful adoption by then, we modeled possible scenarios where that level of adoption occurs up to almost 20 years earlier or later.

Box E2. Automation technologies could provide significant performance benefits for companies beyond labor substitution

The deployment of automation technologies could bring a range of performance benefits for companies. These benefits are varied, depending on the individual use case, and potentially very substantial—in some cases, considerably larger than cost reductions associated with labor substitution. They include, but are not limited to, greater throughput, higher quality, improved safety, reduced variability, a reduction of waste, and higher customer satisfaction.

We developed several hypothetical case studies to gain a better understanding of the potential for automation in different settings and sought to quantify the economic impact of realizing this vision. The case studies are of a hospital emergency department, aircraft maintenance, oil and gas operations, a grocery store, and mortgage brokering. The results—while forward-looking—are nonetheless striking. The value of the potential benefits of automation, calculated as a percentage of operating costs, ranges from between 10-15 percent for a hospital emergency department and a grocery store, to 25 percent for aircraft maintenance, and more than 90 percent for mortgage origination.

We also see automation being deployed today that is already generating real value. For example, Rio Tinto has deployed automated haul trucks and drilling machines at its mines in Pilbara, Australia, and says it is seeing 10–20 percent increases in utilization there as a result.[1] Google has applied artificial intelligence from its DeepMind machine learning to its own data centers, cutting the amount of energy they use by 40 percent.[2] In financial services, automation in the form of "straight-through processing," where transaction workflows are digitized end-to-end, can increase the scalability of transaction throughput by 80 percent, while concurrently reducing errors by half.[3] Safety is another area that could benefit from increased automation. For example, of the approximately 35,000 road death in the United States annually, about 94 percent are the result of human error or choice.[4]

The relative cost of automation can be modest compared with the value it can create. The types and sizes of investment needed to automate will differ by industry and sector. For example, industries with high capital intensity that require substantial hardware solutions to automate and are subject to heavy safety regulation will likely see longer lags between the time of investment and the benefits than sectors where automation will be mostly software-based and less capital-intensive. For the former, this will mean a longer journey to breakeven on automation investment. However, our analysis suggests that the business case can be compelling regardless of the degree of capital intensity.

1 *Productivity improvements in a changing world*, presentation by Michael Gollschewski, managing director Pilbara Mines, Rio Tinto, July 13, 2015.
2 Rich Evans and Jim Gao, *DeepMind AI reduces energy used for cooling Google data centers by 40%*, Google, blog post, July 20, 2016.
3 João Bueno, Yran Bartolumeu Dias, Alexandre Sawaya, Jorge Valadas. "End-to-end digitization for securities services," *McKinsey on Payments*, September 2014.
4 "Barack Obama: Self-driving, yes, but also safe," *Pittsburgh Post-Gazette*, September 19, 2016.

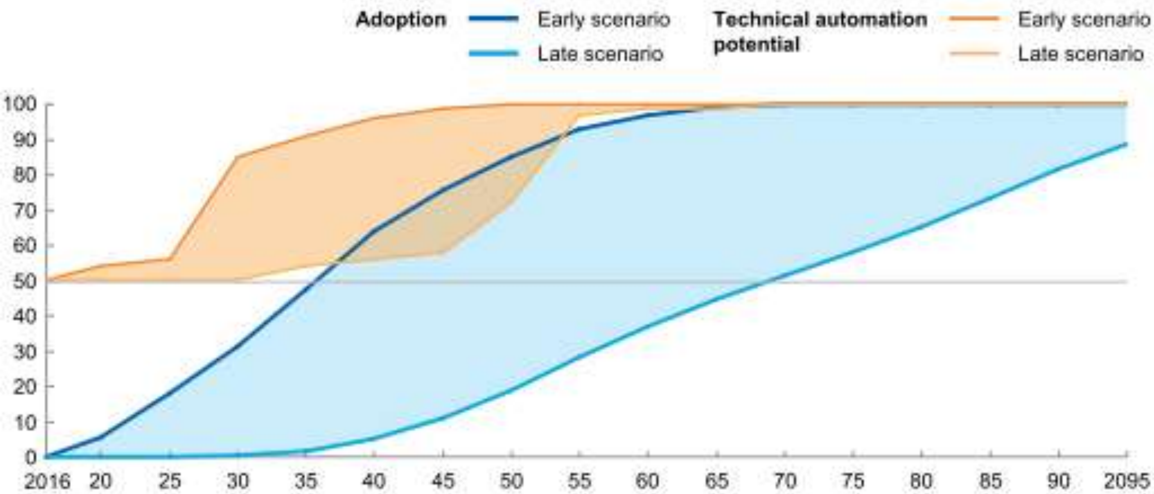
Among the first sectors likely to feel the impact of automation will be those that involve types of activities we categorize as having the highest automation potential today based on currently demonstrated technology. From a geographical perspective, advanced economies are also likely to deploy automation ahead of many emerging economies, largely because of higher wage levels, which make a stronger business case for deployment.

This magnitude of shifts in work activities over multiple decades is not unprecedented. In the United States, for example, the share of farm employment fell from 40 percent in 1900 to 2 percent in 2000, while the share of manufacturing employment fell from approximately 25 percent in 1950 to less than 10 percent in 2010 (Exhibit E7). In both cases, new activities and jobs were created that offset those that disappeared, although it was not possible to predict what those new activities and jobs would be while these shifts were occurring.

Exhibit E6

Automation will be a global force, but adoption will take decades and there is significant uncertainty on timing

Time spent on current work activities[1]
%



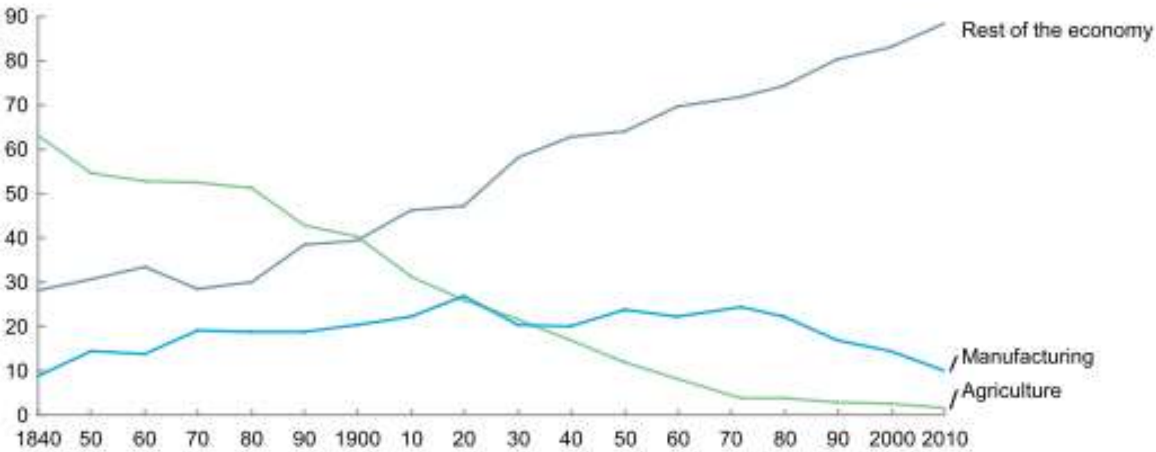
1 Forty-six countries used in this calculation, representing about 80% of global labor force.

SOURCE: McKinsey Global Institute analysis

Exhibit E7

Employment in agriculture has fallen from 40 percent in 1900 to less than 2 percent today

Distribution of labor share by sector in the United States, 1840–2010
%



SOURCE: Stanley Lebergott, "Labor force and employment 1800–1960," in *Output, employment, and productivity in the United States after 1800*, Dorothy S. Brady, ed., NBER, 1966; World Data Bank, World Bank Group; FRED: Economic Research, Federal Reserve Bank of St. Louis; Mack Ott, "The growing share of services in the US economy—degeneration or evolution?" *Federal Reserve Bank of St. Louis Review*, June/July 1987; McKinsey Global Institute analysis

Modelling scenarios for the pace and extent of automation adoption

Capability development is the first stage that we modelled for the timing of automation adoption. Deployment in the workplace can begin only when machines have reached the required level of performance in the capabilities required to carry out particular activities.

Once the technical capabilities have been developed, they must be integrated into solutions that can execute specific activities in context, that is, to create commercially available systems. Our analysis suggests that, on average, this solution development process can take between one and nine years.

The third stage we modelled for scenario timelines is when automation is economically feasible. For modelling purposes, we assume that adoption begins when the developed solution for any given activity is at or below the cost for human workers to perform that activity in a specific occupation and within a particular country. While the performance benefits of automation sometimes exceed those related to labour cost savings, our conservative modelling assumes that decision-makers discount the benefits of initial labour cost savings by roughly the same amount as they believe the also uncertain non-labour cost-related benefits will be captured.

Adoption and deployment of automation, the fourth stage we modelled to develop scenarios, can also be a slow process. For our analysis, we looked at the historical adoption rates a wide range of 25 technologies, involving both hardware and software, as well as business and consumer technologies. The time between the commercial availability of these technologies and their eventual maximum level of adoption generally took at least nearly a decade and in some cases multiple decades, with the time range between eight and 28 years.

EVEN AS IT CAUSES SHIFTS IN EMPLOYMENT, AUTOMATION CAN GIVE A STRONG BOOST TO PRODUCTIVITY AND GLOBAL GDP GROWTH

Automation will cause significant labour displacement and could exacerbate a growing skills and employment gap that already exists between high-skill and low-skill workers. Our analysis of automation potential also suggests that many occupations could be partially automated before they are fully automated, which could have different implications for high- and low-skill workers. Especially for low-skill workers, this process could depress wages unless demand grows. Viewed through a long-term perspective, however, as we described previously, large-scale historical structural shifts in the workplace where technology has caused job losses have, over time, been accompanied by the creation of a multitude of new jobs, activities, and types of work. Furthermore, labour markets can be quite dynamic: almost five million people leave their jobs every month in the United States, of whom about three million do so voluntarily. Most of these people are not unemployed for long periods as they move on to other jobs.

That said, automation also represents a very substantial opportunity to support global economic growth. Our estimates suggest it has the potential to contribute meaningfully to the growth necessary to meet the per capita GDP aspirations of every country, at a time when changing demographics call those aspirations into question. Indeed, for this growth to take place, rather than having a massive labour surplus, everyone needs to keep working—with the robots working alongside them.

Automation can help close a GDP growth gap resulting from declining growth rates of working-age populations

GDP growth was brisk over the past half century, driven by the twin engines of employment growth and rising productivity, both contributing approximately the same amount. However, declining birthrates and the trend toward aging in many advanced and some emerging economies mean that peak employment will occur in most countries within 50 years. The expected decline in the share of the working-age population will open an economic growth gap: roughly half of the sources of economic growth from the past half century (employment growth) will evaporate as populations age. Even at historical rates of productivity growth, economic growth could be nearly halved.

Automation could compensate for at least some of these demographic trends. We estimate the productivity injection it could give to the global economy as being between 0.8 and 1.4 percent of global GDP annually, assuming that human labour replaced by automation would rejoin the workforce and be as productive as it was in 2014. Considering the labour substitution effect alone, we calculate that, by 2065, automation could potentially add productivity growth in the largest economies in the world (G19 plus Nigeria) that is the equivalent of an additional 1.1 billion to 2.3 billion full-time workers (Exhibit E8).

The productivity growth enabled by automation can ensure continued prosperity in aging nations and provide an additional boost to fast-growing ones. Automation on its own will not be sufficient to achieve long-term economic growth aspirations across the world; for that, additional productivity-boosting measures will be needed, including reworking business processes or developing new products and services.

Potential impact of automation in three groups of countries

Automation could boost productivity and help close the economic growth gap in the 20 largest economies in the medium term, to 2030. We have divided these countries into three groups, each of which could use automation to further national economic growth objectives, depending on their demographic trends and growth aspirations. The three groups are:

- Advanced economies, including Australia, Canada, France, Germany, Italy, Japan, South Korea, the United Kingdom, and the United States. These economies typically face an aging workforce, with the decline in working-age population growth more immediate in some (Germany, Italy, and Japan) than in others. Automation can provide the productivity boost required to meet economic growth projections that they otherwise would struggle to attain without other significant productivity growth accelerators. These economies thus have a major interest in pursuing rapid automation adoption.
- Emerging economies with aging populations. This category includes Argentina, Brazil, China, and Russia, which face economic growth gaps as a result of projected declines in the growth of their working population. For these economies, automation can provide the productivity injection needed just to maintain current GDP per capita. To achieve a faster growth trajectory that is more commensurate with their developmental aspirations, these countries would need to supplement automation with additional sources of productivity, such as process transformations, and would benefit from more rapid adoption of automation.
- Emerging economies with younger populations. These include India, Indonesia, Mexico, Nigeria, Saudi Arabia, South Africa, and Turkey. The continued growth of the working-age population in these countries could support maintaining current GDP per capita. However, given their high growth aspirations, automation plus additional productivity-raising measures will be necessary to sustain their economic development.

The advances in automation and their potential impact on national economies could upend some prevailing models of development and challenge ideas about globalization.

Countries experiencing population declines or stagnation will be able to maintain living standards even as the labour force wanes. Meanwhile, countries with high birthrates and a significant growth in the working-age population may have to worry more about generating new jobs in a new age of automation. Moreover, low-cost labour may lose some of its edge as an essential developmental tool for emerging economies, as automation drives down the cost of manufacturing globally.

Exhibit E8

Globally, automation could become a significant economic growth engine as employment growth wanes

GDP growth for G19 and Nigeria
Compound annual growth rate
%

	Historical	Required to maintain current GDP per capita	Required to achieve projected GDP per capita	Early scenario / Late scenario
GDP per capita growth Compound annual growth rate %	2.1	0	2.5	0.5–1.1
Full-time equivalent gap[1] Billion		0.1	6.7	

1 Additional full-time equivalents (FTEs) needed to achieve growth target.
NOTE: Numbers may not sum due to rounding.

SOURCE: The Conference Board Total Economy database; United Nations Population Division; McKinsey Global Institute analysis

HOW BUSINESS LEADERS, POLICY MAKERS, AND WORKERS CAN PREPARE FOR THE NEW AUTOMATION AGE

Business leaders, policy makers, and workers everywhere face considerable challenges in capturing the full potential of automation's beneficial effect on the economy, even as they navigate the major uncertainties about the social and employment repercussions.

Automation will give business leaders opportunities to improve their performance and enter new markets, but they will need to rework their processes and organizations

Automation of various activities can improve the performance of almost any business process. Beyond enabling reduction in labour costs, automation can raise throughput, increase reliability, and improve quality, among other performance gains.

To assess where automation could be most profitably applied to improve performance, business leaders may want to conduct a thorough inventory of their organization's activities and create a heat map of where automation potential is high. Once they have identified business processes with activities that have high automation potential, these could be reimagined to take full advantage of automation technologies (rather than just mechanically attempting to automate individual activities in the current processes). They could then assess the benefits and feasibility of these automation-enabled process transformations.

Taking advantage of these transformations could lead to significant displacements in labour. Business leaders would be well served to consider how to best redeploy that labour, whether within their own organizations or elsewhere, both to improve their own performance and to act as good corporate citizens. Retraining and skill-raising programs will be important to support workers shifting to new roles and taking on new activities. It will also be critical for corporate leaders to ensure that the organizational elements of their companies are adapting to the advent of automation.

On a strategic level, automation could enable the emergence of massively scaled organizations, instantly able to propagate changes that come from headquarters. Technology will make measuring and monitoring easier, providing effective new tools for managers. However, greater scale means that errors could be more consequential, which in turn will require stronger quality controls.

Even as some corporations could be scaling up, automation and digital technologies more generally will enable small players, including individuals and small companies, to undertake project work that is now largely carried out within bigger firms. The growth of very small and very large companies could create a barbell-shaped economy, in which mid-sized companies lose out. In all sectors, automation could heighten competition, enabling firms to enter new areas outside their previous core businesses, and creating a growing divide between technological leaders and laggards in every sector.

For policy makers, an embrace of automation could be accompanied by measures to raise skills and promote job creation, and by rethinking incomes and social safety nets

Policy makers globally will have a strong incentive to encourage and enable rapid adoption of automation technologies in order to capture the full productivity boost necessary to support economic growth targets. At the same time, they will need to think through how to support the redeployment of potentially large numbers of displaced workers, since the full economic benefits of automation depend on workers continuing to work.

Early adoption of automation could benefit from policy support, both in regard to the technology development, and for its deployment. That will require investment in developing the technologies themselves, and also in digitally enabled infrastructure to support automation.

Labour redeployment will be one of the most important societal challenges. Governments are often not particularly adept at anticipating the types of jobs that could be created, or new industries that will develop. However, they could initiate and foster dialogues about what work needs doing, and about the grand societal challenges that require more attention and effort. Governments could also seek to encourage new forms of technology-enabled entrepreneurship, and intervene to help workers develop skills best suited for the automation age. For example, many economies are already facing a shortage of data scientists and business translators. Governments working with the private sector could take steps to ensure that such gaps are filled, establishing new education and training possibilities.

One of the challenges of the new era will be to ensure that wages are high enough for the new types of employment that will be created, to prevent continuing erosion of the wage share of GDP, which has dropped sharply since the 1970s. If automation does result in greater pressure on many workers' wages, some ideas such as earned income tax credits, universal basic income, conditional transfers, shorter workweeks, and adapted social safety nets could be considered and tested. As work evolves at higher rates of change among sectors, locations, activities, and skill requirements, many workers may need assistance in adjusting to the new age.

Workers will need to work more closely with technology, freeing up more time to focus on intrinsically human capabilities that machines cannot yet match

Men and women in the workplace will need to engage more comprehensively with machines as part of their everyday activities. Tighter integration with technology will free up time for human workers including managers to focus more fully on activities to which they bring skills that machines have yet to master. This could make work more complex, and harder to organize, with managers spending more time on coaching.

As people make education and career choices, it will be important for them to be made aware of the factors driving automation in particular sectors, to help them identify the skills that could be useful for them to acquire from a labour-market perspective, and what activities will be complements of activities that are likely to be automated.

High-skill workers who work closely with technology will likely be in strong demand, and may be able to take advantage of new opportunities for independent work as the corporate landscape shifts and project work is outsourced by companies. Middle-skill workers whose activities have the highest technical potential for automation (predictable physical activities, collecting and analyzing data) can seek opportunities for retraining to prepare for shifts in their activities toward those that are complements of activities the machines will start to perform.

Low-skill workers working with technology will be able to achieve more in terms of output and productivity but may experience wage pressure given the potentially large supply of similarly low-skill workers.

Education systems will need to evolve for a changed workplace, with policy makers working with education providers to improve basic skills in the STEM fields of science, technology, engineering, and mathematics, and put a new emphasis on creativity, as well as on critical and systems thinking. For all, developing agility, resilience, and flexibility will be important at a time when everybody's job is likely to change to some degree.

Finally, automation will create an opportunity for those in work to make use of the innate human skills that machines have the hardest time replicating: logical thinking and problem solving, social and emotional capabilities, providing expertise, coaching and developing others, and creativity. For now, the world of work still expects men and women to undertake rote tasks that do not stretch these innate capabilities as far as they could. As machines take on ever more of the predictable activities of the workday, these skills will be at a premium. Automation could make us all more human.

•••

Automation will play an essential role in providing at least some of the productivity boost that the global economy needs over the next half century as growth in working-age populations declines. It will contribute meaningfully to GDP per capita growth, even if it will not on its own enable emerging economies to meet their fast-growth aspirations. Given the range of scenarios around the pace and extent of adoption of automation technologies, there are sure to be surprises. We will see large-scale shifts in workplace activities over the next century. These trends are already under way. Policy makers, business leaders, and workers themselves must not wait to take action: already today, there are measures that can be taken to prepare, so that the global economy can capture the opportunities offered by automation, even as it avoids the drawbacks.

8.3 The Fourth Industrial Revolution: Managing Disruption

[Extracts from [37], pp 14, 35-39, 43-51]

Evidence suggests that technological change provides a better explanation than globalization for the industrial decline and deteriorating labour-market prospects that have catalyzed anti-establishment voting in many of the world's advanced economies. Today's world is one in which production, mobility, communication, energy and other systems are changing with unprecedented speed and scope, disrupting everything from employment patterns to social relationships and geopolitical stability (Fig 1). Driven by the convergence between digital, biological and physical technologies, the Fourth Industrial Revolution (4IR) is creating new global risks and exacerbating existing risks.

According to the economists Michael Hicks and Srikant Devaraj, 86% of manufacturing job losses in the United States between 1997 and 2007 were the result of rising productivity, compared to less than 14% lost because of trade. Most assessments suggest that technology's disruptive effect on labour markets will accelerate across non-manufacturing sectors in the years ahead, as rapid advances in robotics, sensors and machine learning enable capital to replace labour in an expanding range of service-sector jobs. In 2015 a McKinsey study concluded that 45% of the activities that workers do today could already be automated if companies choose to do so. Respondents to this year's GRPS rate artificial intelligence and robotics as the emerging technology with the greatest potential for negative consequences over the coming decade.

Technology has always created jobs as well as destroying them, but there is evidence that the engine of technological job creation is sputtering. The Oxford Martin School estimates that only 0.5% of today's US workforce is employed in sectors created since 2000, compared with approximately 8% in industries created during the 1980s. Technological change is shifting the distribution of income from labour to capital: according to the OECD, up to 80% of the decline in labour's share of national income between 1990 and 2007 was the result of the impact of technology. At a global level, however, many people are being left behind altogether: more than 4 billion people still lack access to the internet, and more than 1.2 billion people are without even electricity.

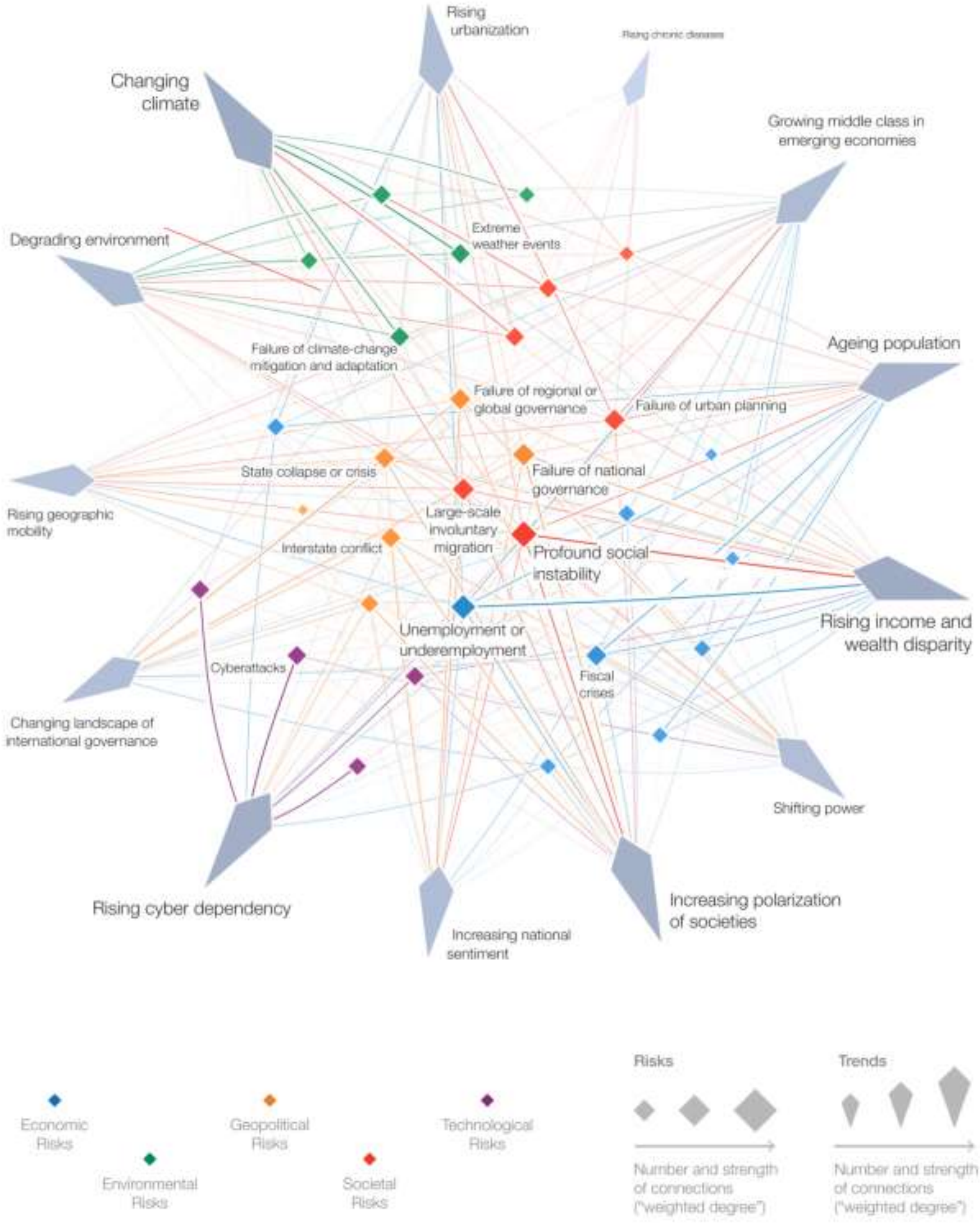
We are in a highly disruptive phase of technological development, at a time of rising challenges to social cohesion and policy-makers' legitimacy. Given the power of the 4IR to create and exacerbate global risks, the associated governance challenges are both huge and pressing, as discussed below. It is critical that policy-makers and other stakeholders – across government, civil society, academia and the media – collaborate to create more agile and adaptive forms of local, national and global governance and risk management.

The Future of Work and Other Challenges Impacting Social Protection

The Fourth Industrial Revolution is fundamentally changing the ways that people work and live in three main ways. First, it is untethering some types of work from a physical location, making it easier to remotely connect workers in one region or country to jobs in another – but also making it less clear which set of employment laws and taxes apply, creating greater global competition for workers, potentially weakening employment protections and draining public social protection coffers.

Second, human labour is being displaced by automation, robotics and artificial intelligence. Opinions differ on the extent of what is possible: Frey and Osborne's (2013) study found that 47% of US employment is at high risk of being automated over the next two decades. In general, lower-skilled workers are more likely to see their jobs disappear to automation, increasing their vulnerability and exacerbating societal inequality.

Figure 1: The Risks-Trends Interconnections Map



Source: World Economic Forum Global Risks Perception Survey 2016
Note: Survey respondents were asked to select the three trends that are the most important in shaping global development in the next 10 years. For each of the three trends identified, respondents were asked to select the risks that are most strongly driven by those trends. The global risks with the most connections to trends are spelled out in the figure. See Appendix B for more details. To ensure legibility, the names of the global risks are abbreviated; see Appendix A for the full name and description

Finally, the nature of the contract between employer and employee is changing, at the same time that the move to a sharing and collaborative economy increases the prevalence of jobs that fall outside the standard employment contract model. The shift has some positive implications for workers, as it potentially offers more control over when and whether to work and opportunities to supplement their incomes – renting out a room through Airbnb, for example, or driving part-time for a service such as Uber.

But this shift also has negative implications: it means workers can expect more volatility in their earnings and leaves them without the employment protections enjoyed by "standard" employees. The rise of zero-hour contracts is one manifestation of this change. Some governments, such as the government of New Zealand, have already banned their use. New employment models also hinder the collection of taxes from both employer and worker, reducing the amount governments have available to fund social protections (see Box 2.3.1).

These three transformations are coinciding with four seismic challenges.

- First, demographic pressures are further straining formal and informal safety nets. The OECD expects old-age dependency ratios in member countries to double by 2075 as populations age and birth rates fall.
- Second, persistently low interest rates are eating into pension value and exacerbating the funding gap. Without supplements, increased life expectancy could see future generations' pensions reduced by almost half.
- Third, mass migration of labour poses challenges for social protection. Migration is generally seen as a net economic positive. However, large and sudden inflows of people can put additional and unpredictable strain on social systems and resources.
- Finally, increasing levels of wealth and income inequality in many countries across the developed and developing world are putting even greater pressure on fragile or inadequate social protections, particularly for vulnerable lower-income groups.

Inability to address these challenges adequately through social security systems could have explosive impacts on social stability (Box 2.3.2).

New Social Protection Systems: A Whole-of-Life Approach

New systems will need to address gaps in social protection across typical life events including periods of education, raising families, work including career gaps, retirement, and later elder care. Systems will need to provide sufficient flexibility to support individuals following substantially different life and career paths while maintaining some inter-group equity, and bolster individual *resilience*.

A sustainable social protection system needs to address the changes and challenges described above, ensuring fair payments from employees and employers during times of earning to fund payments that ensure appropriate income support when earnings are not possible. New social protection systems could include a range of approaches.

Implementing alternative models of income distribution: There are an increasing number of proposals for fundamentally new models of income distribution, which do not tie welfare benefits to being out of work. These include a ***negative income tax***, in which people earning below a certain threshold receive supplemental pay from the government; ***wage supplements***, in which the government makes up the difference between what a person earns and a recognized minimum income; and a ***universal basic income*** paid to all members of society regardless of their means. Such income distribution systems would make it much easier for people to take on part-time work or intermittent work as desired.

Box 2.3.2: Advanced versus Emerging Economies: Differing Challenges and Opportunities

Advanced and emerging economies face different challenges and opportunities for developing social protections that support economic growth and social stability in the context of the Fourth Industrial Revolution.

Advanced economies have had the resources to create layered social safety nets, with costs shared across individuals, employers and government, resulting in many more people than in the developing world enjoying some level of protection today. For example, the US Social Security programme, funded by employers and workers, was providing benefits to 60 million people at the end of 2015, while Medicare and Medicaid covered healthcare for 55 million. But such programmes were not designed for the extreme demographic shifts, chronic healthcare challenges, and the effects of the Fourth Industrial Revolution that are reshaping societies. Advanced economies face the challenge of reforming them without incurring a crippling debt burden.

Many emerging market economies arguably have an opportunity to avoid these pitfalls, potentially leapfrogging their wealthier neighbours by formulating sustainable social protection systems that are responsive to the risks of the Fourth Industrial Revolution. Brazil, for example, has implemented the largest cash transfer programme in the world, the Bolsa Familia, which today reaches 55 million of its poorest citizens, costs 30% less per person than more traditional aid programmes, and has helped lift 36 million people out of extreme poverty.[1]

Nonetheless, the varying demographic profiles of growth economies pose different challenges. Asia Pacific is the world's fastest ageing region, with a 71% increase in the number of people aged 65 years and above projected by 2030. Singapore's elderly population will rise from 11% to 20% in the next 15 years; in France, the same shift took 49 years. A rapidly contracting workforce and reallocation of resources towards elderly healthcare weakens these economies' fiscal position and erodes the adequacy and sustainability of pension and social security systems.[2]

Conversely, India has significant potential to reap a demographic dividend, but its limited capacity to create employment poses a serious challenge: between 1991 and 2013 the size of the working-age population increased by 300 million, yet the number of employed only increased by 140 million.[3] By 2017, a staggering 93% of Indians will hold jobs without social security benefits.[4] Solutions are being sought, as the government launches three mega social security schemes – accident coverage, life insurance and pensions.

Sub-Saharan Africa is growing faster than any other region, with an average birth rate of five to seven children per mother and little effective birth control.[5] This scale of growth undermines efforts to reduce poverty or to create jobs, and youth unemployment is high – 50% in South Africa. The ability of nations in Sub-Saharan Africa to create sustainable safety nets will require both political will and economic activity sufficient to create the necessary resources.

Notes
[1] Tepperman 2016.
[2] Marsh & McLennan Companies' APRC 2016.
[3] UNDP 2016.
[4] Waghmare 2016.
[5] UNICEF 2014.

Voters in Switzerland recently rejected a proposal for a universal basic income, but the idea is attracting growing interest around the world. The government of Finland is considering a pilot programme that would guarantee citizens a partial basic income whether or not they work. Other recent experiments include a pilot programme funded by UNICEF in eight villages in Madhya Pradesh, India, in which every man, woman and child was provided a monthly payment without conditions for 18 months. Improvements in the pilot villages, compared with "control" villages, were seen in the areas of sanitation, access to drinking water, food sufficiency, number of hours worked, children's nutrition, and enrolment levels in secondary schools, particularly for girls.

As the Fourth Industrial Revolution accelerates, many individuals – including lower-skilled workers more easily displaced by automation, part-time and self-employed workers without access to employer-sponsored protections, and older workers and retirees without sufficient savings or pensions – face a potential crisis. There is an urgent need to develop a comprehensive and interconnected set of options that adapt social protection to new-style employment patterns, reskill workers, and respond to the opportunities and threats posed by increasing longevity.

Understanding the Technology Risks Landscape

The emerging technologies of the Fourth Industrial Revolution (4IR) will inevitably transform the world in many ways – some that are desirable and others that are not. The extent to which the benefits are maximized and the risks mitigated will depend on the quality of governance – the rules, norms, standards, incentives, institutions, and other mechanisms that shape the development and deployment of each particular technology.

Too often the debate about emerging technologies takes place at the extremes of possible responses: among those who focus intently on the potential gains and others who dwell on the potential dangers. The real challenge lies in navigating between these two poles: building understanding and awareness of the trade-offs and tensions we face, and making informed decisions about how to proceed. This task is becoming more pressing as technological change deepens and accelerates, and as we become more aware of the lagged societal, political and even geopolitical impact of earlier waves of innovation.

Over the years The Global Risks Report has repeatedly highlighted technological risks. In the second edition of the Report, as far back as 2006, echoes of current concerns were noted in one of the technology scenarios we considered, in which the "elimination of privacy reduces social cohesion". This was classified as a worst-case scenario, with a likelihood of below 1%. In 2013, the Report discussed the risk of "the rapid spread of misinformation", observing that trust was being eroded and that incentives were insufficiently aligned to ensure the maintenance of robust systems of quality control or fact-checking. Four years later, this is a growing concern.

In 2015, emerging technology was one of the Report's "risks in focus", highlighting, among other things, the ethical dilemmas that exist in areas such as artificial intelligence (AI).

Governance Dilemmas

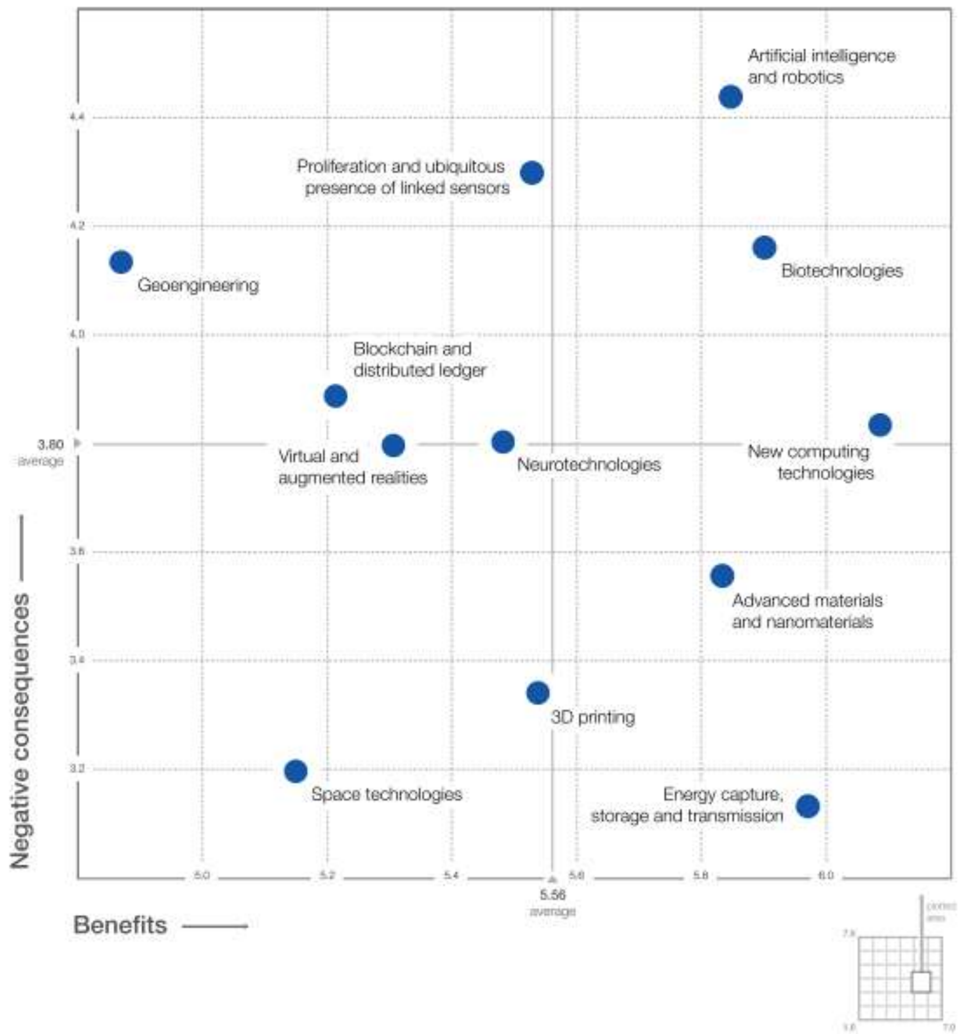
How to govern emerging technologies is a complex question. Imposing overly strict restrictions on the development of a technology can delay or prevent potential benefits. But so can continued regulatory uncertainty: investors will be reluctant to back the development of technologies that they fear may later be banned or shunned if the absence of effective governance leads to irresponsible use and a loss of public confidence. Ideally, governance regimes should be stable, predictable and transparent enough to build confidence among investors, companies and scientists, and should generate a sufficient level of trust and awareness among the general public to enable users to evaluate the significance of early reports of negative consequences. For example, autonomous vehicles will inevitably cause some accidents; whether this leads to calls for bans will depend on whether people trust the mechanisms that have been set up to govern their development.

But governance regimes also need to be agile and adaptive enough to remain relevant in the face of rapid changes in technologies and how they are used. Unexpected new capabilities can rapidly emerge where technologies intersect, or where one technology provides a platform to advance technologies in other areas.

To the extent that potential trade-offs of a new technology can be anticipated, there is scope for debate about how to approach them. There may be arguments for allowing a technology to advance even if it is expected to create some negative consequences at first, if there is also a reasonable expectation that other innovations will create new ways to mitigate those consequences.

The growing popular awareness of the dilemmas associated with governing new technologies is revealed by media analysis: relevant mentions of such quandaries in major news sources doubled between 2013 and 2016. But which technologies should we be focusing on? In the latest GRPS, we asked respondents to assess 12 technologies on their potential benefits and adverse consequences, public understanding and need for better governance.

Figure 3.1.1: Perceived Benefits and Negative Consequences of 12 Emerging Technologies



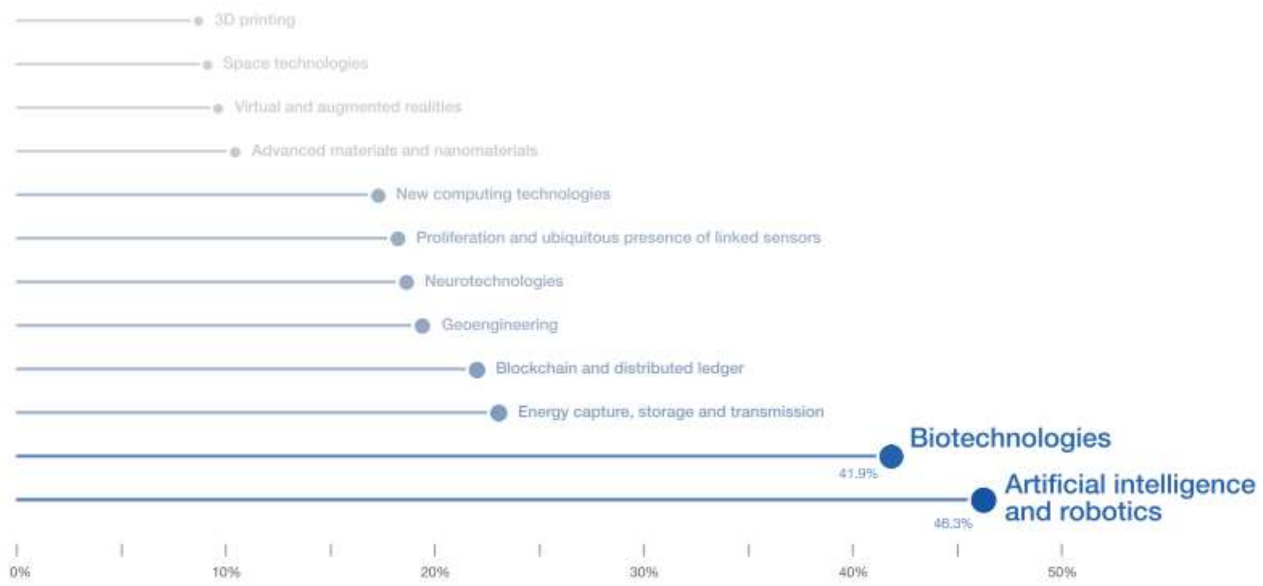
Source: World Economic Forum Global Risks Perception Survey 2016.

Figure 3.1.1 plots respondents' perceptions of the potential benefits and negative consequences of the 12 technologies included in the GRPS. The average score for benefits is much higher than it is for adverse consequences, suggesting that respondents are optimistic about the net impact of emerging technologies as a whole. Technologies considered to have above-average risks and below-average benefits, in the upper left quadrant of the figure, tended to be those where respondents felt least confident of their own assessments and also least confident of the public's understanding.

Technologies that Need Better Governance

Three technologies occupy the upper-right quadrant of Figure 3.1.1, indicating an above-average score for both potential benefits and risks: artificial intelligence (AI) and robotics, biotechnologies, and new computing technologies. Analysis of media coverage resonates with respondents' high ranking for the risk associated with AI: from 2013 to 2016 there was a steady rise in reporting on whether we should fear AI technologies. Respondents also cited artificial intelligence (AI) and robotics most frequently when asked how the 12 emerging technologies exacerbate the five categories of global risk covered by The Global Risks Report. This was seen as the most important driver of risks in the economic, geopolitical and technological categories.

Figure 3.1.3: Emerging Technologies Perceived as Needing Better Governance



Source: World Economic Forum Global Risks Perception Survey 2016.

Note: Respondents were asked to select the three emerging technologies that they believe most need better governance. The figure presents the percentage of respondents who selected each technology.

In Figure 3.1.3, two technologies stand out as requiring better governance: both artificial intelligence (AI) and robotics and biotechnologies were cited by more than 40% of respondents. These two technologies differ greatly in terms of the current state of their governance. Biotechnologies, which involve the modification of living organisms for medicinal, agricultural or industrial uses, tend to be highly regulated.

AI and robotics, meanwhile, are only lightly governed in most parts of the world. As "general purpose technologies", in the words of economic historian Gavin Wright, they have applications in many fields that already have their own governance regimes. For example, where machine learning is used in areas such as online translation, internet search and speech recognition, it comes under governance related to the use of data. Industrial robots are governed by International Organization for Standardization (ISO) standards, while domestic robots are primarily governed by existing product certification regulations. There is increasing debate about the governance of AI given the risks involved, which are further discussed below.

The Disruptive Impact of Emerging Technologies

The potential of emerging technologies to disrupt established business models is large and growing. It is tempting to think of technological disruption as involving dramatic moments of transformation, but in many areas disruption due to emerging technologies is already quietly under way, the result of gradual evolution rather than radical change. Consider autonomous vehicles: we are not yet in a world of vehicles that require little or no human intervention, but the technologies that underpin autonomy are increasingly present in our "ordinary" cars.

As the technological changes entailed by the 4IR deepen, so will the strain on many business models. The automotive sector remains a good example. It has been clear for some time that car manufacturers need to plan ahead for a world in which many of the factors that determine current levels of car ownership may no longer be present. Increasing evidence of this planning is now starting to shape commercial decision-making. For example, in December 2016, Volkswagen launched a new “mobility services” venture, MOIA, in recognition of “an ever-stronger trend away from owning a vehicle towards shared mobility as well as mobility on demand”.

The deep interconnectedness of global risks means that technological transitions can exert a multiplier effect on the risk landscape. This does not apply only to newly emerging technologies: arguably much of the recent social and political volatility reflects, in part at least, the lagged impact of earlier periods of technological change. One obvious channel through which technological change can lead to wider disruption is the labour market, with incomes pushed down and unemployment pushed up in affected sectors and geographical regions. This in turn can lead to disruptive social instability, in line with the GRPS finding this year that *the most important interconnection of global risks is the pairing of unemployment and social instability*.

One of the challenges of responding to accelerating technological change in the 4IR will be ensuring that the evolution of our critical social infrastructure keeps pace.

Assessing the Risk of Artificial Intelligence

Every step forward in artificial intelligence (AI) challenges assumptions about what machines can do. Myriad opportunities for economic benefit have created a stable flow of investment into AI research and development, but with the opportunities come risks to decision-making, security and governance. Increasingly intelligent systems supplanting both blue- and white-collar employees are exposing the fault lines in our economic and social systems and requiring policy-makers to look for measures that will build resilience to the impact of automation.

Leading entrepreneurs and scientists are also concerned about how to engineer intelligent systems as these systems begin implicitly taking on social obligations and responsibilities, and several of them penned an Open Letter on Research Priorities for Robust and Beneficial Artificial Intelligence in late 2015. Whether or not we are comfortable with AI may already be moot: more pertinent questions might be whether we can and ought to build trust in systems that can make decisions beyond human oversight that may have irreversible consequences.

Growing Investment, Benefits and Potential Risk

By providing new information and improving decision-making through data-driven strategies, AI could potentially help to solve some of the complex global challenges of the 21st century, from climate change and resource utilization to the impact of population growth and healthcare issues. Start-ups specializing in AI applications received US$2.4 billion in venture capital funding globally in 2015 and more than US$1.5 billion in the first half of 2016. Government programmes and existing technology companies add further billions. Leading players are not just hiring from universities, they are hiring the universities: Amazon, Google and Microsoft have moved to funding professorships and directly acquiring university researchers in the search for competitive advantage.

Machine learning techniques are now revealing valuable patterns in large data sets and adding value to enterprises by tackling problems at a scale beyond human capability. For example, Stanford’s computational pathologist (C-Path) has highlighted unnoticed indicators for breast cancer by analysing thousands of cellular features on hundreds of tumour images, while DeepMind increased the power usage efficiency of Alphabet Inc.'s data centres by 15%. AI applications can reduce costs and improve diagnostics with staggering speed and surprising creativity.

The generic term AI covers a wide range of capabilities and potential capabilities. Some serious thinkers fear that AI could one day pose an existential threat: a "superintelligence" might pursue goals that prove not to be aligned with the continued existence of humankind. Such fears relate to "strong" AI or "artificial general intelligence" (AGI), which would be the equivalent of human-level awareness, but which does not yet exist. Current AI applications are forms of "weak" or "narrow" AI or "artificial specialized intelligence" (ASI); they are directed at solving specific problems or taking actions within a limited set of parameters, some of which may be unknown and must be discovered and learned.

Tasks such as trading stocks, writing sports summaries, flying military planes and keeping a car within its lane on the highway are now all within the domain of ASI. As ASI applications expand, so do the risks of these applications operating in unforeseeable ways or outside the control of humans. The 2010 and 2015 stock market "flash crashes" illustrate how ASI applications can have unanticipated real-world impacts, while AlphaGo shows how ASI can surprise human experts with novel but effective tactics. In combination with robotics, AI applications are already affecting employment and shaping risks related to social inequality.

AI has great potential to augment human decision-making by countering cognitive biases and making rapid sense of extremely large data sets: at least one venture capital firm has already appointed an AI application to help determine its financial decisions. Gradually removing human oversight can increase efficiency and is necessary for some applications, such as automated vehicles. However, there are dangers in coming to depend entirely on the decisions of AI systems when we do not fully understand how the systems are making those decisions.

Risks to Decision-Making, Security and Safety

In any complex and chaotic system, including AI systems, potential dangers include mismanagement, design vulnerabilities, accidents and unforeseen occurrences. These pose serious challenges to ensuring the security and safety of individuals, governments and enterprises. It may be tolerable for a bug to cause an AI mobile phone application to freeze or misunderstand a request, for example, but when an AI weapons system or autonomous navigation system encounters a mistake in a line of code, the results could be lethal.

Machine-learning algorithms can also develop their own biases, depending on the data they analyse. For example, an experimental Twitter account run by an AI application ended up being taken down for making socially unacceptable remarks; search engine algorithms have also come under fire for undesirable race-related results. Decision-making that is either fully or partially dependent on AI systems will need to consider management protocols to avoid or remedy such outcomes.

AI systems in the Cloud are of particular concern because of issues of control and governance. Some experts propose that robust AI systems should run in a "sandbox" – an experimental space disconnected from external systems – but some cognitive services already depend on their connection to the internet. The AI legal assistant ROSS, for example, must have access to electronically available databases. IBM's Watson accesses electronic journals, delivers its services, and even teaches a university course via the internet. The data extraction program TextRunner is successful precisely because it is left to explore the web and draw its own conclusions unsupervised.

Can AI Be Governed – Now or in the Future?

So far, AI development has occurred in the absence of almost any regulatory environment. As AI systems inhabit more technologies in daily life, calls for regulatory guidelines will increase. But can AI systems be sufficiently governed? Such governance would require multiple layers that include ethical standards, normative expectations of AI applications, implementation scenarios, and assessments of responsibility and accountability for actions taken by or on behalf of an autonomous AI system.

Scholars, philosophers, futurists and tech enthusiasts vary in their predictions for the advent of artificial general intelligence (AGI), with timelines ranging from the 2030s to never. However, given the possibility of an AGI working out how to improve itself into a superintelligence, it may be prudent – or even morally obligatory – to consider potentially feasible scenarios, and how serious or even existential threats may be avoided.

The creation of AGI may depend on converging technologies and hybrid platforms. Much of human intelligence is developed by the use of a body and the occupation of physical space, and robotics provides such embodiment for experimental and exploratory AI applications. Proof-of-concept for muscle and brain–computer interfaces has already been established: Massachusetts Institute of Technology (MIT) scientists have shown that memories can be encoded in silicon, and Japanese researchers have used electroencephalogram (EEG) patterns to predict the next syllable someone will say with up to 90% accuracy, which may lead to the ability to control machines simply by thinking.

Superintelligence could potentially also be achieved by augmenting human intelligence through smart systems, biotech, and robotics rather than by being embodied in a computational or robotic form. Potential barriers to integrating humans with intelligence-augmenting technology include people’s cognitive load, physical acceptance and concepts of personal identity. Should these challenges be overcome, keeping watch over the state of converging technologies will become an ever more important task as AI capabilities grow and fuse with other technologies and organisms.

Advances in computing technologies such as quantum computing, parallel systems, and neurosynaptic computing research may create new opportunities for AI applications or unleash new unforeseen behaviours in computing systems. New computing technologies are already having an impact: for instance, IBM’s TrueNorth chip – with a design inspired by the human brain and built for “exascale” computing – already has contracts from Lawrence Livermore National Laboratory in California to work on nuclear weapons security. While adding great benefit to scenario modelling today, the possibility of a superintelligence could turn this into a risk.

Both existing ASI systems and the plausibility of AGI demand mature consideration. Major firms such as Microsoft, Google, IBM, Facebook and Amazon have formed the Partnership on Artificial Intelligence to Benefit People and Society to focus on ethical issues and helping the public better understand AI. AI will become ever more integrated into daily life as businesses employ it in applications to provide interactive digital interfaces and services, increase efficiencies and lower costs. Superintelligent systems remain, for now, only a theoretical threat, but artificial intelligence is here to stay and it makes sense to see whether it can help us to create a better future. To ensure that AI stays within the boundaries that we set for it, we must continue to grapple with building trust in systems that will transform our social, political and business environments, make decisions for us, and become an indispensable faculty for interpreting the world around us.

Preparing for the future of Artificial Intelligence

[Extracts from [33], pp1-4]

As a contribution toward preparing the United States for a future in which Artificial Intelligence (AI) plays a growing role, we survey the current state of AI, its existing and potential applications, and the questions that are raised for society and public policy by progress in AI.

The Current State of AI

Remarkable progress has been made on what is known as Narrow AI, which addresses specific application areas such as playing strategic games, language translation, self-driving vehicles, and image recognition. ***Narrow AI*** underpins many commercial services such as trip planning, shopper recommendation systems, and ad targeting, and is finding important applications in medical diagnosis, education, and scientific research. These have all had significant societal benefits and have contributed to the economic vitality of the Nation.(1)

General AI (sometimes called Artificial General Intelligence, or AGI) refers to a notional future AI system that exhibits apparently intelligent behavior at least as advanced as a person across the full range of cognitive tasks. A broad chasm seems to separate today's Narrow AI from the much more difficult challenge of General AI. Attempts to reach General AI by expanding Narrow AI solutions have made little headway over many decades of research. The current consensus of the private-sector expert community, with which the NSTC Committee on Technology concurs, is that General AI will not be achieved for at least decades.

People have long speculated on the implications of computers becoming more intelligent than humans. Some predict that a sufficiently intelligent AI could be tasked with developing even better, more intelligent systems, and that these in turn could be used to create systems with yet greater intelligence, and so on, leading in principle to an "intelligence explosion" or "singularity" in which machines quickly race far ahead of humans in intelligence.

In a dystopian vision of this process, these super-intelligent machines would exceed the ability of humanity to understand or control. If computers could exert control over many critical systems, the result could be havoc, with humans no longer in control of their destiny at best and extinct at worst. This scenario has long been the subject of science fiction stories, and recent pronouncements from some influential industry leaders have highlighted these fears.

A more positive view of the future held by many researchers sees instead the development of intelligent systems that work well as helpers, assistants, trainers, and teammates of humans, and are designed to operate safely and ethically.

The NSTC Committee on Technology's assessment is that long-term concerns about super-intelligent General AI should have little impact on current policy. The policies the Federal Government should adopt in the near-to-medium term if these fears are justified are almost exactly the same policies the Federal Government should adopt if they are not justified. The best way to build capacity for addressing the longer-term speculative risks is to attack the less extreme risks already seen today, such as current security, privacy, and safety risks, while investing in research on longer-term capabilities and how their challenges might be managed. Additionally, as research and applications in the field continue to mature, practitioners of AI in government and business should approach advances with appropriate consideration of the long-term societal and ethical questions – in additional to just the technical questions – that such advances portend. Although prudence dictates some attention to the possibility that harmful super-intelligence might someday become possible, these concerns should not be the main driver of public policy for AI.

Autonomy, Automation and Human-machine Teaming

AI is often applied to systems that can control physical actuators or trigger online actions. When AI comes into contact with the everyday world, issues of autonomy, automation, and human-machine teaming arise.

Autonomy refers to the ability of a system to operate and adapt to changing circumstances with reduced or without human control. For example, an autonomous car could drive itself to its destination. Despite the focus in much of the literature on cars and aircraft, autonomy is a much broader concept that includes scenarios such as automated financial trading and automated content curation systems. Autonomy also includes systems that can diagnose and repair faults in their own operation, such as identifying and fixing security vulnerabilities.

Automation occurs when a machine does work that might previously have been done by a person. The term relates to both physical work and mental or cognitive work that might be replaced by AI. Automation, and its impact on employment, have been significant social and economic phenomena since at least the Industrial Revolution. It is widely accepted that AI will automate some jobs, but there is more debate about whether this is just the next chapter in the history of automation or whether AI will affect the economy differently than past waves of automation have previously.

Human-Machine Teaming: in contrast to automation, where a machine substitutes for human work, in some cases a machine will complement human work. This may happen as a side-effect of AI development, or a system might be developed specifically with the goal of creating a human-machine team. Systems that aim to complement human cognitive capabilities are sometimes referred to as intelligence augmentation.

In many applications, a human-machine team can be more effective than either one alone, using the strengths of one to compensate for the weaknesses of the other. One example is in chess playing, where a weaker computer can often beat a stronger computer player, if the weaker computer is given a human teammate—this is true even though top computers are much stronger players than any human.(2) Another example is in radiology. In one recent study, given images of lymph node cells, and asked to determine whether or not the cells contained cancer, an AI-based approach had a 7.5 percent error rate, where a human pathologist had a 3.5 percent error rate; a combined approach, using both AI and human input, lowered the error rate to 0.5 percent, representing an 85 percent reduction in error.(3)

Economic Impacts of AI and Automation

AI's central economic effect in the short term will be the automation of tasks that could not be automated before. There is some historical precedent for waves of new automation from which we can learn, and some ways in which AI will be different. Government must understand the potential impacts so it can put in place policies and institutions that will support the benefits of AI, while mitigating the costs.(4)

Like past waves of innovation, AI will create both benefits and costs. The primary benefit of previous waves of automation has been productivity growth; today's wave of automation is no different. For example, a 2015 study of robots in 17 countries found that they added an estimated 0.4 percentage point on average to those countries' annual GDP growth between 1993 and 2007, accounting for just over one-tenth of those countries' overall GDP growth during that time.(5)

One important concern arising from prior waves of automation, however, is the potential impact on certain types of jobs and sectors, and the resulting impacts on income inequality. Because AI has the potential to eliminate or drive down wages of some jobs, especially low- and medium-skill jobs, policy interventions will likely be needed to ensure that AI's economic benefits are broadly shared and that inequality is diminished and not worsened as a consequence.

Applications of AI for Public Good

One area of great optimism about AI and machine learning is their potential to improve people's lives by helping to solve some of the world's greatest challenges and inefficiencies. Many have compared the promise of AI to the transformative impacts of advancements in mobile computing. Public- and private-sector investments in basic and applied R&D on AI have already begun reaping major benefits to the public in fields as diverse as health care, transportation, the environment, criminal justice, and economic inclusion. The effectiveness of government itself is being increased as agencies build their capacity to use AI to carry out their missions more quickly, responsively, and efficiently.

AI and Regulation

AI has applications in many products, such as cars and aircraft, which are subject to regulation designed to protect the public from harm and ensure fairness in economic competition. How will the incorporation of AI into these products affect the relevant regulatory approaches? In general, the approach to regulation of AI-enabled products to protect public safety should be informed by assessment of the aspects of risk that the addition of AI may reduce alongside the aspects of risk that it may increase. If a risk falls within the bounds of an existing regulatory regime, moreover, the policy discussion should start by considering whether the existing regulations already adequately address the risk, or whether they need to be adapted to the addition of AI. Also, where regulatory responses to the addition of AI threaten to increase the cost of compliance, or slow the development or adoption of beneficial innovations, policymakers should consider how those responses could be adjusted to lower costs and barriers to innovation without adversely impacting safety or market fairness.

Research and Workforce

Government also has an important role to play in the advancement of AI through research and development and the growth of a skilled, diverse workforce.

Given the strategic importance of AI, moreover, it is appropriate for the Federal Government to monitor developments in the field worldwide in order to get early warning of important changes arising elsewhere in case these require changes in U.S. policy.

The rapid growth of AI has dramatically increased the need for people with relevant skills to support and advance the field. An AI-enabled world demands a data-literate citizenry that is able to read, use, interpret, and communicate about data, and participate in policy debates about matters affected by AI. AI knowledge and education are increasingly emphasized in Federal Science, Technology, Engineering, and Mathematics (STEM) education programs. AI education is also a component of Computer Science for All, the President's initiative to empower all American students from kindergarten through high school to learn computer science and be equipped with the computational thinking skills they need in a technology-driven world.

Preparing for the Future

AI holds the potential to be a major driver of economic growth and social progress, if industry, civil society, government, and the public work together to support development of the technology with thoughtful attention to its potential and to managing its risks.

Government has several roles to play. It can convene conversations about important issues and help to set the agenda for public debate. It can monitor the safety and fairness of applications as they develop, and adapt regulatory frameworks to encourage innovation while protecting the public. It can provide public policy tools to ensure that disruption in the means and methods of work enabled by AI increases productivity while avoiding negative economic consequences for certain sectors of the workforce. It can support basic research and the application of AI to public good. It can support development of a skilled, diverse workforce. And government can use AI itself to serve the public faster, more effectively, and at lower cost. Many areas of public policy, from education and the economic safety net, to defense, environmental preservation, and criminal justice, will see new opportunities and new challenges driven by the continued progress of AI. Government must continue to build its capacity to understand and adapt to these changes.

As the technology of AI continues to develop, practitioners must ensure that AI-enabled systems are governable; that they are open, transparent, and understandable; that they can work effectively with people; and that their operation will remain consistent with human values and aspirations. Researchers and practitioners have increased their attention to these challenges, and should continue to focus on them.

Developing and studying machine intelligence can help us better understand and appreciate our human intelligence. Used thoughtfully, AI can augment our intelligence, helping us chart a better and wiser path forward.

8.4 Do labour-saving technologies result in job losses in the developing world?

[Extracts from [36], pp 20-23]

Throughout history, the arrival of revolutionary technologies—such as the railroad, the automobile, and the telephone—have created vast employment opportunities and delivered transformative improvements in living standards. However, these innovations also destroyed large numbers of existing jobs, necessitating extensive periods of retraining and adaptation. Indeed, a 2015 Harvard Business Review article noted that over the last 200 years technological change has often been associated with stagnant wages and rising inequality, at least for a time.

Why today's technological revolution may be different

What may be different about the current revolution? It is plausible that today's technology sectors have not provided the same opportunities, particularly for less-educated workers, as the industries that preceded them. This downward trend in new job creation in technology industries is particularly evident since the "computer revolution" of the 1980s. For example, economist Jeffrey Lin estimates that while about 8.2 percent of the U.S. workforce shifted into new jobs associated with technological advances during the 1980s, there was only a 4.4 percent shift during the 1990s. During the 2000s, less than 0.5 percent of workers shifted into technology industries, including online auctions, video and audio streaming, and web design. Similarly, there is evidence that the rate of business dynamism (such as the number of new businesses created) in the U.S. technology sector has been declining through the 2000s.

Meanwhile, the labour-saving impact of digital technologies is substantial and likely to increase. Economist David Autor and his colleagues showed in the early 1980s that computers had displaced workers in a wide range of routine work, including many clerking and manufacturing jobs—work that is typically concentrated at the middle of the income distribution. Other research has shown that employment continued to grow both at the top and the bottom end of the skill and income distribution. The automation of routine work, therefore, appears to have contributed to the hollowing out of labour markets across the industrial world. Recent technological breakthroughs and the prospect of further technological advances are quickly expanding the potential scope of job automation, making it likely that the labour market effects of technological change are also likely to become even more significant over time. Historically, computerization has largely been confined to routine tasks that involve explicit rules-based activities that can easily be specified in computer code. Recent technological advances, in contrast, have made it possible to also automate a growing range of non-routine tasks. Some tasks, such as driving a car or deciphering scrawled handwriting, were deemed non-automatable only a decade ago. Today such tasks to a large extent can be automated or are close to that stage.

Implications for the developing world

Both the benefits and the challenges of digital technologies and automation in particular are not limited to the industrial world alone. Indeed, there is reason to believe that its effects could be more dramatic on the developing world. Job polarization, with some exceptions, is also already taking place in developing economies. The World Bank's World Development Report 2016 noted that between 1995 and 2012 the share of routine employment has fallen by almost eight percentage points while the share of non-routine jobs (both high-skilled and low-skilled) increased in most countries (the decline of routine jobs among industrial countries was even larger at roughly 12 percentage points). The "hollowing out" was visible across a large number of developing countries, including Macedonia, Turkey, Mexico, and Malaysia. The most notable exception to the trend was observed in China, where middle-income jobs have rapidly expanded, following the offshoring of manufacturing jobs in advanced economies and the mechanization of agriculture (commodity exporters also partly bucked the trend away from automation during the commodity super-cycle, but that is likely to reverse soon).

However, China may be one of the last countries to ride the wave of industrialization to prosperity. Technological breakthroughs of the 20th century—such as the container ship and the computer—significantly contributed to the rise of global supply chains, enabling companies to locate production where labour is cheap. Yet, recent developments in robotics and additive manufacturing, or "3D printing," have made it increasingly economical for companies in advanced countries to "reshore" production to mostly automated factories. The Harvard economist Dani Rodrik has shown that over the 20th century peak manufacturing employment has steadily declined among emerging economies, a phenomenon sometimes called "premature deindustrialization." This global trend may well be related to, and likely reinforced by, increasing automation of the workforce, posing significant challenges for developing economies to create jobs, let alone "good" jobs.

The expanding scope of automation might constitute a watershed for labour markets worldwide. According to a recent study, around 47 percent of U.S. employment may be susceptible to automation as a result of ongoing technological improvements. It is no longer only production and back office jobs that are at risk, but also areas of logistics and transportation, construction, sales, and services. Thus, the reach of potentially automatable professions is now reaching sectors previously deemed relatively safe from technological replacement.

Again, developing economies may face even greater challenges than industrial economies. This is in part because the share of manufacturing and agriculture—still among the easiest to be mechanized and automatized—in many developing countries is substantially larger than in the average industrial country. According to World Bank data, employment in agriculture and industry still accounts for around 55 percent of total employment in low- and middle-income countries, while it is only around 26 percent in high-income countries.

Indeed, applying the Frey-Osborne methodology, the World Bank recently estimated that the share of jobs at risk of automation is even higher in developing countries—77 percent and 69 percent of all jobs in China or India, respectively—and perhaps 85 percent in Ethiopia, against an average 57 percent of jobs in member countries of the Organization for Economic Cooperation and Development (OECD). Since this methodology only reflects the technological capabilities and does not take into account differential labour costs, it should not be interpreted as implying that automation is likely to replace jobs even faster in developing countries than in industrial ones. After all, labour costs are of course lower in developing countries and automation is currently happening at a faster pace in industrial economies. But developing economies are by no means insulated from these trends (indeed, China is already one of the largest markets for robots in the world) and, importantly, automation may hinder the ability of developing economies to use their labour-cost advantage to build prosperous economies and societies over time.

Given the potentially transformative impact of automation and related technological trends on labour markets, decisive policy responses are likely to be needed to ensure that the gains will be shared and the losers looked after, including measures to improve the quality of education and training, fiscal incentives for employment, and some measure of protection and subsidies for the vulnerable. That is likely to be a tall order for most countries, but developing countries may find it even more difficult because of lower government effectiveness and less resilient economic and political systems. For instance, according to World Bank data, low- and middle-income countries significantly underperform high-income countries across all six categories of measured governance indicators (voice and accountability, political stability and absence of violence/terrorism, government effectiveness, regulatory quality, rule of law, and control of corruption) and show high levels of inequality.

In addition, developing countries are likely to be less capable of taking advantage of many of the opportunities that the new technologies offer. This is because, outside of concentrated areas like China and India's technology hotspots, much of the populations lack the skills that would be most complementary to new technologies and the physical and soft infrastructure (including extensive and fast broadband networks).

How realistic is the prospect of technological unemployment?

If technology is becoming less job-creating and more labour-saving, should we resign ourselves to a fate of technological unemployment, and, in the case of developing countries, bid any hopes of prosperity farewell? The answer is no, for various reasons.

First, not all jobs that are automatable are in fact automated—despite the promise of self-service technology, there are still more than 3 million cashiers in employment in the U.S. There are a variety of hurdles, including the need to adapt processes to make automation economically worthwhile and the flexibility to time and shape the introduction of technologies.

Second, job creation depends on factors other than technology. Importantly, most job creation since the computer revolution of the 1980s has come from non-technology sectors of the economy. A study by the Council on Foreign Relations, for example, showed that non-tradable sectors producing goods and services that are consumed locally can account for as much as 98 percent of total U.S. employment growth between 1990 and 2008. Around 40 percent of this growth, in turn, came from government and health care services (sectors that are not primarily driven by market forces), while retail, construction, and food and accommodation industries also contributed significantly.

Third, technology has had significant impacts on jobs beyond the technology sector. Technology-using sectors, such as professional services, have expanded rapidly as advances in information and communications technology has made many of these jobs tradable. Furthermore, technology jobs create significant spill-overs on local demand for services—it is estimated that one additional technology job creates around five new jobs in the local non-tradable sector. As increasingly automated factories mean that manufacturing is absorbing fewer workers, including in the developing world, the future of job creation will depend on making the transition toward more skilled modes of production. Importantly, skilled jobs (and in particular non-routine jobs) are typically less susceptible to automation, and such jobs have the potential to create more demand for local services. Multipliers for one additional skilled manufacturing job in developing countries are at least three times higher than multipliers for unskilled jobs (the multiplier for skilled manufacturing jobs ranges from 16 in South Africa to 21 in India). It would therefore be misleading to focus merely on the job-destroying effects of technology or indeed only take into account those directly created by technology sectors.

Overall, the impact new technologies may have on labour markets and conventional developments models in developing countries is likely to be very significant and pose major challenges for policymakers who may already be stretched by a combination of economic pressures and political instability. The primary concern may not be widespread, technologically-created unemployment, but rather creating rewarding jobs and inclusive growth. Widening inequalities of income and wealth could in turn stretch social cohesion and further complicate the capacity of policymakers to address these challenges. Of course, the threat that disruptive technological progress poses is not unmitigated. Even though technology jobs may be few and far between, the additional demand for job creation in loosely related or unrelated sectors is likely to be significant. It is currently difficult to predict where these jobs will be, but for now we are very far from an abundance of jobs that would cause a lack of demand for job creation. Meanwhile, the same technological advances that threaten jobs and development models also bear unprecedented possibilities to boost productivity, reduce poverty, and improve the efficiency of public services.

8.5 Rising inequality: The race between skills and technology

[Extracts from [31], pp 20-23]

If the internet and related technologies promote growth, how are the gains shared in the labour market? While digital technologies raise productivity and enhance overall welfare, labour market disruptions can be painful and can result in higher inequality. Global trends provide some indication. One is that the share of national income that has gone to labour, especially routine labour, has fallen quite sharply in many developing countries—though Brazil and Ukraine are exceptions.

Inequality has increased more where this shift in incomes toward capital and away from labour has been higher. A number of recent studies have linked techno-logical change to this rising inequality.

A related trend is the polarization—or “hollowing out”—of the labour market, not only in advanced economies, but increasingly also in many developing countries. The share of employment in high-skilled occupations is up, as is the share of low-skilled jobs. The share of middle-skilled employment, in contrast, is down in most developing countries for which detailed data are available (figure O.17). And these types of jobs are often near the top of the income distribution in low-income countries, as in Africa. A notable exception to these global trends is China, where growing mechanization in agriculture has led to a (perhaps temporary) increase in routine, mid-level labour. Exceptions also include some countries rich in natural resources and commodity exporters, which include several countries in Central Asia and Latin America.

What explains all this? Machines can increasingly perform routine tasks more quickly and cheaply than humans, and much of what is considered non-routine today—such as translation, insurance underwriting, or even medical diagnostics—computers might do just as well tomorrow. Unlike previous technological transformations such as the mechanization of agriculture or the automation of manufacturing, the internet affects well-paying white-collar jobs even more than blue-collar jobs.

Some mid-level workers will have additional skills that allow them to switch to better-paid non-routine occupations in which technology tends to augment human capital and make skilled workers more productive. These workers will gain from technological disruption. In developing countries, returns to education are highest among those with tertiary education, and they are higher and rising faster in ICT-intensive occupations. 32 Those who do not have such skills will need to seek work in lower-skilled, non-routine occupations, such as janitorial services, hospitality, or personal care. Demand for such services could increase, but perhaps not enough to prevent downward wage pressure as the available workforce in these sectors grows. These dynamics are consistent with the rising returns to education and income inequality we see in many countries.

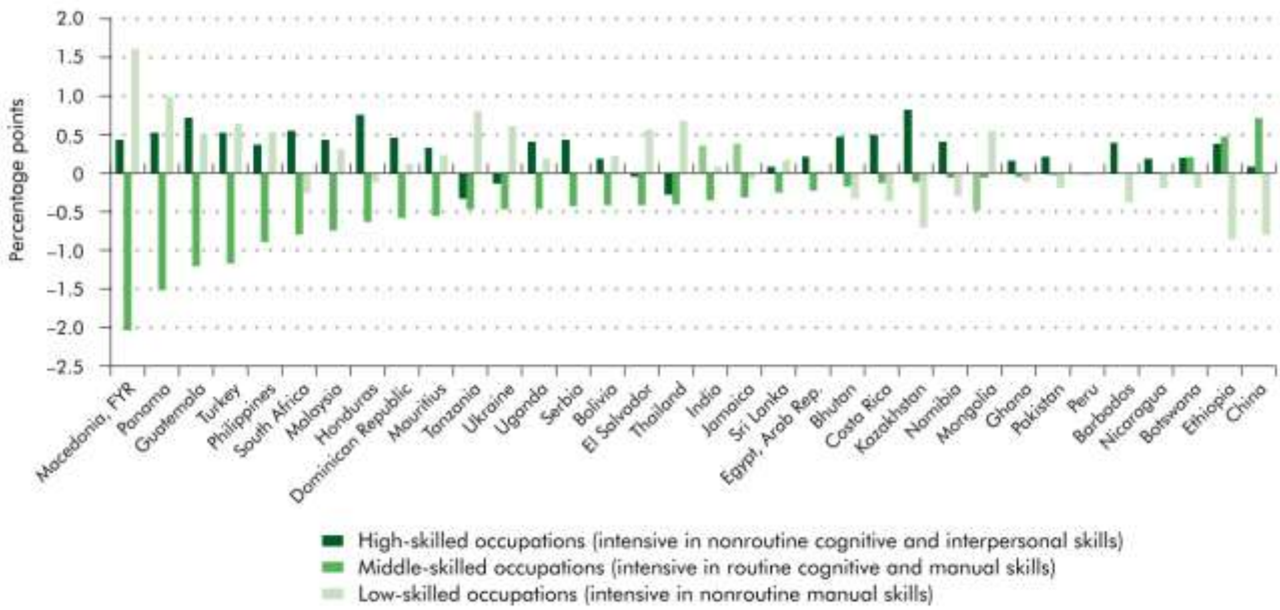
The implications for developing countries depend on the pace of technological disruption. The share of occupations that could experience significant automation is actually higher in developing countries than in more advanced ones, where many of these jobs have already disappeared (figure O.18). But it will likely take longer in lower-income countries. Most of them are still fairly low-tech, with only about one-third of urban jobs in a sample of developing countries using any ICTs at work. And wage rates are still low, with a larger share of manual non-routine labour, so investments in technology will be less profitable for firms. This does not mean, however, that lower -income countries need not pay attention to these trends. Most important, even without significant employment shifts, the nature of jobs is changing toward skills that remain hard for technology to emu-late: that is, advanced cognitive and socio-emotional skills. The policy response, besides rethinking social protection systems, is better and more responsive education and training—areas where reforms take many years to pay off.

It is important to keep in mind the historical perspective that job displacement and job losses from technological change are an integral part of economic progress. It is precisely rising productivity—as technology replaces some human labour but augments the skills of remaining and new workers—that generates growth and frees human and financial resources for deployment in sectors with higher returns. It also reduces the need for humans to do physically hard, repetitive, or dangerous work. Such trends will be welcome in countries that are rapidly aging or where the population is declining, or in professions where skills are in short supply. Telemedicine and automated diagnostics, for instance, allow medical experts to serve many more people, even remotely in areas with a shortage of doctors.

And fears of "technological unemployment" go back to the industrial revolution. Even such thinkers as the economist John Maynard Keynes and the writer Isaac Asimov submitted to this fallacy. Keynes, in the 1930s, predicted 15-hour workweeks by the end of the 20th century, and Asimov, in a 1964 essay, expected that one of the most pressing problems for humanity by 2014 would be boredom "in a society of enforced leisure." Yet over the centuries, economies have adapted to massive changes in labour markets—the largest by far, being the shift out of agriculture. In 1910, there were 12 million farmworkers in the United States. One hundred years later, there were only 700,000 in a population more than three times larger. Still, nobody can predict the full impact of techno-logical change in coming decades, which may be faster and broader than previous ones. What is clear, however, is that policy makers face a race between technology and education, and the winners will be those who encourage skill upgrading so that all can benefit from digital opportunities.

Figure O.17 The labor market is becoming more polarized in many developing countries

Annual average change in employment share, circa 1995–circa 2012

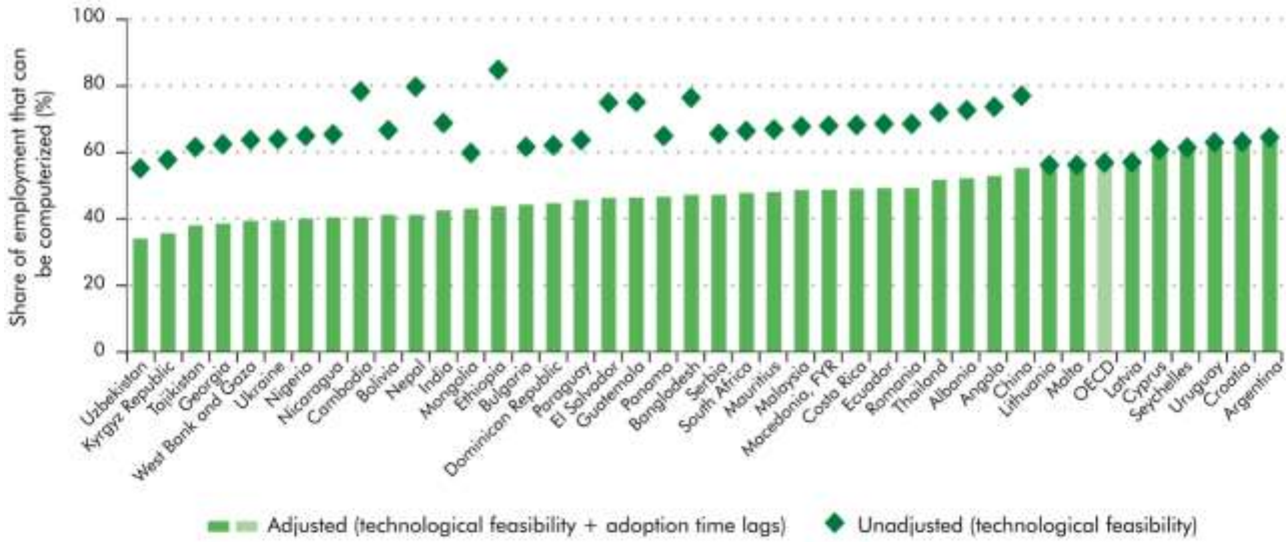


Sources: WDR 2016 team, based on ILO KILM (ILO, various years); the International Income Distribution database (I2D2; World Bank, various years); National Bureau of Statistics of China (various years). Data at http://bit.do/WDR2016-FigO_17.

Note: The figure displays changes in employment shares between circa 1995 and circa 2012 for countries with at least seven years of data. The classification follows Autor 2014. High-skilled occupations include legislators, senior officials and managers, professionals, and technicians and associate professionals. Middle-skilled occupations comprise clerks, craft and related trades workers, plant and machine operators and assemblers. Low-skilled occupations refer to service and sales workers and elementary occupations. For more details see figure 2.15 in the full Report.

Figure O.18 From a technological standpoint, two-thirds of all jobs are susceptible to automation in the developing world, but the effects are moderated by lower wages and slower technology adoption

Estimated share of employment that is susceptible to automation, latest year



Source: WDR 2016 team. See figure 2.24 in the full Report for more details. Data at http://bit.do/WDR2016-FigO_18.

Note: For more details see figure 2.24 in the full Report. OECD = Organisation for Economic Co-operation and Development.

8.6 Are technology and globalization destined to drive up inequality

[Extracts from [32], pp 4-9]

What's the issue?

Over the past several years, concerns that technology and globalization lead to ever greater inequality have reached fever pitch in the U.S. and beyond. To understand what's behind this anxiety, three distinctions are useful.

First is to distinguish global inequality and its two components: inequality within countries and inequality between countries. Global inequality, as popularized by economist Branko Milanovic, looks at the distribution of income between all the world's citizens irrespective of country borders. Inequality by this measure is exceptionally high. Over the past generation, between-country disparities fell, due to the fast growth of emerging economies, even while inequality within several countries has risen. The net effect has been a small reduction in recorded global inequality (Lakner & Milanovic, 2015). This pattern will continue if poor countries such as India continue to quickly converge on income levels prevailing in high-income countries and this convergence outweighs any widening of within-country distributions (Hellebrandt & Mauro, 2015). Yet that would not quiet grievances about inequality. On the contrary, the middle class in industrialized economies, one of the world's most vocal and powerful constituencies, has seen global growth benefit high earners in their economies along with the expanding middle class in emerging economies, while their own incomes have stagnated. Their sense of being short-changed is increasingly recognized as a source of political instability.

Since politics is organized principally around the nation state, it is the level and change in inequality within countries that is the most potent source of tension and debate.

This brings us to distinction **two**: inequality in developed versus developing economies. In the former, the trend is clear—nearly all developed economies have seen inequality rise over the past generation. In Anglophone countries, rising inequality has been especially pronounced at the top end of the distribution, with the top 1 percent of earners seeing their share of national income rise. In developing countries, on average, inequality rose in the 1990s but stabilized in the 2000s (Ravallion, 2014). In most developing economies where recent data exist, inequality is trending downward (World Bank, 2015). However, information about the top end of the distribution in developing economies is limited, given the absence of complete tax records.

Distinction **three** is between inequality in market income and disposable income. Until now we have described the inequality of disposable income, net of the effects of government taxes and benefits, which serve to reduce the inequality of market outcomes. This redistributive effect tends to be greater in developed countries than in developing countries, where government is typically a smaller share of the economy. In most advanced economies, redistribution through taxes and benefits grew over the past generation, offsetting some but not all of the increase in market inequality. However, these effects have diminished on average since the late 1990s, due to policy choices such as the application of more stringent criteria to government benefits (OECD, 2011). Public policies can also shape the distribution of market income. For instance, weakened employment protection, such as rules regarding sick leave and severance pay, has contributed to widening inequality over this period.

What's the debate?

Debates over the causes of inequality are fraught, reflecting the multiple and complex channels through which technology and globalization are changing the global economy.

Arguably the most prominent effect of technology on inequality is through the increased premium it places on skills. Modern technology substitutes for many of the jobs and tasks traditionally performed by unskilled workers, while acting as a complement to skilled workers. In advanced countries, trade reinforces this effect by encouraging specialization in high-skill sectors in which those economies have a comparative advantage. The same logic should see income inequality narrow in developing economies that specialize in low-skill sectors. However, in practice, skilled workers in developing economies may take those jobs, so that distributions widen (Maskin, 2015).

By substituting for unskilled workers, technology has not only increased the premium on skills, but increased the role of capital in production. Historically the share of income that accrues to workers relative to capital owners was stable, but since the 1980s, it has declined across most countries and industries as technology has made capital goods ever cheaper (Karabarbounis & Neiman, 2013). This adds to inequality, as capital ownership is especially unequal and generates large investment income for many of the same individuals already earning high wages (Atkinson & Lakner, 2013).

Technology has often led to the creation of strongly monopolistic markets for new goods and services. This is especially apparent in the digital economy, where behemoths like Google and Apple dominate. Globalization has expanded the scale of these winner-takes-all markets, enabling vast salaries and profits to be shared among a narrow set of employees and shareholders.

At the same time, globalization and technology have served to lower market barriers and information costs. For instance, while digital platforms for taxis (Uber), retail (Amazon), and accommodation (AirBnB) are themselves quasi-monopolies, they have simultaneously lowered barriers to entry for self-employed drivers, sellers, and would-be hoteliers, creating highly contestable markets. This has redistributed rents and generated new income-earning opportunities for the unskilled.

Finally, globalization has encouraged a race to the bottom on some regulations and redistributive policies, as the mobility of firms, investment, and skilled workers compels governments to match the conditions of their competitors so as to retain and attract business (Bertola & Lo Prete, 2008).

What to watch out for?

The effects of technology and globalization on inequality are neither inevitable nor entirely predictable. We identify three areas to watch closely:

Job automation. The past year has seen a rapid uptick in sales of robots, coinciding with breakthroughs in the capability of machines and artificial intelligence in increasingly complex, non-routine tasks such as driverless vehicles and semi-cognitive skills such as voice-recognition. This has led to growing anxiety over the prospect of widespread automation of jobs. Estimates on the share of jobs that are at risk of automation over the medium term vary from 9 to 47 percent for OECD economies (Frey & Osborne, 2013; Arntz et al, 2016). Equally uncertain are what, and how many, new jobs may emerge and the adjustment costs of moving lots of workers into new roles.

Prospects for developing economies. The replacement of workers by machines poses a threat to developing economies' traditional comparative advantage in global markets—their surfeit of cheap labor. Evidence is emerging of the hollowing out of labor markets in developing economies, mirroring the pattern already observed in the west, and of premature deindustrialization as developing economies struggle to establish a manufacturing base, in stark contrast to the path taken by western economies and Asia's tiger economies (World Bank, 2016; Rodrik, 2015). At the same time, the digital economy provides opportunities to link workers in poor economies with companies and customers in rich markets, thus offering a temporary reprieve from the risks associated with labor-saving technologies (Basu, 2016). It is unclear which of these two effects will win out in shaping developing economies' fortunes in the near term. But the rate of their convergence with rich economy living standards is set to be a major determinant of global inequality trends.

Perceptions of inequality. Public anger over the inequitable effects of technology and globalization is cited as a cause of myriad social ills—from rising nationalism and identity politics, to disdain for institutions, and a fracturing of the rules-based international system. Whether that anger persists will depend less on any objective measure of inequality than on how inequality is perceived and managed (Nieheus, 2014). One important factor is the way global integration shifts the reference points people use to judge and compare their lives.

Policy has a vital role to play in promoting greater equality, both through redistribution, where taxes and benefits moderate the unequal distribution of market income into a more equitable distribution of disposable income, and "pre-distribution" where market forces and rules are engineered to improve the distribution of market income itself.

Given the alarming trends in inequality, and the tendency for political stalemate over changes in tax and benefits, attention is increasingly focused on policies that support pre-distribution. Some of the most creative ideas seek to reshape the forces of technology and globalization themselves. For instance, policies can be put in place to incentivize research and development on innovations that generate more jobs. Alternatively, governments can deploy public funds to acquire stakes in technological innovations and their commercialization so that the profits they generate can be shared with citizens rather than benefit only a narrow group of shareholders. With regard to globalization, multilateral efforts can eliminate tax inversions, whereby one corporation acquires another to re-domicile to a lower-tax jurisdiction.

More generally, there can be little doubt that focusing almost exclusively on average incomes and their growth has been a disservice to policymaking and to the economics profession. A growth strategy that doesn't work for all members of an economy is incomplete and unsustainable, no matter how much redistribution there may be. The definition of economic success must therefore include the extent to which growth is inclusive. Inclusiveness cannot be an afterthought.

8.7 Robots and industrialization in developing countries

[Extracts from [34], pp1-4]

Industrialization has historically been synonymous with development, while deindustrialization is a well-established trend in mature developed economies as they move towards services-based economies. Yet recent trends show that many developing countries – especially in Africa and Latin America – have witnessed their shares of manufacturing employment and output shrinking long before they have attained income levels comparable to those in the developed world. Such premature deindustrialization began during the adjustment programmes in the 1980s and 1990s, yet has continued, as commodity booms and speculative financial inflows have led to currency appreciation and a loss of manufacturing competitiveness, compounded by the rise of China's manufacturing exports. The current question is therefore: now that the commodity bonanza is over, capital flows are reversing and China is turning towards a more balanced growth path driven more by domestic demand than exports, how can Africa and Latin America reignite industrialization? Whatever the chosen strategy, it will have to account for the rapidly increasing spread of new automation technologies and artificial intelligence in the form of robots.

Much of the discussion on the economic effects of the use of robots has concentrated on the effects in developed countries. Optimists state that any adverse effects will be shortlived and that robots may help overcome slowdowns in productivity growth and increase worker income and well-being. Pessimists point to the rapid pace and increasing scope of new technological breakthroughs, and state that, due to their microprocessors, robots may require only a small number of better-skilled workers for their operation, rather than the requirement for large numbers of low-skilled workers that complemented earlier technological breakthroughs such as the steam engine. The result may be enduring adverse employment and distributional effects. Both narratives are coherent and may actually occur simultaneously, with benefits accruing in productivity growth and for better-skilled workers and the owners of robots, while low-skilled workers risk being impoverished.

Potential north–south industrialization effects of the use of robots

The increased use of robots in developed countries risks eroding the traditional labour-cost advantage of developing countries. If robots are considered a form of capital that is a close substitute for low-skilled workers, then their growing use reduces the share of human labour in total production costs. Adverse effects for developing countries may be significant. According to some estimates, for developing countries as a group, the "share of occupations that could experience significant automation is actually higher in developing countries than in more advanced ones, where many of these jobs have already disappeared", and this concerns about two thirds of all jobs.

Reshoring economic activities to developed countries is one mechanism that could lead to shrinking output and employment in the manufacturing sector of developing countries. Developed countries may aim to reshore in order to regain international competitiveness in manufacturing and stem the decline in manufacturing employment and the polarization of income that is to the detriment of middle-class workers. Reshoring could turn global value chains on their head, and lead to their decline as a potential industrialization strategy for developing countries.

Yet there is mixed evidence for the importance of reshoring and its underlying motivations. Some reshoring has occurred, especially in activities where automation and other technological advancements are important for production processes. However, economy-wide effects are minor. The slow pace of reshoring may partly be explained by tepid investment and sluggish aggregate demand more generally. In addition, developed countries now lack the supplier networks that some developing countries have built to complement assembly activities. Finally, offshoring continues to take place, and while labour-cost differentials remain a factor in the decision of firms on where to locate production, especially of goods with a high labour content, demand factors such as the size and growth of local markets are becoming increasingly important determinants. This means that the production of labour-intensive manufactures destined for rapidly growing markets in large developing countries that have domestic production linkages is unlikely to be reshored. The evidence also shows, however, that where reshoring to developed countries has occurred, it has fallen short of expected re-industrialization effects. Reshoring has mostly been accompanied by capital investment, such as in robots, with the minimal job creation that has occurred being concentrated in high-skilled activities, and has thereby sharpened income polarization.

Potential impacts of the use of robots on industrial development in developing countries

How might the use of robots affect industrialization prospects within the group of developing countries?

Would the deployment of robots in Africa and Latin America help economies in these regions benefit from potential export opportunities in manufacturing activities vacated by China as it shifts towards a new growth model?

To the extent that relative factor endowments determine the international division of labour, the use of robots could alter the location of manufacturing of particular sorts of goods and services by altering their relative factor intensities. Assuming that low-skilled human labour and the use of robots are close substitutes and that robots controlled by high-skilled workers could perform, for example, clothing production and electronics assembly more efficiently than low-skilled workers, then these activities become relatively more skill-intensive. Deploying more robots than others would allow countries to increase their relative supplies of effective low-skilled labour (including both low-skilled human workers and robots). Doing so would allow countries with a low ratio of low-skilled to high-skilled workers to reduce their labour-cost disadvantage and make labour-intensive manufacturing more competitive. Accordingly, such activities could shift from countries with a relatively high ratio of low-skilled to high-skilled workers, such as China, to countries with a relatively low ratio, such as in parts of Africa and Latin America. The result would be a shift in the latter countries' sectoral structure of output and export towards a larger share of manufactures.

It is not clear whether such shifts in activity in entire sectors may be expected to occur. Drawing on insights from more recent trade theory, which stresses the importance of firms and their heterogeneity in terms of productivity even within economic sectors, gives different results. Productivity differences may arise because some firms choose to produce in more technology-intensive ways, for example by deploying more robots than other firms. This may make them sufficiently competitive to begin exporting. Such effects may be reinforced by combining robotization with other new automation technologies, such as three-dimensional printing. The latter lowers the costs of prototyping and small-volume production, and could facilitate the initiation of manufacturing of new products, whose large-scale production could become economically feasible through the deployment of robots. Imitation by other manufacturers ready to undertake fixed-cost investments in robots and other automation technologies could boost a country's industrialization level generally and ignite a gradual increase in the share of manufacturing in its output and export structure. Another effect of deploying robots may be that this type of technology upgrading helps firms at initially lower productivity levels avoid being driven out of the market through import competition, and this could help stem deindustrialization. Intra-industry reallocations of market shares and productive resources between firms are likely to be much more pronounced than sector-wide inter-industry reallocations that would require factor-intensity changes of a much wider range.

A country wishing to benefit from such effects must deploy more robots than others. According to data from the International Federation of Robotics, recent deployments of industrial robots in developing countries have been concentrated in China, and the country is expected to maintain its front-runner status. In response to a shrinking working-age population and rising labour costs, which have eroded the country's cheap-labour advantage, China has embarked on a government-backed robot-driven industrial strategy entitled "Made in China 2025". Each year since 2013, China has bought more industrial robots than any other country and, by the end of 2016, is likely to overtake Japan as the world's biggest operator of industrial robots. While its robot density – robots per industrial workers – continues to fall short of that of Germany, Japan and the Republic of Korea, the rapid pace of robot deployment is likely to significantly reduce the erosion of China's comparative advantage in labour-intensive manufacturing.

The data also show, however, that industrial robots have primarily been deployed in the automotive, electrical and electronics industries. This means that in developing countries – such as Mexico and many countries in Asia – those engaged in export activities in these two sectors are the most exposed to reshoring. By contrast, in many labour-intensive industries, such as garment-making, widespread automation is not yet suitable. While robots have become cheaper, some developing countries continue to have a large pool of cheap labour. Thus, for those countries whose major challenge is to create jobs for a large number of low-skilled entrants to the labour force – such as in many parts of Africa – deploying robots under current cost structures may drive production costs up, rather than down.

Looking beyond output effects, the distributional impacts of robots on employment and income in developing countries will, at least initially, tend to move against inclusiveness, as in developed countries. Job creation will tend to be concentrated in high-skill activities with comparatively fewer benefits for low-skilled and medium-skilled workers.

The fiscal implications of robot deployment remain an open question. Clearly, without the introduction of a major tax on robots as capital equipment, robot-based manufacturing cannot boost the fiscal revenues needed to finance both social transfers, to support workers made redundant by robots, and minimum wages, to stem a decline in the living standards of low-skilled and medium-skilled workers.

Policy implications

Much of the debate on the economic impacts of the use of robots remains speculative, and disruptive technologies always bring a mix of benefits and risks. Whatever the impacts, final outcomes will be shaped by policies. A comprehensive approach aimed at maximizing the benefits of the use of robots for industrialization in developing countries includes consideration of the following elements:• Any industrialization strategy in developing countries will benefit from stable but expansionary global economic conditions driven by sustained productive investment and supported by broad-based global income growth. A policy shift in developed countries towards combining expansionary monetary and credit policies with a proactive fiscal stance and a sustained increase in the share of wages in national income could ignite a sustained expansion of consumption and productive investment, based on the favourable income expectations of consumers and positive demand expectations of entrepreneurs. This could turn around slowdowns in productivity and global demand growth, in the process boosting the opportunities of developing countries for industrialization through manufactured exports.

- To fully benefit from an expanding global economy, developing countries should embrace the digital revolution. This requires redesigning education systems to create the managerial and labour skills needed to operate new technologies and widely diffuse the benefits of their use, as well as to complement them, as the combination of skilled labour and automation may be superior to either on its own. It also requires establishing Internet links between massive data storage and the computing devices that power the increased use of robots, and developing the associated regulatory frameworks. In addition to creating benefits from automation, digitization could open up new development opportunities. Combining robots and three-dimensional printing could create new possibilities for small enterprises to overcome size limits in production and to conduct business – both cross-border and national – on a much larger scale.
- Robots are not yet suitable for a range of labour-intensive industries, leaving the door open for developing countries to enter industrialization processes along traditional lines. Garment-making has been a stepping stone in many cases of industrialization, supported by preferential market access conditions. An expansion of the trade preference programmes of developed countries – such as

by providing comprehensive coverage of duty-free and quota-free market access to labour-intensive exports from developing countries, combined with rules of origin that are simple to use and flexible in meeting producer needs – could prove crucial, especially for least developed countries, in order to benefit from China's shift towards a new growth model and to support initial stages of industrialization in these countries. Moreover, enhanced regional trade integration among developing countries could help them attain a market size that is sufficiently large for even affiliates of transnational corporations to forego reshoring and maintain production in these countries.

- Building a dense network of intra-sectoral and cross-sectoral linkages and complementarities could further stem the risk of reshoring, even as the cost of owning and operating robotics systems further declines and the scope of economically feasible automation gradually broadens, to also affect traditional, labour-intensive sectors such as garment-making. This requires enhanced public investment in logistics and telecommunications infrastructure and power and water utilities, as well as in a supportive technological environment and innovation system. Also needed are reliable supply networks that provide production inputs of the right quality at the right place and at the right time.All of the above policies must be undertaken within a whole-of-government approach that also guarantees macroeconomic stability and the availability of investment finance, adopts supportive industrial policy, pursues an industrialization strategy aimed at the deployment of automation technologies that boosts the upgrading of labour skills and the international competitiveness of firms, and that expands social safety nets and redistributive policies to address the adverse effects on employment and inclusiveness that will undoubtedly occur, at least in the short term.

8.8 Reasons for universal basic income

[Extracts from [35], pp 1-2]

From Mongolia to Finland to India, we are seeing heightened interest in the idea of a universal basic income (UBI)—an unconditional cash grant given to every citizen, regardless of their employment status or wealth. To sharpen the debate, it's useful to distinguish three separate arguments for UBI:

- Adjusting to labour-saving technologies
- Improving the welfare of the poor
- Efficient use of natural-resource rents

Adjusting to labour-saving technologies. Advances in artificial intelligence, robotics, and other technologies have called into question the future of work. The dilemma is that with these technologies productivity will increase but many people will lose their jobs (self-driving trucks are an example). Managing this transition is difficult from an economic, political, and moral viewpoint. A system where part of the increase in productivity is taxed, and then distributed as cash transfers to all citizens, whether they are working or not, could help resolve some of the tension. The programs being piloted or proposed in Finland, Switzerland, and New Zealand are essentially aimed in this direction. They challenge the basic notion that you earn your income by working in a job. While this notion has been around at least since the Industrial Revolution, perhaps it needs to be revisited in light of rapid changes in technology. We could envision a society where productivity is high enough that everyone receives a basic minimum income, and people choose to work on whatever they're good at (including not working at all).

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Annexure B: List of Initial Candidate STI Domains

#	Name	Description
1	Additive Manufacturing (or 3D Printing)	Additive Manufacturing is "the process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies, such as traditional machining." - ASTM definition
2	Advanced Energy Storage Technologies – batteries	Develop new battery technologies for energy storage based on vanadium or manganese
3	Advanced Energy Storage Technologies – alternatives	There are many forms of alternate green technologies such as new energy, however, the challenge is how to store energy that can be used as and when needed. Battery technologies are very costly and not a green solution, hence the need to identify alternative mass energy storage technologies.
4	Agricultural Biotechnology	The use of biotechnology tools to develop improved plants and microorganisms for specific agricultural applications. This includes the New Plant Breeding Technologies (NPBT, e.g. CRISPR/Cas9 genome editing, intragenesis, cisgenesis, etc.), molecular markers, molecular diagnostics, vaccine development and production, tissue culture micropropagation, etc.
5	Agro Processing	A subset of manufacturing that processes raw materials and intermediate products derived from the agricultural sector. Agro-processing thus means transforming products that originate from agriculture, forestry and fisheries.
6	Agro-processing, community health	Identifying the complementary medicines industries need for medicinal herbal plants (estimated value of the industry R3.8 billion in 2016), characterising plants with best activity / efficacy, identify areas they can be grown, develop community farms, processing, and quality systems for local and international markets.
7	Applied Analytical Chemistry	This discipline is required across most, if not all, of the STI domains listed. I propose a re-investment into this discipline and possibly the formation of a centralised government laboratory (NOT at the CSIR) to support STI activities, and other functions, across the country.

#	Name	Description
8	Artificial Intelligence and Machine Learning	The on-going industrial revolution towards full digitalisation of our approach of producing things, interacting with things, travelling and learning, etc. Three pillars will drive this new era: - Artificial Intelligence: Machine learning as a support for improving economic development - Cloud Robotics and Internet of Things (IoT): This is the key for Industry 4.0 revolution - Infrastructure to support digitalisation.
9	Big Data Analytics	Big Data Analytics refers to the analysis of large-scale data.
10	Biodiversity: Restoration and Protection of Biodiversity in the Human Footprint	Biodiversity refers to the variability among living organisms from all sources. This proposal recommends a focus on the restoration and protection of biodiversity in the anthropogenic domain, since biodiversity loss due to human activity has reached crisis proportions.
11	Biological Waste Conversion and Beneficiation	Millions of tons of biological waste are literally wasted in South Africa. A massive untapped economy exists through the beneficiation and conversion of this waste into new resources, energy, food and pure water.
12	BioMathematics (also called Mathematical Biology)	A branch of biology which employs theoretical analysis, mathematical models and abstractions of the living organisms to investigate the principles that govern the structure, development and behaviour of the systems, as opposed to experimental biology which deals with the conducting of experiments to prove and validate the scientific theories.
13	Blockchain in Agriculture	Across the Agriculture value chain there are various challenges that may be addressed by blockchain technology, which can provide a secure solution to assist government in improving governance within the agricultural domain. The technology is very secure by design, there is no need to store information with third parties.
14	Blue Economy	South Africa has more territory under the sea than above it. This STI speaks to sustainable development of the “Blue” economy through the provision of sound science and innovation. As identified by Operation Phakisa.

#	Name	Description
15	Cloud Robotics and Internet of Things	Industry 4.0 will change the way things are produced. It is mainly based on large automation with a support of large data exchange in manufacturing environments to improve the efficiency of production systems leading to the Smart Factory. Robotics will be the basis of several components, among them IoT, Intelligent manufacturing machines, as rapid prototyping, and more general cyber-physical systems in addition to the augmented reality platforms, cloud computing infrastructure and AI components.
16	Cognitive and Behavioural Neuroscience (Human & Social Dynamics)	According to NATURE, cognitive neuroscience is “the field of study focusing on the neural substrates of mental processes. It is at the intersection of psychology and neuroscience, but also overlaps with physiological psychology, cognitive psychology and neuropsychology. It combines the theories of cognitive psychology and computational modelling with experimental data about the brain”.
17	Community Health	Establishing ways to prevent diseases, of identifying the health problems and managing the physical and mental well-being of community members and ensuring that community members work together with health service providers to achieve the necessary goals and objectives.
18	Cooperative Agriculture 101	A working model for full cooperation between farmers (large scale and small), business (established and start-up, science councils, universities (focussing on crop yields) and government to dramatically increase production for local and export consumption of selected produce.
19	Coordination	There are a number of complex projects and a number of institutions in South Africa focusing on commercialising technology. A gap exists for better coordination.
20	CRISPR in Cancer Research	CRISPR/Cas9 is a recently developed technology which enables gene editing. CRISPR is being studied to see whether it can be used to repair genes that cause cancer. The first clinical trial started in 2016 and involved CRISPR editing of immune cells from people with lung cancer. In another clinical trial CRISPR is being used to alter T cells extracted from people with different kinds of cancer. At least 20 other trials are currently underway.

#	Name	Description
21	Design for the Circular Economy	The circular economy is where consumer products are designed to circulate through the economy repeatedly, and not to report to landfill. Looking beyond the current "take, make and dispose" extractive industrial model, the circular economy is restorative and regenerative by design. The circular economy aims to redefine products and services to design waste out, while minimising negative impacts.
22	Distributed Energy Infrastructure	Exploring options to develop wireless high voltage power distribution in power stations and/or power plants. Also research in wireless high voltage power transmission throughout the country.
23	Domestic Solar Water Heating	Remove the domestic water heating load from the electricity grid.
24	Economy Digitalisation and Telecommunication Infrastructure	The transformation of telecommunication infrastructure is central to the digitalisation of the economy. This transformation will concern the “softwarisation” of the telecommunication infrastructure and services to support the traffic and services demand from other sectors. Virtualisation is the main pillar.
25	Educational Technology (Ed-Tech)	The use of emerging technologies (e.g. AI/ML, VR, IoT, networking, data science) to enhance access to learning and improve learning outcomes, improve the efficiency and effectiveness of the SA education sector, across the primary, secondary, tertiary and continuing adult education sectors in South Africa.
26	Efficient Energy Use	I am proposing to innovate a fuzzy logic geyser control consisting of artificial intelligence.
27	Efficient Nutrient Use	Efficient nutrient use generally refers to the use of nitrogen fertilisers in agriculture. Fertilisers represent a significant input cost in agriculture yet most of the fertilisers applied are lost before it can be used by the plant (up to 70% depending on the crop). Ensuring efficient uptake and use of applied fertilisers are critical not only to reduce costs but also to protect the environment.
28	Efficient Water Use	Reducing *water* wastage by measuring the amount of *water* required for a particular purpose and the amount of *water used* or delivered. *Water efficiency* differs from *water* conservation in that it focuses on reducing waste, not restricting *use*.

#	Name	Description
29	Harnessing Data Science for Socio-Economic Innovation and Development	The main focus of “Big Data” seems to be on “Data-Intensive Research”. We propose a multidiscplinary approach to activities across a broad spectrum. From fundamental research in mathematics, statistics and computational sciences to development of tools and technologies that will unearth new insights and to applications of these, including innovations that can improve the quality of life of our people.
30	Health technology for development	The use of technology to improve health in low resource settings and developing countries, by addressing the particular needs of these contexts.
31	Health Data Analytics	Information that would be used by the health department, hospitals, private sector, health suppliers, health manufacturers, communities and citizens to bring about a disruptive change in the South African health organisations to positively address health challenges in South Africa.
32	Higher Education in the Era of Artificial Intelligence	We need to prepare future graduates for a world in which AI and AI-assisted technology plays an increasingly dominant role. The best strategy is to teach skills that make humans human, rather than training students to outcompete new technologies.
38	Horticultural Exports	Increasing the volumes and types of horticultural products exported from South Africa to lucrative markets.
39	Humans and Machines in the Workplace	This domain includes aspects of Industry 4.0, artificial intelligence, digitalisation, automation, the algorithm economy and relates to how humans and intelligent machines will co-learn, co-work and form partnerships and relationships.
40	ICT for Water-Related Citizen Science	Water related citizen science is the domain that includes smartphones, Google Earth Outreach and cell phone banking applications to monitor, evaluate and reward citizen science activities related to water, in poor urban communities.
41	Innovation for a Green or Greener Economy	“Green(er) Economy” refers to the promotion of innovation in the country’s economic activities, such as the production, distribution and consumption of goods and services, which result in improved human well-being without exposing future generations to environmental risks and ecological scarcities.

#	Name	Description
42	Integrative Design-Led Systems Thinking (IDLST) for the 4th Industrial Revolution	In order to respond to the 4IR we need the ability to use integrative design thinking, systems thinking and formal systems engineering processes to craft differentiated, sustainable, impactful and economically beneficial solution to African opportunities, using diverse component parts or sub-solutions. This brings together traditional systems engineering disciplines with integrative systems thinking and the perhaps “faddish” concept of design thinking, in a skills-enabled, structured, capacitated, and methodical approach.
38	Mathematical Modelling and Computer Simulation	Mathematical modelling and computer simulation
39	Mechanobiology	Mechanobiology deals with processes (e.g. mechanosensing and mechanotransduction) through which cells receive mechanical cues from their environment and act on these cues, e.g. through autocrine and paracrine biochemical signalling, the reorganisation of the cytoskeleton and cell migration. These processes at cellular and subcellular level play crucial roles in development and disease.
40	Modelling and Simulation for Human Health (MSHH)	Use of statistical and dynamical models to improve decision-making in clinical medicine and public health. Importantly, MSHH can provide insights when many complex factors interact, e.g., how to escape so-called poverty traps, which are much harder to understand without these tools.
41	Molecular Farming Biotechnology	Plants are the most cost-effective vehicles for production of complex biologics for preventing infectious disease, and making therapeutics and diagnostic reagents.
42	Nanomaterials	Nanomaterials describe, in principle, materials of which a single unit is sized (in at least one dimension) between 1 to 1000 nanometres (10^{-9} meter) but usually is 1 to 100 nm
43	New Agriculture	New crops on new substrates, new producers.
44	New Applications for Platinum Group Metals	New applications for platinum group metals
45	Next Generation Innovation Labs	These are innovation labs that seek to plug into the current entrepreneurial ecosystem of hubs in major cities to provide university students with access to resources to better equip themselves with skills by helping entrepreneurs build the technological prototypes they require.

#	Name	Description
46	Nutrition and Food Security	When food becomes scarce, hygiene, safety and nutrition are often ignored. Poor quality diets have become the single most important factor in the global burden of disease. Food security rests on consistent access to sufficient, safe nutritious foods to meet dietary needs for everyone.
47	Nutrition Security	Nutrition security is the state of having reliable access to a sufficient quantity of affordable, safe and nutritious food to meet their dietary needs for an active and healthy life.
48	Online University (meUniversity of South Africa) - MOOC (Massive Open Online Course)	Online learning similar to, for example, edX, Coursera, Khans's Academy and Udemy.
49	Optimal Design and Use Of New Materials for Low Cost Housing	A mission to establish an optimal configuration for low cost housing utilising new materials and design expertise.
50	Palaeosciences	Palaeoscience is a unique discipline in that it incorporates numerous fields such as palaeontology, palaeoanthropology, archaeology, palaeoenvironments, palaeoclimates, palaeobiology, palynology, palaeopedology etc.
51	Photonics	Photonics is the science of the harnessing of light. Photonics encompasses the generation of light, the detection of light, the management of light through guidance, manipulation, amplification, for utilisation for the benefit of mankind.
52	Post-Capitalism and the Emergence of a New Political Economy	This STI domain would need to converge research from Politics, Economics, Sociology, and Philosophy to better understand changes within the construction of a national democratic society with the global changes in how civil society is organised and represented.
53	Precision Agriculture	Precision Agriculture is a farming management concept that is underpinned by the convergence of emerging digital technologies directed at improving efficiencies related to agricultural land use. The concept is based on risk management principles aimed at maximizing/optimizing return on inputs and investment and preservation of scarce resources generally impacted by crops variability.
54	Precision Medicine	The use of new technologies in molecular medicine that take into consideration individual's variability to ensure that a patient gets the right treatment at the right time for the best health outcome.

#	Name	Description
55	Precision Public Health or Big Health Data	Africa severely lacks detailed epidemiological data tracking populations over time, hence making it difficult to apply new precise initiatives or technologies to improve the dire health situation. This applies to the growing burden of non-communicable diseases (cardiovascular disease, diabetes, obesity), but also to rapid outbreaks of infectious diseases (e.g. Ebola).
56	Prevention of Cervical Cancer	Over the past 60 or so years, cancer of the cervix in well-resourced countries has been prevented through the use of the Pap smear, which is able to detect abnormalities on the skin of the cervix and once removed prevents these abnormalities from progressing to cervical cancer. Cervical cancer is the second commonest cancer among women in South Africa.
57	Public Health (Related to Climate Variability & Change)	To consider the implications of changes to climate variability (intensification of seasonal extremes) and the impact on climate change on public health and the public health system.
58	Rain-fed agriculture	Following the Brazil-EMBRAPA conversion of cerrado into cropland, do similar in the valleys of E Cape and KZN.
59	Residential Solar Generated Electricity Available for the Grid	We have smart meters capable of controlling supply of urban residential generated electricity to the grid and hectares of sun-drenched roofing to do the generation.
60	Space Applications for Sustainable Socio-Economic Development	Space technology, products and services has and continues to contribute to sustainable development and offers many benefits to the country. Space-derived services (e.g. earth observation, satellite communications, navigation and positioning, and space science), are increasingly being used as decision-making tools for policy choices. This is a good example of “Science for Policy”
61	Sustainable Energy	The whole network of sustainable (renewable) energy from harvesting solar, wind and bio energy through storage and distribution.
62	The Education System’s Use of ICTs	The education system is seen as: Primary, Secondary, Tertiary education institutions, as well as employer-driven and life-long education processes, and their use of ICT to support the new ways of learning that are made possible (e.g. use of virtual and augmented reality applications).

#	Name	Description
63	Tourism	South Africa has an abundance of fauna and flora together with cultural and historic resources which are greatly underutilised.
64	Transport - Mobility-As-A-Service	Transport is undergoing massive transformations – electric vehicles; pooling and sharing; driverless vehicles etc. The old paradigm of private vehicle ownership is fast disappearing To effectively diffuse the new technologies, a systemic approach is needed which includes issues such as infrastructure, urban planning, public works, regulatory issues and others.
65	Transport Infrastructure – 1	Consists of the fixed installations, including roads, railways, airways, waterways, canals and pipelines and terminals such as airports, railway stations, bus stations, warehouses, trucking terminals, refuelling depots (including fuelling docks and fuel stations) and seaports
66	Transport Infrastructure – 2	Transport infrastructure refers to the framework that supports our transport system. This includes roads, railways, ports and airports.
67	Waste Disposal	Improved furnace treatment of waste streams
68	Water and Agriculture – 1	Designing new agricultural systems and optimising existing agricultural systems to reduce water use in agriculture.
69	Water and Agriculture – 2	The efficient and judicious use of water resources to enhance smallholder agricultural production in the previously disadvantaged areas of the country.
70	Water and Energy Optimization: Water-Energy Nexus in Industry	Considers design, synthesis and optimization of chemical processes with an objective to minimise water and energy use. Both continuous and batch chemical processes are considered.
71	Water and Natural Ecosystem Services	Fresh water comes from living ecosystems such as rivers and wetlands. These ecosystems provide billions of Rands of ecosystem services to the economy. It is essential that South Africa maintains its research into how these water resources are best managed in a sustainable manner.
72	Water Quality and Wastewater Management	While almost all South Africans residing in metropolitan areas are provided with high quality drinking water through piped infrastructures, many rural communities still depend on untreated ground or surface water sources or inadequately treated water as their daily water supply. Integrated management of water and wastewater should therefore be adopted in order to avoid the ripple effect on the environmental, social and economic growth.

#	Name	Description
73	Water Recycling	Treat water for re-use instead of disposal after first use and pollution of subsequent surface and underground water streams.
74	Agro-processing industry 4.0	This domain will consider the application of so-called Industry 4.0 principles to agro-processing industries to enhance efficiencies and reduce costs.
75	Biobanking, genebanking	Bioethics will undergo huge revision in the age of big data. How will personal information and biological material be protected. The ethical aspects of mining of big data sets, of developing predictive medicine from human data, and exploitation of human big data.
76	Biomass beneficiation	Beneficiation of agricultural residues and alien vegetation to valuable energy and fibre-based products.
77	Discovery and sustainable management of earth resources	The discovery and sustainable management of metal, mineral, energy and groundwater resources is vital to meet the needs of South Africa's growing population in the context of rapid social, technological and climatic change.
78	Functional ecology for land stewardship	This domain studies how ecosystems work, on land and associated water systems. It underpins all-natural resource management, ecosystem service supply and most of the responses to climate change. It encompasses ecosystem ecology and ecophysiology, and increasingly social-ecological studies.
79	Single use plastic	Plastic is choking our planet, destroying our waterways and oceans and decimating the animals that live in them. Microparticles of plastic, the result of the partial degradation of plastic that enters the environment, are now in our food and drinking water and therefore in us. Particularly damaging are the polymers that have been created by joining organic, plant-based materials to petroleum-based materials.
80	Sustainable agriculture and food security	This STI domain would focus on science-based pathways to agriculture that are productive, climate-smart, and sustainable in the long-term (from an environmental, social and economic perspective) so as to provide access to safe, affordable and nutritious food, all of the time to all people.

Annexure C: List of Candidate STI Domains produced by the First Workshop

#	Name of Candidate STI domain
1	Accelerated digitisation for the smart economy
2	Agriculture and climate for health and nutrition security
3	Automation technology for manufacturing processes
4	Big data and block chain for planning
5	Biodiversity: Restoration and protection of biodiversity in the human footprint
6	Border control – object detection
7	Broadband infrastructure SMME development
8	Capable state – e.g. freedom of movement, professionalism
9	Circular economy
10	Commercialise scientific IP framework
11	Crime detection and ICTs
12	Developing entrepreneurial opportunities
13	Digital incubators for skills development
14	E-Governance and integrated identity systems
15	Educational technology and skills transfer
16	Energy efficiency
17	Foundation for learning and skills of the future
18	Health technology for development
19	Human and social dynamics
20	ICT for citizen science in the water, energy, biodiversity and urban agriculture space
21	ICT for crime prevention
22	ICT Infrastructure for addressing the digital divide (inclusivity)
23	Indigenous Knowledge Systems for artisans and oral traditions
24	Infrastructure for smart cities and villages

#	**Name of Candidate STI domain**
25	Infrastructure in rural areas
26	Integrated rural economy
27	Leveraging resources for sustainable development
28	Maintenance and upgrading of natural resources
29	Next-generation innovation labs
30	Population health
31	Recycled waste for building
32	Regulation of the Internet
33	ReNEWing the NSI for societal development
34	Re-thinking governance using e-technology
35	ROBOCOP – e.g. surveillance, biometric identification
36	Rule-based society
37	Serious gaming for town planning
38	Spatial planning for resilience
39	Systemic human centred design learning imperatives for STI
40	Technology requirements for learning for STI
41	Transport for seamless access
42	Value adding industry for rural areas
43	Virtual Reality and AI for wellness (education)
44	Water security
45	Water, energy, food and chemicals nexus

Annexure D: Candidate STI Domains for Web-Based Voting

The following STI domains were published on the website. Stakeholders were invited to vote for those which in their view were the most important for the foresight exercise.

	STI Domain Name	Notes
V01	Nutrition security for a healthy population	Emphasising agriculture, including the impact of climate change
V02	Precision agriculture	Farming management to optimise return on inputs and investment and preserve scarce resources based on the convergence of digital technologies
V03	Agro-processing	Processing products from agriculture, forestry and fisheries
V04	Agro-processing, in the context of Indigenous Knowledge	Identifying and processing indigenous flora and fauna for medical and other uses, based on indigenous knowledge
V05	Biodiversity: Restoration and protection of biodiversity in the human footprint	Loss of biodiversity is accelerating due to human activity. Biodiversity forms the foundation of ecosystem services to which human wellbeing is intimately linked
V06	The circular economy	Generate products which are restorative and regenerative by design, and which circulate through the economy repeatedly, thereby avoiding waste.
V07	Waste conversion and beneficiation	Convert biological and non-biological waste into new resources and materials
V08	Advanced manufacturing systems	Including technologies such as robotics, artificial intelligence, IoT and additive manufacturing
V09	The blue economy	The ocean economy, considering at least marine transport and manufacturing, offshore oil and gas exploration, and aquaculture
V10	Health technology to prevent ill-health and advance the well-being of those who are marginalised	Strategies to prevent ill-health through a range of approaches, including big data analytics
V11	Health technology to resolve and manage disease amongst the marginalised	Including technologies such as big data analytics in conjunction with emerging technologies such as CRISPR/Cas9

	STI Domain Name	Notes
V12	Indigenous Knowledge Systems to build sustainable livelihoods	Includes IKS for artisans, and for oral traditions
V13	Affordable technologies for basic infrastructure in rural areas	Such as for water resources, building houses, farming, dealing with waste, and energy resources
V14	Technologies and mechanisms for developing value-adding industries in rural areas	Addresses non-agricultural industry
V15	Smart technologies for agriculture and rural communities	Including technologies such as big data, block chain and drones
V16	Smart technologies for town and land use planning	Including technologies such as big data, block chain, drones and gaming technologies
V17	New approaches to learning based on cognitive neuroscience	For entrepreneurs, the classroom, the workplace, teaching STIs, etc. Also addressing social aspects
V18	Technology for education and learning	Enhance access to learning and improve learning outcomes through applying technologies
V19	Sustainable energy technologies for the marginalised	Affordable, implementable, maintainable technologies, considering at least the harvesting of solar, wind and bio energy, as well as storage and distribution options
V20	Advanced energy storage technologies	Develop new, green technologies for energy storage
V21	Reducing the pressures of the water-energy nexus	Maximising energy production, while minimising water and energy use
V22	Integrated solutions for water security	Including reducing water wastage, pollution of water, usage of water
V23	Re-thinking governance using e-technology	Including technologies such as big data analytics, block chain, gaming technologies and drones
V24	Smart technologies for crime prevention and detection	Covering a range of approaches and applications including robotic surveillance and intervention, and object detection for border control

	STI Domain Name	Notes
V25	Transport technologies for seamless movement of people and goods	Addressing the full range of modes of transport, including road, rail, sea and air
V26	Digitisation for the smart economy	Optimise the efficiency of the operations and services of human settlements, and connection to their citizens
V27	New materials for low-cost housing	
V28	Processes and digital technologies for citizen science	Citizen science: the collection and analysis of data relating to the natural and built environment by members of the public, in collaboration with professional scientists
V29	Space applications for sustainable socio-economic development	Considering at least earth observation, satellite communications, navigation and positioning, and space science, for use for analysis and decision-making
V30	Innovative use of strategic mineral resources	Including, for example, the platinum group metals
V31	New mechanisms for supporting innovation and entrepreneurship	Considering options such as next generation innovation labs

Annexure E: Shortlist of Candidate STI Domains

The following are the top thirteen candidate STI Domains based on the web voting. The column V% indicates the percentage of the vote received by the candidate Domain.

#	V#	V%	STI domain	Description/notes
1	V01	36%	Nutrition security for a healthy population	Emphasising agriculture, including the impact of climate change
2	V02	28%	Precision agriculture	Farming management to optimise return on inputs and investment and preserve scarce resources based on the convergence of digital technologies
3	V05	29%	Biodiversity: Restoration and protection of biodiversity in the human footprint	Loss of biodiversity is accelerating due to human activity. Biodiversity forms the foundation of ecosystem services to which human wellbeing is intimately linked
4	V06	30%	The circular economy	Generate products which are restorative and regenerative by design, and which circulate through the economy repeatedly, thereby avoiding waste.
5	V07	30%	Waste conversion and beneficiation	Convert biological and non-biological waste into new resources and materials
6	V08	27%	Advanced manufacturing systems	Including technologies such as robotics, artificial intelligence, IoT and additive manufacturing
7	V09	26%	The blue economy	The ocean economy, considering at least marine transport and manufacturing, offshore oil and gas exploration, and aquaculture
8	V10	28%	Health technology to prevent ill-health and advance the well-being of those who are marginalised	Strategies to prevent ill-health through a range of approaches, including big data analytics
9	V13	27%	Affordable technologies for basic infrastructure in rural areas	Such as for water resources, building houses, farming, dealing with waste, and energy resources
10	V18	29%	Technology for education and learning	Enhance access to learning and improve learning outcomes through applying technologies

#	V#	V%	STI domain	Description/notes
11	V19	27%	Sustainable energy technologies for the marginalised	Affordable, implementable, maintainable technologies, considering at least the harvesting of solar, wind and bio energy, as well as storage and distribution options
12	V22	35%	Integrated solutions for water security	Including reducing water wastage, pollution of water, usage of water
13	V31	25%	New mechanisms for supporting innovation and entrepreneurship	Considering options such as next generation innovation labs

Annexure F: STI Thrust Proposal Outlines

STI Domain	#	STI Thrust
Circular Economy	CE1	Reducing, reusing and recycling waste
	CE2	Ensuring sustainable water, energy and food (agriculture) security.
	CE3	Low-carbon and climate-resilient economy
	CE4	Smart connectivity (Human Machine Interface) and mobility in communities
Education	ED1	Skills for the 4th Industrial Revolution
	ED2	Inclusive innovation and development
	ED3	Curriculum development 2030
Energy	EN1	Clean, affordable and sustainable energy for all
	EN2	Renewable energy sources and technologies
	EN3	Energy efficiency solutions for industry plus household use
	EN4	Distributed energy generation and storage
Future of Society	FS1	Policies and Indicators for STI in a changing South African society
	FS2	STI for inclusive, people-led development
Health	HE1	Optimisation of health systems
	HE2	Improving the quality of healthcare
	HE3	Digitisation of health systems
High-Tech Industry	HT1	Enabling small business to adopt high tech
	HT3	New thinking for new industries
	HT4	New thinking for old industries
ICTs	IT1	Checks and balances for a digital future
	IT2	ICT infrastructure and Internet access
	IT3	Big data, data analytics and decision support
	IT4	Smart and sustainable municipal service delivery
Nutrition	NU1	Zero impact agriculture
	NU2	Use and acceptance of modern biotechnology
	NU3	Personalised information for healthy nutrition for all
	NU4	Precision and big data in agri-businesses
Water	WA1	Future-oriented Water and Sanitation Solutions
	WA2	Embedding the Water Sector in the Fourth Industrial Revolution (4IR)
	WA3	Off-grid and decentralised water, wastewater and sanitation solutions

STI Thrust Proposal – CE1

Working group	
Name of STI domain / working group	Circular Economy

1. Title and description of STI Thrust	
Title of Thrust (Eight words or less)	Reducing, reusing and recycling waste
Summary description Provide a brief description of the Thrust so that we can be sure we understand what you are referring to. (Just a few sentences)	• The development and deployment of performance improvements in waste management has delivered a significant contribution to the strengthening of a sustainable, regional secondary resources economy in South Africa. • This applies to a range of waste streams including – mining, agri/food, human waste, e-waste, etc.
2. Results – Description	
Problems to be addressed What are the problems which the Thrust is intended and is likely to address by 2030?	Maximisation of diversion of waste from landfill towards value-adding opportunities, including prevention of waste and the optimised extraction of value from reuse, recycling and recovery, in order to create significant social, economic, and environmental benefit
Outputs What are the likely outputs of the Thrust by 2030? (The outputs are the immediate results of the Thrust)	• Decision-making and planning informed by robust modelling and analytics (business models, socio-economic environmental modelling, impact assessments, etc). • Effective waste logistics system (well designed network, planning and management systems, operational logistics and processes). • Well management intersection between waste and the environment (including impacts on water, land, atmosphere, climate change). • Appropriate technology solutions (performance optimization, technology development, technology evaluation evaluation and demo, technology localisation, including resource recovery). • Sensitively managed waste/society nexus (behaviour, awareness, health, business practice, jobs and labour).
Outcomes and impact What are the likely outcomes and impact of the Thrust? What is the value of the outcomes and impact, and when are they likely to manifest? (The outcomes and impact are the medium-term and long-term results of the Thrust, respectively)	• More effective decision-making • Faster insertion of context-appropriate technology • Export of know-how and technology • Strengthened RDI capability and capacity

<table>
<tr><th colspan="2">3. Results – Alignment and scope</th></tr>
<tr><td>Alignment with NDP vision
To what extent is the Thrust aligned with the vision of the NDP? Please specify:
• Fully aligned
• Mostly aligned
• Partially aligned
• Poorly aligned

Please explain your choice.

In other words, how will the Thrust contribute, both directly and indirectly, towards eliminating poverty, reducing inequality and increasing employment?

Please distinguish clearly between direct and indirect contributions.</td><td>Fully aligned

• Creating jobs and livelihoods
• Expanding infrastructure
• Transitioning to a low carbon economy
• Transforming urban and rural spaces
• Improving education, training and innovation</td></tr>
<tr><td>Scope of the benefits
What is the scope of the benefits of the results which the Thrust is likely to have, by 2030? Please specify:
• Very broad scope
• Broad scope
• Medium scope
• Narrow scope

Please explain your choice. Who will benefit? How many people will benefit (order of magnitude estimate)? In what way will they benefit?</td><td>Broad scope – all people and industries including government produce waste

• Medium scope – Focus on a particular sector/area.
• The society at large, including the government, as they don’t have to deal with waste piling up at landfill sites.
• There will be new jobs created from recycling of wastes.
• Policy implementation will enable the broader participation by the society at large.</td></tr>
<tr><th colspan="2">4. High-level implementation</th></tr>
<tr><td>High-level steps
What are the high-level interim objectives or milestones which need to be achieved?
What are the high-level activities/steps/ stages needed to achieve the objectives/milestones?
In other words, what are the high-level steps required to deliver on the outputs, outcomes and impact mentioned above?</td><td>• Implement the Waste RDI Roadmap
(Taken from the strategic framework of the Waster RDI Roadmap)
▪ Strategic planning: Build and strengthen the basis and application of strategic analysis and advice for the purposes of evidence-based decision-making to inform strategy formulation, planning and its execution and management.
▪ Modelling and analytics: Develop and use methods, tools, techniques, platforms, systems and frameworks for the analysis, monitoring and evaluation of technical, economic, social and environmental opportunities and impacts associated with secondary resources.
▪ Technology solutions: Design, development, evaluation, demonstration, localisation and deployment of</td></tr>
</table>

	technologies – both local and inbound – for customer-driven performance improvement. ▪ Waste logistics performance: Optimisation of strategic, tactical and operational decision-making in respect of logistics objectives, assets and resources. ▪ Waste and environment: Strengthen the ability to identify, monitor, evaluate and report on environmental impacts of waste and its management, in order to inform better targeted and more effective responses. ▪ Waste and society: Deepen understanding of waste-related opportunities and threats, to increase the success of influencing perception and practice positively. • Ensure synergy between DEA policy and strategy and waste related planning and RDI • Monitoring & evaluation of policy implementation.
Resources required What are the resources which are required to achieve the outputs, outcomes and impact? Examples of such resources can include: • Knowledge and expertise • Technologies • Technical infrastructure • Institutional infrastructure • Research results • Partnerships established • Funding	• Price tag on waste RDI roadmap over a 10 year period is approximately R5 billion. • Investment in training and skills development. • Setting up of facilities for waste recycling including the collection points. • Development of technologies for treatment of waste. • Funding for R & D which includes having the skills and researchers.
Resources to be established Which of the required resources are already established? Which need to be established, and what will be needed to establish them? For example, what STI-related research will be needed to achieve the intended results of the Thrust?	• Investment in training and skills development. • Setting up of facilities for waste recycling including the collection points. • Development of technologies for treatment of waste. • The RDI roadmap. • Draft DEA policy.
Policy and regulatory environment What changes are required, if any, to the current STI policy and regulatory environment? What new policy and regulatory provisions, if any, will the Thrust require?	• Approval of the DEA policy. • M & E of the policy implementation.

5. Risk	
Risk of not achieving results Explain the level of difficulty involved in achieving the intended results. Please specify: • Straightforward to achieve • Fairly difficult to achieve • Moderately difficult to achieve • Very difficult to achieve. Please explain your choice. What are the anticipated obstacles and challenges, and what is the likelihood of their being overcome? What are the risks associated with not achieving the intended results of the Thrust?	• The risk of not achieving the thrust will results with the collapse of the management of waste processes. • Straight forward to achieve – policy approval & implementation. • Fairly difficult to achieve – M & E of policy implementation. • Moderately difficult to achieve – willingness to get a buy in. • Very difficult to achieve – society buy in including industries in the adherence to policy implementation.
Social and ethical acceptability How ethically and socially acceptable is the Thrust? Specify: • Highly acceptable • Mostly acceptable • Fairly unacceptable • Mostly unacceptable Please explain your choice.	Highly acceptable
Unintended consequences Are there unintended consequences that may result from the Thrust? Explain the level of risk of these possible consequences.	None known.
6. Other	
Other information Is there any other information which you wish to provide to support this Proposal for a Thrust?	This is critical to ensure that our environment is sustained for a very long time.

STI Thrust Proposal – CE2

Working group	
Name of STI domain / working group	Circular Economy

1. Title and description of STI Thrust	
Title of Thrust (Eight words or less)	Ensuring sustainable water, energy and food (agriculture) security.
Summary description Provide a brief description of the Thrust so that we can be sure we understand what you are referring to. (Just a few sentences)	Food, water and energy security form the basis of a self-sufficient economy in South Africa. The water, energy and food security nexus means that water security, energy security and food security are inextricably linked and that actions in any one area usually have impacts in one or both of the others. Climate change will also have serious implications for the supply of food, energy and water.
2. Results – Description	
Problems to be addressed What are the problems which the Thrust is intended and is likely to address by 2030?	A possible crisis in any of the three systems will directly affect the other two and that such a crisis may be imminent as the era of inexpensive food draws to a close. Thus by 2030 this problem needs to be addressed.
Outputs What are the likely outputs of the Thrust by 2030? (The outputs are the immediate results of the Thrust)	Outputs/Activities: • Shift towards and more integrated, cross sectoral governance, planning and management paradigm – land management, access to resources, equity are big drivers in this conversation. • Intersectoral 'business model' for collaboration • Waste re-use – mine, agriculture, human, e-waste, battery, food etc (as it links to energy production, food security, water efficiency) • Appropriately targeted resource recovery technologies, • Water – unlocking alternative sources (reuse included), improved built infrastructure innovation, efficiency, more innovative monitoring and metering • Energy – renewables, storage, grids, re-use, recycling • Agriculture – precision farming, drip irrigation, permaculture, drought resistant crops.
Outcomes and impact What are the likely outcomes and impact of the Thrust? What is the value of the outcomes and impact, and when are they likely to manifest? (The outcomes and impact are the medium-term and long-term results of the Thrust, respectively)	Water security - access to safe drinking water and sanitation. Responsible use of water, reuse and recycling. Energy security - access to clean, uninterrupted, reliable and affordable (renewable) energy for cooking and heating, lighting, communications and productive uses at a price which is affordable to all South Africans while respecting environmental concerns. Food security - availability and access to sufficient, safe and nutritious food to meet the dietary needs of all South Africans for an active and healthy lifestyle.

<table>
<tr><th colspan="2">3. Results – Alignment and scope</th></tr>
<tr><td>Alignment with NDP vision
To what extent is the Thrust aligned with the vision of the NDP? Please specify:
• Fully aligned
• Mostly aligned
• Partially aligned
• Poorly aligned

Please explain your choice.

In other words, how will the Thrust contribute, both directly and indirectly, towards eliminating poverty, reducing inequality and increasing employment?

Please distinguish clearly between direct and indirect contributions.</td><td>Fully aligned

From the NDP 2030:
• Economy infrastructure – The foundation of social and economic development
  o Access to basic electricity, water and sanitation, and public transport
  o The energy sector: empowering south Africa
  o Water resources and services
• Environmental sustainability - An equitable transition to a low-carbon economy
  o Responding effectively to climate change</td></tr>
<tr><td>Scope of the benefits
What is the scope of the benefits of the results which the Thrust is likely to have, by 2030? Please specify:
• Very broad scope
• Broad scope
• Medium scope
• Narrow scope

Please explain your choice. Who will benefit? How many people will benefit (order of magnitude estimate)? In what way will they benefit?</td><td>Very broad scope

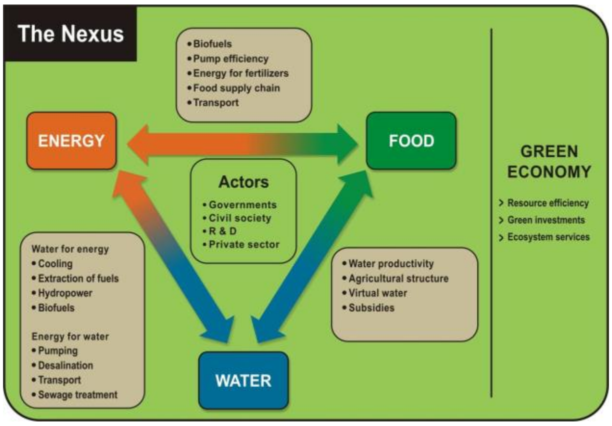
Entire country would benefit and not just a specific area or community. >60 million people.</td></tr>
<tr><th colspan="2">4. High-level implementation</th></tr>
<tr><td>High-level steps
What are the high-level interim objectives or milestones which need to be achieved?
What are the high-level activities/steps/ stages needed to achieve the objectives/milestones?

In other words, what are the high-level steps required to deliver on the outputs, outcomes and impact mentioned above?</td><td>Develop a roadmap, taking into account the following:
• Involve stakeholders and experts from the water, energy and agriculture sectors, including government, civil society, research and the private sector
• Address energy/food issues such as biofuels, pump efficiency, energy for fertilizers, food supply chain, transport
• Address water for energy issues such as cooling, extraction of fuels, hydropower, biofuels
• Address energy for water issues such as pumping, desalination, transport, sewage treatment
• Address water/food issues such as water productivity, agricultural structure, virtual water, subsidies
• Identify who is involved in the roadmap and what exactly their roles are.</td></tr>
<tr><td>Resources required</td><td>Resources:</td></tr>
</table>

<table>
<tr>
<td>What are the resources which are required to achieve the outputs, outcomes and impact?

Examples of such resources can include:
• Knowledge and expertise
• Technologies
• Technical infrastructure
• Institutional infrastructure
• Research results
• Partnerships established
• Funding
• Etc</td>
<td>• Funding
• Knowledge and expertise in water and water technologies, energy and energy technologies, agriculture and agricultural technologies, and the interaction between the three
• Collaboration amongst government departments (Water, Energy, Agriculture, Science Councils etc)
• R&D – Technologies and Processes
• Public Private Partnerships</td>
</tr>
<tr>
<td>Resources to be established
Which of the required resources are already established?
Which need to be established, and what will be needed to establish them?

For example, what STI-related research will be needed to achieve the intended results of the Thrust?</td>
<td>There are already programmes established and funded by the DST in the areas of water, energy, food and agriculture.

Areas that research needs to be done on include:


</td>
</tr>
<tr>
<td>Policy and regulatory environment
What changes are required, if any, to the current STI policy and regulatory environment?

What new policy and regulatory provisions, if any, will the Thrust require?</td>
<td>The Draft 2018 White Paper on Science, Technology and Innovation already in place.

2016/17 Waste RDI Roadmap exists

The challenge however is that Science Councils, Academia and Industry are still working in silos. This will need to change,</td>
</tr>
<tr>
<td colspan="2">5. Risk</td>
</tr>
<tr>
<td>Risk of not achieving results
Explain the level of difficulty involved in achieving the intended results. Please specify:
• Straightforward to achieve
• Fairly difficult to achieve
• Moderately difficult to achieve
• Very difficult to achieve.
Please explain your choice.

What are the anticipated obstacles and challenges, and</td>
<td>Fairly difficult to achieve

Obstacles:
• Cannot be business as usual!
• New thinking, new materials and new understanding of how things work and are to be done.
• The food sector part of the nexus is perhaps simplest to comprehend but the interdependence between water and energy is far more complex.
• Availability of data

Risks:</td>
</tr>
</table>

what is the likelihood of their being overcome? What are the risks associated with not achieving the intended results of the Thrust?	• A possible crisis – i.e. insufficient (or too expensive) water, energy and food for South Africans in 2030.
Social and ethical acceptability How ethically and socially acceptable is the Thrust? Specify: • Highly acceptable • Mostly acceptable • Fairly unacceptable • Mostly unacceptable Please explain your choice.	Mostly acceptable. It's imperative that this be done but people would need to be educated (especially in rural and marginalised communities) to understand its importance and what role they can play and how it will benefit.
Unintended consequences Are there unintended consequences that may result from the Thrust? Explain the level of risk of these possible consequences.	Competition amongst those that have these resources available i.e. water, energy etc Could result in shortages in water, energy or food and hence increases in prices, and hence increases in levels of poverty.
6. Other	
Other information Is there any other information which you wish to provide to support this Proposal for a Thrust?	

STI Thrust Proposal – CE3

Working group	
Name of STI domain / working group	Circular Economy

1. Title and description of STI Thrust	
Title of Thrust (Eight words or less)	Low-carbon and climate resilient economy
Summary description Provide a brief description of the Thrust so that we can be sure we understand what you are referring to. (Just a few sentences)	Decarbonising the economy is a cross-cutting thrust that must be achieved within and between other CE thrusts. This thrust must move the economy from high carbon to carbon neutral, via climate change mitigation efforts that promote synergies between environmental and socio-economic sustainability. In addition, climate change adaptation efforts must improve the climate change resilience of the economy. This involves investing in and promoting ecological infrastructure, such as, for example, indigenous forests (carbon sinks), wetlands (flood mitigation) and various other types of ecological infrastructure that provides climate resilience of the economy but specifically for marginalised communities.
2. Results – Description	
Problems to be addressed What are the problems which the Thrust is intended and is likely to address by 2030?	Direct: The economy's addiction to fossil fuels and unsustainable GHG emissions, climate change and climate change vulnerability. Indirect: Poverty, inequality and unemployment
Outputs What are the likely outputs of the Thrust by 2030? (The outputs are the immediate results of the Thrust)	- (30%?) reduction in carbon emissions across the country - (10%?) increase in urban forest cover; (20%?) increase in rural forest cover (without threatening biodiversity in Savanah biomes etc.) - Critical ecological infrastructure has been identified and restored within urban and rural areas
Outcomes and impact What are the likely outcomes and impact of the Thrust? What is the value of the outcomes and impact, and when are they likely to manifest? (The outcomes and impact are the medium-term and long-term results of the Thrust, respectively)	- The environmental outcomes of decarbonising the economy are long-term and difficult to say when they are likely to materialise. These include more stable and moderate weather conditions/events. - There is a reduction in unemployment, poverty and inequality due to the creation of new low-carbon jobs across the economy. - Improved resilience to natural disasters of marginalised communities also contributes to poverty and inequality reduction (or at least stabilisation). - Impacts of floods and droughts begin to stabilise due to improvement of ecological infrastructure, which also begins to contribute to increase biodiversity and healthier urban and rural ecosystems.

	- Reduction in air and water pollution related health impacts.
3. Results – Alignment and scope	
Alignment with NDP vision To what extent is the Thrust aligned with the vision of the NDP? Please specify: • Fully aligned • Mostly aligned • Partially aligned • Poorly aligned Please explain your choice. In other words, how will the Thrust contribute, both directly and indirectly, towards eliminating poverty, reducing inequality and increasing employment? Please distinguish clearly between direct and indirect contributions.	Mostly aligned - Decarbonising the economy will contribute to the environmental sustainability objectives of the NDP - Creating new low-carbon sectors and decarbonising existing sectors will contribute to job creation - Promoting (rehabilitating and constructing) ecological infrastructure will contribute to job creation - The benefits of ecological infrastructure (flood, drought, fire mitigation) will contribute to socio-economic and marginalised communities' resilience to climate change, and, therefore, reduce climate change impacts on poverty, inequality and unemployment
Scope of the benefits What is the scope of the benefits of the results which the Thrust is likely to have, by 2030? Please specify: • Very broad scope • Broad scope • Medium scope • Narrow scope Please explain your choice. Who will benefit? How many people will benefit (order of magnitude estimate)? In what way will they benefit?	Very broad scope - South African society in general will benefit from decarbonisation and increased climate change resilience (from the reduction of GHG related externalities for example) - Poor, marginalised communities will benefit the most (although this is likely to be an indirect/intangible benefit)
4. High-level implementation	
High-level steps What are the high-level interim objectives or milestones which need to be achieved? What are the high-level activities/steps/ stages needed to achieve the objectives/milestones? In other words, what are the high-level steps required to deliver on the outputs, outcomes and impact mentioned above?	Redirect fossil fuel subsidies to fund a just transition to a low-carbon economy. - Reskilling/retraining of "fossil fuel jobs" - Socio-economic support for previously "dirty" communities to become inclusive and sustainable communities who are no longer reliant on those previous dirty industries. Promote a quicker transition from coal to RE - Improve and clarify climate change mitigation and adaptation policy (Eg. increase carbon tax rate to what is required by science to achieve 2ºC target and use carbon tax revenue to fund a just transition).

	- This must take place at both a private level (REIP) and via increased government investment in RE across the RE value chain - Domestic production of RE technologies and broader recycling of waste streams (*Speaks to the reduce, reuse and recycle thrust*) Research and investment in rail freight transport - Move road freight to rail Research and investment in sustainable public transport (move away from fossil fuels). Research into and identification of critical ecological infrastructure and rehabilitation strategies/options Increased R&D into carbon sinks, including natural (forests) and technological (carbon capture and storage)
Resources required What are the resources which are required to achieve the outputs, outcomes and impact? Examples of such resources can include: • Knowledge and expertise • Technologies • Technical infrastructure • Institutional infrastructure • Research results • Partnerships established • Funding • Etc	- Funding (can come from fossil fuel subsidies) - Technology (RE, carbon capture and storage, energy efficient production and transport, new production processes) - Institutional infrastructure - Partnerships (public-private partnerships that promote synergies between climate change mitigation and adaptation strategies and minimise trade-offs) - Research (identify and map critical ecological infrastructure and how to promote and develop that infrastructure; carbon sinks; climate change mitigation and adaptation opportunities; blockchain technology for carbon accounting)
Resources to be established Which of the required resources are already established? Which need to be established, and what will be needed to establish them? For example, what STI-related research will be needed to achieve the intended results of the Thrust?	- A smart carbon accounting system based on blockchain technology
Policy and regulatory environment What changes are required, if any, to the current STI policy and regulatory environment? What new policy and regulatory provisions, if any, will the Thrust require?	Strengthen and clarification of climate change policies such as the Mitigation System, Carbon Tax and Climate Change Bill. All government departments must have a climate change mandate and climate change elements in their various policies. New policies that promote ecological infrastructure

5. Risk	
Risk of not achieving results Explain the level of difficulty involved in achieving the intended results. Please specify: • Straightforward to achieve • Fairly difficult to achieve • Moderately difficult to achieve • Very difficult to achieve. Please explain your choice. What are the anticipated obstacles and challenges, and what is the likelihood of their being overcome? What are the risks associated with not achieving the intended results of the Thrust?	Very difficult to achieve. - Transitioning the economy towards a low-carbon and inclusive one has various challenges at various levels. - Job losses in high-carbon industries (such as coal mining and liquid fuels) - Push back from Labour regarding these job losses and the ownership model of RE solutions (private vs state owned/REIP vs Eskom)
Social and ethical acceptability How ethically and socially acceptable is the Thrust? Specify: • Highly acceptable • Mostly acceptable • Fairly unacceptable • Mostly unacceptable Please explain your choice.	Difficult to say. - Most people would agree with decarbonising the economy, but it poses a risk to thousands of jobs, which is unacceptable given the already high unemployment, poverty and inequality rates in SA
Unintended consequences Are there unintended consequences that may result from the Thrust? Explain the level of risk of these possible consequences.	- Job losses - Dispossession/disruption of communities in area/regions of critical ecological infrastructure - Promoting forests as carbon sinks may intrude on different biomes and threaten biodiversity - Land use change for biofuel crops (which takes land away for food crops and natural habitat). - Ghost towns were ‘dirty’ industry used to be
6. Other	
Other information Is there any other information which you wish to provide to support this Proposal for a Thrust?	

STI Thrust Proposal – CE4

Working group	
Name of STI domain / working group	Circular Economy

1. Title and description of STI Thrust	
Title of Thrust (Eight words or less)	Smart connectivity and mobility in communities, supporting the circular economy
Summary description Provide a brief description of the Thrust so that we can be sure we understand what you are referring to. (Just a few sentences)	• This thrust looks at the Internet of Things (IoT) and the way communities, utilities, industry and businesses could connect in a new way that drives a more sustainable future in the circular economy. • This future would allow people access to a range of resources in a more virtual manner (education, market, banking, health diagnostics, information sharing). • This will also more rapidly open up a trade and exchange space for circular economy goods and services (micro and macro level).
2. Results – Description	
Problems to be addressed What are the problems which the Thrust is intended and is likely to address by 2030?	• Currently marginalised and rural communities receive services and access to services via various departments. They lack certain skills and information which could help to enhance their lives. • Currently there are weakly coordinated inter- and intra-sectoral transport and logistics linkages which represent a missed circular economy opportunity. • An IoT focus shifts the lens to how to do this better, and whether one needs to re-design, and when and where people need to go for assistance. The aim is to get to productive societies that take ownership because they have options and information. Implicit in this is a series of envisioned behavioural shifts.
Outputs What are the likely outputs of the Thrust by 2030? (The outputs are the immediate results of the Thrust)	• Smart ICT and transport systems. • People gain access to a range of resources in a more virtual manner (education, markets, banking, health diagnostics, information sharing). • SMMEs in rural and marginalised communities providing goods and services around ICT, transport, efficiency (water, energy, waste, agriculture, health, banking). • SMMEs providing new products from waste that can be used or exchanged (traded) by households, villages, settlements and larger designated trade zones within the value chain. • Shift towards more circular households and suburbs in urban and peri-urban settings, driven by technology interconnections, and behavioural influences. • Reskilling of communities and driving behavioural shifts through using smart systems. • Reduction in bureaucracy, smart government services providing access to and livelihoods related to health, food,

	water, energy, transport and waste (beyond municipal service delivery). • Linked to this is increased ownership and productive communities who no longer wait for government to come and deliver services (the delivery mechanism changes). • Resilient communities because information is easily available. • More ownership and productive communities who no longer wait for government to come and deliver services.
Outcomes and impact What are the likely outcomes and impact of the Thrust? What is the value of the outcomes and impact, and when are they likely to manifest? (The outcomes and impact are the medium-term and long-term results of the Thrust, respectively)	• Self-empowered, productive and informed communities. • Communities that have significant creative skills imparted for solving basics service issues that can be "monetized" using new economic models. • Fully integrated human and machine communities that enable a generally higher quality of life. • The youth become pioneers in new thinking for circular economies and their advantages. • New circular economy businesses are now part of the norm in urban, rural and peri-urban settlements and "benefits" are broadly measured through improved service delivery, time saved, ecological services, water and energy and food security. • New education options emerge through virtual learning opportunities. • Ecosystems are embedded into social awareness and response structures.
3. Results – Alignment and scope	
Alignment with NDP vision To what extent is the Thrust aligned with the vision of the NDP? Please specify: • Fully aligned • Mostly aligned • Partially aligned • Poorly aligned Please explain your choice. In other words, how will the Thrust contribute, both directly and indirectly, towards eliminating poverty, reducing inequality and increasing employment? Please distinguish clearly between direct and indirect contributions.	Fully aligned Direct • Better information about service delivery, behaviours, etc. Indirect: • Capacitated society by making information, skilling more easily accessible and available. • By shifting services and access to a local level of ownership and delivery using circular economy opportunities, it increases employment and reduces inequality. We shift from tenders to payment for services at each local level, but this requires technologies and innovations that can be managed at household or decentralised level (not centralised). • Poverty and unemployment are reduced because the value chains associated with waste reuse, recycling, resource recovery, water, energy and food security and transport create jobs at local level that are sustainable and offer a quality of life.
Scope of the benefits What is the scope of the benefits of the results which the Thrust is likely to have, by 2030? Please specify:	• Broad if rolled out at scale (South Africa wide, and potential regional trade opportunities) • We would advise that we work on the approach of scenario 1 where 3 strategic sites are selected in a rural, peri-urban

• Very broad scope • Broad scope • Medium scope • Narrow scope Please explain your choice. Who will benefit? How many people will benefit (order of magnitude estimate)? In what way will they benefit?	and urban space to demonstrate options and advise the future roll-out – 600 to 1000 people.
4. High-level implementation	
High-level steps What are the high-level interim objectives or milestones which need to be achieved? What are the high-level activities/steps/ stages needed to achieve the objectives/milestones? In other words, what are the high-level steps required to deliver on the outputs, outcomes and impact mentioned above?	• Clarify collaborative coordination partners • Political buy-in • Site identification • Agree on funding arrangements • Multi-sector pitching approach to building project components • Programme clarification and roll out
Resources required What are the resources which are required to achieve the outputs, outcomes and impact? Examples of such resources can include: • Knowledge and expertise • Technologies • Technical infrastructure • Institutional infrastructure • Research results • Partnerships established • Funding • Etc.	• Knowledge and expertise – implementation, technology, social process and governance experts are essential. • Technologies – tech largely exists, but options are multiple – thus pitching. • Technical infrastructure – heavily dependent on ICTs, broadband access roll-out. Technology literacy is key. • Institutional infrastructure – cooperative governance key. • Research results – big focus would be on the interoperability of systems, impact narrative, social process considerations. • Partnerships established – governance arrangements to be formalised; test beds would have various partners. • Funding – in kind and leveraged funding is key. GCF may be an option with R&D support that would need to be negotiated in parallel.
Resources to be established Which of the required resources are already established? Which need to be established, and what will be needed to establish them? For example, what STI-related research will be needed to achieve the	• Coordination and implementation unit would be important to kick start the collaboration. This unit would also need to synergise with existing innovation initiatives e.g. water, waste, ICT roadmaps driven by DST. • Department to take ownership of the initiative and lead it. • STI process to 'imagine' the project, approach, partners and pull together the existing 'state of the art'.

intended results of the Thrust?	
Policy and regulatory environment What changes are required, if any, to the current STI policy and regulatory environment? What new policy and regulatory provisions, if any, will the Thrust require?	• Would have impact on implementation policy – e.g. feeding energy back into the grid, privacy legislation, etc. • Cannot think of any STI policy impacts at this point.
5. Risk	
Risk of not achieving results Explain the level of difficulty involved in achieving the intended results. Please specify: • Straightforward to achieve • Fairly difficult to achieve • Moderately difficult to achieve • Very difficult to achieve. Please explain your choice. What are the anticipated obstacles and challenges, and what is the likelihood of their being overcome? What are the risks associated with not achieving the intended results of the Thrust?	• Moderately difficult to achieve ▪ Deeply vested individual, industry and societal ways of doing things ▪ Potential threat to existing businesses ▪ Potential threat to current municipal service delivery approaches and associated revenue streams. • Not achieving this is going to continue the status quo of stunted service delivery in large parts of SA and limited ability of individuals to take ownership of their consumption behaviours. This has large environmental 'limits' implications overall.
Social and ethical acceptability How ethically and socially acceptable is the Thrust? Specify: • Highly acceptable • Mostly acceptable • Fairly unacceptable • Mostly unacceptable Please explain your choice.	• At face value this starts in the "Mostly acceptable" space – particularly as expanded broadband access and other services delivery improvements arise. • This status may change, and the business landscape starts shifting and vested businesses and services are threatened.
Unintended consequences Are there unintended consequences that may result from the Thrust? Explain the level of risk of these possible consequences.	• Competition issues (e.g. competition over waste streams, possible collusion and monopolising resources) • New business approaches emerging that undermine existing ways of doing (e.g. can a parallel, circular service delivery emerge that renders municipal services in certain areas redundant?)

Other	
Other information Is there any other information which you wish to provide to support this Proposal for a Thrust?	• Generally, the notion of a circular economy has strong links with all the other thematic areas. Currently the circular economy language and synergy is not coming through clearly in the way the different clusters are articulating things. This should be addressed when overall streamlining of the priority initiatives takes place. • *This has strong links to the municipal thrust of the ICT challenge and ICT area in general. Please check that the ICT area has cross pollination in language and approach with circular economy.* • This has strong links with education – particularly in terms of expanded education and learning options being driven by online opportunities • This has strong links with industry in terms of logistics and communication.

STI Thrust Proposal – ED1

Working group	
Name of STI domain / working group	Education for the Future

1. Title and description of STI Thrust	
Title of Thrust (Eight words or less)	Skills for the 4th Industrial Revolution
Summary description Provide a brief description of the Thrust so that we can be sure we understand what you are referring to. (Just a few sentences)	The purpose of this is to: • Identify & highlight skills sets required across sectors for the future through the Skills Audit/Mapping. • Identify industries that are using 4th IR technologies and available skills to develop and train for the implementation of 4th IR. • To develop human capacity to fill the gaps that will be identified through the above process. • High technology industrialisation – Develop new ways of teaching using AI, machine learning AR, VR videos and simulation software to enable children, students, employed and unemployed individuals to be appropriately trained for the new digital world. • Provide a variety of ways of learning eg. Distance learning via apps and web based tools, remote learning, life-long learning. • Provide a central point where education (Education for all) can be obtained by everybody making use of the IOT and other technologies rather than the attendance of education institutions.
2. Results – Description	
Problems to be addressed What are the problems which the Thrust is intended and is likely to address by 2030?	• Low skills levels in the use of 4th IR technologies; • Lack of capacity to offer training and development. • Skills for the future – Technical skills (AI, Robotics, IOT, Mechatronics, Coding, cybernetics, etc.) • Soft skills (life skills) (critical thinking, creative thinking, collaborative thinking, problem solving, EI, Cognitive flexibility, service orientation, Entrepreneurship, Innovative thinking) • Rural and marginalised are left behind in terms of the digital revolution due to a lack of basic infrastructure, skills and education.
Outputs What are the likely outputs of the Thrust by 2030?	• Improve the Capacity to deliver on the above skills needed.

(The outputs are the immediate results of the Thrust)	• Highly skilled and self-driven workforce, a reformed education system, capacitated academics. • Capacity to deliver on the 4th industrial revolution. • Informed gap analysis providing a capacity building know how (reformed curricular economy). • Planning & resource allocation efficacy. • Bridging of the digital divide that exists. • Enhanced and improved methods of teaching and learning by everybody. • Improved access to training and development opportunities by the rural and marginalised.
Outcomes and impact What are the likely outcomes and impact of the Thrust? What is the value of the outcomes and impact, and when are they likely to manifest? (The outcomes and impact are the medium-term and long-term results of the Thrust, respectively)	• Have a skilled workforce • An education system that is responsive to the 4th industrial revolution. • Poverty alleviation, increased job opportunities, increase in economically active population; • Address Gov triple challenge. • Globally competitive individuals and industries. • New programs and skills offered by education and research Centres of Excellence. • Societies that are more resilient and are equipped with the appropriate skills to be able to live and work in the 4th IR. • Higher levels of employment for all because of the improved education and skills development.
3. Results – Alignment and scope	
Alignment with NDP vision To what extent is the Thrust aligned with the vision of the NDP? Please specify: • Fully aligned • Mostly aligned • Partially aligned • Poorly aligned Please explain your choice. In other words, how will the Thrust contribute, both directly and indirectly, towards eliminating poverty, reducing inequality and increasing employment? Please distinguish clearly between direct and indirect contributions.	Fully aligned with NDP as it has the capacity to assist with the elevation of poverty by job creation with new skilling and Technology implementation. This can be a direct contribution. The skills audit will assist towards eliminating inequality by creating wider capacity and easy access to education and skills development. Better skilled workforce will increase employment opportunities for more individuals that were previously marginalised, including the youth and disabled. More job opportunities for this sector with the use of technology and AI that was not previously available.
Scope of the benefits What is the scope of the benefits of the results which the Thrust is	Broad scope. It is envisaged that substantial number of marginalised and disadvantaged communities will benefit by 2030.

likely to have, by 2030? Please specify: • Very broad scope • Broad scope • Medium scope • Narrow scope Please explain your choice. Who will benefit? How many people will benefit (order of magnitude estimate)? In what way will they benefit?	All individuals irrespective of their location will have access to training and skills development that will prepare them for the 4th IR. More opportunities for youth and the disabled. Lifelong learning for all. This thrust is also applicable to all the other STI domains that have been identified and can benefit all industries and sectors in the country.
4. High-level implementation	
High-level steps What are the high-level interim objectives or milestones which need to be achieved? What are the high-level activities/steps/ stages needed to achieve the objectives/milestones? In other words, what are the high-level steps required to deliver on the outputs, outcomes and impact mentioned above?	Buy in from all role players and stakeholders (industry, communities' academia, funding bodies and government). Higher Education & Basic Education Ministries in particular. Allocation of adequate funding and resources. Partnerships with global and national experts. Engagement with all departments and industry sectors to establish cooperation, collaboration and agreement on the skills needed and the capacity to deliver. Establishment of a high level committee to facilitate the skills audit to determine what 4th IR skills are already in place, by which industries and what is still needed as well as the capacity available to train and develop individuals in this area. High level teams comprising of researchers, academics, industry, communities and experts to help develop 4th IR curriculum and the creation of a central education platform that offers education opportunities for all in one place (online via digital, web and other app based and smart ICT). Research teams and experts to undertake research to be able to develop appropriate/ alternate and innovative teaching methodologies suitable the 4th IR.
Resources required What are the resources which are required to achieve the outputs, outcomes and impact? Examples of such resources can include: • Knowledge and expertise • Technologies • Technical infrastructure • Institutional infrastructure • Research results • Partnerships established • Funding • Etc	• Knowledge and expertise – Skill audit will be able to provide a better indication of what is required. • Technologies- innovative technologies to make access to education and trailing possible. • Technical infrastructure. Access to technology especially for the rural and marginalised communities. • Institutional infrastructure is required for research, innovation and skills development. This will include spaces for brainstorming and collaboration by all parties. • Research results from skills audits that can be used to plan and develop innovative education and skills development programmes. • Partnerships established with industry, communities and academia

	• Funding to be made available for research, skills audits, use of experts, facilities, technologies and labs for developing and testing.
Resources to be established Which of the required resources are already established? Which need to be established, and what will be needed to establish them? For example, what STI-related research will be needed to achieve the intended results of the Thrust?	As listed above. While some resources are available at the educational institutions, when it comes to 4th IR, most of these institutions lack the technologies, experts and labs required.
Policy and regulatory environment What changes are required, if any, to the current STI policy and regulatory environment? What new policy and regulatory provisions, if any, will the Thrust require?	New Policies and regulations will be required to allow this thrust to succeed. Current education and training policies, assessment policies and frameworks such as SAQA will need to be revisited and amended to fit in with the 4th IR. HEQF, Basic Education policy, etc.
5. Risk	
Risk of not achieving results Explain the level of difficulty involved in achieving the intended results. Please specify: • Straightforward to achieve • Fairly difficult to achieve • Moderately difficult to achieve • Very difficult to achieve. Please explain your choice. What are the anticipated obstacles and challenges, and what is the likelihood of their being overcome? What are the risks associated with not achieving the intended results of the Thrust?	There are some straightforward aspects that can be easily achieved such partnerships with government, industry, communities and academic. It is straightforward to get the skills audit started. However, more aspects are challenging and moderately difficult to achieve such as funding, resources and technology acquisition and security. Providing technology infrastructure to rural and marginalised communities will still be a challenge.
Social and ethical acceptability How ethically and socially acceptable is the Thrust? Specify: • Highly acceptable	This thrust should be mostly acceptable as there is already a notion that the 4th IR is upon us and more needs to be done to prepare for this and to survive in this environment. Since this thrust can assist greatly with the

• Mostly acceptable • Fairly unacceptable • Mostly unacceptable Please explain your choice.	reduction in poverty, inequality and unemployment, it should have widespread support.
Unintended consequences Are there unintended consequences that may result from the Thrust? Explain the level of risk of these possible consequences.	There may be some resistance from the older generation to this change and reluctance to use technology.
6. Other	
Other information Is there any other information which you wish to provide to support this Proposal for a Thrust?	Education and training has to keep pace with the changes going on globally. SA cannot afford to be a global role player unless there is sufficient motivation to change the way things are done. Education can no longer be offered as it is currently. The new generation is very technologically motivated and if it is expected of them to be the leaders of the future, they need new ways of doing things. Business environments are transforming very rapidly and in order to keep pace with this, new methods of education are required to develop individuals for the skills needed for the future.

STI Thrust Proposal – ED2

Working group	
Name of STI domain / working group	Education for the Future

1. Title and description of STI Thrust	
Title of Thrust (Eight words or less)	Inclusive innovation & development
Summary description Provide a brief description of the Thrust so that we can be sure we understand what you are referring to. (Just a few sentences)	• Align and develop STI initiatives and activities for communities and industries, through academia and global partners. • Produce African solutions for African challenges.
2. Results – Description	
Problems to be addressed What are the problems which the Thrust is intended and is likely to address by 2030?	• A lack of lifelong learning, starting with ECD and continuing to ABET and artisan development. • Inadequate capacity which is relevant to industry. • A lack of entrepreneurship education and training across all disciplines.
Outputs What are the likely outputs of the Thrust by 2030? (The outputs are the immediate results of the Thrust)	• Lifelong learning established: ECD/ ABET/ artisan development. • Strong sustainable circular economy supported. • Capacity developed which is driven by industry. • Embed entrepreneurship education and training in all curricula across all disciplines. • Increased number of people trained on entrepreneurship and innovation skills. • Increased number of SMME start-ups. • Increased number of economically-active citizens.
Outcomes and impact What are the likely outcomes and impact of the Thrust? What is the value of the outcomes and impact, and when are they likely to manifest? (The outcomes and impact are the medium-term and long-term results of the Thrust, respectively)	• Grassroots innovation is serving communities. • The Government's triple challenges, the NDP goals, are addressed. • Entrepreneurship is embedded across all curricula. • Communities operate based on a self-sustaining model.
3. Results – Alignment and scope	
Alignment with NDP vision To what extent is the Thrust aligned with the vision of the NDP? Please specify:	Fully aligned The Thrust focuses on a multi-disciplinary/ inter-disciplinary set of skills that cuts across all other STI domains.

• Fully aligned • Mostly aligned • Partially aligned • Poorly aligned Please explain your choice. In other words, how will the Thrust contribute, both directly and indirectly, towards eliminating poverty, reducing inequality and increasing employment? Please distinguish clearly between direct and indirect contributions.	
Scope of the benefits What is the scope of the benefits of the results which the Thrust is likely to have, by 2030? Please specify: • Very broad scope • Broad scope • Medium scope • Narrow scope Please explain your choice. Who will benefit? How many people will benefit (order of magnitude estimate)? In what way will they benefit?	Broad scope as it encompasses all disciplines and fields and will have an impact on a number of different fields.
4. High-level implementation	
High-level steps What are the high-level interim objectives or milestones which need to be achieved? What are the high-level activities/steps/ stages needed to achieve the objectives/milestones? In other words, what are the high-level steps required to deliver on the outputs, outcomes and impact mentioned above?	1. Increase the number of ABET and artisan graduates by 2030. Provide funding to grade 10 drop outs to pursue ABET/artisanship. 2. Build recycling and refurbishment plants for ICT waste in all provinces by 2022, underpinned by training which will then generate jobs. 3. Establish ICT refurbishment centres at educational centres across the country. Larger provinces (those generating more waste) would require more centres. This could provide sustainable livelihoods through refurbishment of ICTs. These centres would provide training for learners. 4. Introduce entrepreneurship courses in the country's high schools and develop curricula for business courses. 5. Train at least 4 million learners in entrepreneurship education and innovation skills by 2030. 6. Provide funding to new ICT SMEs in the next 10 years. 7. Provide incentives to private companies to hire new graduates
Resources required	• Teachers are not well-equipped in ICTs; children are more fluent in ICT literacy than their teachers. Teachers require

What are the resources which are required to achieve the outputs, outcomes and impact? Examples of such resources can include: • Knowledge and expertise • Technologies • Technical infrastructure • Institutional infrastructure • Research results • Partnerships established • Funding	re-training in entrepreneurial skills, and more are required with an economics background. • The move towards lifelong learning requires an overhaul of the whole system. It is likely that more learners will be home schooled or learning through self-directed learning in future. This requires a different skills base, with teachers as facilitators of learning, and the ability to use new devices to access study resources on the internet. • Research is needed to understand how to promote self-driven learning. See below for requirements.
Resources to be established Which of the required resources are already established? Which need to be established, and what will be needed to establish them? For example, what STI-related research will be needed to achieve the intended results of the Thrust?	• ABET / Artisan training Nothing in place • Refurbishment Plants Knowledge and expertise, partnerships established • Refurbishment Centres Knowledge and expertise, Technologies, Technical infrastructure, Institutional infrastructure, Partnerships established, Funding • Entrepreneurship training and courses in schools Knowledge and expertise, Technical infrastructure, Institutional infrastructure. There is not much in place. • Funding of SMEs and private sector incentives Very limited resources in place.
Policy and regulatory environment What changes are required, if any, to the current STI policy and regulatory environment? What new policy and regulatory provisions, if any, will the Thrust require?	• No policy changes required at this stage. The bottleneck is not with policy but with implementation. • Revisit policy relation to the rollout of infrastructure in schools and the social responsibility mandate for telcos. • There is a need to strengthen monitoring and evaluation. There are no consequences for non-compliance, e.g. social responsibility mandates for infrastructure rollout.
5. Risk	
Risk of not achieving results Explain the level of difficulty involved in achieving the intended results. Please specify: • Straightforward to achieve • Fairly difficult to achieve • Moderately difficult to achieve • Very difficult to achieve.	• The biggest risk is that there is no funding to implement recommendations when the economy is stagnant and not performing. • Loss of skills - some that are leaving the country, resulting in no qualified teachers. • Unreliable energy resources from ESKOM are a major limiting factor. Straightforward to achieve:

Please explain your choice. What are the anticipated obstacles and challenges, and what is the likelihood of their being overcome? What are the risks associated with not achieving the intended results of the Thrust?	• Refurbishment plants; entrepreneurship training in schools; private sector incentives Fairly difficult • Setting up refurbishment centres; and training of people to refurbish devices. Moderately difficult • Artisan training, support for ICT SMEs; job creation for ICT graduates
Social and ethical acceptability How ethically and socially acceptable is the Thrust? Specify: • Highly acceptable • Mostly acceptable • Fairly unacceptable • Mostly unacceptable Please explain your choice.	Highly acceptable. The country will be left behind if the proposed thrust recommendations are not implemented.
Unintended consequences Are there unintended consequences that may result from the Thrust? Explain the level of risk of these possible consequences.	Positive: Those who cannot find employment or establish their businesses will be skilled enough to venture into other sectors of the economy. Negative: Digital divides are likely to increase as new devices increasingly make their way into the market. The more technology develops, the more the risk of increasing the divide.
6. Other	
Other information Is there any other information which you wish to provide to support this Proposal for a Thrust?	None.

STI Thrust Proposal – ED3

Working group	
Name of STI domain / working group	Education for the Future

1. Title and description of STI Thrust	
Title of Thrust (Eight words or less)	Curriculum development 2030
Summary description Provide a brief description of the Thrust so that we can be sure we understand what you are referring to. (Just a few sentences)	To design a curriculum that is fit for STI educational development
2. Results – Description	
Problems to be addressed What are the problems which the Thrust is intended and is likely to address by 2030?	• The current curriculum does not adequately support entrepreneurship (STI, critical thinking & technology enhanced learning). • Methodologies are needed for teaching in the future (interactive & innovative teaching methods). • The curriculum is not aligned with the needs of industry. • The marginalised and people from poorly developed areas are deprived of proper access to education.
Outputs What are the likely outputs of the Thrust by 2030? (The outputs are the immediate results of the Thrust)	• Create accessible e-learning platforms. • New teaching methods (technology enhanced teaching, blended learning environments). • Create a culture of STI in the learning sphere. • Targeted innovative learning technologies.
Outcomes and impact What are the likely outcomes and impact of the Thrust? What is the value of the outcomes and impact, and when are they likely to manifest? (The outcomes and impact are the medium-term and long-term results of the Thrust, respectively)	• Accelerated business development (job creation opportunities). • Realization of STI within the community at large. • Active STI communities of practice. • Improved business performances and growth in the economy.
3. Results – Alignment and scope	
Alignment with NDP vision	• Fully aligned with NDP as it has the capacity to assist with the elevation of poverty by job creation with new skilling and Technology implementation.

To what extent is the Thrust aligned with the vision of the NDP? Please specify: • Fully aligned • Mostly aligned • Partially aligned • Poorly aligned Please explain your choice. In other words, how will the Thrust contribute, both directly and indirectly, towards eliminating poverty, reducing inequality and increasing employment? Please distinguish clearly between direct and indirect contributions.	• STI driven economic stimulators. Increased number of tech start-ups and SMME's & self-reliant communities. • Better skilled workforce will increase employment opportunities for more individuals that were previously marginalised, including the youth and disabled. • More job opportunities for this sector with the use of technology and entrepreneurship skills that was not previously available. • Blended learning environments allow for inclusion of everybody.
Scope of the benefits What is the scope of the benefits of the results which the Thrust is likely to have, by 2030? Please specify: • Very broad scope • Broad scope • Medium scope • Narrow scope Please explain your choice. Who will benefit? How many people will benefit (order of magnitude estimate)? In what way will they benefit?	Broad scope as it cuts across all fields as well as all the STI domains identified. Education and work opportunities afforded to all communities.
4. High-level implementation	
High-level steps What are the high-level interim objectives or milestones which need to be achieved? What are the high-level activities/steps/ stages needed to achieve the objectives/milestones? In other words, what are the high-level steps required to deliver on the outputs, outcomes and impact mentioned above?	• Buy in from all role players and stakeholders (industry, communities' academia, funding bodies and government), Higher Education & Basic Education Ministries in particular. • Allocation of adequate funding and resources. • Partnerships with global and national experts to be able to benchmark against what is the global trends are. • Engagement with all departments and industry sectors to establish cooperation, collaboration and agreement on the skills needed and the capacity to deliver. • Research teams and experts to undertake research to be able to develop appropriate/ alternate curriculum. • Transform the curriculum: entrepreneurship to be embedded as part of the curriculum for all fields (STI, critical thinking & technology enhanced learning). • Conduct R&D in order to identify methodologies for teaching in the future (interactive & innovative teaching methods).

	• Engage industry to establish sector needs/foresight and incorporate that into the respective curricula. • Engage global experts and researchers to establish and benchmark with global trends. • Investigate the possibility of a blended learning opportunity to allow for the marginalised and people from poorly developed areas to still have access to education.
Resources required What are the resources which are required to achieve the outputs, outcomes and impact? Examples of such resources can include: • Knowledge and expertise • Technologies • Technical infrastructure • Institutional infrastructure • Research results • Partnerships established • Funding • Etc	• Knowledge and expertise for developing curricula and teaching methodologies to support STI and entrepreneurship. • Technologies and technical infrastructure which support widespread learning. • Institutional infrastructure. • Research results related to appropriate and alternative curricula and for teaching methodologies. • Partnerships established with global and national experts, and with industry and industry sectors. • Funding.
Resources to be established Which of the required resources are already established? Which need to be established, and what will be needed to establish them? For example, what STI-related research will be needed to achieve the intended results of the Thrust?	As listed above. While some resources are available at the educational institutions for curriculum development, in order to design new curriculum for 2030, more interaction with global experts, researchers and institutions will be required.
Policy and regulatory environment What changes are required, if any, to the current STI policy and regulatory environment? What new policy and regulatory provisions, if any, will the Thrust require?	All Basis and Higher Education policies and regulations will need to be revisited and appropriately amended.
5. Risk	
Risk of not achieving results Explain the level of difficulty involved in achieving the	Moderately difficult to achieve as it will require motivation and convincing of several role players and partners.

intended results. Please specify: • Straightforward to achieve • Fairly difficult to achieve • Moderately difficult to achieve • Very difficult to achieve. Please explain your choice. What are the anticipated obstacles and challenges, and what is the likelihood of their being overcome? What are the risks associated with not achieving the intended results of the Thrust?	Existing entrepreneurship education service providers may be reluctant to give up their specialisation as it will now be incorporated in all fields of study.
Social and ethical acceptability How ethically and socially acceptable is the Thrust? Specify: • Highly acceptable • Mostly acceptable • Fairly unacceptable • Mostly unacceptable Please explain your choice.	Highly acceptable as this has the potential to create more entrepreneurs and SMMEs. Hence this will lead to more job creation, poverty alleviation and marginalisation of communities. More sustainable communities doing things for themselves rather than expecting it from government.
Unintended consequences Are there unintended consequences that may result from the Thrust? Explain the level of risk of these possible consequences.	This can lead to more industries that are competitive and the risk of anti-competitive behaviour is possible.
6. Other	
Other information Is there any other information which you wish to provide to support this Proposal for a Thrust?	None.

STI Thrust Proposal – EN1

Working group	
Name of STI domain / working group	Energy for the Marginalised

1. Title and description of STI Thrust	
Title of Thrust (Eight words or less)	Clean, affordable and sustainable energy for all
Summary description Provide a brief description of the Thrust so that we can be sure we understand what you are referring to. (Just a few sentences)	• To optimize the cost of energy provision to make it affordable and sustainable for easy access by all, especially the marginalised. • To provide solutions for mobility, industry and household use.
2. Results – Description	
Problems to be addressed What are the problems which the Thrust is intended and is likely to address by 2030?	• Closing the energy gap due to decommissioned coal plants that have reached their end of life. • New generation technologies. • Introducing new, energy efficient solutions. • Mobility solutions for industry and personal use. • Economic development from green economy initiatives.
Outputs What are the likely outputs of the Thrust by 2030? (The outputs are the immediate results of the Thrust)	• Although electricity tariffs will increase going forward, the future with higher renewables share will have lower tariffs. • Affordable technologies for household applications. • Diverse generation and storage technology options for affordable micro and small generation solutions. • Relevant skills for the sector.
Outcomes and impact What are the likely outcomes and impact of the Thrust? What is the value of the outcomes and impact, and when are they likely to manifest? (The outcomes and impact are the medium-term and long-term results of the Thrust, respectively)	• Manufacturing of such affordable technologies. • Most people will have energy access. • Increased self-reliance for energy needs.
3. Results – Alignment and scope	
Alignment with NDP vision To what extent is the Thrust aligned with the vision of the NDP? Please specify: • Fully aligned	• The energy thrusts identified fully align with the NDP under the intent of connecting all to the grid and promoting the green economy. Fully alignment with the NDP's Strategic Integrated Projects (SIPs) 8, 9 and 10.

• Mostly aligned • Partially aligned • Poorly aligned Please explain your choice. In other words, how will the Thrust contribute, both directly and indirectly, towards eliminating poverty, reducing inequality and increasing employment? Please distinguish clearly between direct and indirect contributions.	• The thrust will contribute to the improvement of the quality of life of South Africans and the SADC region by having cleaner energy supply, more people grid connected, and using energy to address the imbalances of the past.
Scope of the benefits What is the scope of the benefits of the results which the Thrust is likely to have, by 2030? Please specify: • Very broad scope • Broad scope • Medium scope • Narrow scope Please explain your choice. Who will benefit? How many people will benefit (order of magnitude estimate)? In what way will they benefit?	**Broad scope**. The long-term cost and security of supply of electricity affects all citizens.
4. High-level implementation	
High-level steps What are the high-level interim objectives or milestones which need to be achieved? What are the high-level activities/steps/ stages needed to achieve the objectives/milestones? In other words, what are the high-level steps required to deliver on the outputs, outcomes and impact mentioned above?	• Establish an operational model to mobilise the expertise in the country to be focused on delivering the outputs of the Thrust. • Establish technical infrastructure, such as national laboratories and research institutes, to undertake the required research. • Build local technical capacity and establish international partnerships. • Undertake research into energy solutions for industry, household and mobility use.
Resources required What are the resources which are required to achieve the outputs, outcomes and impact?	South Africa has expertise in this space, however, they are located in different institutions focusing on diverse topics, with limited collaboration or national programmes that respond to local energy transition topics. There is also a need to establish technical infrastructure (national labs, research institutes) that focus on these issues with associated national

Examples of such resources can include: • Knowledge and expertise • Technologies • Technical infrastructure • Institutional infrastructure • Research results • Partnerships established • Funding • Etc.	funding to proactively address future problems. International partnerships are critical in this space. However, it is critical to ensure that there is local technical capacity building and the research work is conducted by local experts utilising local laboratories/ institutes as much as possible.
Resources to be established Which of the required resources are already established? Which need to be established, and what will be needed to establish them? For example, what STI-related research will be needed to achieve the intended results of the Thrust?	Local expertise exists, however, there is a lack of funding to harness and mobilise this expertise to be focused on the activities required by the Thrust.
Policy and regulatory environment What changes are required, if any, to the current STI policy and regulatory environment? What new policy and regulatory provisions, if any, will the Thrust require?	Eskom is a vertically integrated utility responsible for generation, transmission and distribution of electricity. Eskom is the single buyer from Independent Power Producers (IPPs) making it conflicted. Therefore, it is important to create the so-called Independent System and Market Operator (ISMO). For Eskom's sustainability, the business model will have to change, and this could mean changes to the polices related to electricity and related services provision.
5. Risk	
Risk of not achieving results Explain the level of difficulty involved in achieving the intended results. Please specify: • Straightforward to achieve • Fairly difficult to achieve • Moderately difficult to achieve • Very difficult to achieve. Please explain your choice. What are the anticipated obstacles and challenges, and what is the likelihood of their being overcome?	Fairly difficult: There are policies in place to make to transition the country toward a low carbon electricity supply, and the country has abundant solar and wind energy resources to achieve this. However, the implementation of this new low carbon energy dispensation has to benefit the entire society. If the results are not achieved, the country will likely miss its emission reduction targets for climate change, and the cost of energy provision will be much higher. Communities that are adversely affected by pollution will continue to suffer the health effects; sadly it is mostly the marginalised who live areas exposed to high pollution levels.

What are the risks associated with not achieving the intended results of the Thrust?	
Social and ethical acceptability How ethically and socially acceptable is the Thrust? Specify: • Highly acceptable • Mostly acceptable • Fairly unacceptable • Mostly unacceptable Please explain your choice.	Mostly acceptable: Transition into low carbon energy supply is generally understood by the population, and the promise of the new sources being affordable is key. However, community participation and ownership of these energy sources is critical
Unintended consequences Are there unintended consequences that may result from the Thrust? Explain the level of risk of these possible consequences.	With the current municipal model that relies on electricity sales to subsidise other services, the proliferation of distributed generation sources can negatively affect the municipal revenues unless the municipalities change their business model to participate in distributed generation supply.
6. Other	
Other information Is there any other information which you wish to provide to support this Proposal for a Thrust?	This thrust provides an avenue for communities to be part of energy provision, thus democratising the supply of energy. However, legislation and regulations will be required to make it possible for communities to participate in the energy supply as both consumers and producers of energy.

STI Thrust Proposal – EN2

Working group	
Name of STI domain / working group	Energy

1. Title and description of STI Thrust	
Title of Thrust (Eight words or less)	Renewable Energy sources and technologies
Summary description Provide a brief description of the Thrust so that we can be sure we understand what you are referring to. (Just a few sentences)	The focus of this thrust is the migration of energy source from carbon intensive coal to cleaner and renewable sources. Applicable to micro/medium generation (shorter timeline, 10Y) as well as to baseload generation (longer timeline 50Y).
2. Results – Description	
Problems to be addressed What are the problems which the Thrust is intended and is likely to address by 2030?	• Climate change threats. • Lack of affordable technologies for renewable energy production. • Carbon taxes. • Relatively high cost of micro generation. • Conflicts of biofuels vs food security.
Outputs What are the likely outputs of the Thrust by 2030? (The outputs are the immediate results of the Thrust)	• Significantly increasing the share of renewables in the country's energy mix.
Outcomes and impact What are the likely outcomes and impact of the Thrust? What is the value of the outcomes and impact, and when are they likely to manifest? (The outcomes and impact are the medium-term and long-term results of the Thrust, respectively)	• Savings on carbon taxes. • More distributed job creation in renewable energy generation. • Stimulation of economic activity in rural areas due to the distributed nature of some renewable generation technologies. • Spreading the risk of energy supply security.
3. Results – Alignment and scope	
Alignment with NDP vision To what extent is the Thrust aligned with the vision of the NDP? Please specify: • Fully aligned	• It aligns with the NDP as it focuses on innovating solutions to strengthen and diversify the energy sector. • Community empowerment. • Financial and educational benefits.

• Mostly aligned • Partially aligned • Poorly aligned Please explain your choice. In other words, how will the Thrust contribute, both directly and indirectly, towards eliminating poverty, reducing inequality and increasing employment? Please distinguish clearly between direct and indirect contributions.	
Scope of the benefits What is the scope of the benefits of the results which the Thrust is likely to have, by 2030? Please specify: • Very broad scope • Broad scope • Medium scope • Narrow scope Please explain your choice. Who will benefit? How many people will benefit (order of magnitude estimate)? In what way will they benefit?	**Broad scope** as it benefits the large population through diversification and affordability. Global benefit of reduced carbon footprint.
4. High-level implementation	
High-level steps What are the high-level interim objectives or milestones which need to be achieved? What are the high-level activities/steps/ stages needed to achieve the objectives/milestones? In other words, what are the high-level steps required to deliver on the outputs, outcomes and impact mentioned above?	The implementation seeks to address the country's untapped potential for sourcing energy from wind, solar and biofuels, and possibly from regional hydro. • Develop national databases and systems to make the data readily available for sharing for national planning purposes and for R&D. • Develop standard ways of creating community-based mini-grids or microgrids by incorporating various existing technologies in order to learn how to design and operate such energy systems, considering that mini/microgrids are the building block of the future energy system. • Develop optimized technologies to generate bioenergy from these resources. • Validate and scale up the developed technologies. • Disseminate the developed renewable energy technologies.
Resources required What are the resources which are required to achieve the outputs, outcomes and impact?	• Training and skills development programmes. • Expertise to facilitate the establishment of compliant micro grid systems. • Establishment of demonstration micro grids. • Partnerships with IPPs and SOEs.

Examples of such resources can include: • Knowledge and expertise • Technologies • Technical infrastructure • Institutional infrastructure • Research results • Partnerships established • Funding • Etc	• High level co-ordination of the establishment of distributed micro grids and integration to the national grid.
Resources to be established Which of the required resources are already established? Which need to be established, and what will be needed to establish them? For example, what STI-related research will be needed to achieve the intended results of the Thrust?	Almost none established due to current regulatory barriers.
Policy and regulatory environment What changes are required, if any, to the current STI policy and regulatory environment? What new policy and regulatory provisions, if any, will the Thrust require?	• Changes required to separate distribution from baseload generation. • Changes required to allow private generators to sell into the national grid.
5. Risk	
Risk of not achieving results Explain the level of difficulty involved in achieving the intended results. Please specify: • Straightforward to achieve • Fairly difficult to achieve • Moderately difficult to achieve • Very difficult to achieve. Please explain your choice. What are the anticipated obstacles and challenges, and what is the likelihood of their being overcome?	Fairly difficult. The most difficult aspect will be regulatory changes. The major obstacles are due to resistance from the entrenched monopoly in the energy sector. The risks of not achieving the results of the thrust means the RSA economy is reliant on Eskom SOE alone; if it fails, the economy will fail.

What are the risks associated with not achieving the intended results of the Thrust?	
Social and ethical acceptability How ethically and socially acceptable is the Thrust? Specify: • Highly acceptable • Mostly acceptable • Fairly unacceptable • Mostly unacceptable Please explain your choice.	Highly acceptable. It will contribute to economic transformation – transferring ownership from the state to communities where the scale is practical.
Unintended consequences Are there unintended consequences that may result from the Thrust? Explain the level of risk of these possible consequences.	If there is low or no economic growth, this would result in direct competition with Eskom's adequate capacity that is already installed. This is opposed to a growth scenario where it would complement installed capacity and distribute risk.
6. Other	
Other information Is there any other information which you wish to provide to support this Proposal for a Thrust?	None.

STI Thrust Proposal – EN3

Working group	
Name of STI domain / working group	Energy

1. Title and description of STI Thrust	
Title of Thrust (Eight words or less)	Energy efficiency solutions for industry plus household use
Summary description Provide a brief description of the Thrust so that we can be sure we understand what you are referring to. (Just a few sentences)	Supply side: This thrust focuses on the provision of affordable energy efficient devices, technologies and energy management for both household and industrial applications. Demand side: Second prong is aimed at education and behavioural changes across all sectors in energy efficiency and demand side management.
2. Results – Description	
Problems to be addressed What are the problems which the Thrust is intended and is likely to address by 2030?	• Lack of knowledge of benefits of EE • High cost of energy efficient devices. • High cost of energy management devices. • Rebound effect associated with new technologies. • Tapering off of behavioural interventions, back to old habits.
Outputs What are the likely outputs of the Thrust by 2030? (The outputs are the immediate results of the Thrust)	• Large scale adoption of energy efficient devices. • Dissemination of knowledge on energy efficiency interventions. • Wide scale adoption of efficient operating practices and world class energy management systems throughout Eskom, industry and commercial sectors.
Outcomes and impact What are the likely outcomes and impact of the Thrust? What is the value of the outcomes and impact, and when are they likely to manifest? (The outcomes and impact are the medium-term and long-term results of the Thrust, respectively)	• Significant reduction in energy wastage. • Energy efficiency benefit to marginalised to use savings for other needs.
3. Results – Alignment and scope	
Alignment with NDP vision To what extent is the Thrust aligned with the vision of the NDP? Please specify:	Aligns with the NDP statement that calls for programmes to curb demand.

• Fully aligned • Mostly aligned • Partially aligned • Poorly aligned Please explain your choice. In other words, how will the Thrust contribute, both directly and indirectly, towards eliminating poverty, reducing inequality and increasing employment? Please distinguish clearly between direct and indirect contributions.	
Scope of the benefits What is the scope of the benefits of the results which the Thrust is likely to have, by 2030? Please specify: • Very broad scope • Broad scope • Medium scope • Narrow scope Please explain your choice. Who will benefit? How many people will benefit (order of magnitude estimate)? In what way will they benefit?	**Medium Scope**. This thrust will help curb demand increase and benefit participants with energy savings.
4. High-level implementation	

High-level steps
What are the high-level interim objectives or milestones which need to be achieved?
What are the high-level activities/steps/ stages needed to achieve the objectives/milestones?
 	
In other words, what are the high-level steps required to deliver on the outputs, outcomes and impact mentioned above?
	• Screening and identification of suitable energy-efficient technologies.
	  ▪ Survey energy saving technologies that are already available, and to adapt and localise these.
	  ▪ Initiate R&D of promising technologies specifically for local context.
	• Technology validation.
	  ▪ Programme to support testing and certification of energy saving devices.
	  ▪ Technologies and dissemination (supporting the uptake of energy saving technologies, providing incentives).
	• Dissemination of information and knowledge.
	  ▪ Training of consumers in energy saving devices and aspects of behaviour, providing incentives for frugal use of energy).

Resources required What are the resources which are required to achieve	• Establishment of a funded centre of expertise to collate and drive implementation.

the outputs, outcomes and impact? Examples of such resources can include: • Knowledge and expertise • Technologies • Technical infrastructure • Institutional infrastructure • Research results • Partnerships established • Funding	• Establishment of focused research & technology development programmes at relevant institutions. • Resources to incentivise energy reduction in industry and domestically. • Extensive support for existing successful initiatives such as the National Cleaner Production Centre at the CSIR, and the PSEE program run by the NBI. • Government support for making public the repository of EEDSM data currently residing at Eskom for the purpose of research.
Resources to be established Which of the required resources are already established? Which need to be established, and what will be needed to establish them? For example, what STI-related research will be needed to achieve the intended results of the Thrust?	Available resources not known, and need to be assessed to determine what will be required.
Policy and regulatory environment What changes are required, if any, to the current STI policy and regulatory environment? What new policy and regulatory provisions, if any, will the Thrust require?	Policy is needed to define incentive schemes. Instead of continued calls for new generation (e.g. IPP's), the focus should be on bids to create virtual power plants (VPP's). The VPP bidding system would be to reduce usage due to conservation and efficiency, rather than simply producing more.
5. Risk	
Risk of not achieving results Explain the level of difficulty involved in achieving the intended results. Please specify: • Straightforward to achieve • Fairly difficult to achieve • Moderately difficult to achieve • Very difficult to achieve. Please explain your choice. What are the anticipated obstacles and challenges, and what is the likelihood of their being overcome?	Straightforward to moderately difficult to achieve. There are already many energy-efficient technologies available. The greatest challenge may be to alter behavioural aspects, hence the recommendation for incentivisation. Significant research is required into the behavioural aspects (especially rebound effect) before technology rollouts take place.

What are the risks associated with not achieving the intended results of the Thrust?	
Social and ethical acceptability How ethically and socially acceptable is the Thrust? Specify: • Highly acceptable • Mostly acceptable • Fairly unacceptable • Mostly unacceptable Please explain your choice.	Highly acceptable Primarily from an environmental standpoint, but also from the perspective of consumer costs.
Unintended consequences Are there unintended consequences that may result from the Thrust? Explain the level of risk of these possible consequences.	Surplus redundant energy inefficient devices that may require trade-in and recycle programmes to remove them from circulation. .
6. Other	
Other information Is there any other information which you wish to provide to support this Proposal for a Thrust?	Energy efficiency has been widely recognised for many decades as the first fuel of choice. Yet the inclusion of energy efficiency in the latest IRP demand models is very limited due to lack of data. Eskom, municipal resellers and even renewable IPP's are not at all incentivised to encourage large scale demand-side energy efficiency as sales will be affected. Eskom benefits from supply side energy efficiency interventions as this reduces their primary energy costs.

STI Thrust Proposal – EN4

Working group	
Name of STI domain / working group	Energy

1. Title and description of STI Thrust	
Title of Thrust (Eight words or less)	Distributed energy generation and storage
Summary description Provide a brief description of the Thrust so that we can be sure we understand what you are referring to. (Just a few sentences)	This thrust allows for private and communal generation and storage of energy to be enabled from a micro to small scale. Both off-grid or grid-tied systems.
2. Results – Description	
Problems to be addressed What are the problems which the Thrust is intended and is likely to address by 2030?	• Centralised monopoly in generation and distribution. • Limited opportunities for small players to get involved in energy beyond own consumption.
Outputs What are the likely outputs of the Thrust by 2030? (The outputs are the immediate results of the Thrust)	• Dissemination of knowledge on technologies for energy production and storage.
Outcomes and impact What are the likely outcomes and impact of the Thrust? What is the value of the outcomes and impact, and when are they likely to manifest? (The outcomes and impact are the medium-term and long-term results of the Thrust, respectively)	• Private generation of electricity. • Excluded communities are empowered to generate their own affordable power thus stimulating economic growth in those communities. • Economic value add is enabled on a much wider scale. • Small businesses have greater control over cost of their electricity, reducing risks.
3. Results – Alignment and scope	
Alignment with NDP vision To what extent is the Thrust aligned with the vision of the NDP? Please specify: • Fully aligned • Mostly aligned • Partially aligned • Poorly aligned	• The NDP has a section: 'Diversify power sources and ownership in the electricity sector' The NDP seeks to transform the economy (ownership within the economy to benefit ordinary people): allowing partial privatisation of energy generation on a small & micro scale, that will achieve re-distribution from the

Please explain your choice. In other words, how will the Thrust contribute, both directly and indirectly, towards eliminating poverty, reducing inequality and increasing employment? Please distinguish clearly between direct and indirect contributions.	state to individuals and empower ordinary people to participate in the economy.
Scope of the benefits What is the scope of the benefits of the results which the Thrust is likely to have, by 2030? Please specify: • Very broad scope • Broad scope • Medium scope • Narrow scope Please explain your choice. Who will benefit? How many people will benefit (order of magnitude estimate)? In what way will they benefit?	**Medium scope**. Ownership patterns will change somewhat and unlock economic potential.
4. High-level implementation	
High-level steps What are the high-level interim objectives or milestones which need to be achieved? What are the high-level activities/steps/ stages needed to achieve the objectives/milestones? In other words, what are the high-level steps required to deliver on the outputs, outcomes and impact mentioned above?	• Source appropriate micro and small generation technologies. • Optimise cost of small generation (import or local manufacture). • Review regulatory environment to favour local ownership of generation capacity on micro to medium scale. • Separation of transmission and generation to allow private generators to compete with Eskom to supply Distribution.
Resources required What are the resources which are required to achieve the outputs, outcomes and impact? Examples of such resources can include: • Knowledge and expertise • Technologies • Technical infrastructure • Institutional infrastructure	• Funding to disseminate knowledge through training and establishing networks. • Resources to finance small/medium/micro generation projects. • Funding to stimulate and support/incubate uptake of small & medium generation projects.

• Research results • Partnerships established • Funding • Etc.	
Resources to be established Which of the required resources are already established? Which need to be established, and what will be needed to establish them? For example, what STI-related research will be needed to achieve the intended results of the Thrust?	Better co-ordination of research & development efforts within the NSI to focus on specific implementation, i.e. bias to complete technology development past TRL9 for promising technologies.
Policy and regulatory environment What changes are required, if any, to the current STI policy and regulatory environment? What new policy and regulatory provisions, if any, will the Thrust require?	• Changes required to separate distribution from baseload generation. • Changes required to allow private generators to sell into the national grid.
5. Risk	
Risk of not achieving results Explain the level of difficulty involved in achieving the intended results. Please specify: • Straightforward to achieve • Fairly difficult to achieve • Moderately difficult to achieve • Very difficult to achieve. Please explain your choice. What are the anticipated obstacles and challenges, and what is the likelihood of their being overcome? What are the risks associated with not achieving the intended results of the Thrust?	Fairly difficult. The most difficult aspect will be regulatory changes.
Social and ethical acceptability How ethically and socially acceptable is the Thrust? Specify: • Highly acceptable • Mostly acceptable • Fairly unacceptable • Mostly unacceptable	Highly acceptable, both ethically and socially.

Please explain your choice.	
Unintended consequences Are there unintended consequences that may result from the Thrust? Explain the level of risk of these possible consequences.	Organised labour may object. Risk is high and will have to be managed appropriately.
6. Other	
Other information Is there any other information which you wish to provide to support this Proposal for a Thrust?	None.

STI Thrust Proposal – FS1

Working group	
Name of STI domain / working group	The Future of Society

1. Title and description of STI Thrust	
Title of Thrust (Eight words or less)	**Policies and Indicators for STI in a changing South African society**
Summary description Provide a brief description of the Thrust so that we can be sure we understand what you are referring to. (Just a few sentences)	Societal challenges, such as poverty and the exclusion of women and minority groups, need to be mainstreamed into any future STI policies and implementation strategies. This requires cross-cutting interventions to ensure that societal needs are addressed pro-actively across wide-ranging sectors such as energy, water, education, ICTs, among others. STI policies should also focus on distributional issues, i.e. promoting fair and equitable distribution of the benefits of STI as well as the costs/risks of externalities such as environmental degradation. The SDGs, and the specific targets outlined for 2030, provide direction for relevant indicators that could be included in society-focussed STI. This Thrust addresses the need to ensure that STI policies address appropriately the harnessing of STIs in the context of South Africa's societal challenges, such as the reduction of poverty and inequality, at national through to local and community levels. In addition, this Thrust addresses the need to establish relevant STI indicators, underpinned by a sound research base and supported by a sufficiently resourced monitoring and evaluation system. It aims to stimulate societal change through STI in general and in particular, to enhance the societal engagement and impact of all of the other STI Domains and Thrusts.
2. Results – Description	

Problems to be addressed
What are the problems which the Thrust is intended and is likely to address by 2030?
	• Current STI interventions do not address societal challenges adequately; a 'science for all' approach, that benefits all, needs to be supported more pro-actively:
	  o An NSI must be built that is based on mutual trust and respect at all levels. It must support the building of a cohesive, post-racial, inclusive South Africa
	  o An NSI should stimulate and promote the development of a society that is proud of locally-produced and indigenous technologies
	  o An NSI needs to support structures of state, but also self-sufficiency at the individual and community levels, with active participation and

	contributions from citizens to improve their lives • Problems need to be South African problems. STI policy should avoid getting swept up in trends that identify future STI policy areas "for the world" and that emanate primarily from developed countries • A pro-African / pan-African NSI is needed with RDI programmes that encourage pan-African collaboration • Innovation is market-driven and lies largely outside public policy-making processes; it does not always consider the social aspects of technology • Policy makers and government departments, in collaboration with private sector and civil society players, are not working across domains effectively to respond to complex societal challenges and to make technologies work for the social good • The current national STI policy places little emphasis on local, community-based R&D and social innovation. Strong interventions are needed to build cultural and societal values to make this happen. This requires a bottoms-up approach where communities / businesses determine for themselves what problems need to be solved and where STI could play a part This needs to extend to inclusion and participation in monitoring and evaluation, and indicator development. The process should be inclusive and participatory in order to achieve 'inclusive' outcomes and impact • South Africa has a weak culture of lifelong and self-driven learning, a requirement if our society has to move forward with the capability and resilience to deal with the 4IR • Early Childhood Development (ECD) does not receive enough attention in the present NSI To ensure that these are driven within the NSI, an effective monitoring, evaluation and learning system needs to be implemented, underpinned by policy review, changes in institutional responsibilities, and an active promotion of culturally acceptable STI.
Outputs What are the likely outputs of the Thrust by 2030? (The outputs are the immediate results of the Thrust)	This Thrust is cross-cutting with respect to the other identified STI Domains and their associated Thrusts. Outputs include: • The scoping of the key principles of: o Inclusive growth, sustainable development and well-being; o Human-centred values and fairness [*ubuntu* in the South Africa context]; o Transparency and explainability; o Robustness, security and safety, and accountability • An enhanced policy environment that will promote human- and community-centred application of STI for accelerated socioeconomic development • Relevant and appropriate STI indicators that will effect change in cultural and societal values in the 4IR

	• An appropriate and relevant monitoring and evaluation system that places equal emphasis on societal indicators as existing STI indicators, e.g. the number of women-led enterprises established with government funding, number of youth engaged in local STI activities due to government-assisted programmes, etc. • Adequately resourced governance systems to implement effective monitoring and evaluation that will result in learning and actively promote change in institutions, communities and stakeholders in the NSI to effect societal change through the use of technology for the social good
Outcomes and impact What are the likely outcomes and impact of the Thrust? What is the value of the outcomes and impact, and when are they likely to manifest? (The outcomes and impact are the medium-term and long-term results of the Thrust, respectively)	• Broad acceptance of the importance of STI in improving the lives of all South African citizens, particularly the poor, vulnerable and marginalised • More supported community-driven initiatives that focus on service delivery in hard-to-reach places • More public works emanating from STI-supported projects that speak to the self-determined needs of businesses and communities
3. Results – Alignment and scope	
Alignment with NDP vision To what extent is the Thrust aligned with the vision of the NDP? Please specify: • Fully aligned • Mostly aligned • Partially aligned • Poorly aligned Please explain your choice. In other words, how will the Thrust contribute, both directly and indirectly, towards eliminating poverty, reducing inequality and increasing employment? Please distinguish clearly between direct and indirect contributions.	This Thrust is fully aligned with the vision of the NDP, to eliminate poverty, reduce inequality, and to promote employment in the country. Furthermore, the policy interventions and indicators that arise from this Thrust will be aligned with the SDGs and their targets for 2030.
Scope of the benefits What is the scope of the benefits of the results which the Thrust is likely to have, by 2030? Please specify: • Very broad scope • Broad scope • Medium scope • Narrow scope	Very broad scope This Thrust seeks to enhance the application of STIs, at policy and implementation levels, for the social good of the broader society. In particular, the scope of the benefits of all the other Thrusts will be enhanced. The scope of this Thrust is therefore very broad.

Please explain your choice. Who will benefit? How many people will benefit (order of magnitude estimate)? In what way will they benefit?	
4. High-level implementation	
High-level steps What are the high-level interim objectives or milestones which need to be achieved? What are the high-level activities/steps/ stages needed to achieve the objectives/milestones? In other words, what are the high-level steps required to deliver on the outputs, outcomes and impact mentioned above?	**Approach to implementation** Given its cross-cutting nature, it is essential when implementing this Thrust that a collaborative approach be followed. This will involve the participation of all those who are implementing STI-related interventions and programmes. The envisaged measurement system should not be perceived to be an external system with a policing function. Instead there should be full ownership of and buy-in to the measuring system and its purpose. **Measurement system for STI, including societal innovation** South Africa already has STI measurement systems in place, and to a more limited extent, M&E systems. However, what is needed is a more comprehensive and detailed vision of how measurement and monitoring need to be changed in order to include social innovation. This could be achieved through a combination of growing, adapting, strengthening and/or re-orienting these systems. Appropriate and effective coordination mechanisms will need to underpin these systems. In addition, • Conduct research, based on international good practice and experience, to develop a more relevant set of STI indicators for South Africa • Put in place systems to monitor STI indicators (including societal indicators) relevant to the South African (and regional) context **Policy** • Re-assess and change existing STI (and any other related) policies to include societal issues as a crosscut in relevant STI domains; include policy instruments to support community self-sufficiency
Resources required What are the resources which are required to achieve the outputs, outcomes and impact? Examples of such resources can include: • Knowledge and expertise • Technologies • Technical infrastructure	• Given its cross-cutting nature, an interdisciplinary team is required, comprised of both individuals and institutions, to design and then implement this Thrust. The team should also include participation by those implementing other Thrusts • Knowledge and expertise are required concerning the human-centred deployment of STIs to effectively address rather than exacerbate the social challenges faced in South Africa • Across the board, those responsible for STI-related policy formulation will need to be appropriately briefed

• Institutional infrastructure • Research results • Partnerships established • Funding • Etc	
Resources to be established Which of the required resources are already established? Which need to be established, and what will be needed to establish them? For example, what STI-related research will be needed to achieve the intended results of the Thrust?	• Existing knowledge and expertise concerning the human-centred deployment of STIs will need to be brought together and assessed. Where necessary, this will need to be supplemented by, for example, new research results • The interdisciplinary implementation team will need to be established using an approach that ensures high levels of buy-in by those implementing other Thrusts
Policy and regulatory environment What changes are required, if any, to the current STI policy and regulatory environment? What new policy and regulatory provisions, if any, will the Thrust require?	Significant changes will be required in policies to strengthen the capacity of STIs to address societal issues and to ensure that there is institutional oversight and sufficiently-resourced governance systems to monitor and evaluate the system Policy changes should include the active participation of those who have been excluded in the past – through inclusion in the processes of design, production, uptake of the knowledge and technology of the future
5. Risk	
Risk of not achieving results Explain the level of difficulty involved in achieving the intended results. Please specify: • Straightforward to achieve • Fairly difficult to achieve • Moderately difficult to achieve • Very difficult to achieve. Please explain your choice. What are the anticipated obstacles and challenges, and what is the likelihood of their being overcome? What are the risks associated with not achieving the intended results of the Thrust?	• It will be fairly difficult to put in place enhanced policies and appropriate indicators that have widespread buy-in amongst the relevant stakeholders. • An even greater challenge is presented by the need to bring about the envisaged changes in the NSI.
Social and ethical acceptability How ethically and socially acceptable is the Thrust? Specify: • Highly acceptable • Mostly acceptable • Fairly unacceptable	• The goals of the Thrust have high social and ethical acceptability. However, the approach to implementation will need to consider the need to maintain high levels of acceptability and trust

• Mostly unacceptable Please explain your choice.	• The proposed M&E system should assess the ethical considerations of technological advancements
Unintended consequences Are there unintended consequences that may result from the Thrust? Explain the level of risk of these possible consequences.	• From the perspective of other Thrusts, this Thrust may be viewed as being a “social audit” rather than the means to enable new activities that address issues of inequality and exclusion within each Thrust • There is a risk that the implementation of this Thrust may result in the perception of a surveillance-oriented NSI. The approach to implementation of the Thrust should seek to minimise this risk
6. Other	
Other information Is there any other information which you wish to provide to support this Proposal for a Thrust?	None

STI Thrust Proposal – FS2

Working group	
Name of STI domain / working group	The Future of Society

1. Title and description of STI Thrust	
Title of Thrust (Eight words or less)	STI for inclusive, people-led development
Summary description Provide a brief description of the Thrust so that we can be sure we understand what you are referring to. (Just a few sentences)	Unless South Africa is better able to utilise its scientific and technological capacities, capabilities, and competences to confront enduring and persistent economic, social, and political challenges, the country could worsen its domestic situation whilst retrogressing relative to comparator countries in the world. Balancing between the current stock of scientific and technological capacities, capabilities, and competences in the NSI, new and expanded demands for support from local enterprises and households, and the dynamics of international geopolitics, demands a more compassionate and responsive system of STI. A more compassionate and responsive system of STI will ultimately seek the realisation of a better life for all within the boundaries of the earth's finite resources, on the basis of social, economic, and political justice. It is therefore imperative that the NSI be further transformed to embrace a people-centred orientation and an ecologically-sensitive stance. STI for inclusive development needs to receive far more emphasis within a future South African NSI and in any proposed STI interventions going forward. Listening to, understanding and acting on the needs of people (both their collective and individual needs) will be vitally important in harnessing STIs to tackle societal challenges. Holistic and cross-cutting initiatives are required that will result in, amongst others: • Rebuilding trust within the NSI - between state and citizens, the public and private sectors, and the knowledge-worker and research community; • Removing the systemic and structural barriers which reproduce inequalities in access and participation in the various enterprises of STI, to ensure that STI delivers sustainable benefits to all; • Embracing the value of engaged, progressive scholarship and encouraging greater utilisation of STI in generating high quality public goods; • Expanding cultures of research excellence, while advancing more culturally-sensitive scientific and technologic solutions;

	• A strong, capable, and developmental state that provides an enabling environment for STI development by all players within the NSI; • Resilient communities, with knowledge-seeking capacities, organisational capabilities, and leadership competences to more speedily adopt and adapt science and technology for domestic benefits; • Self-driven, lifelong learning as a social and cultural value; and • Critical, constructive, confident and respectful South Africans, together building a cohesive, united, non-racial, non-sexist, and non-homophobic society in line with the Constitution and the Bill of Rights. This thrust presents options that could facilitate and promote these changes. They are underpinned by a sound research base and supported by enabling policies to stimulate societal change through STI (See Thrust FS1 – *Policies and Indicators for STI in a Changing South African Society*).
2. Results – Description	
Problems to be addressed What are the problems which the Thrust is intended and is likely to address by 2030?	South Africa currently experiences significant challenges in ensuring that the benefits of STI are accessible and distributed in a more transparent, fair, and equitable manner. Contemporary scientific and technological outputs remain largely focused on promoting disembodied technical solutions, with insufficient attention being paid to either social, political or ecological constraints on their utilisation. • People have been marginalised - through exclusion or being treated unequally. They see themselves as having no future, in part because they believe their children do not have equal opportunities to reach their full potential. Some people live precarious lives, particularly those who have fallen through the cracks of society, who live in poverty, who are unemployed, and who find themselves at the mercy of large impersonal forces of globalisation, technological change, large corporations and financial institutions - they want to regain control. • Current STI interventions do not address societal challenges adequately ; a 'science for all' approach needs to be supported more pro-actively • Policy makers and government departments, in collaboration with the private sector, civil society and other players in the NSI, are not working across domains effectively to respond to complex societal challenges and to make technologies work for the social good. Strong interventions are needed to build cultural and societal values to make this happen:

	- Build an NSI based on mutual trust and respect at all levels, and that supports the building of an inclusive and sustainable society and economy. - Build a society that is proud of indigenous knowledge and locally produced technologies and innovations - Build an NSI that supports structures of state but also self-sufficiency at the individual and community levels, with active participation and contributions from citizens to improve their lives - Build a pan-African System of Innovation which encourage pro-African thinking and collaboration - Develop STI interventions that are based on socially acceptable foundations, sound community participation and that are communicated effectively to communities - There is insufficient focus on ‘big-issue’ problem-solving in South Africa, and not enough focussed R&D activity that provides solutions, e.g. inefficiency of mining sector operations, employment growth in township economies, etc. - There is also a need to prepare for the labour transition that is imminent in the new industrial revolutions. Many existing jobs, especially low-skilled jobs, will be more efficiently performed by machines, while new opportunities for employment will emerge, but typically requiring higher skill levels. More broadly, there is a need to empower a wide range of actors, existing and new, in the digital age. - South Africa lacks a strong culture of lifelong and self-driven learning, a requirement if our society is to move forward with the capability and resilience to deal with the industrial revolutions in production, distribution, consumption and waste-treatment; - Current STI initiatives show a bias towards technological innovations for narrow economic competitiveness, and away from innovations for social benefit and the public good.
Outputs What are the likely outputs of the Thrust by 2030? (The outputs are the immediate results of the Thrust)	This Thrust requires a critical appreciation of the social, economic, and political assumptions being made by the application of STI in South Africa in general, and by the other STI Domains and Thrusts in particular. It should also identify effective ways to address social inequalities related to the harnessing of STIs, and thereby enable greater social responsiveness of the all of the other STI Thrusts. Possible outputs include the following. Further outputs should emerge during the detailed design and implementation of the Thrust. A national framework for prioritising R&D, which would guide all NSI players based on domestic needs, and global ecological boundary conditions

	• A framework for community/social innovation (grassroots) – this includes both urban and rural environments with poor and/or vulnerable communities • Mission-oriented policy and programmes to address societal challenges, based on a sound bottom-up research base, and directionality given by a top-down strategic orientation • A fund/programme for technology demonstration and technology-based pilots that promote social and technological innovation, e.g. Living Labs, based in both urban and rural areas • Innovation capabilities within marginalised communities so that they can participate actively and productively in the NSI • Instruments that will increase trust between all NSI players. This includes partnerships and collaboration among industries/sectors (innovation), researchers (multidisciplinary), inventors (technology convergence), communities • A preferential procurement programme to enable communities to become technology providers • RDI programmes that encourage pan-African collaboration and international cooperation • STI Mobility Studies to better understand the movement of people with STI skills, and to further encourage the building, maintenance and expansion of South Africa's endogenous scientific and technological capabilities
Outcomes and impact What are the likely outcomes and impact of the Thrust? What is the value of the outcomes and impact, and when are they likely to manifest? (The outcomes and impact are the medium-term and long-term results of the Thrust, respectively)	• A society in which the STI is geared towards the benefit of all South Africans and responds to development challenges in a human-oriented, ecologically sensitive, and inclusive manner • By 2050, no South Africans are excluded from the economy, and resilience and sustainability are derived from an increased codependency on science, technology, and innovation
3. Results – Alignment and scope	
Alignment with NDP vision To what extent is the Thrust aligned with the vision of the NDP? Please specify: • Fully aligned • Mostly aligned • Partially aligned • Poorly aligned Please explain your choice. In other words, how will the Thrust contribute, both directly and indirectly, towards	This Thrust speaks to how we promote an inclusive society and an NSI that includes the majority of society. It is therefore fully aligned, both directly and indirectly, towards reducing inequality. Through the articulation of how vulnerable and marginalised groups could harness technological opportunities (including funding and other opportunities), it is mostly aligned to indirectly increasing employment and reducing poverty. The NDP vision builds on an active citizenry, strong leadership and effective government. It refers to the need to support and incentivise citizen engagement and moving forward with citizens who are actively involved in determining future solutions to improve their lives.

eliminating poverty, reducing inequality and increasing employment? Please distinguish clearly between direct and indirect contributions.	The NDP also refers to the better use of existing resources and institutions (in the NSI) that facilitate innovation and greater cooperation between public science and technology institutions, and the private sector.
Scope of the benefits What is the scope of the benefits of the results which the Thrust is likely to have, by 2030? Please specify: • Very broad scope • Broad scope • Medium scope • Narrow scope Please explain your choice. Who will benefit? How many people will benefit (order of magnitude estimate)? In what way will they benefit?	Very broad scope • More efficient NSI, with STI solutions that have a direct positive impact on improving the lives of South Africa's people • Inclusive participation in and access to STI will be a given in future interventions. This is likely to result in more projects and programmes that will directly benefit citizens, while creating new opportunities to build skills and technologies more relevant to dealing with the big issues facing South Africa
4. High-level implementation	

High-level steps
What are the high-level interim objectives or milestones which need to be achieved?
What are the high-level activities/steps/ stages needed to achieve the objectives/milestones?
 	
In other words, what are the high-level steps required to deliver on the outputs, outcomes and impact mentioned above?
	• Develop a national framework for R&D priority setting, within the context of social innovation. This will provide strategic direction for existing and future priority thrusts and make provision for inclusion of all relevant players in the NSI (and encourage pan-African collaboration)
	    o Identify social assumptions made when harnessing STIs in South Africa
	    o Conduct social reviews and analyses to identify the assumptions made
	    o Develop interventions to overcome unequal access
	• Create (and/or build on existing) instruments that facilitate partnerships between all NSI players, including communities, e.g. Forum to promote social innovation, strengthening and expanding the quadruple helix (consisting of the public sector, the private sector, the research sector, and local communities) for open innovation
	    o Convene a multi-stakeholder Inclusive Society Forum that draws attention to issues of social inequality and identifies action plans that can be integrated into STI Domain-specific activities.
	    o Host regional, national and provincial workshops to promote dialogue platforms
	• Expand, extend, strengthen programmes for technology demonstration and technology-based pilots that promote social and technological innovation, e.g. Living Labs
	• Build innovation capabilities within marginalised communities, through technology pilots

	• Scale up existing (successful) pilots within prioritised areas – these need to be identified and efforts made to replicate successful models on a national scale • Develop enabling instruments that will stimulate active participation of communities in becoming technology providers, e.g. preferential procurement programmes, incentivisation, technology appropriation fund for marginalise and vulnerable groups
Resources required What are the resources which are required to achieve the outputs, outcomes and impact? Examples of such resources can include: • Knowledge and expertise • Technologies • Technical infrastructure • Institutional infrastructure • Research results • Partnerships established • Funding • Etc	• A multi-stakeholder Inclusive STI Forum • A Technology Appropriation fund and programme for marginalised and vulnerable groups that can be used to enable social responsive activities, and building innovation capabilities in communities e.g. Living Labs • Knowledge and expertise in social cohesion and inclusive knowledge economies • Significant investment will be needed to support applied social science and humanities-based research that enables the harnessing of STIs to be examined within the context of social innovation
Resources to be established Which of the required resources are already established? Which need to be established, and what will be needed to establish them? For example, what STI-related research will be needed to achieve the intended results of the Thrust	• Many of the required resources need to be established, such as the Inclusive STI Forum and the Technology Appropriation Fund. • Furthermore, an interdisciplinary implementation team will need to be established, consisting of individuals and institutions. This team will be the primary vehicle for implementing the Thrust.
Policy and regulatory environment What changes are required, if any, to the current STI policy and regulatory environment? What new policy and regulatory provisions, if any, will the Thrust require?	Significant changes will be required in policies to strengthen the capacity of STIs to address societal issues and to ensure that there is institutional oversight and a sufficiently-resourced governance system to monitor and evaluate implementation Policy changes should include the active participation of those who have been excluded in the past – through inclusion in the processes of design, production, uptake of the knowledge and technology of the future
5. Risk	
Risk of not achieving results Explain the level of difficulty involved in achieving the intended results. Please specify: • Straightforward to achieve • Fairly difficult to achieve	The envisaged changes to society are very difficult to achieve but they are necessary for the future prosperity of all. The involvement of a broad range of experts is needed to ensure the implementation of the Thrust.

• Moderately difficult to achieve • Very difficult to achieve. Please explain your choice. What are the anticipated obstacles and challenges, and what is the likelihood of their being overcome? What are the risks associated with not achieving the intended results of the Thrust?	The risk of not addressing the issues of inclusion and access to STIs, will result in the continued deployment of STIs that benefit only a minority of South Africans.
Social and ethical acceptability How ethically and socially acceptable is the Thrust? Specify: • Highly acceptable • Mostly acceptable • Fairly unacceptable • Mostly unacceptable Please explain your choice.	Mostly to highly acceptable, but this will depend on how effectively the various players in the NSI can agree on the proposed STI solutions and to what extent the benefits are tangible in the short- to medium-term.
Unintended consequences Are there unintended consequences that may result from the Thrust? Explain the level of risk of these possible consequences.	Too much emphasis may be placed on inclusive access and participation, resulting in slow or no progress on STI development – due to lack of focus, and too much effort being spent on finding consensus and too little on moving ahead with implementation.
6. Other	
Other information Is there any other information which you wish to provide to support this Proposal for a Thrust?	None

STI Thrust Proposal – HE1

Working group	
Name of STI domain / working group	Health

1. Title and description of STI Thrust	
Title of Thrust (Eight words or less)	Optimisation of health systems
Summary description Provide a brief description of the Thrust so that we can be sure we understand what you are referring to. (Just a few sentences)	Optimisation of health care provision through provision of quality support systems and equitable resource allocation
2. Results – Description	
Problems to be addressed What are the problems which the Thrust is intended and is likely to address by 2030?	• Supply chains slow, and poorly managed procurement puts patients at risk. • Turnaround time of diagnosis too slow; putting patients at risk. • Infrastructure issues in medical facilities; putting patients at risk, poor safety and sterility in facilities, power supplies, water quality etc. • Lack of coordination between facilities introduces inefficiencies and costs lives. • Data management: lack of access to patient records throughout life, from all care facilities.
Outputs What are the likely outputs of the Thrust by 2030? (The outputs are the immediate results of the Thrust)	• Optimised procurement and delivery systems to ensure reliable access to supplies to all facilities; and to manage issues such as expiration, etc. • Rapid diagnosis technologies (point of care) and access to results (apps and informatics). • Well managed facilities and infrastructure in all locations. • Data management: full access to patient records throughout life, from all care facilities, to ensure correct information available to patient and physician, at all times.
Outcomes and impact What are the likely outcomes and impact of the Thrust? What is the value of the outcomes and impact, and when are they likely to manifest? (The outcomes and impact are the medium-term and long-term results of the Thrust, respectively)	• Reliable and well managed hospital systems, costs reduced, wastage reduced, improved range of resources available, improved outcomes for patients, reduced stress for medical staff. • By 2030; all medical facilities will have reliable supply chain systems, linked to national procurement processes. • Patients have high quality diagnosis from all locations, and systems are optimised for local point of care technologies, and remote access, as well as samples-to-labs needs. Information readily and reliably available to patient and medical staff. • By 2030 all patients will have rapid return rates for routine

	diagnostics results, and access to point-of-care and/or remote diagnostics technologies. • Well managed, modern health care facilities; Improved quality of health care in all locations. • By 2030 – all medical facilities meet minimum standards set by DOH. • Access to reliable patient information from all locations. • By 2030: All people are being recorded in a high-quality national data system. *[NOTE: This is less an output of this thrust and more a data source for continuous improvement and updating of the optimization process. It is an output of the 'digitization of health systems' thrust]* • Improved responsiveness of the health care system (eg, in response to crises such as outbreaks and natural disasters) and robustness (eg, through shared information that helps optimize use of limited resources or sporadically needed resources to improve health outcomes) *[NOTE: An example: post-exposure prophylaxis against rabies. This is an expensive, limited resource that requires cold chain management. It's unrealistic that it will be available at all health care facilities – this would result in high levels of wastage that we can't afford; however, we could develop algorithms that optimize the allocation of this resource to ensure that everyone has access to this life-saving product if and when it is needed (must be received as soon as possible of exposure; the WHO recommendation is "immediately"; practically, this means within 24 hours). The vaccine would be kept in facilities with stable electricity and sufficient refrigeration capacity, with a plan in place for distribution on an as-needed basis (might include drones in some areas; in other areas, it might require the patient to go to the distribution centre – e.g. if it's a short drive away). Information sharing is key for this – the HCW needs to be able to find out where the vaccine is, request it for the patient, and ensure the patient is able to access it (e.g. "the drone will deliver it to the clinic in an hour; please wait and we will administer it as soon as it arrives").]*
3. Results – Alignment and scope	
Alignment with NDP vision To what extent is the Thrust aligned with the vision of the NDP? Please specify: • Fully aligned • Mostly aligned • Partially aligned • Poorly aligned Please explain your choice. In other words, how will the Thrust contribute, both directly and indirectly, towards eliminating poverty, reducing inequality and	Fully aligned • Creates social opportunities through improved health • Promotes transparency and a culture of accountability • Works toward correcting historical inequalities It will "strengthen primary health care services and broad district-based health programmes". It will enable "the state to better service and support poor communities". The impacts on poverty will be mainly indirect, via improved health, particularly in marginalized populations. Equitable allocation of health resources is essential to reducing inequality, with both direct and indirect (e.g. intergenerational)

increasing employment? Please distinguish clearly between direct and indirect contributions.	effects. The impact on employment is unclear but the direct effect is likely to be neutral or positive.
Scope of the benefits What is the scope of the benefits of the results which the Thrust is likely to have, by 2030? Please specify: • Very broad scope • Broad scope • Medium scope • Narrow scope Please explain your choice. Who will benefit? How many people will benefit (order of magnitude estimate)? In what way will they benefit?	Very broad scope The goal is that by 2030, the overall health care system will be improved for all South Africans. The benefits will accrue more toward those who access health care via the public sector than via the private sector. There may be some cases in which resources are reallocated from richer communities to poorer communities in a way that some affluent individuals feel a direct negative effect, even while indirectly benefiting from the overall improvement of the whole health system.
4. High-level implementation	
High-level steps What are the high-level interim objectives or milestones which need to be achieved? What are the high-level activities/steps/ stages needed to achieve the objectives/milestones? In other words, what are the high-level steps required to deliver on the outputs, outcomes and impact mentioned above?	The first step will be a high-level assesessment of all aspects of the current status of all resources that are critical to the health system (including diagnostics, vaccines, therapuetics, etc). All components of the supply chain need to be considered, with a focus on opportunities for fundamental systemic change, rather than just speeding up what's already there. These components are: • **Choice of products** (including: are there new products needed? Different types of vaccines, new antimicrobials, diagnostics, therapeutics, etc.). • **Production** (including: are there things that are currently imported that we should be producing locally? Are there things that are produced locally where efficiency of production can be radically improved?) • **Allocation** (how do ensure that resources get to where they're needed most? This requires knowing where they're needed – links to thrust 1's contribution to population level data and analysis – and for limited resources determining where they will have the most impact – which requires modelling and simulation; potentially also reallocation, either in response to emergency or to ensure efficient use of products prior to expiration). • **Distribution** (including transportation infrastructure and efficient procurement systems; could include adoption of new technology such as drones to reach remote areas). • **Stock management** (including digital monitoring of stock levels, managing expiration, etc.); this could perhaps be merged with allocation/distribution. Specific resources will need to be chosen for initial implementation, and detailed critical reviews of the current supply chain for these resources conducted.

<table>
<tr><td></td><td>Optimization algorithms need to be developed and tested, with very careful construction of utility functions (i.e. definition of what is being optimized and the weighting of different considerations), for each chosen critical resource.

Allocation, distribution, and stock management implementation</td></tr>
<tr><td>Resources required
What are the resources which are required to achieve the outputs, outcomes and impact?

Examples of such resources can include:
• Knowledge and expertise
• Technologies
• Technical infrastructure
• Institutional infrastructure
• Research results
• Partnerships established
• Funding
• Etc.</td><td>• Data on the location of all health care facilities and their current access to critical resources
• Improved data on morbidity and mortality across the country (see below) to inform needs
• Transportation infrastructure necessary for distribution of resources
• Knowledge and expertise in operations research and algorithm development, plus modelling and simulation, and big data analytics (for assessment / evaluation and iterative improvement).
• Sufficient funding will be crucial and is not currently available
• Partnerships will need to be established between health care facilities, particularly in the same area.</td></tr>
<tr><td>Resources to be established
Which of the required resources are already established?
Which need to be established, and what will be needed to establish them?

For example, what STI-related research will be needed to achieve the intended results of the Thrust?</td><td>The thrust will benefit from the outputs of the ‘digitalization of health services’ thrust, which will provide critical new data on population-level health patterns and needs, which will be needed to interatively improve the allocation of resources as the health system develops.

Research needs will include modelling, simulation, and algorithms that can be used to evaluate alternative scenarios for allocating resources. Big data analytics (for assessment / evaluation and iterative improvement).</td></tr>
<tr><td>Policy and regulatory environment
What changes are required, if any, to the current STI policy and regulatory environment?

What new policy and regulatory provisions, if any, will the Thrust require?</td><td>No changes to the regulatory environment are anticipated to be required.</td></tr>
</table>

5. Risk	
Risk of not achieving results Explain the level of difficulty involved in achieving the intended results. Please specify: • Straightforward to achieve • Fairly difficult to achieve • Moderately difficult to achieve • Very difficult to achieve. Please explain your choice. What are the anticipated obstacles and challenges, and what is the likelihood of their being overcome? What are the risks associated with not achieving the intended results of the Thrust?	Moderately difficult to achieve Relies on critical skills that are currently very scarce, and infrastrurcture that is not yet developed; the latter is simpler to overcome than the former.
Social and ethical acceptability How ethically and socially acceptable is the Thrust? Specify: • Highly acceptable • Mostly acceptable • Fairly unacceptable • Mostly unacceptable Please explain your choice.	Mostly acceptable If there is redistribution of access to health resources, this may not be acceptable to affluent communities and will need to be carefully managed. This can be addressed by only applying allocation part of the thrust to publicly-funded resources and ensuring that there is no suppression or stagnation of the private market. Optimimization of the other aspects of the supply chain are highly acceptable.
Unintended consequences Are there unintended consequences that may result from the Thrust? Explain the level of risk of these possible consequences.	Unknown.
6. Other	
Other information Is there any other information which you wish to provide to support this Proposal for a Thrust?	None at this time.

STI Thrust Proposal – HE2

Working group	
Name of STI domain / working group	Health

1. Title and description of STI Thrust	
Title of Thrust (Eight words or less)	Improving the quality of health care
Summary description Provide a brief description of the Thrust so that we can be sure we understand what you are referring to. (Just a few sentences)	To address a range of issues to ensure provision of affordable and high quality health care to all South Africans, regardless of location or economic status.
2. Results – Description	
Problems to be addressed What are the problems which the Thrust is intended and is likely to address by 2030?	• Availability of expert staff at all care facilities – access to appropriate facilities in all communities. (This intersects with the provision of improved health services in Thrust HE3). • Prevention, diagnostics, and treatment strategies required for management of disease burden; behavioural, vaccination, point-of-care diagnostics, new drugs (including in response to antimicrobial resistance). • Advanced technologies; e.g. precision and personalised medicine – for predictive and diagnostic applications. (genome sequencing, stem cell technologies, immunotherapy, gene editing etc).
Outputs What are the likely outputs of the Thrust by 2030? (The outputs are the immediate results of the Thrust)	• Improved health service provision in all communities, through life-long learning by medical staff, and continuous access to high quality information resources. Partial solution toward the challenge of staffing and support in isolated rural medical systems. • A range of strategies and technologies for reducing the rates of communicable and non-communicable diseases. • Widespread access to world-class technologies for hard to diagnose, hard to treat (expensive) diseases.
Outcomes and impact What are the likely outcomes and impact of the Thrust? What is the value of the outcomes and impact, and when are they likely to manifest? (The outcomes and impact are the medium-term and long-term results of the Thrust, respectively)	• Improved health service provision in all communities, through life-long learning by medical staff, and continuous access to high quality information resources. Partial solution toward the challenge of staffing and support in isolated rural medical systems. • By 2030: all medical practitioners are using life-long learning tools to be regularly updated with current and reliable information. • Reduced burden of disease; responsible lifestyles; more rapid diagnostics; increased vaccination programs; new drugs, especially antibiotics • Reduced burden of disease, especially hard to diagnose/treat, genetic diseases, somatic mutation disease

	(cancer). Improved disease management, reduced mortality.
3. Results – Alignment and scope	
Alignment with NDP vision To what extent is the Thrust aligned with the vision of the NDP? Please specify: • Fully aligned • Mostly aligned • Partially aligned • Poorly aligned Please explain your choice. In other words, how will the Thrust contribute, both directly and indirectly, towards eliminating poverty, reducing inequality and increasing employment? Please distinguish clearly between direct and indirect contributions.	Fully aligned with NDP. Chapter 10.
Scope of the benefits What is the scope of the benefits of the results which the Thrust is likely to have, by 2030? Please specify: • Very broad scope • Broad scope • Medium scope • Narrow scope Please explain your choice. Who will benefit? How many people will benefit (order of magnitude estimate)? In what way will they benefit?	Broad scope since everyone will benefit from accessing quality healthcare.
4. High-level implementation	
High-level steps What are the high-level interim objectives or milestones which need to be achieved? What are the high-level activities/steps/ stages needed to achieve the objectives/milestones? In other words, what are the high-level steps required to deliver on the outputs,	• Development of systems that ARE INTEROPERABLE AND SECURE. • Training on data entry and access. • Good interfaces. • Good definitions for database architecture . • Database design that is robust, resilient, forward-looking, adaptable. • App developers. • Ethical considerations about data security. • Policy development for encryption, network security. • Exploration of private sector and international resources . • Turnaround times.

outcomes and impact mentioned above?	• Supply-chain and procurement systems that actually work. • Decentralisation of implementation.
Resources required What are the resources which are required to achieve the outputs, outcomes and impact? Examples of such resources can include: • Knowledge and expertise • Technologies • Technical infrastructure • Institutional infrastructure • Research results • Partnerships established • Funding • Etc	• Funding • Infrastructure: technical, physical and institutional (the specifics need to be determined) • Partnerships • Human resources (skilled) in medical care, biotechnology, IT and database systems development
Resources to be established Which of the required resources are already established? Which need to be established, and what will be needed to establish them? For example, what STI-related research will be needed to achieve the intended results of the Thrust?	• Funding: established but not sufficient. Lots of money will be needed so that it can be established. • Infrastructure: not established. More money needed to establish it. A formal analysis of what type of infrastructure is required. Definition of minimum requirement (cellphones). • Supply-chain and procurement are not functioning optimally, need to be decentralised and optimised.
Policy and regulatory environment What changes are required, if any, to the current STI policy and regulatory environment? What new policy and regulatory provisions, if any, will the Thrust require?	• POPI • Ethics • Improvement of the way the different tiers of governance within the healthcare system are functioning. • Harmonisation of policies.
5. Risk	
Risk of not achieving results Explain the level of difficulty involved in achieving the intended results. Please specify: • Straightforward to achieve	Moderately difficult to achieve. Obstacles: • The cost of ICT • Scalability • Lack of skilled personnel • Lack of funding

• Fairly difficult to achieve • Moderately difficult to achieve • Very difficult to achieve. Please explain your choice. What are the anticipated obstacles and challenges, and what is the likelihood of their being overcome? What are the risks associated with not achieving the intended results of the Thrust?	• Good governance • Lack of well-established regulatory policies The likelihood of them being overcome is moderate. Quality healthcare for all will not be achieved if these things are not achieved.
Social and ethical acceptability How ethically and socially acceptable is the Thrust? Specify: • Highly acceptable • Mostly acceptable • Fairly unacceptable • Mostly unacceptable Please explain your choice.	Highly acceptable because people will be healthy and live longer and it is a high priority among all people.
Unintended consequences Are there unintended consequences that may result from the Thrust? Explain the level of risk of these possible consequences.	None.
6. Other	
Other information Is there any other information which you wish to provide to support this Proposal for a Thrust?	None

STI Thrust Proposal – HE3

Working group	
Name of STI domain / working group	Health

1. Title and description of STI Thrust	
Title of Thrust (Eight words or less)	Digitization of health systems
Summary description Provide a brief description of the Thrust so that we can be sure we understand what you are referring to. (Just a few sentences)	• Applications of ICT to health care; development of unified patient data systems; telemedicine and remote surgery; remote diagnosis/AI; long term data collection for epidemiology and association studies; training of health workers (including curriculum development, remote learning, life-long learning); **By 2030:** • All people are being recorded in a high-quality national data system. • All health care systems are digitised and integrated. • All medical practitioners are using life long learning tools to be regularly updated with current and reliable information.
2. Results – Description	
Problems to be addressed What are the problems which the Thrust is intended and is likely to address by 2030?	• SA Health care system does not record and maintain patient data – requires robust, secure, long term data system. *[NOTE: Need to emphasize linkage across facilities and different components of the health care sector. An integrated system is necessary, and tech challenges include interoperability, cybersecurity, etc. I suggest adding a 'problem to be addressed' that specifically focuses on lags and inefficiencies in patient care that are created by NOT having such a system in case. Currently, point 1 is more about the what, and less about the why, and overall the problems emphasize training over the eHealth component.]* • Do not have enough health care workers (and training programmes are not scalable in the current environment) so we need to use remote tools and informatics to share expertise, provide access to reliable diagnostic apps; remote and AI technologies for diagnostics; remote surgery technology. • Provide distance learning solutions for life long learning with future-looking curriculum through apps/web-based services.
Outputs What are the likely outputs of the Thrust by 2030? (The outputs are the immediate results of the	• Comprehensive, universal, secure, national patient records. • Technology assisted expansion and effective utilisation of available skills in health care system; support for rural medical practice; effective diagnosis and decision support systems in all communities. • Continuous program for training medical staff, with best

<table>
<tr><td>Thrust)</td><td>available curriculum, and best distance learning technology.</td></tr>
<tr><td>Outcomes and impact
What are the likely outcomes and impact of the Thrust? What is the value of the outcomes and impact, and when are they likely to manifest?

(The outcomes and impact are the medium-term and long-term results of the Thrust, respectively)</td><td>• Full access to patient records throughout life, from all care facilities, to ensure correct information available to patient and physician at all times.
• Collection of population and time-series datasets (Big Data) for whole population, anonymised, secured, POPI compliant, complete, flexible to new data resources and technology
• By 2030: All people are being recorded in a high-quality national data system.

• Access to top quality medical solutions in all communities; improved diagnosis and treatment options;
• By 2030: All health care systems are digitised and integrated.

• Improved health service provision in all communities, through life-long learning by medical staff, and continuous access to high quality information resources. Partial solution toward the challenge of staffing and support in isolated rural medical systems.
• By 2030: all medical practitioners are using life long learning tools to be regularly updated with current and reliable information.</td></tr>
<tr><td colspan="2">3. Results – Alignment and scope</td></tr>
<tr><td>Alignment with NDP vision
To what extent is the Thrust aligned with the vision of the NDP? Please specify:
• Fully aligned
• Mostly aligned
• Partially aligned
• Poorly aligned

Please explain your choice.

In other words, how will the Thrust contribute, both directly and indirectly, towards eliminating poverty, reducing inequality and increasing employment?

Please distinguish clearly between direct and indirect contributions.</td><td>FULLY ALIGNED.
Chapter 10:</td></tr>
<tr><td>Scope of the benefits
What is the scope of the benefits of the results which the Thrust is likely to have, by 2030? Please specify:
• Very broad scope
• Broad scope</td><td>Very broad scope.

Everyone will benefit from their lifetime health records being available at all health care service points.</td></tr>
</table>

• Medium scope • Narrow scope Please explain your choice. Who will benefit? How many people will benefit (order of magnitude estimate)? In what way will they benefit?	
4. High-level implementation	
High-level steps What are the high-level interim objectives or milestones which need to be achieved? What are the high-level activities/steps/ stages needed to achieve the objectives/milestones? In other words, what are the high-level steps required to deliver on the outputs, outcomes and impact mentioned above?	• Development of systems that ARE INTEROPERABLE AND SECURE. • Training on data entry and access. • Good interfaces. • Good definitions for database architecture. • Database design that is robust, resilient, forward-looking, adaptable. • App developers. • Ethical considerations about data security. • Policy development for cybersecurity, encryption, network security. • Exploration of private sector and international resources.
Resources required What are the resources which are required to achieve the outputs, outcomes and impact? Examples of such resources can include: • Knowledge and expertise • Technologies • Technical infrastructure • Institutional infrastructure • Research results • Partnerships established • Funding • Etc	• Funding • Developers • Infrastructure: technical and institutional
Resources to be established Which of the required resources are already established? Which need to be established, and what will be needed to establish them? For example, what STI-related research will be needed to achieve the	• Funding: established but not sufficient. Lots of money will be needed so that it can be established. • Developers: not established. Expand computer science schools and the establishment of programming at an early age. Specialised ICT institutions. • Infrastructure: not established. More money needed to establish it. A formal analysis of what type of infrastructure is required. Definition of Minimum requirement (cellphones).

intended results of the Thrust?	
Policy and regulatory environment What changes are required, if any, to the current STI policy and regulatory environment? What new policy and regulatory provisions, if any, will the Thrust require?	• Cybersecurity • POPI • Ethics
5. Risk	
Risk of not achieving results Explain the level of difficulty involved in achieving the intended results. Please specify: • Straightforward to achieve • Fairly difficult to achieve • Moderately difficult to achieve • Very difficult to achieve. Please explain your choice. What are the anticipated obstacles and challenges, and what is the likelihood of their being overcome? What are the risks associated with not achieving the intended results of the Thrust?	Moderately difficult to achieve. Obstacles: • The cost of ICT • Scalability • Lack of skilled personnel • Lack of funding • Good governance • Lack of well-established regulatory policies The likelihood of them being overcome is moderate. Quality healthcare for all will not be achieved if these things are not achieved.
Social and ethical acceptability How ethically and socially acceptable is the Thrust? Specify: • Highly acceptable • Mostly acceptable • Fairly unacceptable • Mostly unacceptable Please explain your choice.	Highly acceptable because people will be healthy and live longer and it is a high priority among all people.
Unintended consequences Are there unintended consequences that may result from the Thrust? Explain the level of risk of these possible consequences	None.

6. Other	
Other information Is there any other information which you wish to provide to support this Proposal for a Thrust?	None.

STI Thrust Proposal – HT1

Working group	
Name of STI domain / working group	High-Technology Industrialisation

1. Title and description of STI Thrust	
Title of Thrust (Eight words or less)	Enabling small business to adopt high tech
Summary description Provide a brief description of the Thrust so that we can be sure we understand what you are referring to. (Just a few sentences)	The Thrust targets a number of enabling factors to assist different types of small businesses to enter the high tech market or use technology to enable small business growth. *[Hi-tech business is defined as one that spends more than 10%-15% of turnover on R&D.]* 1. Enabling tech-intensive small businesses to adopt hi-tech (new or additional) as part of their hi-tech product/service offering. 2. Enabling tech-intensive small businesses to adopt hi-tech to increase/improve their general level of competitiveness. 3. Enabling ordinary small businesses to adopt hi-tech as their hi-tech product/service offering. 4. To grow more hi-tech business through the commercialisation of R&D /technology 5. Enabling ordinary businesses to adopt hi-tech (buy/lease/ develop) to transition into a hi-tech business.
2. Results – Description	
Problems to be addressed What are the problems which the Thrust is intended and is likely to address by 2030?	• Low proportion of high tech start-ups, • Access to IP/technology, • Difficulty of doing business (logistics, financial systems, regulatory barriers)
Outputs What are the likely outputs of the Thrust by 2030? (The outputs are the immediate results of the Thrust)	• Large number of high tech start-ups. • Supportive systems for start-ups created (e.g. cloud services for shared administration, online business services (tax, registration, regulation) and freely available and accessible. • Government IP made available for alternative exploitation. • PPP VC fund established. • PFMA relaxed to promote public procurement from SMEs.
Outcomes and impact What are the likely outcomes and impact of the Thrust? What is the value of the outcomes and impact, and when are they likely to manifest? (The outcomes and impact are the medium-term and	• Number of sustainable and competitive small businesses increases dramatically. • New sectors established on the back of new technology services (AI, Digital integration, Additive manufacturing, cloud services). • GDP growth + % contribution by SMEs increases significantly.

long-term results of the Thrust, respectively)	
3. Results – Alignment and scope	
Alignment with NDP vision To what extent is the Thrust aligned with the vision of the NDP? Please specify: Fully aligned Mostly aligned Partially aligned Poorly aligned Please explain your choice. In other words, how will the Thrust contribute, both directly and indirectly, towards eliminating poverty, reducing inequality and increasing employment? Please distinguish clearly between direct and indirect contributions.	Fully aligned with the themes in the NDP. • Small businesses in different sectors may show varying degrees of alignment e.g. biotech, ICT, manufacturing, mining. • In the short-term there may be negative impacts in terms of growing jobs, but in the longer term there will be a major impact on increasing employment opportunities.
Scope of the benefits What is the scope of the benefits of the results which the Thrust is likely to have, by 2030? Please specify: Very broad scope Broad scope Medium scope Narrow scope Please explain your choice. Who will benefit? How many people will benefit (order of magnitude estimate)? In what way will they benefit?	Broad scope • As per the description of various types of small businesses above, and their adoption of hi-tech, the benefits will be broad in the longer-term as businesses across diverse sectors see the impact of hi-tech adoption. • Small businesses are important multipliers in terms of job creation and economic growth.
4. High-level implementation	
High-level steps What are the high-level interim objectives or milestones which need to be achieved? What are the high-level activities/steps/ stages needed to achieve the objectives/milestones?	The high-level implementation plan has to differentiate between the different types of categories as described above - Is hi-tech being adopted as a service, as a product, or to diffuse it into the business (tech-enabled)? Different implementation plans have to be developed for each of these groups of business types. A generic approach is inappropriate, and the plans will need to address businesses in various sectors, as their needs will be

In other words, what are the high-level steps required to deliver on the outputs, outcomes and impact mentioned above?	different.
Resources required What are the resources which are required to achieve the outputs, outcomes and impact? Examples of such resources can include: Knowledge and expertise Technologies Technical infrastructure Institutional infrastructure Research results Partnerships established Funding	• All businesses need to be ICT-enabled as a generic requirement, e.g. incentivise the provision of ICT services by the private sector, e.g. cloud storage for small business, free wi-fi for small businesses, IT to benefit artisans, e.g. plumbers, etc. • University spin-off businesses require more public sector support. An available resource is the Technology stations programme (TIA), a broad-based instrument to service SMEs with tech services. A sector-specific approach is needed to determine requirements. The ecosystem needs to be mapped for each specific sector, e.g. ICT, Biotech, Manufacturing.
Resources to be established Which of the required resources are already established? Which need to be established, and what will be needed to establish them? For example, what STI-related research will be needed to achieve the intended results of the Thrust?	See above – approach has to be sector-specific and cannot be defined generically for all businesses. Focus must be on priority sectors and those likely to have the most impact, e.g. • Mining - research on mining and mining equipment • Bio-economy – bio-platforms • Indigenous Knowledge • Additive Manufacturing, etc. Government has to play a larger role in creating a better enabling environment. Specific recommendations: • Open innovation programmes required, with calls for competitive participation. • Partnering opportunities between large and small firms, e.g. IP portfolios that will benefit small businesses and can result in partnerships.
Policy and regulatory environment What changes are required, if any, to the current STI policy and regulatory environment? What new policy and regulatory provisions, if any, will the Thrust require?	Needs to be addressed by specific sector.

5. Risk	
Risk of not achieving results Explain the level of difficulty involved in achieving the intended results. Please specify: Straightforward to achieve Fairly difficult to achieve Moderately difficult to achieve Very difficult to achieve. Please explain your choice. What are the anticipated obstacles and challenges, and what is the likelihood of their being overcome? What are the risks associated with not achieving the intended results of the Thrust?	General small businesses must have a mandatory online presence. They will disappear if this is not there. The e-commerce domain will kill small firms as this is unbounded geographically. Small businesses can be overtaken by technology and lack of an online presence, resulting in them being uncompetitive in the market. Hi-tech adoption and access to hi-tech will be crucial. The need for independent advice, as a service, may reduce the risk for small businesses.
Social and ethical acceptability How ethically and socially acceptable is the Thrust? Specify: Highly acceptable Mostly acceptable Fairly unacceptable Mostly unacceptable Please explain your choice.	Mostly acceptable. There are global drivers that are happening and this needs to be understood as a given. There are issues, e.g. in mining and with likely job losses due to introduction of hi-tech solutions. This will need to be addressed, through dialogue and developing an understanding
Unintended consequences Are there unintended consequences that may result from the Thrust? Explain the level of risk of these possible consequences.	The Digital Divide might increase and result in more digital inequality, although e.g. mobile phones leapfrogged over landline rollout.
6. Other	
Other information Is there any other information which you wish to provide to support this Proposal for a Thrust?	None.

STI Thrust Proposal – HT3

Working group	
Name of STI domain / working group	High-Technology Industrialisation

1. Title and description of STI Thrust	
Title of Thrust (Eight words or less)	New thinking for new industries
Summary description Provide a brief description of the Thrust so that we can be sure we understand what you are referring to. (Just a few sentences)	Development of new high-tech sectors for the country, e.g. space technology, green chemistry, cyber-security, biometric security, additive manufacturing, autonomous mining vehicles
2. Results – Description	
Problems to be addressed What are the problems which the Thrust is intended and is likely to address by 2030?	Poor new industry creation Reduction of reliance on legacy industries Risk-aversion by industry
Outputs What are the likely outputs of the Thrust by 2030? (The outputs are the immediate results of the Thrust)	Tech and green enterprise creation and development High-skilled job creation
Outcomes and impact What are the likely outcomes and impact of the Thrust? What is the value of the outcomes and impact, and when are they likely to manifest? (The outcomes and impact are the medium-term and long-term results of the Thrust, respectively)	Supporting the transition to a knowledge-based and greener/circular economy Establishing SA in the global high-tech space
3. Results – Alignment and scope	
Alignment with NDP vision To what extent is the Thrust aligned with the vision of the NDP? Please specify: • Fully aligned • Mostly aligned • Partially aligned • Poorly aligned Please explain your choice.	Will contribute to the transition to a green and knowledge-based economy with a focus on innovation. Creation high-tech and green start-ups will directly to growth and employment creation, and high-skilled, high-paying jobs. Indirectly, these start-ups will contribute (through multiplier effects in the economy and via stimulating supply chains and forwards linkages) towards growth and employment. Also, these start-ups will contribute towards medium- to high-tech export of goods and services, reducing the concentration of SA's current exports.

In other words, how will the Thrust contribute, both directly and indirectly, towards eliminating poverty, reducing inequality and increasing employment? Please distinguish clearly between direct and indirect contributions.	Mostly aligned
Scope of the benefits What is the scope of the benefits of the results which the Thrust is likely to have, by 2030? Please specify: • Very broad scope • Broad scope • Medium scope • Narrow scope Please explain your choice. Who will benefit? How many people will benefit (order of magnitude estimate)? In what way will they benefit?	High-tech start-ups would have a medium to broad scope, via the creation of 1,000s of enterprises (including several 'unicorns'), entailing 1,000,000 to 5,000,000 new jobs and at least R1,000,000,000 turnover. Creation of many high-tech start-ups would also contribute towards improving the resilience of the SA economy would be broad. Improving the proportion of medium- to high-tech exports would also have a medium to broad scope. In terms of supporting the transition to a low-carbon economy, the benefit would be narrow to medium. The new enterprises created would pollute less, but the scope of this thrust does not cover existing/incumbent industries.
4. High-level implementation	
High-level steps What are the high-level interim objectives or milestones which need to be achieved? What are the high-level activities/steps/ stages needed to achieve the objectives/milestones? In other words, what are the high-level steps required to deliver on the outputs, outcomes and impact mentioned above?	Objective: Identifying new S&T areas for development Activity: Undertake a study of scientific and technological outputs Activity: Establish SA readiness and risk appetite for entering such industries Objective: Accelerated high-tech enterprise development and support Activity: Harmonise technological innovation and commercialisation instruments Objective: Create a pool of appropriately-skilled workers. Activity: Determine skills needs and capacity
Resources required What are the resources which are required to achieve the outputs, outcomes and impact? Examples of such resources can include: • Knowledge and expertise • Technologies • Technical infrastructure • Institutional infrastructure • Research results • Partnerships established • Funding	Sufficient financial resources for experimental development and commercialisation of technologies Start-up capital Coaching and mentoring of entrepreneurs Entrepreneurial knowledge High-potential scientific research Highly-trained workers Acquiring foreign technologies for local adaptation and diffusion

Resources to be established Which of the required resources are already established? Which need to be established, and what will be needed to establish them? For example, what STI-related research will be needed to achieve the intended results of the Thrust?	Establishment of a national network of high-tech incubators and accelerators
Policy and regulatory environment What changes are required, if any, to the current STI policy and regulatory environment? What new policy and regulatory provisions, if any, will the Thrust require?	Joint planning between agencies and departments Relaxation of regulatory requirements (including labour laws) for start-ups and SMEs New policy requirements to regulate the digital economy No punitive measures for tech start-up failure
5. Risk	
Risk of not achieving results Explain the level of difficulty involved in achieving the intended results. Please specify: • Straightforward to achieve • Fairly difficult to achieve • Moderately difficult to achieve • Very difficult to achieve. Please explain your choice. What are the anticipated obstacles and challenges, and what is the likelihood of their being overcome? What are the risks associated with not achieving the intended results of the Thrust?	Very difficult to achieve due to the nature of starting a new enterprise, compounded by the inherent uncertainty of technological uncertainty. (See separate risk rating.) This is a very risk endeavour, but a worthwhile goal, given the opportunity and promises of how these technologies might enable a better life and prosperity. If this thrust is not undertaken, SA will continue to deindustrialise and will become unhealthily more dependent on finite natural resources and the services sector.
Social and ethical acceptability How ethically and socially acceptable is the Thrust? Specify: • Highly acceptable • Mostly acceptable • Fairly unacceptable • Mostly unacceptable Please explain your choice.	Mostly acceptable, because enterprises will be green and sustainable, and will create jobs and growth, but not huge numbers of low-skilled jobs
Unintended consequences Are there unintended consequences that may result from the Thrust? Explain the level of risk of these possible consequences.	High entry barriers for work-seekers (high skill requirements)

6. Other	
Other information Is there any other information which you wish to provide to support this Proposal for a Thrust?	

STI Thrust Proposal – HT4

Working group	
Name of STI domain / working group	High-Technology Industrialisation

1. Title and description of STI Thrust	
Title of Thrust (Eight words or less)	New thinking for old industries
Summary description Provide a brief description of the Thrust so that we can be sure we understand what you are referring to. (Just a few sentences)	The use in novel combinations of old, new and advanced technologies and knowledge for improved competitiveness and efficiencies in existing and distressed industries (the current industrial base). Can't ignore the current industrial base – must take current industries into the future. Need to help them to adopt the newer technologies.
2. Results – Description	
Problems to be addressed What are the problems which the Thrust is intended and is likely to address by 2030?	Deindustrialisation Low competitiveness Job losses Some industries need to jump to the next 'S-curve' to stay competitive. However, we need to face the reality that some industries will disappear over the years. What can government incentivise? What regulations are appropriate?
Outputs What are the likely outputs of the Thrust by 2030? (The outputs are the immediate results of the Thrust)	Digital-savvy industries (e.g. for metal casting and plastics) (Challenging because the topic is very broad)
Outcomes and impact What are the likely outcomes and impact of the Thrust? What is the value of the outcomes and impact, and when are they likely to manifest? (The outcomes and impact are the medium-term and long-term results of the Thrust, respectively)	Job preservation, saving as many businesses as possible, transforming the current industrial base. More resilient and competitive industries
3. Results – Alignment and scope	
Alignment with NDP vision To what extent is the Thrust aligned with the vision of the NDP? Please specify:	Will help existing industries transition a green and knowledge-based economy through the adoption of new technologies.

• Fully aligned • Mostly aligned • Partially aligned • Poorly aligned Please explain your choice. In other words, how will the Thrust contribute, both directly and indirectly, towards eliminating poverty, reducing inequality and increasing employment? Please distinguish clearly between direct and indirect contributions.	Adoption of new technologies and green/ sustainable practices directly contribute to revitalising 'brown' industries, preserving jobs and enterprises. Indirectly, preserving these jobs and enterprises will mitigate the potentially devastating effects of business closures on the affected families and communities. Mostly aligned
Scope of the benefits What is the scope of the benefits of the results which the Thrust is likely to have, by 2030? Please specify: • Very broad scope • Broad scope • Medium scope • Narrow scope Please explain your choice. Who will benefit? How many people will benefit (order of magnitude estimate)? In what way will they benefit?	More resilient firms due technological upgrading. More resilient workers due to reskilling. Very broad scope This will serve to support the current distressed sectors – massive potential to preserve of jobs and growth in e.g. metal casting, metal fabrication, plastics, etc.
4. High-level implementation	
High-level steps What are the high-level interim objectives or milestones which need to be achieved? What are the high-level activities/steps/ stages needed to achieve the objectives/milestones? In other words, what are the high-level steps required to deliver on the outputs, outcomes and impact mentioned above?	Objectives: Technological upgrading of distressed industries, including digitalisation Activities: Comprehensive audit with an emphasis on technologies; determine feasibility and impact of improvements/solutions; identify and secure/ procure appropriate existing productivity-enhancing technologies and knowledge; deployment within firm Activity: Technology scouting (new/emerging technologies) to improve and enhance industry competitiveness Objective: Skills improvement and new skills Activity: Linked to the above-mentioned audit, implement a skills upgrading and improvement programme
Resources required What are the resources which are required to achieve the outputs, outcomes and impact?	Establishment of industry extension programme Funding for acquiring foreign technologies for local adaptation and diffusion Establish and fund a new products and services development programme

Examples of such resources can include: • Knowledge and expertise • Technologies • Technical infrastructure • Institutional infrastructure • Research results • Partnerships established • Funding • Etc	
Resources to be established Which of the required resources are already established? Which need to be established, and what will be needed to establish them? For example, what STI-related research will be needed to achieve the intended results of the Thrust?	Massification of existing Technology Localisation Implementation Programme (CSIR)
Policy and regulatory environment What changes are required, if any, to the current STI policy and regulatory environment? What new policy and regulatory provisions, if any, will the Thrust require?	Policy to expand the existing Technology Localisation Programme, via the establishment of new instruments and programmes
5. Risk	
Risk of not achieving results Explain the level of difficulty involved in achieving the intended results. Please specify: • Straightforward to achieve • Fairly difficult to achieve • Moderately difficult to achieve • Very difficult to achieve. Please explain your choice. What are the anticipated obstacles and challenges, and what is the likelihood of their being overcome? What are the risks associated with not achieving the intended results of the Thrust?	Fairly difficult to moderate. On the one hand, distressed firms should be receptive to being supported with solutions to save their business. But on the other hand, solution providers may encounter resistance based on existing poor or conservative corporate cultures and reluctance to change. (See separate risk rating.) The likelihood of overcoming reluctance to change is mixed. The risks associated with not achieving the intended results would be continued large-scale job losses, and associated increased potential for social unrest.

Social and ethical acceptability How ethically and socially acceptable is the Thrust? Specify: • Highly acceptable • Mostly acceptable • Fairly unacceptable • Mostly unacceptable Please explain your choice.	Highly acceptable, as success will contribute towards not worsening the triple challenges.
Unintended consequences Are there unintended consequences that may result from the Thrust? Explain the level of risk of these possible consequences.	Possible job losses due to technological upgrading, resulting in productivity improvements and redundancies
6. Other	
Other information Is there any other information which you wish to provide to support this Proposal for a Thrust?	

STI Thrust Proposal – IT1

Working group	
Name of STI domain / working group	Opportunities, threats and impact of ICTs on Society

1. Title and description of STI Thrust	
Title of Thrust (Eight words or less)	Checks and balances for a digital future
Summary description Provide a brief description of the Thrust so that we can be sure we understand what you are referring to. (Just a few sentences)	We have observed far-reaching societal impacts from the advent of new ICTs, some of which have taken us unawares. Obvious examples are the impact of social media on personality development, social interactions, the behaviour of corporates and political systems. New developments in ICTs are producing new unintended outcomes some of which have significant societal impacts. There are a number of areas of concern… As people and systems become more connected and depend increasingly on data and software stored in the cloud, there are increasing opportunities for cybercrime and security threats. The potential of big data has resulted in the collection of more and more data, sometimes with but often without the knowledge and consent of individuals. This results in opportunities for exploitation and threats to privacy, particularly directed at those who are less tech-savvy and least able to defend themselves. The ubiquity of information makes it more difficult for individuals to filter unwanted information and easier for those providing information to manipulate public opinion and perceptions of the truth. The spectre of artificial intelligence creates ethical dilemmas for what algorithms ought to be allowed to do and when we should limit their decision-making. These possibilities require us to engage with a new set of moral and ethical problems and to develop appropriate societal norms to address them. We need to identify and implement effective checks and balances to manage the risks presented by these technologies. Such checks and balances may be processes, policies, information, technology solutions or legislation. South Africa has made some progress towards addressing some of these challenges through legislation such as the PoPI Act, but the implementation has been poor and there is a sense that these measures do not go far enough. When compared to the kinds of privacy protection that people in Europe enjoy, South Africans are at risk of exploitation. This thrust addresses some of the threats of ICTs, and in doing so makes it possible to take advantage of more opportunities.

2. Results – Description	
Problems to be addressed What are the problems which the Thrust is intended and is likely to address by 2030?	Some of the problems are enumerated in the narrative above. Here is a list: The full implications of AI on society is unknown and includes moral and ethical dilemmas. AI affects what information we see, how we are treated, who makes decision and how those decisions are made. Algorithms are great at landing planes, for example, but may also promote racist attitudes by building algorithms based on existing human prejudices. Before AI is widely deployed we need to think through what decisions can be left to AI and where doing so will pose unacceptable moral and ethical risks and what checks and balances can be put in place to limit negative impacts. South Africa enjoys high levels of cybercrime which has negative effects for individuals and businesses. It limits the attractiveness of the country to business and makes it hard for local businesses to compete internationally. Small business websites, for example, are automatically flagged as suspect by web browsers if they are based in South Africa. The implications of sharing personal data are not well understood in the South African context. We have less protection than people in Europe, for example. Research shows that South Africans may be more willing than people in Europe to share personal data if it benefits society as a whole, so privacy regulations and policies need to be developed to reflect the local context. Research is needed into potential risks posed by ICTs and effective mechanisms to mitigate those risks. A sober and informed public discourse needs to be promoted and supported, going beyond fear-mongering, to inform the public about the realistic threats and appropriate responses. Projects to implement and monitor the success of these mechanism need to be fleshed out.
Outputs What are the likely outputs of the Thrust by 2030? (The outputs are the immediate results of the Thrust)	At a philosophical level, ways to understand the moral and ethical dilemmas presented by new technologies, developed from local perspectives. (Philosophy departments will at last have access to research funds!). Governance research that examines the best kinds of policy interventions, including those in use in other countries and makes recommendations as to the direction that should be taken in South Africa. Critique of existing laws, comparative studies and proposed appropriate legal frameworks for the South African context, provided by legal experts. New technologies and procedures that address security issues and can be used to combat cybercrime as well as new understandings of local cybercrime, the dynamics

	that support cybercrime and how best to combat it, from criminologists. New technologies to support personal choice and empower individuals – for example news filtering applications that ensure that our news feed reflect our personal choices and not those of media algorithms. Informational products that inform people of the moral and ethical challenges, the risks and the mechanisms to mitigate those risks. These may take the form of advertising campaigns, informational web sites, public debate, or information provided through traditional and new media. A sober and informed public debate about these issues (not just another scare story) that creates wider understanding and an informed populace who are empowered to defend themselves against risks. Implemented policies, processes and laws supported by monitoring mechanisms that give feedback on the level of public knowledge, the tone of public discourse, the roll out of checks and balances and the success of strategies to reduce harmful impacts of ICTs.
Outcomes and impact What are the likely outcomes and impact of the Thrust? What is the value of the outcomes and impact, and when are they likely to manifest? (The outcomes and impact are the medium-term and long-term results of the Thrust, respectively)	This thrust makes it possible to enjoy the benefits of ICTs while guarding against negative consequences. There is a lot of basic research to be undertaken in this thrust. Such research will take around five years to materialise. (medium-term) This then will inform the development of appropriate checks and balances, which may take another five years to emerge. (long-term) In the meanwhile the monitoring of current mechanisms as well as the development of new technological solutions and applications can run in parallel and may produce results in a shorter timeframe, depending on the kinds of artefacts being produced.
3. Results – Alignment and scope	
Alignment with NDP vision To what extent is the Thrust aligned with the vision of the NDP? Please specify: • Fully aligned • Mostly aligned • Partially aligned • Poorly aligned Please explain your choice. In other words, how will the Thrust contribute, both directly and indirectly, towards eliminating poverty, reducing inequality and increasing employment?	By making the South African cyber-space safer, local businesses will find it easier to engage with international markets and foreign businesses will be encouraged to invest in South Africa. This will have economic benefits that will increase employment and reduce poverty. (Indirect) People, especially those that are less tech-savvy will be empowered to resist identity theft and exploitation (direct), and be better protected by policy and legal frameworks, thus reducing inequality (indirect). By engaging in debates about the ethical application of AI we can avoid scenarios where AI contributes to increasing social divides and we can ensure that AI is used for public benefit rather than for maximising profit (direct). This will

Please distinguish clearly between direct and indirect contributions.	assist in eliminating poverty and reducing inequality (indirect).
Scope of the benefits What is the scope of the benefits of the results which the Thrust is likely to have, by 2030? Please specify: • Very broad scope • Broad scope • Medium scope • Narrow scope Please explain your choice. Who will benefit? How many people will benefit (order of magnitude estimate)? In what way will they benefit?	The overall benefits of this thrust are very broad, in that they will have a number of different societal impacts. All the people in the country will benefit by living in a safer, saner country where decisions on what technology is allowed to do and facilitate is informed by moral and ethical positions. Laws and policies that are national in scope will have broad impacts, providing protection for businesses and individuals. Some benefits have a medium scope in that they will inform specific industries. For example the roll-out of driverless cars. Having the legal and ethical frameworks in place for this kind of development will make it possible for the country to move quickly on providing shared transport solutions that address inequality. Some might have narrow scope. An example is to develop specific technologies and software to address specific security threats or to filter news according to personally developed criteria.
4. High-level implementation	
High-level steps What are the high-level interim objectives or milestones which need to be achieved? What are the high-level activities/steps/ stages needed to achieve the objectives/milestones? In other words, what are the high-level steps required to deliver on the outputs, outcomes and impact mentioned above?	The following steps are envisaged: 1) Evaluate who in the country is doing research in these areas. 2) Examine current research for the state of knowledge. 3) Define a research agenda to understand the moral, ethical dimensions as well as the potential checks and balances that could be implemented. 4) Examine the state of implementation of current checks and balances, their effectiveness and their implementation challenges. 5) Examine the technological solutions under development that may assist in addressing security and privacy challenges. 6) Create a high-level forum of interested researchers and practitioners to facilitate communication across different disciplines and institutions. 7) Arrange a regular national conference to share research. 8) Create national mechanisms to support the translation of research results into policy and legal frameworks and other implementation processes. 9) Set up a national working group to propose and create informational products to encourage national debate and inform members of the public about the results of the research.
Resources required What are the resources which are required to achieve the outputs, outcomes and impact?	Some knowledge and expertise already exists but needs to be identified and brought together.

Examples of such resources can include: • Knowledge and expertise • Technologies • Technical infrastructure • Institutional infrastructure • Research results • Partnerships established • Funding • Etc	New technologies need to be developed. There may be a need for infrastructure to support these development processes. The research results that this thrust produces will become inputs into the thrust and the next actions that need to be taken. Partnerships with appropriate bodies from other countries will assist in developing this research thrust. Funding will be needed for the tasks identified.
Resources to be established Which of the required resources are already established? Which need to be established, and what will be needed to establish them? For example, what STI-related research will be needed to achieve the intended results of the Thrust?	There is probably a substantial body of research already existing. This may need to be brought together, curated and shared with interested people working in the thrust. The research listed under output above is needed for this thrust. Some may be in place, but more is needed that is specific to the South African context. A national coordinating group should be established, drawing on existing groups such those working on computer security at UJ, ICT policy at Wits and social impacts of ICT at NMMU.
Policy and regulatory environment What changes are required, if any, to the current STI policy and regulatory environment? What new policy and regulatory provisions, if any, will the Thrust require?	No changes are required to initiate this thrust. We need to understand what is in place in the regulatory environment that can act as checks and balances for the digital future. These mechanisms need to be catalogued and their effectiveness assessed. Based on the research that emerges, changes may be needed to refine the current environment.
5. Risk	
Risk of not achieving results Explain the level of difficulty involved in achieving the intended results. Please specify: • Straightforward to achieve • Fairly difficult to achieve • Moderately difficult to achieve • Very difficult to achieve. Please explain your choice. What are the anticipated obstacles and challenges, and what is the likelihood of their being overcome? What are the risks associated with not achieving the intended results of the Thrust?	South Africa has high levels of cybercrime that impact companies and individuals. This leads to mistrust in digital solutions and resistance to using them. If this persists it will be difficult for the country to take advantage of new developments in ICT and will limit economic growth. If AI has free reign without ethical guidelines we run the risk of companies using algorithms to optimise profits without considering the social impacts. This may lead to widening social divides as algorithms feed people information that fuels mistrust and entrenches divergent positions. The research required can be achieved, although there may be some challenges. Developing new technologies can also be achieved although the outcomes are unpredictable.

	The challenge will be to bring the right parties together, and to coordinate research efforts. The risk is that companies who drive the development of new ICTs may exploit the populace, government and other businesses for their own end. Often exploitative practices are targeted at the least informed in society, increasing divides.
Social and ethical acceptability How ethically and socially acceptable is the Thrust? Specify: • Highly acceptable • Mostly acceptable • Fairly unacceptable • Mostly unacceptable Please explain your choice.	There is widespread concern about the ethical and social impacts of ICTs, so there is likely to be widespread support for this thrust. Businesses and criminals who see the potential for exploiting ignorance about new ICTs may oppose the thrust.
Unintended consequences Are there unintended consequences that may result from the Thrust? Explain the level of risk of these possible consequences.	Difficult to anticipate.
6. Other	
Other information Is there any other information which you wish to provide to support this Proposal for a Thrust?	Research has shown that South Africans may be more open to sharing personal data if there is a social benefit that will result. This suggests that South Africans may want privacy regulations that differ from, for example, those in Europe. There is a need to develop locally nuanced responses to the social challenges of new technologies.

STI Thrust Proposal – IT2

Working group	
Name of STI domain / working group	Opportunities, threats and impact of ICTs on Society

1. Title and description of STI Thrust	
Title of Thrust (Eight words or less)	Internet Access & the Network & Information Infrastructure of the 2030
Summary description Provide a brief description of the Thrust so that we can be sure we understand what you are referring to. (Just a few sentences)	Affordable broadband internet access enabled by digital communications and information networks play an important role in realizing the digital future we aspire. Access to internet is enshrined as a basic human right for all by the UN and the international telecommunications union(ITU), it is the tool that will help us innovate and develop new 4th IR based applications and services in the 2030s in South Africa. South Africa benefitting from the digital economy through innovative ICT Technologies and Services
2. Results – Description	
Problems to be addressed What are the problems which the Thrust is intended and is likely to address by 2030?	1- High Cost of ICT infrastructure New and innovative technologies to reduce the cost of ICT infrastructure are being developed and should be incentivised through the universal access UASF and policy interventions. 2- Uneven ICT Infrastructure roll out: Rural & Urban digital divide. Traditionally urban areas where the population density and income is higher are provided with high quality ICT infrastructure by industry stakeholders. 3- Lack of skills in the digital sector. Rural and marginalised areas are left behind (from the digital revolution/transformation) due to techno-economic considerations, lack of basic infrastructure and skills.
Outputs What are the likely outputs of the Thrust by 2030? (The outputs are the immediate results of the Thrust)	A seamless ICT infrastructure is deployed to give affordable broadband internet access to all: independent of their location & the access device they use. Efficient communication and information exchange between the ICT eco-system stakeholders will be enhanced: Gov, industry & society. Thereby bridging the digital divide, and ushering the Emergence of network and ICT service provider SME sector. The emergence of an abundance of digital skills in the areas of software development, electronics/telecommunications devices and equipment manufacturing, and ICT project management
Outcomes and impact What are the likely outcomes and impact of the Thrust? What is the value of the outcomes and	Studies have shown that a 10 % increase in broadband internet connectivity is expected to result in equivalent ~2 % GDP improvement.

impact, and when are they likely to manifest? (The outcomes and impact are the medium-term and long-term results of the Thrust, respectively)	An increased number ICT service & tech SMEs will create more job opportunities and make their value added services available using the deployed affordable broadband networks and ICT infrastructure and access to the internet will become universal. R&D and test-bed requirements will be fulfilled helping the rapid development and deployment of ICT and networking technologies affordably everywhere in the country. The Internet, information and communications networks are regarded as the nervous system for the new interconnected smart systems, big data and digital information society of the 2030. Current internetworking technologies provide a significant step towards developing a low latency tactile access network by providing new additional wireless nerve tracts, i.e., data pipes. With the increase in the number of smart autonomous systems, the protection of the 'nervous system' against malicious attacks becomes increasingly important. Moreover, the system autonomy and the large number of distributed sensor systems demand the simultaneous integration of energy efficient networking concepts. The move from personalized communication to machine-type communication also demands radically new communication network, data collection, data analytics algorithms and architectures, including the seamless and secure access to the internet by people and things. South Africa will have adequate technical skills in the ICT sector (both hardware and software perspective) to even export regionally & globally.
3. Results – Alignment and scope	
Alignment with NDP vision To what extent is the Thrust aligned with the vision of the NDP? Please specify: • Fully aligned • Mostly aligned • Partially aligned • Poorly aligned Please explain your choice. In other words, how will the Thrust contribute, both directly and indirectly, towards eliminating poverty, reducing inequality and increasing employment? Please distinguish clearly between direct and indirect contributions.	Fully Aligned: Affordable broadband internet access will provide local businesses easier access to market their products to local & international customers. Foreign direct investment in businesses will accelerate the investment climate in South Africa. This will have economic benefits and possible increase in employment and reduction of poverty. Affordable internet access indirectly supports development of improved societal ICT services in sectors such as education, health and transportation.

<table>
<tr><td></td><td></td></tr>
<tr><td>Scope of the benefits
What is the scope of the benefits of the results which the Thrust is likely to have, by 2030? Please specify:
• Very broad scope
• Broad scope
• Medium scope
• Narrow scope

Please explain your choice. Who will benefit? How many people will benefit (order of magnitude estimate)? In what way will they benefit?</td><td>The benefits of the internet access thrust are very broad, in that they will have a number of different social and economic impacts.

All society and industry in the country will benefit through improved market opportunities, and the access to relevant information through big data cloud based systems to the largest digital library through affordable broadband access. Public & Gov. organizations can also provide their services affordably to society.

Additional benefits would be realised through increased job opportunities and entrepreneurship in the ICT sector.</td></tr>
<tr><td colspan="2">4. High-level implementation</td></tr>
<tr><td>High-level steps
What are the high-level interim objectives or milestones which need to be achieved?
What are the high-level activities/steps/ stages needed to achieve the objectives/milestones?

In other words, what are the high-level steps required to deliver on the outputs, outcomes and impact mentioned above?</td><td>Evaluate who in the country is doing research in the areas of affordable broadband internet access.
Examine current research and future knowledge requirements.
Examine the current state and new technological solutions under development that may assist in addressing broadband internet access for all
Create a high-level forum of interested researchers and practitioners to facilitate communication across different disciplines and institutions.
Arrange a regular national conference to share research.
Create national public & private sector forum to support the translation of research results into test-bed deployment and implementation processes.
Set up a national working group to propose and create informational products to encourage national debate and inform members of the public about the results of the research.

Enhancing and developing new technical college focused on hands-on training for ICT skills, from hardware development/manufacturing to software development.
Supporting most previously disadvantaged universities to produce highly qualified scientists and ICT engineers.</td></tr>
<tr><td>Resources required
What are the resources which are required to achieve the outputs, outcomes and impact?

Examples of such resources can include:
• Knowledge and expertise
• Technologies
• Technical infrastructure
• Institutional infrastructure</td><td>Knowledge and expertise: Much already exists but needs to be identified and brought together. Especially in the rural or previously disadvantaged universities.
Innovation in existing internet access technologies and development of new affordable network technologies need to be undertaken.
Network technology test-beds needed as PoC for the research results that this thrust produces. Industry Partnerships with appropriate industry, standards and regulatory bodies from other countries will assist in developing this research thrust.
Funding will be needed for the tasks identified.</td></tr>
</table>

• Research results • Partnerships established • Funding • Etc	
Resources to be established Which of the required resources are already established? Which need to be established, and what will be needed to establish them? For example, what STI-related research will be needed to achieve the intended results of the Thrust?	A well-functioning research and innovation climate, technical regulation and enabling policy frameworks. The research and technology PoC test-beds listed under output above is needed for this thrust. Some may be in place, but more is needed that is specific to the South African context.
Policy and regulatory environment What changes are required, if any, to the current STI policy and regulatory environment? What new policy and regulatory provisions, if any, will the Thrust require?	Need enabling policy & technical regulations to : 1- Guarantee QoS of networks and the internet service provision. 2- Guarantee Different network, data & information systems interoperate and co-exist with minimum of interference. 3- Provide sufficient spectrum resources and the tools for spectrum sharing. 4- Provide a level playing field, avoid monopoly and collusion and encourage new and affordable broadband network technologies.
5. Risk	
Risk of not achieving results Explain the level of difficulty involved in achieving the intended results. Please specify: • Straightforward to achieve • Fairly difficult to achieve • Moderately difficult to achieve • Very difficult to achieve. Please explain your choice. What are the anticipated obstacles and challenges, and what is the likelihood of their being overcome? What are the risks associated with not achieving the intended results of the Thrust?	Straight forward: Broadband internet access is a thrust that will accelerate economic and social growth in South Africa. Failing to provide internet access to society will deprive the country from taking advantage of sustainable development opportunities in the digital economy and the 4^{th} IR. The challenge will be to provide basic infrastructure for rural communities and bring the right parties and municipalities together, and to coordinate research efforts.
Social and ethical acceptability How ethically and socially acceptable is the Thrust? Specify: • Highly acceptable	There is widespread support, socio-economic benefits and impacts of internet access and associated ICT services, so there is likely to be widespread support for this thrust.

• Mostly acceptable • Fairly unacceptable • Mostly unacceptable Please explain your choice.	
Unintended consequences Are there unintended consequences that may result from the Thrust? Explain the level of risk of these possible consequences.	Depending on skills and economic shortages, some sectors of the society, might be left behind again.
6. Other	
Other information Is there any other information which you wish to provide to support this Proposal for a Thrust?	Adoption of new and emerging network and information technologies is hampered by legacy infrastructure and the need to be backward compatible, the RoI requirement by industry & society. The current economic structure of South Africa has not changed from the pre-democracy setting, where black dwellings are located far away, at the outskirts of the big town or cities of economic hubs. This kind of setup has not only disabled the economic participation of townships and rural villages residence, it continues to exclude such residence from gaining adequate access to the ICT services such as high-speed broadband. For instance, providing fibre-to-the-home (FTTH) in rural and townships still remains a challenge in South Africa. ICT Innovation centres should be established beyond the big cities, e.g. in provinces which are seen to be more rural.

STI Thrust Proposal – IT3

Working group	
Name of STI domain / working group	ICT

1. Title and description of STI Thrust	
Title of Thrust (Eight words or less)	Big Data, Data Analytics and Decision Support
Summary description Provide a brief description of the Thrust so that we can be sure we understand what you are referring to. (Just a few sentences)	The development of skills and systems to enable decision support within government and private sector. Within the government sector, focus will be on enabling evidence-based policy decisions on resource management through utilisation, processing and contextualisation of data from ground based and space based (satellite) sensor networks. Within the private sector, focus will be on development of data analytic skills, as well as the development and deployment of sensor networks (ground and space).
2. Results – Description	
Problems to be addressed What are the problems which the Thrust is intended and is likely to address by 2030?	i. Government policy and regulatory decisions on resource management, planning for infrastructure investment, and other areas that have spatial context are often not evidence based; ii. Monitoring and evaluation, at a national level, is conducted by on-the-ground deployment of people, resulting in highly inefficient processes undertaken at high costs; iii. Lack of big data skills is resulting in a substantial opportunity cost to South Africa, given the global gap that exists in big data skills; iv. Targeted interventions by government on a variety of social, and other, issues are often misdirected or inappropriate as a result of lack of contextualisation of the problem – there is a lack of interpretation of 'what the data says'
Outputs What are the likely outputs of the Thrust by 2030? (The outputs are the immediate results of the Thrust)	i. Intra-government decision support platform, utilising both ground and space based sensor networks, that provides spatial knowledge for strategic spatial planning and resource management; ii. Government awareness and utilisation of big data end products; iii. Data democracy within government; iv. Sensor networks (ground and space based) developed within public and private institutions v. Enhanced and increased data science and data analytics programs at universities and research institutions vi. National Data Science Centre, providing critical big data analytics services to state agencies,

	resourced within infrastructure and data scientists and which includes artificial intelligence and machine learning competency
Outcomes and impact What are the likely outcomes and impact of the Thrust? What is the value of the outcomes and impact, and when are they likely to manifest? (The outcomes and impact are the medium-term and long-term results of the Thrust, respectively)	i. Substantially improved monitoring and evaluation function for government that is multi-sectorial (health, nutrition, urban planning, environment, global change) ii. Substantially more efficient resource management, and effective evidence based policy decision making iii. Improved efficiency in a variety of public focused services and programs, some of which may result in targeted and personalised service delivery for citizens (ie. health) iv. Higher impact from public infrastructure investment vii. Critical mass of big data skills across South Africa, and possibly an appreciable share of the global market viii. Long term risk mitigation, enabling the assessment of resources hazards (eg. acid mine drainage, water pollution, pest control) to be conducted in days as opposed to months
3. Results – Alignment and scope	
Alignment with NDP vision To what extent is the Thrust aligned with the vision of the NDP? Please specify: • Fully aligned • Mostly aligned • Partially aligned • Poorly aligned Please explain your choice. In other words, how will the Thrust contribute, both directly and indirectly, towards eliminating poverty, reducing inequality and increasing employment? Please distinguish clearly between direct and indirect contributions.	Fully aligned – this thrust enables improved resource management, and greater impact from investments directed towards NDP programs – ranging from health, agriculture, nutrition, the environment etc. It provides a substantial risk mitigation tool as enables insight into trends on far shorter timescales than previously done (eg. from months to days). In some cases (ie. hyperspectral imaging on satellites and drones), it enables the identification of hazards not easily mapped previously (eg. hydro-carbons, acid mine drainage, pests).
Scope of the benefits What is the scope of the benefits of the results which the Thrust is likely to have, by 2030? Please specify: • Very broad scope • Broad scope	Very broad scope, as the thrust will enable decision makers in a variety of sectors.

• Medium scope • Narrow scope Please explain your choice. Who will benefit? How many people will benefit (order of magnitude estimate)? In what way will they benefit?	
4. High-level implementation	
High-level steps What are the high-level interim objectives or milestones which need to be achieved? What are the high-level activities/steps/ stages needed to achieve the objectives/milestones? In other words, what are the high-level steps required to deliver on the outputs, outcomes and impact mentioned above?	i. Engagement with, and funding of, relevant funding agencies to establish and facilitate instruments for research into and commercialisation of data analytics and sensor networks ii. Engagement with all government departments to understand key decisions being made concerning deployment of infrastructure and resource management iii. Establishment of a funded unit within the DST (or relevant agency), with the primacy purpose of implementing a platform that utilises publically and commercially available datasets from ground based and space based sensor networks and develops data products that are key to government level decision makers and are at the right contextual level (this can be done on a very short timescale). Such a platform will become and enterprise-based platform iv. Policy on data democracy to ensure sharing of data amongst government departments v. Establish a National Centre of Data Analytics – that may be located within an existing national facility at this early stage – with the mandate to deliver big data, data analytics and decision support to government agencies and SOE's
Resources required What are the resources which are required to achieve the outputs, outcomes and impact? Examples of such resources can include: • Knowledge and expertise • Technologies • Technical infrastructure • Institutional infrastructure • Research results • Partnerships established • Funding • Etc	i. Intra-government coordination ii. IT systems iii. Acquisition of publically and commercially available datasets iv. Funding instruments for universities and research institutions v. Awareness campaign within government vi. Appropriate institutional vehicle vii. Skills

Resources to be established Which of the required resources are already established? Which need to be established, and what will be needed to establish them? For example, what STI-related research will be needed to achieve the intended results of the Thrust?	i. Platforms already exist for exploitation of satellite based data (hence, the inter-governmental support unit can be implemented on a very short term) – continued data acquisition will be required ii. Continued and increased investment into institutions currently identified as having critical mass of computing resources and/or data analytics skills (eg. CHPC, SKA) – exploit the critical mass already established for skills development iii. Institutional vehicle will need to be established in the long term, but could be located within an existing national facility in the short term iv. Need to undertake awareness campaign and political buy-in at departmental level
Policy and regulatory environment What changes are required, if any, to the current STI policy and regulatory environment? What new policy and regulatory provisions, if any, will the Thrust require?	i. This will be address in Checks & Balances for a Digital Future, however the policy development will depend on the focus. Government Focus: a. Utilisation of commercially and publicly available data would not require policy and regulatory provision at this stage. b. A policy on data democracy, ensuring sharing of all government generated datasets, is important (but not critical to initiating the thrust) Public Citizen Focus: a. Utilisation of sensor networks to enable personalised information of people does require consideration of privacy concerns, with possibly policy and regulatory development required
5. Risk	
Risk of not achieving results Explain the level of difficulty involved in achieving the intended results. Please specify: • Straightforward to achieve • Fairly difficult to achieve • Moderately difficult to achieve • Very difficult to achieve. Please explain your choice. What are the anticipated obstacles and challenges, and what is the likelihood of their being overcome? What are the risks associated with not achieving the intended results of the Thrust?	There are some easy wins that are straightforward to achieve (ie. intra-government platform), whilst the more longer term steps are fairly difficult to achieve due to the funding requirements as well as buy-in (this is particularly so for public citizen focus areas, which will have privacy issues – however, this has been solved in other countries). In general, the thrust is achievable.

Social and ethical acceptability How ethically and socially acceptable is the Thrust? Specify: • Highly acceptable • Mostly acceptable • Fairly unacceptable • Mostly unacceptable Please explain your choice.	Where the thrust covers privacy and personalised information, there are social and ethical concerns. This is primarily derived from ground-based sensor networks that are able to personalise information. However, where sensor information is de-personalised (eg. population trends), or is derived from passive sensing (eg. landcover, water) this should encounter no social and ethical problems.
Unintended consequences Are there unintended consequences that may result from the Thrust? Explain the level of risk of these possible consequences.	None identified.
6. Other	
Other information Is there any other information which you wish to provide to support this Proposal for a Thrust?	The technology exists, and there are quick and easy wins.

STI Thrust Proposal – IT4

Working group	
Name of STI domain / working group	The opportunities, threats and impact of smart systems on society

1. Title and description of STI Thrust	
Title of Thrust (Eight words or less)	Smart and sustainable Municipal Service delivery
Summary description Provide a brief description of the Thrust so that we can be sure we understand what you are referring to. (Just a few sentences)	Internationally, governments recognise that urbanisation is a reality and that service delivery, unless properly planned and coordinated, will be insufficient. Smart systems will enable better targeted planning and investment. Using ICT and smart systems we can enable smart cities (e government, e health, transport, citizens, energy, water etc.) to become a reality. To realise this vision requires that we develop a coherent but integrated strategy which allows us to leverage the technology investments that need to be made. We also have the opportunity to standardise the policy, structure, systems, processes, technology, training for all municipalities.
2. Results – Description	
Problems to be addressed What are the problems which the Thrust is intended and is likely to address by 2030?	A smart and sustainable municipality is one that optimises its utilisation of human resources, technology and processes to efficiently and effectively deliver its mandate of serving communities. Since 1994, municipalities have faced service delivery challenges which are attributed to poor financial management, inadequate human and institutional capacity, overstretched infrastructure and weak governance systems. The service delivery challenges persist despite government channelling increasing resources (transfers) to the local government sphere. The increased resources going into the local sphere have not translated into commensurate service delivery improvements in the majority of municipalities. It is evident that local government service delivery failures cannot be remedied with only increased funding; a fundamental shift in the institutional arrangements is required. It is time to embark on a transformation journey to transform municipalities with a developmental agenda towards becoming "Smart and Sustainable". We need to make municipalities relevant to the people.
Outputs What are the likely outputs of the Thrust by 2030? (The outputs are the immediate results of the Thrust)	• Organisational Transformation Strategy • Stakeholder Engagement Plan • Business Case • Technical and implementation guidelines and toolkit • Training manuals

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- Proof of concept, standardised solution with a reference case
- Lessons learnt report

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Outcomes and impact
What are the likely outcomes and impact of the Thrust? What is the value of the outcomes and impact, and when are they likely to manifest?

(The outcomes and impact are the medium-term and long-term results of the Thrust, respectively)

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Overall Objective: To transform financially distressed[1] category B municipalities into "**Smart and Sustainable municipalities**" using technology as a key enabler for change.

Specific Objectives include:

a. To improve the financial sustainability of Category B municipalities
b. To optimise and pilot a Smart and Sustainable Service delivery Solution (Smart Utility in the Box) at one category B municipality (Reference Case)
c. To develop standardised training programmes for all staff within category B municipal (pilot municipality)
d. To develop standardised organisational transformation and implementation guidelines for category B municipalities

<u>Outcomes</u>

a. Improved revenue generation and expenditure management efficiencies within the municipality.
b. Demonstrate the Smart and Sustainable service delivery Solution (Smart Utility in the Box) at one category B municipality (Reference Case for all municipalities)
c. Training platform for continuous development of skills for category B municipal officials
d. Transformation and implementation guidelines for category B municipalities documented as a toolkit.
e. Safe, reliable, efficient, environmentally friendly, economic, secure service delivery to all residents
f. Responsive and resilient municipality that is able to deal with service delivery by balancing supply and demand in response to the climate change challenges we may face.

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3. Results – Alignment and scope

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Alignment with NDP vision
To what extent is the Thrust aligned with the vision of the NDP? Please specify:

- Fully aligned
- Mostly aligned
- Partially aligned
- Poorly aligned

Please explain your choice.

In other words, how will the Thrust contribute, both directly and indirectly, towards eliminating poverty, reducing

</td><td>

Outcome 6:

An efficient, competitive, and responsive economic infrastructure network

Outcome 9:

Responsive, accountable, effective, and efficient development of local government system

Outcome 10:
Protect and enhance our environmental assets and natural resources

Outcome 12:
An efficient, effective and development orientated public service

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[1] Section 138, MFMA

<table>
<tr><td>inequality and increasing employment?

Please distinguish clearly between direct and indirect contributions.</td><td>Fully aligned</td></tr>
<tr><td>Scope of the benefits
What is the scope of the benefits of the results which the Thrust is likely to have, by 2030? Please specify:
• Very broad scope
• Broad scope
• Medium scope
• Narrow scope

Please explain your choice. Who will benefit? How many people will benefit (order of magnitude estimate)? In what way will they benefit?</td><td>• Safe, reliable, efficient, sustainable, economic, secure service delivery delivered in a standardised way to all residences
• Category B municipal customers: will receive reliable and quality service thereby reducing service delivery protests
• Category B Municipalities: Revenue collection will be optimised thereby reducing fiscal dependence
• Eskom: current account and long-term debt will be repaid.
• Department of Water Affairs: for National water security
• National Treasury: reduction of equitable grants to category B municipalities
• Responsive and resilient municipality that is able to deal with service delivery by balancing supply and demand in response to the climate change challenges we may face.</td></tr>
<tr><td colspan="2">4. High-level implementation</td></tr>
<tr><td>High-level steps
What are the high-level interim objectives or milestones which need to be achieved?
What are the high-level activities/steps/ stages needed to achieve the objectives/milestones?

In other words, what are the high-level steps required to deliver on the outputs, outcomes and impact mentioned above?</td><td>Activity 1: Establishment of a Municipal Transformation Steering Committee (MTSC) for governance and strategic decision making
Activity 2: MTSC identifies and selects 1 category B municipality for review (Pilot Site)
Activity 3: Establish a Project Technical Working Group (PTWG)
Activity 4: Establish baselines by doing a review of Pilot Municipality. The following components will be reviewed:
• Strategy
• Institutional arrangements
• Governance structures
• Organisational structure
• People
• Policy alignment
• Business processes (Service operations)
• Work flow and asset management
• Technology
• Customer
• Value chain integration and automation
• Social and environmental alignment

Activity 5: Involves industry best practices review, analysis and synthesis and demonstration of a working solution

Activity 6: Implementation of pilot demonstration at one category B municipality based upon the review of Activity 4 & 5 and best practices.</td></tr>
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Resources required
What are the resources which are required to achieve the outputs, outcomes and impact?

Examples of such resources can include:

Knowledge and expertise
Technologies
Technical infrastructure
Institutional infrastructure
Research results
Partnerships established
Funding
Etc

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Knowledge and expertise

Strategist
Business analyst
Research Manager (non-existent in municipalities – local govt is bombarded with technical solutions but cannot manage this interface. Need for strong research capability where solutions can be developed ad piloted. In-house research capacity to deal with wastewater, water, electricity with more intensive research on waste recycling)
Change management specialist
Business Process Mapping expert
Systems engineers
Systems integrators
HR Specialist
Operations specialist
Service delivery specialist
Business architects
Project managers
Consultants / Researchers (partnerships with research institutions such as the CSIR, entrepreneurs with innovative solutions – must include expertise from the municipality)

Technologies

Smart electricity and water metering
Smart Asset management and sensors
ICT hardware and software

Technical infrastructure

Advanced Sensing and Measurement Solutions (ASMS) to support faster and more accurate response such as remote monitoring, time-of-use pricing, and demand-side management.
Integrated Communications, Security Solutions (ICSS), connecting components to open architecture for real-time information transmission and control.
Advanced Components, Subsystems and Solutions (ACSS) for storage, power electronics, and diagnostics.
Advanced Control Methods and Solutions (ACMS) to monitor essential components, enabling rapid diagnosis and precise solutions appropriate to any event, and to automate operations and controls.
Decision and Operations Support Solutions (DOSS) to reduce operator error and latency in responding to ordinary and emergency events, enable informed customer participation in the smart service, and provide greater observation/visibility of the system and its interface.

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	▪ Advanced Sensing and Measurement Solutions (ASMS) to support faster and more accurate response such as remote monitoring, time-of-use pricing, and demand-side management. ▪ Integrated Communications, Security Solutions (ICSS), connecting components to open architecture for real-time information transmission and control. ▪ Advanced Components, Subsystems and Solutions (ACSS) for storage, power electronics, and diagnostics. ▪ Advanced Control Methods and Solutions (ACMS) to monitor essential components, enabling rapid diagnosis and precise solutions appropriate to any event, and to automate operations and controls. ▪ Decision and Operations Support Solutions (DOSS) to reduce operator error and latency in responding to ordinary and emergency events, enable informed customer participation in the smart service, and provide greater observation/visibility of the system and its interface. • Institutional infrastructure ▪ Test benches ▪ Modelling, analysis and verification tools ▪ Service delivery specific operations verification test equipment ▪ Labs ▪ Simulators • Research results ▪ Establish international best practices for (policy, systems, processes, technology, standards, training) • Partnerships established ▪ Category B municipalities ▪ AMEU ▪ Cogta ▪ NT (Intergovernmental Relations, specifically, Local Government Budget Analysis as key stakeholder and other relevant units as required) SALGA ▪ DWAF ▪ Eskom ▪ Unions • Funding e.g. Municipal innovation fund
Resources to be established Which of the required resources are already established? Which need to be established, and what will be needed to establish them?	Largely, local govt has been excluded from innovation decision-making processes. • Map out the innovation ecosystem, with local government included, and outline the different roles played by the different institutions. e.g. municipalities are approached for funding by entrepreneurs, but they are not the right institution to fulfil this function. What can different players offer?

For example, what STI-related research will be needed to achieve the intended results of the Thrust?	• Municipalities could offer platforms for testing solutions, making it easier for entrepreneurs to find alternative funding. • Entrepreneurs have to be guided to scale their businesses. • Different funding is required for different stages of development – this appears to be missing. • Municipalities need to play a leadership role in innovation, e.g. Tshwane is positioned as the Innovation Capital with the World Bank.
Policy and regulatory environment What changes are required, if any, to the current STI policy and regulatory environment? What new policy and regulatory provisions, if any, will the Thrust require?	• Successful pilot solutions with entrepreneurs cannot be adopted due to limitations in the MFMA, e.g. a recent app in City of Tshwane won national awards and was hugely successful but cannot be implemented due to procurement procedures. The solution will now be tested in Washington DC. • Too much emphasis on compliance in the policies, with burdensome workloads due to the number of reports that have to be generated and too many compliance committees. More emphasis is needed on performance and the actual doing. • No municipalities have IP policies – this needs to be addressed. Municipalities also do not understand their IP and its value. • Policies needed to address data ownership and use of data – at what stage should data be opened up for public consumption?
5. Risk	
Risk of not achieving results Explain the level of difficulty involved in achieving the intended results. Please specify: • Straightforward to achieve • Fairly difficult to achieve • Moderately difficult to achieve • Very difficult to achieve. Please explain your choice. What are the anticipated obstacles and challenges, and what is the likelihood of their being overcome? What are the risks associated with not achieving the intended results of the Thrust?	Moderate to fairly difficult Decision-making and delegation authorities are difficult. Protests are a daily challenge and could escalate into violent protest. Intensified research efforts needed to address: • Waste reduction and to find alternatives to landfills. Not doing so will result in dirty and unliveable cities. • Alternative energy resources.
Social and ethical acceptability	Mostly to highly acceptable. • There are problems with corruption in municipal supply chain processes.

How ethically and socially acceptable is the Thrust? Specify: • Highly acceptable • Mostly acceptable • Fairly unacceptable • Mostly unacceptable Please explain your choice.	• Data security and big data will have an impact and there will be job losses.
Unintended consequences Are there unintended consequences that may result from the Thrust? Explain the level of risk of these possible consequences.	Positive: The innovation revolution will create the platforms needed by Millenials to create companies. It will see the creation of more businesses and more positive engagement between citizens and local government. Negative: Job losses in the short-term.
6. Other	
Other information Is there any other information which you wish to provide to support this Proposal for a Thrust?	None.

STI Thrust Proposal – NU1

Working group	
Name of STI domain / working group	**Nutrition Security & Agriculture**

1. Title and description of STI Thrust	
Title of Thrust (Eight words or less)	**Zero Impact Agriculture**
Summary description Provide a brief description of the Thrust so that we can be sure we understand what you are referring to. (Just a few sentences)	Closing the food, water, energy and social nexuses. Agriculture goes off the grids (water and energy grids) by using dispersed, small but intensive production facilities in both rural and urban areas to produce balanced animal and plant products for local consumption. The risks of climate change (temperature, light intensities, water availability, etc.) are mediated through the use of controlled environments (ranging from “closed irrigation systems under netting to fully automated aquaponic, climate controlled greenhouses), which allows - by design - higher yields, healthier and diverse crops and livestock (aquaponics) production while lowering operational costs (nitrogen requirements (aquaponics/fertilising), energy (energy capture and recycling by design) and water (saltwater to fresh water conversion via evaporation)), to address “hidden hunger”. “For the people by people” address food nutrition and production requirements by empowering small, local producers to produce high value crops on small patches of land for their local society, thus driving the circular economy, ensuring sustainability and nutritional food production, etc.
2. Results – Description	
Problems to be addressed What are the problems which the Thrust is intended and is likely to address by 2030?	Climate change Water scarcity Nutrition diversity and improvement Soil/environmental impacts Local small enterprises Circular economy
Outputs What are the likely outputs of the Thrust by 2030? (The outputs are the immediate results of the Thrust)	Lowering production costs (nitrogen, energy, water requirements) Producing plant, animal and fish food sources at a community level Utilising low quality water to produce, conserve and enhance water quality. Driving local economies, food nutrition and security in a sustainable manner
Outcomes and impact What are the likely outcomes and impact of the Thrust? What is the value of the outcomes and impact, and when are they likely to manifest?	Ensure sustainable food production under extreme and changing climatic conditions across SA – rural and urban Reduced nutrition insecurity by providing a variety of food sources, e.g. crops, animal and fish Lowering SA’s carbon, nitrogen (big carbon player), water and energy footprints

<table>
<tr><td>(The outcomes and impact are the medium-term and long-term results of the Thrust, respectively)</td><td>Increased sustainability of agribusiness, especially small and remote (rural) producers thought technology</td></tr>
<tr><td colspan="2">3. Results – Alignment and scope</td></tr>
<tr><td>Alignment with NDP vision
To what extent is the Thrust aligned with the vision of the NDP? Please specify:
• Fully aligned
• Mostly aligned
• Partially aligned
• Poorly aligned

Please explain your choice.

In other words, how will the Thrust contribute, both directly and indirectly, towards eliminating poverty, reducing inequality and increasing employment?

Please distinguish clearly between direct and indirect contributions.</td><td>• Fully aligned
• Local small producers are developed to drive “the rural/urban village’s” economy in a “circular manner” (i.e. food are sold locally with that same Rand then going from community-to-producer-to-worker-to-local shop-to-local workers-etc.) while earning a sustainable and sufficient income (not only to be subsistence but entrepreneurial successful) – direct
• Food selection (nutrition), quality and quantity are being addressed in both rural and urban areas – direct.
• Only through economic upliftment can inequality be reduced and wealth redistributed in a sustainable manner. Driving small, but intensive local production with systems lowering production risks, subsistence producers can be converted to entrepreneurially successful producers using smaller, but intensively utilised, production areas – direct.
Adding technology (buyer-to-producer linked apps), niche markets (“organically grown”) could be accessed and additional employment opportunities could be developed, e.g. small local logistics – direct.</td></tr>
<tr><td>Scope of the benefits
What is the scope of the benefits of the results which the Thrust is likely to have, by 2030? Please specify:
• Very broad scope
• Broad scope
• Medium scope
• Narrow scope

Please explain your choice. Who will benefit? How many people will benefit (order of magnitude estimate)? In what way will they benefit?</td><td>A narrow to medium scope for the individual smallholder farmer and community participating – which may end in a total sector realignment (very broad scope).

Very broad scope: the general public will benefit from more diverse, locally produced, healthier food.

Medium scope BUT with multiplication factor (implemented across communities) a very broad scope: The idea is that local, small scale or even “gardener size” farmers produce vegetables and other nutritious foods (e.g. fish) under climate mitigated conditions (e.g. aquaponics, shade netting, tunnels, etc), for their local community. If this is combined with a “children/elderly nutritional improvement scheme through food diversification” in communities, a local market is immediately generated. Additionally, the single Rand invested in the nutritional improvement scheme will now also support a second marginalised group in the community – the small producer. A healthy meal will draw children to the school, feeding them with appropriate nutritional food would improve their learning ability and support physical and mental development, while local small scale producers have a market: Food for the people by the people! This could be rolled out in both rural and urban areas.</td></tr>
<tr><td colspan="2">4. High-level implementation</td></tr>
</table>

High-level steps What are the high-level interim objectives or milestones which need to be achieved? What are the high-level activities/steps/ stages needed to achieve the objectives/milestones? In other words, what are the high-level steps required to deliver on the outputs, outcomes and impact mentioned above?	Objectives: All the appropriate Governmental departments will have to agree to work together on this STI thrust. DST can drive new and cheaper technologies, DAFF with Dept of Health, the "appropriate food basket" and cultivation, training, etc, TIA local commercialisation of developments, DoE – renewable energy, etc. Social grant funding might be used as a possible funding source: No increases, but "a food basket" is given. Activities: *Improve cooperation* between Governmental departments to gain access to the *required expertise* and develop *a single thrust* to push together! This process must have the main to be *self-sustainable in the future*, i.e. *leave a small business* behind capable of producing food in an *economically viable manner*. Institutional capacity, vision and infrastructure Transform the concept of "farming" to "small agri-business" to make it more appealing to younger people
Resources required What are the resources which are required to achieve the outputs, outcomes and impact? Examples of such resources can include: • Knowledge and expertise • Technologies • Technical infrastructure • Institutional infrastructure • Research results • Partnerships established • Funding • Etc	1. Knowledge and expertise through cooperation – nationally, provincially, across departments in these and with external support from councils. 2. Technologies to aid communication – develop easily accessible information, i.e. "howtos", "wheretos", etc. – from howto grow xyz, howto build abc, howto operate a business, howto market your crop, howto link with the nutritional scheme, howto link to a producer, howto access the health benefit of a crop, whereto get funding (community funded?, local businesses, government, banks?), whereto get expert support (if needed), etc. 3. Developing technical and institutional infrastructure aligning to the thrust. 4. Research to enable low input "small agri-businesses", better utilisation and recycling of resources in small and medium producers, better crop/livestock production under intensive production systems, etc. 5. Partnerships through participation, cooperation, collaboration and incentives. 6. Strategic funding and implementation to obtain the desired outcomes. 7. Communication! Food-for-the-people-by-the-people can also be Food-for-the-people-taught-by-the people. Linking all the role players effectively and innovatively will allow easier rollout, commerce, business development, etc.
Resources to be established Which of the required resources are already established? Which need to be established, and what will be needed to establish them? For example, what STI-related research will be needed to achieve	• Nutritional values for a lot of crops have been established already. Many cultivation practises of these crops are known – for infield production. Evaluating the easy of producing some of these crops under "economic, water, etc restrains" might be required. • Expanding on existing communication apps to allow links between farmer and producer might be required.

the intended results of the Thrust?	- Research areas include growth structures, suitable crops for these and for the nutritional requirements, production systems, disease, water, energy, etc. management, etc. - ranging from solutions for “low economic food production” to those required for optimal production systems at the high end (this is the growth path for the small producer) all aimed at mitigating climate change effects, lowering water, nitrogen, energy, chemical, etc. requirements, to produce a diverse array of healthier foods across South Africa in both rural and urban areas. - Research covering “available resources in an area” – would also be needed, e.g. seawater at coastal areas might be used in cooling growth facilities, with condensation producing water to irrigate the crops. This resource might be replaced by poor water, saline water source in the Karoo, or well water in Mpumalanga. Inter “department and institute” communication research and technical solutions is also really required.
Policy and regulatory environment What changes are required, if any, to the current STI policy and regulatory environment? What new policy and regulatory provisions, if any, will the Thrust require?	Alignment and cooperation within Governmental departments to drive together on a single thrust is critical. Policy changes that lead to enable individuals that can, though hard work and participation, build profitable, sustainable small agri-businesses in their communities to drive the local economy, i.e. become contributors to the economy. Access to data, knowhow, etc. should be easily available, with initial work required by participants to show commitment. Funding should be made available in a competitive manner and should be in the form of a “loan”. The aim is to not only develop a “producer” but also a “business”. Understanding and implementing business principals should therefore form a key component in this thrust!
5. Risk	
Risk of not achieving results Explain the level of difficulty involved in achieving the intended results. Please specify: - Straightforward to achieve - Fairly difficult to achieve - Moderately difficult to achieve - Very difficult to achieve. Please explain your choice. What are the anticipated obstacles and challenges, and what is the likelihood of their being overcome? What are the risks associated with not achieving the intended results of the Thrust?	Moderately difficult to achieve. Obstacles include: - Cooperation and participation of a lot of departments and role players - A mind shift required in participants, from one of receiving to one of building a life through participation and hard work - Good communication: From inter department and institutions, to between producer and client. - Appropriate technologies for low, medium and high funding scenarios. - Funding to develop resources – from infrastructure to communication, research to training participants, etc. Risks if intended results not achieved:

	• Small producers across the country does not develop (and … into sustainable, profitable, businesses) • Small agribusinesses will not improve and grow, leading to increased poverty and inequality • Effects of climate change will lead to food and nutrition shortages
Social and ethical acceptability How ethically and socially acceptable is the Thrust? Specify: • Highly acceptable • Mostly acceptable • Fairly unacceptable • Mostly unacceptable Please explain your choice.	Highly acceptable: Both Socially and ethically! • Work generation in communities • "Agriculture" as "business" more readily acceptable by young people as a career path • Nutritional food more readily availability Marginalised in society benefit from food availability and an opportunity to lift themselves up through hard work and the initiative
Unintended consequences Are there unintended consequences that may result from the Thrust? Explain the level of risk of these possible consequences.	None cooperation between departments and/or none combined push of the thrust – moderate None acceptance of society – low risk Larger commercial entities experience lower sales that might lead to job losses – low risk since new produce will be taken up by those previously not capable to afford it.
6. Other	
Other information Is there any other information which you wish to provide to support this Proposal for a Thrust?	Climate change will impact SA, mostly the poor and marginalised. The limited funding in this sector does not provide it with "a way out" to accommodate or absorb these fluctuations' losses, and therefore, its sustainability will be either be depending on external funding or it would terminate.

STI Thrust Proposal – NU2

Working group	
Name of STI domain / working group	Nutrition

1. Title and description of STI Thrust	
Title of Thrust (Eight words or less)	**Use and acceptance of modern biotechnology**
Summary description Provide a brief description of the Thrust so that we can be sure we understand what you are referring to. (Just a few sentences)	Genetically modified and genome edited organisms (crops, livestock, microbes) and genomics and phenomics technologies offer huge opportunities to enhance and secure agricultural productivity across the sector. Traits include improved abiotic and biotic stresses, as well as traits aiding in nutrition, production, etc.
2. Results – Description	
Problems to be addressed What are the problems which the Thrust is intended and is likely to address by 2030?	• Climate change negatively impacting agribusiness. • Poor nutrition – increasing levels of obesity, high levels of stunting and micronutrient deficiencies. • Pests, pathogens and diseases. • High production costs.
Outputs What are the likely outputs of the Thrust by 2030? (The outputs are the immediate results of the Thrust)	• Climate adaptable crops and livestock. • Pest, pathogen, and disease resistant crops and livestock. • Enhanced nutrition from agricultural products. • Cheaper, healthier food. • Increased quality and quantity of agricultural outputs.
Outcomes and impact What are the likely outcomes and impact of the Thrust? What is the value of the outcomes and impact, and when are they likely to manifest? (The outcomes and impact are the medium-term and long-term results of the Thrust, respectively)	• Reduced levels of food and nutrition insecurity. • A viable and sustainable smallholder agribusiness sector.
3. Results – Alignment and scope	
Alignment with NDP vision To what extent is the Thrust aligned with the vision of the NDP? Please specify: • Fully aligned	Fully aligned • Eliminating poverty: cheaper, healthier food (direct) • Reducing inequality: cheaper, healthier food (indirect)

• Mostly aligned • Partially aligned • Poorly aligned Please explain your choice. In other words, how will the Thrust contribute, both directly and indirectly, towards eliminating poverty, reducing inequality and increasing employment? Please distinguish clearly between direct and indirect contributions.	• Increasing employment: improved agribusiness for small holder farmers (direct)
Scope of the benefits What is the scope of the benefits of the results which the Thrust is likely to have, by 2030? Please specify: • Very broad scope • Broad scope • Medium scope • Narrow scope Please explain your choice. Who will benefit? How many people will benefit (order of magnitude estimate)? In what way will they benefit?	Very broad scope: the general public will benefit from cheaper, healthier food. Narrow scope: improved small holder farmers' productivity and wealth.
4. High-level implementation	
High-level steps What are the high-level interim objectives or milestones which need to be achieved? What are the high-level activities/steps/ stages needed to achieve the objectives/milestones? In other words, what are the high-level steps required to deliver on the outputs, outcomes and impact mentioned above?	Objectives: Regulatory authorities need to accept that gene inputs is not a GMO technology and therefore needs to be regulated separately – regulate the product not the process. Activities: • Have regulations amended to regulate GM products rather than the GM process. • Improve expertise. • Build institutional capacity and infrastructure. • Undertake research on climate adaptable crops and livestock. • Undertake research on pest, pathogen, and disease resistant crops and livestock.
Resources required What are the resources which are required to achieve the outputs, outcomes and impact?	Many need to be established e.g.: • Knowledge and expertise: genome editing, genomics and phenomics. • Technical and institutional infrastructure to undertake the research.

Examples of such resources can include: • Knowledge and expertise • Technologies • Technical infrastructure • Institutional infrastructure • Research results • Partnerships established • Funding • Etc.	• FUNDING
Resources to be established Which of the required resources are already established? Which need to be established, and what will be needed to establish them? For example, what STI-related research will be needed to achieve the intended results of the Thrust?	It is difficult to itemise which of the above list needs to be established from scratch and which need to be improved. This will have to be determined on a case-by-case basis at different institutions.
Policy and regulatory environment What changes are required, if any, to the current STI policy and regulatory environment? What new policy and regulatory provisions, if any, will the Thrust require?	A new policy needs to be implemented that recognises that gene inputs are not the same as genetic engineering. The end product needs to be regulated, not the process.
5. Risk	
Risk of not achieving results Explain the level of difficulty involved in achieving the intended results. Please specify: • Straightforward to achieve • Fairly difficult to achieve • Moderately difficult to achieve • Very difficult to achieve. Please explain your choice. What are the anticipated obstacles and challenges, and what is the likelihood of their being overcome?	Moderately difficult to achieve. Obstacles mainly due to lack of funding for training and infrastructure. Risks if intended results not achieved: • Effects of climate change will lead to food and nutrition shortages. • Agribusinesses will not improve, leading to increased poverty and inequality.

What are the risks associated with not achieving the intended results of the Thrust?	
Social and ethical acceptability How ethically and socially acceptable is the Thrust? Specify: • Highly acceptable • Mostly acceptable • Fairly unacceptable • Mostly unacceptable Please explain your choice.	Mostly acceptable. South Africans have been eating food derived from GM crops for 20 years without any ill effects. The anti-GM lobby is relatively small. Education on GM vs genome edited non-GM, needs to take place since any “lab work” on crops is associated as GM. This “perception” and current need to treat “everything as GM unless otherwise indicated”, deters participation of local businesses – thus preventing SA from building expertise in the area.
Unintended consequences Are there unintended consequences that may result from the Thrust? Explain the level of risk of these possible consequences.	Crops, animals or microbes are harmful to humans, animals or environment. VERY low risk. South Africa does not accept the technology and does not develop technologies to address local needs but have to import these at high costs – high risk if not accepted and rolled out. Regulations treating “non-GM” methods as “GM” prevents local investment due to “costs”, “regulation” or “sentiment” linked to GM regulation locally – high risk since small companies cannot afford the GM requirements/sentiment.
6. Other	
Other information Is there any other information which you wish to provide to support this Proposal for a Thrust?	Canada and the USA have approved gene editing as equivalent to what could occur in nature. They are regulating the products, not the processes. By keeping all the genome editing methods under the GM act, non-GM crop producers will not accept the technology as non-GM and therefore will not include it as part of their crop development strategy as they do not want to lose their non-GM status!

STI Thrust Proposal – NU3

Working group	
Name of STI domain / working group	Nutrition

1. Title and description of STI Thrust	
Title of Thrust (Eight words or less)	**Personalised information for healthy nutrition for all**
Summary description Provide a brief description of the Thrust so that we can be sure we understand what you are referring to. (Just a few sentences)	Use and apply ICTs to provide personalised information on nutrition and nutritional status for all groups focusing on mothers, caregivers and young children. This will enhance nutrition security through improving health and nutrition outcomes and providing information on the population levels of malnutrition.
2. Results – Description	
Problems to be addressed What are the problems which the Thrust is intended and is likely to address by 2030?	• High levels of malnutrition especially stunting, obesity and accompanying NCDs and micronutrient deficiencies. • Inadequate information on food choices and needs for the population, for example, pregnant women, caregivers and children. • Inadequate knowledge on the nutritional status of all groups in the population.
Outputs What are the likely outputs of the Thrust by 2030? (The outputs are the immediate results of the Thrust)	• Lower levels of malnutrition. • Knowledge/ information on nutritional status for all groups in the population. • Information on relevant food needs to enable good food choices for the population. • A reduction in gaps in knowledge, especially at the national level on the nutritional status of the population.
Outcomes and impact What are the likely outcomes and impact of the Thrust? What is the value of the outcomes and impact, and when are they likely to manifest? (The outcomes and impact are the medium-term and long-term results of the Thrust, respectively)	• A reduction in the levels of malnutrition and food insecurity. • An informed and healthier workforce and population. • Increased information will feed directly into improved and better-targeted policies on nutrition. • Reduced national expenditures on health as an outcome of healthier choices, especially related to the cost of management of NCDs and malnutrition-related.
3. Results – Alignment and scope	
Alignment with NDP vision To what extent is the Thrust aligned with the vision of the NDP? Please specify: • Fully aligned • Mostly aligned	Fully aligned with NDP and global goals SDGs. NDP: Eliminating poverty: cheaper, healthier food (direct). NDP: Reducing inequality: cheaper, healthier food (direct).

• Partially aligned • Poorly aligned Please explain your choice. In other words, how will the Thrust contribute, both directly and indirectly, towards eliminating poverty, reducing inequality and increasing employment? Please distinguish clearly between direct and indirect contributions.	SDG: Zero hunger, Good health and well-being.
Scope of the benefits What is the scope of the benefits of the results which the Thrust is likely to have, by 2030? Please specify: • Very broad scope • Broad scope • Medium scope • Narrow scope Please explain your choice. Who will benefit? How many people will benefit (order of magnitude estimate)? In what way will they benefit?	Very broad scope: While the thrust will benefit the entire population, it also has the added advantages on focusing on vulnerable groups who are most affected by malnutrition: these groups include mothers, children and the poor.
4. High-level implementation	
High-level steps What are the high-level interim objectives or milestones which need to be achieved? What are the high-level activities/steps/ stages needed to achieve the objectives/milestones? In other words, what are the high-level steps required to deliver on the outputs, outcomes and impact mentioned above?	• Mainly investment. • Improve expertise. • Build institutional capacity. • Develop and then execute an implementation strategy to capture and make available personalised nutritional status for all groups, focusing on mothers, care-givers and young children. • Develop and then execute an implementation strategy to make information available on nutrition needs, to enable healthy food choices by the population.
Resources required What are the resources which are required to achieve the outputs, outcomes and impact? Examples of such resources can include:	• Knowledge and expertise. • Adaptation of technologies. • Technical infrastructure. • Institutional infrastructure. • Partnerships established. • Funding. • Research results.

• Knowledge and expertise • Technologies • Technical infrastructure • Institutional infrastructure • Research results • Partnerships established • Funding • Etc	
Resources to be established Which of the required resources are already established? Which need to be established, and what will be needed to establish them? For example, what STI-related research will be needed to achieve the intended results of the Thrust?	There are some resources available; many need to be adapted and scaled. Also, the distribution of these resources in the country needs to be a focus for attention as they tend to be concentrated in particular groups and sectors. These include: • Knowledge and expertise. • Adaptation of technologies. • Technical infrastructure. • Institutional infrastructure (distribution). • Partnerships established. • Funding. • Research results (exists partially)
Policy and regulatory environment What changes are required, if any, to the current STI policy and regulatory environment? What new policy and regulatory provisions, if any, will the Thrust require?	The most significant change required in the regulatory environment is the distribution of these resources. Also, new technologies for measuring population nutritional status when developed will need regulation to be rolled out widely.
5. Risk	
Risk of not achieving results Explain the level of difficulty involved in achieving the intended results. Please specify: • Straightforward to achieve • Fairly difficult to achieve • Moderately difficult to achieve • Very difficult to achieve. Please explain your choice. What are the anticipated obstacles and challenges, and what is the likelihood of their being overcome? What are the risks associated with not achieving the intended results of the Thrust?	Moderately difficult to achieve. The main obstacles are funding, research and institutional capacity. Nutritional outcomes will not improve, and there will be a rise in obesity accompanied by NCDs. Costs of health care will progressively increase for an increasingly unhealthy population. Inequalities in malnutrition will persist, and the gap in nutritional outcomes between the rich and poor will widen.
Social and ethical acceptability How ethically and socially acceptable is the Thrust? Specify:	Highly acceptable

• Highly acceptable • Mostly acceptable • Fairly unacceptable • Mostly unacceptable Please explain your choice.	The food and nutrition challenges in South Africa are widely acknowledged, and all players are interested in a possible solution. The problems are in finding solutions to this.
Unintended consequences Are there unintended consequences that may result from the Thrust? Explain the level of risk of these possible consequences.	With technologies that provide an accurate and personalised measurement of nutritional outcomes of the population comes the availability of personal information on people that could get into the wrong hands.
6. Other	
Other information Is there any other information which you wish to provide to support this Proposal for a Thrust?	None.

STI Thrust Proposal – NU4

Working group	
Name of STI domain / working group	Nutrition

1. Title and description of STI Thrust	
Title of Thrust (Eight words or less)	**Precision & big data in agri-businesses**
Summary description Provide a brief description of the Thrust so that we can be sure we understand what you are referring to. (Just a few sentences)	Streamlining agribusiness across the value chain through the use of ICT, communication systems and other high throughput technologies, ranging from developing new cultivars using genomics, phenomics, etc., to lowering the impact on the environment during production through satellite and other precision technologies, the tracking of produce from the field to plate, etc.
2. Results – Description	
Problems to be addressed What are the problems which the Thrust is intended and is likely to address by 2030?	• Information flow through the whole agri-business value chain: from technologies and data in crop/livestock development, cultivation, security, to information on climate change mediating solutions. • Closing the circle: Information feedback from the end user, retailer, transporter, etc. to the produce developer. • Water scarcity – when, what and how to plant. • Nutrition diversity through better resources and knowledge. • Pest, disease, and pathogen management and tracking. • Alternative production systems to increase soil health, lower nitrogen and other requirements, etc. • Soil improvement through better management, knowledge, etc. • Better optimised transport and food distribution based on current and relevant information.
Outputs What are the likely outputs of the Thrust by 2030? (The outputs are the immediate results of the Thrust)	• Agri-data: Access to current and relevant agri-sector data for decision-making at all levels of the value chain, including government. • Better water, soil and resource conservation. • Lower production costs and less wastage of produce. • Sustainability and lower impact agribusiness.
Outcomes and impact What are the likely outcomes and impact of the Thrust? What is the value of the outcomes and impact, and when are they likely to manifest? (The outcomes and impact are the medium-term and	• Informed sector with better and more relevant production for better local nutrition (communities) to exports (large agriculture – better viscos). • Faster and better identification, tracking and targeted breeding for pest, pathogens and diseases. • Reduced levels of food insecurity – by providing plant, animal and fish food sources. • Reversal of the effects of climate change on soil and water resources. • Increased sustainability of agribusiness.

long-term results of the Thrust, respectively)	
3. Results – Alignment and scope	
Alignment with NDP vision To what extent is the Thrust aligned with the vision of the NDP? Please specify: • Fully aligned • Mostly aligned • Partially aligned • Poorly aligned Please explain your choice. In other words, how will the Thrust contribute, both directly and indirectly, towards eliminating poverty, reducing inequality and increasing employment? Please distinguish clearly between direct and indirect contributions.	Fully aligned. • A better informed sector with new technologies would require artisans and other skilled personnel to support it. This would provide new, well-paying job opportunities for existing and new businesses, thus addressing poverty and employment (direct). • Access to information would aid Thrust 1, thus helping to readdress inequality (indirect).
Scope of the benefits What is the scope of the benefits of the results which the Thrust is likely to have, by 2030? Please specify: • Very broad scope • Broad scope • Medium scope • Narrow scope Please explain your choice. Who will benefit? How many people will benefit (order of magnitude estimate)? In what way will they benefit?	Broad scope The whole sector would be covered. Information gathered this way will benefit all, especially the resource poor and marginalised, since data useful for big agri-business would also be required for the resource poor. Medium scope – jobs would be generated to support this thrust.
4. High-level implementation	
High-level steps What are the high-level interim objectives or milestones which need to be achieved? What are the high-level activities/steps/ stages needed to achieve the objectives/milestones? In other words, what are the high-level steps required to	Objectives: Cooperation within the sector for a coordinated effort. Activities: • Improve expertise, institutional capacity and infrastructure. • Undertake research into developing new cultivars using genomics and phenomics. • Develop and then execute an implementation strategy to track produce from the field to the plate. • Develop and then execute an implementation strategy for making agri-sector data available at all levels of the value chain.

deliver on the outputs, outcomes and impact mentioned above?	
Resources required What are the resources which are required to achieve the outputs, outcomes and impact? Examples of such resources can include: • Knowledge and expertise • Technologies • Technical infrastructure • Institutional infrastructure • Research results • Partnerships established • Funding • Etc.	• Knowledge and expertise in the various data generation and distribution technologies. • Technologies and technical infrastructure for the agri-value chain. • Institutional infrastructure to help develop cheaper and more widely implemented technologies for the sector. • Research aligned with technologies to produce desired results required for analyses and information dissemination. • Partnerships across the sector units. • Funding to allow the processes to be implemented and coordinated.
Resources to be established Which of the required resources are already established? Which need to be established, and what will be needed to establish them? For example, what STI-related research will be needed to achieve the intended results of the Thrust?	It is difficult to list the exact resources for this thrust since DST is already rolling out digital infrastructure, with other role players and is already starting to produce some of these deliverables. Funding, and optimal alignment with the latest technologies, would, however, greatly facilitate rollout of technologies. Centralising some of these technologies would further allow SA to remain cutting edge continuously rolling out the latest tech, which is the full utilised.
Policy and regulatory environment What changes are required, if any, to the current STI policy and regulatory environment? What new policy and regulatory provisions, if any, will the Thrust require?	• Research activities are often done outside SA's borders. This prevents local development of IP and expertise. • Additionally, high costs of research consumables due to import taxes, etc. prevent local technology providers from being internationally competitive. • Government can influence and facilitate cheaper high technologies for developing relevant items in the research environment, e.g. cheaper reagents for sequencing, to be competitive internationally and allow local expertise to develop. Forcing researchers to use local resources would further develop the local expertise and drive the sector.
5. Risk	
Risk of not achieving results Explain the level of difficulty involved in achieving the intended results. Please specify:	Straightforward to achieve in some areas, moderately difficult in others. Aligning all the different role players to work together will pose a possible risk.

• Straightforward to achieve • Fairly difficult to achieve • Moderately difficult to achieve • Very difficult to achieve. Please explain your choice. What are the anticipated obstacles and challenges, and what is the likelihood of their being overcome? What are the risks associated with not achieving the intended results of the Thrust?	Implementing, but also developing the latest technologies for this sector, would be moderately difficult due to continual advancements internationally and lower levels of local expertise in these sectors, e.g. imaging technologies. Not achieving this thrust will result in continual losses in the sector, especially in resource poor environments. This will negatively impact the sustainability of the sector and its capacity to provide diverse food sources for all the nutritional needs, under increasingly difficult production environments (climate change, world production, etc.)
Social and ethical acceptability How ethically and socially acceptable is the Thrust? Specify: • Highly acceptable • Mostly acceptable • Fairly unacceptable • Mostly unacceptable Please explain your choice.	Highly acceptable since the latest technologies would be used to enable the sector, from small subsistence farmers to large agribusiness, to remain operational within increasingly difficult production environments (climates) and international trade. Using agri-data would also impact the consumer since they could trace the source of their food and how it was produced. This will ensure that food producers are more ethical, conservative in their operations/production.
Unintended consequences Are there unintended consequences that may result from the Thrust? Explain the level of risk of these possible consequences.	Large data is used to target “non-conforming” businesses, thus leading to lower purchases of these non-ethical/responsible food producers. The uninformed could interpret data wrongly and cause unintentional outcries.
6. Other	
Other information Is there any other information which you wish to provide to support this Proposal for a Thrust?	This thrust covers large data, from molecular large data sets to satellite imaging to improve the whole sector. By incorporating large commercial agri-business, tools could be developed and offered for smaller, marginalised producers. More data usage in the sector would attract “young interest” and offer easier transferable knowledge.

STI Thrust Proposal – WA1

Working group	
Name of STI domain / working group	Integrated Solutions for Water Security

1. Title and description of STI Thrust	
Title of Thrust (Eight words or less)	**Future-oriented Water and Sanitation Solutions**
Summary description Provide a brief description of the Thrust so that we can be sure we understand what you are referring to. (Just a few sentences)	Water Security as a basis for a thriving society and economy will depend on water and sanitation solutions that are responsive to new challenges and emerging needs and opportunities. There are three pillars that are key to driving water security into the future: 1) water supply will need to be driven by an integrated mix of context appropriate sources of water at the bulk, regional and local level 2) the next generation of sanitation and wastewater (urban and industrial) solutions will need to be introduced, understood and then mainstreamed (low or no water use toilets, energy and water efficient technology, waste-smart) 3) water sensitive design (WSD) for urban, peri-urban and rural spaces must be core to all planning and should include water and sanitation planning and implementation (including management of the intersection between grey and green, climate resilient infrastructure, circular planning around water, sanitation and wastewater flows, etc). A water and sanitation management paradigm that is prepared for the knowns and unknowns of the future can only thrive if supported by an innovation synergised water industry that is able to deploy new solutions through efficient manufacturing support and effective water sector businesses that work in collaboration with the public sector. This should operate within a comprehensive data monitoring and management space.
2. Results – Description	
Problems to be addressed What are the problems which the Thrust is intended and is likely to address by 2030?	Water security is the basis for thriving economies and societies and thus needs to be shifted from a constraint to an enabler in the economy. However, South Africa faces a range of complexities in the process of managing its water security. 1) Water resource perspective: South African has globally low rainfall averages (490mm per year in contrast to the 814 mm global average) and we experience high evaporation rates. This is coupled with an uneven geographical water production with 8% of our land areas contributing more than 50% of the surface water we have available for use. Also, the landscapes through which water runs are impacted by a range of land management and associated ecosystem degradation issues (alien plants, mines, farming practice, degraded wetlands, mines, etc)

	2) Water Services Perspective: Approximately 15% of our population does not yet have access to piped water and approximately 23% of South Africans do not have access to improved sanitation. Our bulk infrastructure systems for drinking water are under strain with 37% of water losses that occur in most South African municipalities. Our wastewater infrastructure is also under strain with the majority of our wastewater plants performing poorly. We continue to grapple with a range of industry related water quality challenges Thus, whilst South Africa has come a long way in terms of basic service delivery, there are real challenges to be managed in terms of reliable and effective service provision; access to improved and more appropriate water and sanitation service delivery; and changed planning and water use paradigms that are more sensitive to the water scarce and changing climate realities South Africa experiences. This shift will also be key to South Africa delivering on the Sustainable Development Goals. This particularly pertains to SDG 6 (clean water and sanitation) but has cross cutting linkages with SDG 2 (zero hunger), SDG 3 (good health and wellbeing), SDG 7 (affordable and clean energy), SDG 11 (sustainable cities and communities), SDG 13 (climate action), SDG 14 (life below water), SDG 15 (life on land).

Outputs
What are the likely outputs of the Thrust by 2030?
 	
(The outputs are the immediate results of the Thrust)
	Outputs/Activities:
	
	• Water mix diversification and use of alternative sources of water:
	    o Municipalities will shift to a more diverse water mix to increase resilience during drought periods, informed by science, stakeholder engagement and input from local residents
	  o New urban planning for infrastructure will consider, amongst others, wastewater and stormwater as part of the water mix, underpinned by a broader suite of governance systems
	  o New technologies and an associated industry for household and community water capture, storage, treatment and monitoring will be mainstreamed, thereby driving a thriving new water industry
	• Next generation sanitation and wastewater solutions will be mainstreamed, while addressing issues of social acceptance
	    o Alternative toilets (low or no water and smart use of waste) will be mainstreamed both in addressing the 23% sanitation backlog and in innovating better within serviced areas – issues of social acceptance must be addressed as part of the solution
	    o Where centralised water treatment still has application innovation will take place to be more waste and energy efficient, and, where possible, to reduce dependence on large

	volumes of potable water to move waste through pipe networks
	    o Industry will shift to a more circular water re-use paradigm and invest in appropriate technology to realise this.
	• Water sensitive design for urban, peri-urban and rural spaces informs all water and sanitation planning and implementation. This will also influence the approach to which water intensive industry undertakes its business.
	    o Infrastructure planning and implementation for drinking water, industry and sanitation will internalise climate resilience and adaptability (relating to infrastructure selection, life-span planning, management, etc)
	    o Grey-green infrastructure nexus management is key in terms of planning for maintenance, costing of solutions, design of the water security system.
	    o Policy incentives and rules in place to incentivise a water sensitive design shift
	    o Reuse of wastewater.
	    o New innovations allow industry to become more water and climate independent and resilient.

Outcomes and impact What are the likely outcomes and impact of the Thrust? What is the value of the outcomes and impact, and when are they likely to manifest? (The outcomes and impact are the medium-term and long-term results of the Thrust, respectively)	• Water security • Access to safe and context appropriate drinking water and sanitation. • Responsible and efficient use of water, reuse and recycling. • Mature water industry as a meaningful player in the economy • New industry players with a diversified market inclusive of municipalities, communities and industry
3. Results – Alignment and scope	

Alignment with NDP vision
To what extent is the Thrust aligned with the vision of the NDP? Please specify:
• Fully aligned
• Mostly aligned
• Partially aligned
• Poorly aligned
 	
Please explain your choice.
 	
In other words, how will the Thrust contribute, both directly and indirectly, towards eliminating poverty, reducing inequality and increasing employment?
 	
Please distinguish clearly between direct and indirect contributions.
	Fully aligned
	
	From the NDP 2030:
	• Economy infrastructure – as part of social and economic development
	    o Access to basic electricity, water and sanitation, (Direct)
	    o The energy sector: empowering south Africa (indirect – water can be an energy generator through the pipe system, human waste reuse in treatment plants taking them off the grid, etc)
	    o Water resources and services (Direct)
	• Environmental sustainability - An equitable transition to a low-carbon economy
	    o Sustaining South Africa’s ecosystems and using natural resources efficiently (Direct)
	    o Responding effectively to climate change (indirect – changing climate-oriented planning builds resilience)

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- An integrated and inclusive rural economy
    - Agriculture (indirect – water availability to the sector)
    - Food security and basic services (indirect – water availability to the sector)
    - 4th IR unlocks real time relevant information
- Transforming human settlements
    - Recognising differences and inequalities within rural areas (indirect – water services planning and solutions for different contexts, tech standardisation for the building sector, etc)
    - Urban inefficiencies (indirect – water services planning and solutions for different contexts, tech standardisation for the building sector, etc)
    - Strong links with water sensitive design

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Scope of the benefits
What is the scope of the benefits of the results which the Thrust is likely to have, by 2030? Please specify:

- Very broad scope
- Broad scope
- Medium scope
- Narrow scope

Please explain your choice. Who will benefit? How many people will benefit (order of magnitude estimate)? In what way will they benefit?

</td><td>

Very broad scope

Entire country would benefit and not just a specific area or community. >60 million people.

Particular beneficiaries would be the currently poorly serviced parts of the population and the vulnerable (in terms of water and sanitation).

Water is no longer a constraint to economic growth, unemployment decreases and quality of life increases

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4. High-level implementation

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High-level steps
What are the high-level interim objectives or milestones which need to be achieved?
What are the high-level activities/steps/ stages needed to achieve the objectives/milestones?

In other words, what are the high-level steps required to deliver on the outputs, outcomes and impact mentioned above?

</td><td>

- Buy in from all role players and stakeholders, including all levels of government (water sector, RDI sector, housing, planning, finance, energy, education – school sanitation, etc)
- Research and Innovation project/initiative prioritization process
    - Research gaps, including societal and governance needs
    - High end skills interventions
    - Large scale tech and solution demonstrators that can be scaled up in different locations in communities – these must focus not just on technology but also the enabling governance, planning and capacity processes to scale up and local acceptability
- Requires a framework to be developed that clearly states who is involved and what exactly their roles are.
- Co-learning platforms to bring together researchers, implementers, planners, funders, users, etc
- Large rural knowledge transfer labs

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Resources required

</td><td>

Resources:

- Knowledge and expertise: investment into research opportunities, smart consolidation of the different

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What are the resources which are required to achieve the outputs, outcomes and impact? Examples of such resources can include: • Knowledge and expertise • Technologies • Technical infrastructure • Institutional infrastructure • Research results • Partnerships established • Funding • Etc	research nodes around SA to maximise on the innovation capacity in the sector, ongoing investment in skills and expertise, clear understanding of water sector skills demand and jobs of the future (reorientation of universities and training providers around this; networking funding to integrate efforts across universities and ensure units are not working in silos) • Technologies: local technologies need to be supported through well-coordinated sectoral demonstrations and engagement with end-users to ensure that designs are context relevant, standardised (where possible); business development support; processes for handling incoming tech localisation • Technical infrastructure: local manufacturing sector for sanitation sector in particular needs development, more activated national network of public testbeds • Institutional infrastructure: more formal links are critically important and need to be established between the research community, DWS and water sector implementing agencies, as well as relevant related functions (energy, agriculture, housing, etc) • Research results: focus on knowledge dissemination, consolidation of knowledge outputs, access and deployment issues, with appropriate stakeholder engagement and communication management • Partnerships established • Funding: R&D and early stage testing funding is key to building a diverse pipeline of solutions, water sector finance issues need to be looked at carefully (including water price) to drive more investment into the sector • Impact investing into entrepreneurs to grow entrepreneurship, business sustainability and revenue models
Resources to be established Which of the required resources are already established? Which need to be established, and what will be needed to establish them? For example, what STI-related research will be needed to achieve the intended results of the Thrust?	Existing: • Water RDI Roadmap and Implementation Unit housed at WRC, supported by DST • Water Technologies Demonstration Programme (WADER) housed at WRC, supported by DST • South African Sanitation Demonstration Programme – DST, WRC, BMGF • Water Research Commission to support the implementation of Water RDI Priorities Nationally • A variety of tertiary institution research units across the country dedicated to water-related research Going forward: • WADER will need to be resourced (funds, personal) to support more engagement and demonstrations; multi-partner funding model for demos will be key • More standard national technology validation approaches • Consolidated national network of municipal and utility test bed/ learning facilities (‘living laboratories’ and demonstration sites) • Smart solution matchmaking function and support (particularly to municipalities)

	• Well-resourced new water and sanitation R&D programme (will need to extend beyond just the water levy and needs multi-sectoral support and collaboration) • Better coordination of existing R&D investments in the Water RDI System • Close partnerships and collaborative spaces between Research and implementation communities (advisory service platforms, communities of practise, etc) • Plan partnerships into the SADC and the wider African region to ensure opportunities for regional solution deployment and collaboration and export.
Policy and regulatory environment What changes are required, if any, to the current STI policy and regulatory environment? What new policy and regulatory provisions, if any, will the Thrust require?	• Synergise the National Water RDI Roadmap, National Water and Sanitation Master Plan and water components of the Industrial Policy Action Plan – Water Phakisa could be part of the process of undertaking this task. • Synergise and work with all municipalities, regardless of political affiliations • Ensure oversight across national to regional groups • Better coordination of institutions engaged in water research, innovation and solution deployment.
5. Risk	
Risk of not achieving results Explain the level of difficulty involved in achieving the intended results. Please specify: • Straightforward to achieve • Fairly difficult to achieve • Moderately difficult to achieve • Very difficult to achieve. Please explain your choice. What are the anticipated obstacles and challenges, and what is the likelihood of their being overcome? What are the risks associated with not achieving the intended results of the Thrust?	Fairly difficult to achieve Obstacles: • Cannot be business as usual, but there are deeply institutionalised ways of doing and approaching water sector management that will need to be challenged and redeveloped • New thinking, new materials and new understanding of how things work and are to be done. • Not a mature water tech industry to deploy solutions; where expertise exists, it is difficult to engage with leading water technologists • Low levels of water sector investment • Low levels of trust in the ability of government to make decisions on behalf of its people Risks: • A water crisis (early seeds of the types of challenges that emerge have already been experienced in the KZN, Western Cape, Eastern Cape droughts). • SA in continuous crisis curbing economic growth and limiting opportunities for rural communities, farmers and businesses • Unmanaged urbanisation leads to deterioration of cities • Droughts increase the prevalence of waterborne diseases, thus increasing the cost of health provision • Tourism declines due to degraded ecosystems and water limitation for the hospitality industry and water quality issues • Investors move into neighbouring countries with greater water security

Social and ethical acceptability How ethically and socially acceptable is the Thrust? Specify: • Highly acceptable • Mostly acceptable • Fairly unacceptable • Mostly unacceptable Please explain your choice.	Mostly acceptable. In principle the proposed approach may be acceptable – however sanitation, drinking water and perceptions around service delivery come with deeply personal views and values. New approaches need to be designed with the involvement of local players. Any new approach needs to come with carefully considered governance incentives, and a sensitively managed approach to behavioural complexities and reasons for resistance. Detailed and long-term research is needed on social acceptability before interventions are rolled out.
Unintended consequences Are there unintended consequences that may result from the Thrust? Explain the level of risk of these possible consequences.	• Stronger possible role for private sector in supporting service delivery which has implications for how municipalities manage their service delivery approaches and responsibilities. • Unions become territorial and damage the public sector and its limited capability
6. Other	
Other information Is there any other information which you wish to provide to support this Proposal for a Thrust?	The new water and sanitation management paradigm can only thrive if supported by an innovation synergised water industry, with stronger emphasis on stakeholder management, and that is able to deploy new solutions through efficient manufacturing support and effective water sector businesses.

STI Thrust Proposal – WA2

Working group	
Name of STI domain / working group	Integrated Solutions for Water Security

1. Title and description of STI Thrust	
Title of Thrust (Eight words or less)	Embedding the Water Sector in the Fourth Industrial Revolution (4IR)
Summary description Provide a brief description of the Thrust so that we can be sure we understand what you are referring to. (Just a few sentences)	4IR is characterized by the enmeshing of the physical, digital and biological spheres, through technology referred to as cyber-physical systems. Cyber-physical systems have the potential to positively bring change in the way we manage our water and sanitation resources and services. This will demand deepened insight and attention in five areas: 1) linking of appropriate ICT technology to water resource management and service delivery 2) increasing the data intensity with which we make decisions 3) using cyber-physical systems to support appropriate behaviours 4) innovative water sector monitoring and data aggregation, and 5) re-skilling to operate in a data intensive water sector environment. Underlying these requirements will be the need to do groundwork in building trust and relationships so that the required changes can be implemented.
2. Results – Description	
Problems to be addressed What are the problems which the Thrust is intended and is likely to address by 2030?	Despite deepened understanding of the benefits of cyber-physical systems, the water sector has not geared itself up to make best use of the increasingly ubiquitous access to technology, data and associated decision support. This manifests in many ways, such as 1) weakly maintained hydrological monitoring systems 2) cooperative challenges in storing and sharing data 3) limited skill sets to define what type of cyber-physical systems and technologies are needed leading to mistrust of ICT technology and poorly selected options 4) policy and decision-making based on out-dated data 5) sector growth is limited due to the inability to adapt to new ways of working 6) sector planning and preparedness is limited leading to continuous crisis 7) inability to manage complexity as cities grow and the sector resources become more integrated 8) cyber security is poorly understood, compromising national key points and bulk infrastructure It is apparent that many of the challenges faced by the water sector in South Africa can be supported by cyber system enabled foresight (in application to design of policies, training and strategies, and responses to challenges).
Outputs What are the likely outputs of the Thrust by 2030?	• ICT technologies (diagnostics, robotics, artificial intelligence, distributed sensor networks, etc.) are smartly linked to water resource and supply management and

(The outputs are the immediate results of the Thrust)	service delivery through well connected smart networks with timely preventative maintenance • Water sector data (enhanced by big data analytics) is more widely available, up to date and accessible to inform decisions. This is supported by increased intelligence and processes related to cyber security. • Appropriate technologies, supported by appropriate stakeholder communications and engagements, are used to influence sustainable water behaviours, awareness, decision making at farm and community level, and education interventions • Hydrological monitoring is undertaken using smart, cost effective technology. Part of this will require refinement of the impact metrics that should be monitored in order to focus and give meaning to monitoring data. • Re-skilling needs are identified, and appropriate partners who are able to roll out training to support water sector role players operating in a data intensive water sector environment • Water investment in operations, maintenance, refurbishment and replacement is based on smart analytics, saving municipalities significant money
Outcomes and impact What are the likely outcomes and impact of the Thrust? What is the value of the outcomes and impact, and when are they likely to manifest? (The outcomes and impact are the medium-term and long-term results of the Thrust, respectively)	• Water security and quality is supported by access to evidence and data to inform decision making (More effective planning can take place due to better data access) • Water sector behaviours are more sustainable • New business opportunities for the ICT sector in water
3. Results – Alignment and scope	
Alignment with NDP vision To what extent is the Thrust aligned with the vision of the NDP? Please specify: • Fully aligned • Mostly aligned • Partially aligned • Poorly aligned Please explain your choice. In other words, how will the Thrust contribute, both directly and indirectly, towards eliminating poverty, reducing inequality and increasing employment? Please distinguish clearly between direct and indirect contributions.	- Fully aligned Economy infrastructure – ICT infrastructure Direct - better information about service delivery, behaviours, etc Indirect: - Capacitated society by making information, skilling more easily accessible and available.

<table>
<tr><td>Scope of the benefits
What is the scope of the benefits of the results which the Thrust is likely to have, by 2030? Please specify:
Very broad scope
Broad scope
Medium scope
Narrow scope
Please explain your choice. Who will benefit? How many people will benefit (order of magnitude estimate)? In what way will they benefit?</td><td>Medium scope

Main beneficiaries would be water sector role players (estimated 30000 people)

Secondary beneficiaries are the public, as part of the larger system, who are influenced by smart meters, training / awareness interventions, etc. (numbers would depend on the scale of roll-out)

Tertiary – the sector opens more opportunities for entrepreneurs, linking water, energy, health, service data at the household level</td></tr>
<tr><td colspan="2">4. High-level implementation</td></tr>
<tr><td>High-level steps
What are the high-level interim objectives or milestones which need to be achieved?
What are the high-level activities/steps/ stages needed to achieve the objectives/milestones?

In other words, what are the high-level steps required to deliver on the outputs, outcomes and impact mentioned above?</td><td>Buy in from all role players and stakeholders (current main data producers, relevant departments, ICT role players)
Research and Innovation project/initiative prioritization process
Coordinate related research, development and innovation activities and investments to focus on areas where local expertise and solutions are needed (part of this must be a focus on impact indicators in order to give meaning to data AND a focus on water quality and emerging contaminants)
High end skills interventions
Large scale tech and solution demonstrators that can be scaled up in different locations in communities – these must focus not just on technology but also the enabling governance, planning and capacity processes to scale up
Inclusion of societal and governance needs in initiative prioritization
Requires a framework to be developed that clearly states who is involved and what exactly their roles are.
Co-learning platforms to bring together researchers, implementers, planners, funders, users, etc</td></tr>
<tr><td>Resources required
What are the resources which are required to achieve the outputs, outcomes and impact?

Examples of such resources can include:
Knowledge and expertise
Technologies
Technical infrastructure
Institutional infrastructure
Research results
Partnerships established
Funding
Etc</td><td>Resources:
Knowledge and expertise: investment into research opportunities, smart consolidation of the different research nodes around South Africa to maximise on the innovation capacity in the sector, ongoing investment in skills and expertise, clear understanding of water sector skills demand and jobs of the future (reorientation of universities and training providers around this; networking funding to integrate efforts across universities and ensure units are not working in silos)
Technologies: local technologies need to be supported through well-coordinated sectoral demonstrations, standardisation (where possible), business development support, processes for handling incoming tech localisation
Technical infrastructure: agreement between key role players on the ICT infrastructure solutions, and hosts that will shift the sector forward. Careful planning in terms of cyber security.</td></tr>
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	• Institutional infrastructure: more formal links between the research community, DWS and water sector implementing agencies, as well as relevant related functions (energy, agriculture, housing, etc) • Research results: focus on knowledge dissemination, consolidation of knowledge outputs, access and deployment issues, with appropriate stakeholder engagement and communication management • Partnerships established • Funding: R&D and early stage testing funding is key to building a diverse pipeline of solutions
Resources to be established Which of the required resources are already established? Which need to be established, and what will be needed to establish them? For example, what STI-related research will be needed to achieve the intended results of the Thrust?	Existing: • Water RDI Roadmap and Implementation Unit housed at WRC, supported by DST • Water Technologies Demonstration Programme (WADER) housed at WRC, supported by DST • South African Sanitation Demonstration Programme – DST, WRC, BMGF • Water Research Commission to support the implementation of Water RDI Priorities Nationally • A variety of tertiary institution research units across the country dedicated to water-related research Going forward: • WADER will need to be resourced (funds, personal) to handle more demonstrations, multi-partner funding model for demos will be key • More standard national technology validation approaches • Consolidated national network of municipal and utility test bed/ learning facilities ('living laboratories' and demonstration sites) • Smart solution matchmaking function and support (particularly to municipalities) • Well-resourced new water and sanitation R&D programme (will need to extend beyond just the water levy and needs multi-sectoral support and collaboration) • Close partnerships and collaborative spaces between research and implementation communities (advisory service platforms, communities of practice, etc) • Revive South Africa's hydrological monitoring capacity as a centre • Plan partnerships into the SADC and the wider African region to ensure opportunities for regional solution deployment and collaboration. • Increased private sector involvement around integrated solutions for water users • Increased venture capital
Policy and regulatory environment What changes are required, if any, to the current STI policy and regulatory environment? What new policy and regulatory provisions, if any, will the Thrust require?	• Synergise the National Water RDI Roadmap, ICT Roadmap, National Water and Sanitation Master Plan and water components of the Industrial Policy Action Plan – Water Phakisa could be part of the process of undertaking this task. • Better coordination of institutions engaged in water research, innovation and solution deployment.

5. Risk	
Risk of not achieving results Explain the level of difficulty involved in achieving the intended results. Please specify: • Straightforward to achieve • Fairly difficult to achieve • Moderately difficult to achieve • Very difficult to achieve. Please explain your choice. What are the anticipated obstacles and challenges, and what is the likelihood of their being overcome? What are the risks associated with not achieving the intended results of the Thrust?	Fairly difficult to achieve Obstacles: • Cannot be business as usual, but there are deeply institutionalised ways of doing and approaching water sector management that will need to be challenged and redeveloped • New thinking, new materials and new understanding of how things work and are to be done • Low levels of water sector investment • Low levels of trust in the ability of government to make decisions on behalf of its people Risks: • SA water sector will be left behind global trends and abilities • We will have insufficient data to make well informed decisions • Relying on quick-fix technologies that may not resolve underlying problems
Social and ethical acceptability How ethically and socially acceptable is the Thrust? Specify: • Highly acceptable • Mostly acceptable • Fairly unacceptable • Mostly unacceptable Please explain your choice.	Mostly acceptable. In principle the proposed approach is acceptable – however careful planning around appropriate technology and associated skills sets must be undertaken in order to avoid investment in systems that are not effective or sustainable.
Unintended consequences Are there unintended consequences that may result from the Thrust? Explain the level of risk of these possible consequences.	Stronger possible role for private sector in supporting service delivery which has implications for how municipalities manage their service delivery approaches and responsibilities. Challenges to the business models of organisations who hold current monopolies of certain data Cyber security challenges
6. Other	
Other information Is there any other information which you wish to provide to support this Proposal for a Thrust?	None

STI Thrust Proposal – WA3

Working group	
Name of STI domain / working group	Integrated Solutions for Water Security

1. Title and description of STI Thrust	
Title of Thrust (Eight words or less)	**Off-grid and decentralised water, wastewater and sanitation solutions**
Summary description Provide a brief description of the Thrust so that we can be sure we understand what you are referring to. (Just a few sentences)	One of the key shifts that could bring the water sector closer to the opportunities of a circular economy is a transition to off-grid and decentralised water, wastewater and sanitation solutions. These off-grid, decentralised solutions have application at different scales and in different contexts. Firstly, there is a public market for these solutions in underserviced areas and in municipalities who are willing to explore alternatives to the mainstream large-scale infrastructure planning approaches. Secondly, there is the private market which supports solutions for individual households, privately owned housing estates, private companies/industrial role players with water quality impacts and needs. A water sector innovating around off-grid and decentralised solutions could, potentially, provide an opportunity in South Africa to 1) drive down service delivery costs 2) allow for agility and responsiveness under circumstances of unpredictability and change 3) promote the proliferation of innovation focused water sector businesses 4) help to drive the industrial development of the water sector.
2. Results – Description	
Problems to be addressed What are the problems which the Thrust is intended and is likely to address by 2030?	Thrust 1 on “Future-oriented Water and Sanitation Management Solutions” highlighted some of the water resources and services challenges that South Africa experience which have reference to this thrust too. From a water resources perspective South Africa’s uneven water distribution pattern, high evaporation rates, and low rainfall; coupled with high levels of unpredictability related to climatic changes, make large scale infrastructure investments difficult to plan and at times risky investments. Similarly, water services also need to be provided across a vastly diverse set of geographic, social, population, governance and planning dynamics. This also makes large scale centralised planning challenging and could provide an opportunity for consideration of alternative approaches. Increased dangers of pollution and emerging pollutants destroying ecosystems, rivers and affecting health of humans and animals. This presents an opportunity to think differently about the way we manage and plan water resources and associated

	service delivery using more modular, small, cost effective, locally managed solutions.
Outputs What are the likely outputs of the Thrust by 2030? (The outputs are the immediate results of the Thrust)	• Suites of off-grid and/or decentralised solutions exist that are suitable for both the needs of a private market (individual households, privately owned housing estates, private companies/industrial role players with water quality impacts and needs) and a public market (solutions in underserviced areas, low cost solutions) • More direct/circular water and wastewater reuse occurs on site. • A set of policy and regulatory incentives is in place to support the flourishing of off-grid and/or decentralised solutions • An ecosystem of businesses and associated manufacturing capabilities exists to handle the sale and operation of these solutions • Innovative business, funding and partnership models are explored in the process of implementing off-grid and/or decentralised solutions • Incentivizing the green industry through public sector impact investing
Outcomes and impact What are the likely outcomes and impact of the Thrust? What is the value of the outcomes and impact, and when are they likely to manifest? (The outcomes and impact are the medium-term and long-term results of the Thrust, respectively)	• Water security • More rapid nexus synergies can be built with food and agricultural issues on more mobile, decentralised, rapidly deployed water solutions. • Access to safe and context appropriate drinking water and sanitation. • Responsible and efficient use of water, reuse and recycling. • Mature water industry as a meaningful player in the economy • Changes in the fertiliser market • Offering opportunities for energy generation off the water grids thereby contributing to increased options for independent power production and grid • Creating new high value products thereby strengthening the chemical industry in SA • Contributing to low carbon/circular economy
3. Results – Alignment and scope	

Alignment with NDP vision
To what extent is the Thrust aligned with the vision of the NDP? Please specify:
• Fully aligned
• Mostly aligned
• Partially aligned
• Poorly aligned
 	
Please explain your choice.
 	
In other words, how will the Thrust contribute, both directly and indirectly, towards eliminating poverty,
	Fully aligned
	
	From the NDP 2030:
	• Economy infrastructure – The foundation of social and economic development
	    o Access to basic electricity, water and sanitation (direct)
	    o The energy sector: empowering south Africa (direct – off grid solutions independent of main electrical grid)
	• Environmental sustainability - An equitable transition to a low-carbon economy
	    o Responding effectively to climate change (direct – more mobile, rapid, flexible, scale able solutions)
	• An integrated and inclusive rural economy

reducing inequality and increasing employment? Please distinguish clearly between direct and indirect contributions.	○ Food security and basic services (indirect – nexus potential of decentralised solutions • Transforming human settlements ○ Recognising differences and inequalities within rural areas (indirect – more responsive, niche, customisable local solutions)
Scope of the benefits What is the scope of the benefits of the results which the Thrust is likely to have, by 2030? Please specify: • Very broad scope • Broad scope • Medium scope • Narrow scope Please explain your choice. Who will benefit? How many people will benefit (order of magnitude estimate)? In what way will they benefit?	Narrow scope Decentralised solutions, using smart scalable revenue models, inherently focus on a particular user or group of users – they thus have a narrower scope. There is however potential to massify the application of the approach to larger parts of South Africa.
4. High-level implementation	
High-level steps What are the high-level interim objectives or milestones which need to be achieved? What are the high-level activities/steps/ stages needed to achieve the objectives/milestones? In other words, what are the high-level steps required to deliver on the outputs, outcomes and impact mentioned above?	• Buy in from all role players and stakeholders, including all levels of government (water sector, RDI sector, housing, Planning, finance, energy) • Research and Innovation project/initiative prioritization process ○ Research gaps, including societal and governance needs ○ High end skills interventions ○ Tech and solution demonstrators that can be scaled up in different locations in communities – these must focus not just on technology but also the enabling governance, planning and capacity processes to scale up and local acceptability • Requires a framework to be developed that clearly states who is involved and what exactly their roles are. • Co-learning platforms to bring together researchers, implementers, planners, funders, users, etc
Resources required What are the resources which are required to achieve the outputs, outcomes and impact? Examples of such resources can include: • Knowledge and expertise • Technologies • Technical infrastructure • Institutional infrastructure • Research results	Resources: • Knowledge and expertise: investment into research opportunities, smart consolidation of the different research nodes around SA to maximise on the innovation capacity in the sector, ongoing investment in skills and expertise, clear understanding of water sector skills demand and jobs of the future (reorientation of universities and training providers around this; networking funding to integrate efforts across universities and ensure units are not working in silos) • Technologies: local technologies need to be supported through well-coordinated sectoral demonstrations and engagement with end-users to ensure that designs are context relevant, standardised (where possible); business

• Partnerships established • Funding • Etc	development support; processes for handling incoming tech localisation • Institutional infrastructure: more formal links between the research community, DWS and water sector implementing agencies, as well as relevant related functions (energy, agriculture, housing, etc) • Research results: focus on knowledge dissemination, consolidation of knowledge outputs, access and deployment issues, with appropriate stakeholder engagement and communication management • Partnerships established • Funding: R&D and early stage testing funding is key to building a diverse pipeline of solutions, water sector finance issues need to be looked at carefully (including water price) to drive more investment into the sector • Private sector market development
Resources to be established Which of the required resources are already established? Which need to be established, and what will be needed to establish them? For example, what STI-related research will be needed to achieve the intended results of the Thrust?	Existing: • Water RDI Roadmap and Implementation Unit housed at WRC, supported by DST • Water Technologies Demonstration Programme (WADER) housed at WRC, supported by DST • South African Sanitation Demonstration Programme – DST, WRC, BMGF • Water Research Commission to support the implementation of Water RDI Priorities Nationally • A variety of tertiary institution research units across the country dedicated to water-related research Going forward: • WADER will need to be resourced (funds, personal) to support more engagement and demonstrations; multi-partner funding model for demos will be key • More standard national technology validation approaches • Consolidated national network of municipal and utility test bed/ learning facilities ('living laboratories' and demonstration sites) • Matchmaking of solutions with potential implementation and/or business partners • Well-resourced new water and sanitation R&D programme (will need to extend beyond just the water levy and needs multi-sectoral support and collaboration) • Close partnerships and collaborative spaces between Research and implementation communities (advisory service platforms, communities of practise, etc) • Plan partnerships into the SADC and the wider African region to ensure opportunities for regional solution deployment and collaboration.
Policy and regulatory environment What changes are required, if any, to the current STI policy and regulatory environment? What new policy and regulatory provisions, if any, will the Thrust require?	• Synergise the National Water RDI Roadmap, National Water and Sanitation Master Plan and water components of the Industrial Policy Action Plan – Water Phakisa could be part of the process of undertaking this task. • Synergise and work with all municipalities, regardless of political affiliations • Better coordination of institutions engaged in water research, innovation and solution deployment. • Strengthen public private partnerships

5. Risk	
Risk of not achieving results Explain the level of difficulty involved in achieving the intended results. Please specify: • Straightforward to achieve • Fairly difficult to achieve • Moderately difficult to achieve • Very difficult to achieve. Please explain your choice. What are the anticipated obstacles and challenges, and what is the likelihood of their being overcome? What are the risks associated with not achieving the intended results of the Thrust?	Fairly difficult to achieve Obstacles: • There are deeply institutionalised ways of doing and approaching water sector management that will need to be challenged and redeveloped • Not a mature water tech industry to deploy solutions; where expertise exists, it is difficult to engage with leading water technologists • Low levels of water sector investment • Low levels of trust in the ability of government to make decisions on behalf of its people Risks: • Large scale infrastructure ceases to be effective before it has paid back its loan • Service delivery backlogs due to delays in building large scale infrastructure projects • Dependence on the public sector for service delivery.
Social and ethical acceptability How ethically and socially acceptable is the Thrust? Specify: • Highly acceptable • Mostly acceptable • Fairly unacceptable • Mostly unacceptable Please explain your choice.	Mostly acceptable. In principle the proposed approach is acceptable but, - Decentralised & off-grid solutions, if mainstreamed sufficiently, will cut into municipal revenue streams. This is in itself an underlying problem that needs to be addressed before necessary changes can be made. - Heightened role of private sector can also challenge established public sector roles and the basic rights of citizens as set out in the Constitution. These issues will need to be re-thought. - Any new approach needs to come with carefully considered governance incentives, and a sensitively managed approach to behavioural complexities and reasons for resistance. Detailed and long-term research is needed on social acceptability before interventions are rolled out.
Unintended consequences Are there unintended consequences that may result from the Thrust? Explain the level of risk of these possible consequences.	Stronger possible role for private sector in supporting service delivery which has implications for how municipalities manage their service delivery approaches and responsibilities.
6. Other	
Other information Is there any other information which you wish to provide to support this Proposal for a Thrust?	The new water and sanitation management paradigm can only thrive if supported by an innovation synergised water industry that is able to deploy new solutions through efficient manufacturing support and effective water sector businesses.

STI Thrust Proposal – WA2

Working group	
Name of STI domain / working group	Integrated Solutions for Water Security

1. Title and description of STI Thrust	
Title of Thrust (Eight words or less)	Embedding the Water Sector in the Fourth Industrial Revolution (4IR)
Summary description Provide a brief description of the Thrust so that we can be sure we understand what you are referring to. (Just a few sentences)	4IR is characterized by the enmeshing of the physical, digital and biological spheres, through technology referred to as cyber-physical systems. Cyber-physical systems have the potential to positively bring change in the way we manage our water and sanitation resources and services. This will demand deepened insight and attention in five areas: 1) linking of appropriate ICT technology to water resource management and service delivery 2) increasing the data intensity with which we make decisions 3) using cyber-physical systems to support appropriate behaviours 4) innovative water sector monitoring and data aggregation, and 5) re-skilling to operate in a data intensive water sector environment. Underlying these requirements will be the need to do groundwork in building trust and relationships so that the required changes can be implemented.
2. Results – Description	
Problems to be addressed What are the problems which the Thrust is intended and is likely to address by 2030?	Despite deepened understanding of the benefits of cyber-physical systems, the water sector has not geared itself up to make best use of the increasingly ubiquitous access to technology, data and associated decision support. This manifests in many ways, such as 1) weakly maintained hydrological monitoring systems 2) cooperative challenges in storing and sharing data 3) limited skill sets to define what type of cyber-physical systems and technologies are needed leading to mistrust of ICT technology and poorly selected options 4) policy and decision-making based on out-dated data 5) sector growth is limited due to the inability to adapt to new ways of working 6) sector planning and preparedness is limited leading to continuous crisis 7) inability to manage complexity as cities grow and the sector resources become more integrated 8) cyber security is poorly understood, compromising national key points and bulk infrastructure It is apparent that many of the challenges faced by the water sector in South Africa can be supported by cyber system enabled foresight (in application to design of policies, training and strategies, and responses to challenges).
Outputs What are the likely outputs of the Thrust by 2030?	• ICT technologies (diagnostics, robotics, artificial intelligence, distributed sensor networks, etc.) are smartly linked to water resource and supply management and

(The outputs are the immediate results of the Thrust)	service delivery through well connected smart networks with timely preventative maintenance • Water sector data (enhanced by big data analytics) is more widely available, up to date and accessible to inform decisions. This is supported by increased intelligence and processes related to cyber security. • Appropriate technologies, supported by appropriate stakeholder communications and engagements, are used to influence sustainable water behaviours, awareness, decision making at farm and community level, and education interventions • Hydrological monitoring is undertaken using smart, cost effective technology. Part of this will require refinement of the impact metrics that should be monitored in order to focus and give meaning to monitoring data. • Re-skilling needs are identified, and appropriate partners who are able to roll out training to support water sector role players operating in a data intensive water sector environment • Water investment in operations, maintenance, refurbishment and replacement is based on smart analytics, saving municipalities significant money
Outcomes and impact What are the likely outcomes and impact of the Thrust? What is the value of the outcomes and impact, and when are they likely to manifest? (The outcomes and impact are the medium-term and long-term results of the Thrust, respectively)	• Water security and quality is supported by access to evidence and data to inform decision making (More effective planning can take place due to better data access) • Water sector behaviours are more sustainable • New business opportunities for the ICT sector in water
3. Results – Alignment and scope	
Alignment with NDP vision To what extent is the Thrust aligned with the vision of the NDP? Please specify: • Fully aligned • Mostly aligned • Partially aligned • Poorly aligned Please explain your choice. In other words, how will the Thrust contribute, both directly and indirectly, towards eliminating poverty, reducing inequality and increasing employment? Please distinguish clearly between direct and indirect contributions.	- Fully aligned Economy infrastructure – ICT infrastructure Direct - better information about service delivery, behaviours, etc Indirect: - Capacitated society by making information, skilling more easily accessible and available.

<table>
<tr><td>Scope of the benefits
What is the scope of the benefits of the results which the Thrust is likely to have, by 2030? Please specify:
• Very broad scope
• Broad scope
• Medium scope
• Narrow scope

Please explain your choice. Who will benefit? How many people will benefit (order of magnitude estimate)? In what way will they benefit?</td><td>Medium scope

Main beneficiaries would be water sector role players (estimated 30000 people)

Secondary beneficiaries are the public, as part of the larger system, who are influenced by smart meters, training / awareness interventions, etc. (numbers would depend on the scale of roll-out)

Tertiary – the sector opens more opportunities for entrepreneurs, linking water, energy, health, service data at the household level</td></tr>
<tr><td colspan="2">4. High-level implementation</td></tr>
<tr><td>High-level steps
What are the high-level interim objectives or milestones which need to be achieved?
What are the high-level activities/steps/ stages needed to achieve the objectives/milestones?

In other words, what are the high-level steps required to deliver on the outputs, outcomes and impact mentioned above?</td><td>• Buy in from all role players and stakeholders (current main data producers, relevant departments, ICT role players)
• Research and Innovation project/initiative prioritization process
  o Coordinate related research, development and innovation activities and investments to focus on areas where local expertise and solutions are needed (part of this must be a focus on impact indicators in order to give meaning to data AND a focus on water quality and emerging contaminants)
  o High end skills interventions
  o Large scale tech and solution demonstrators that can be scaled up in different locations in communities – these must focus not just on technology but also the enabling governance, planning and capacity processes to scale up
  o Inclusion of societal and governance needs in initiative prioritization
• Requires a framework to be developed that clearly states who is involved and what exactly their roles are.
• Co-learning platforms to bring together researchers, implementers, planners, funders, users, etc</td></tr>
<tr><td>Resources required
What are the resources which are required to achieve the outputs, outcomes and impact?

Examples of such resources can include:
• Knowledge and expertise
• Technologies
• Technical infrastructure
• Institutional infrastructure
• Research results
• Partnerships established
• Funding
• Etc</td><td>Resources:
• Knowledge and expertise: investment into research opportunities, smart consolidation of the different research nodes around South Africa to maximise on the innovation capacity in the sector, ongoing investment in skills and expertise, clear understanding of water sector skills demand and jobs of the future (reorientation of universities and training providers around this; networking funding to integrate efforts across universities and ensure units are not working in silos)
• Technologies: local technologies need to be supported through well-coordinated sectoral demonstrations, standardisation (where possible), business development support, processes for handling incoming tech localisation
• Technical infrastructure: agreement between key role players on the ICT infrastructure solutions, and hosts that will shift the sector forward. Careful planning in terms of cyber security.</td></tr>
</table>

	• Institutional infrastructure: more formal links between the research community, DWS and water sector implementing agencies, as well as relevant related functions (energy, agriculture, housing, etc) • Research results: focus on knowledge dissemination, consolidation of knowledge outputs, access and deployment issues, with appropriate stakeholder engagement and communication management • Partnerships established • Funding: R&D and early stage testing funding is key to building a diverse pipeline of solutions
Resources to be established Which of the required resources are already established? Which need to be established, and what will be needed to establish them? For example, what STI-related research will be needed to achieve the intended results of the Thrust?	Existing: • Water RDI Roadmap and Implementation Unit housed at WRC, supported by DST • Water Technologies Demonstration Programme (WADER) housed at WRC, supported by DST • South African Sanitation Demonstration Programme – DST, WRC, BMGF • Water Research Commission to support the implementation of Water RDI Priorities Nationally • A variety of tertiary institution research units across the country dedicated to water-related research Going forward: • WADER will need to be resourced (funds, personal) to handle more demonstrations, multi-partner funding model for demos will be key • More standard national technology validation approaches • Consolidated national network of municipal and utility test bed/ learning facilities ('living laboratories' and demonstration sites) • Smart solution matchmaking function and support (particularly to municipalities) • Well-resourced new water and sanitation R&D programme (will need to extend beyond just the water levy and needs multi-sectoral support and collaboration) • Close partnerships and collaborative spaces between research and implementation communities (advisory service platforms, communities of practice, etc) • Revive South Africa's hydrological monitoring capacity as a centre • Plan partnerships into the SADC and the wider African region to ensure opportunities for regional solution deployment and collaboration. • Increased private sector involvement around integrated solutions for water users • Increased venture capital
Policy and regulatory environment What changes are required, if any, to the current STI policy and regulatory environment? What new policy and regulatory provisions, if any, will the Thrust require?	• Synergise the National Water RDI Roadmap, ICT Roadmap, National Water and Sanitation Master Plan and water components of the Industrial Policy Action Plan – Water Phakisa could be part of the process of undertaking this task. • Better coordination of institutions engaged in water research, innovation and solution deployment.

5. Risk	
Risk of not achieving results Explain the level of difficulty involved in achieving the intended results. Please specify: • Straightforward to achieve • Fairly difficult to achieve • Moderately difficult to achieve • Very difficult to achieve. Please explain your choice. What are the anticipated obstacles and challenges, and what is the likelihood of their being overcome? What are the risks associated with not achieving the intended results of the Thrust?	Fairly difficult to achieve Obstacles: • Cannot be business as usual, but there are deeply institutionalised ways of doing and approaching water sector management that will need to be challenged and redeveloped • New thinking, new materials and new understanding of how things work and are to be done • Low levels of water sector investment • Low levels of trust in the ability of government to make decisions on behalf of its people Risks: • SA water sector will be left behind global trends and abilities • We will have insufficient data to make well informed decisions • Relying on quick-fix technologies that may not resolve underlying problems
Social and ethical acceptability How ethically and socially acceptable is the Thrust? Specify: • Highly acceptable • Mostly acceptable • Fairly unacceptable • Mostly unacceptable Please explain your choice.	Mostly acceptable. In principle the proposed approach is acceptable – however careful planning around appropriate technology and associated skills sets must be undertaken in order to avoid investment in systems that are not effective or sustainable.
Unintended consequences Are there unintended consequences that may result from the Thrust? Explain the level of risk of these possible consequences.	Stronger possible role for private sector in supporting service delivery which has implications for how municipalities manage their service delivery approaches and responsibilities. Challenges to the business models of organisations who hold current monopolies of certain data Cyber security challenges
6. Other	
Other information Is there any other information which you wish to provide to support this Proposal for a Thrust?	None

STI Thrust Proposal – WA3

Working group	
Name of STI domain / working group	Integrated Solutions for Water Security

1. Title and description of STI Thrust	
Title of Thrust (Eight words or less)	**Off-grid and decentralised water, wastewater and sanitation solutions**
Summary description Provide a brief description of the Thrust so that we can be sure we understand what you are referring to. (Just a few sentences)	One of the key shifts that could bring the water sector closer to the opportunities of a circular economy is a transition to off-grid and decentralised water, wastewater and sanitation solutions. These off-grid, decentralised solutions have application at different scales and in different contexts. Firstly, there is a public market for these solutions in underserviced areas and in municipalities who are willing to explore alternatives to the mainstream large-scale infrastructure planning approaches. Secondly, there is the private market which supports solutions for individual households, privately owned housing estates, private companies/industrial role players with water quality impacts and needs. Second A water sector innovating around off-grid and decentralised solutions could, potentially, provide an opportunity in South Africa to 1) drive down service delivery costs 2) allow for agility and responsiveness under circumstances of unpredictability and change 3) promote the proliferation of innovation focused water sector businesses 4) help to drive the industrial development of the water sector.
2. Results – Description	
Problems to be addressed What are the problems which the Thrust is intended and is likely to address by 2030?	Thrust 1 on “Future-oriented Water and Sanitation Management Solutions” highlighted some of the water resources and services challenges that South Africa experience which have reference to this thrust too. From a water resources perspective South Africa’s uneven water distribution pattern, high evaporation rates, and low rainfall; coupled with high levels of unpredictability related to climatic changes, make large scale infrastructure investments difficult to plan and at times risky investments. Similarly, water services also need to be provided across a vastly diverse set of geographic, social, population, governance and planning dynamics. This also makes large scale centralised planning challenging and could provide an opportunity for consideration of alternative approaches. Increased dangers of pollution and emerging pollutants destroying ecosystems, rivers and affecting health of humans and animals. This presents an opportunity to think differently about the way we manage and plan water resources and associated

	service delivery using more modular, small, cost effective, locally managed solutions.
Outputs What are the likely outputs of the Thrust by 2030? (The outputs are the immediate results of the Thrust)	• Suites of off-grid and/or decentralised solutions exist that are suitable for both the needs of a private market (individual households, privately owned housing estates, private companies/industrial role players with water quality impacts and needs) and a public market (solutions in underserviced areas, low cost solutions) • More direct/circular water and wastewater reuse occurs on site. • A set of policy and regulatory incentives is in place to support the flourishing of off-grid and/or decentralised solutions • An ecosystem of businesses and associated manufacturing capabilities exists to handle the sale and operation of these solutions • Innovative business, funding and partnership models are explored in the process of implementing off-grid and/or decentralised solutions • Incentivizing the green industry through public sector impact investing
Outcomes and impact What are the likely outcomes and impact of the Thrust? What is the value of the outcomes and impact, and when are they likely to manifest? (The outcomes and impact are the medium-term and long-term results of the Thrust, respectively)	• Water security • More rapid nexus synergies can be built with food and agricultural issues on more mobile, decentralised, rapidly deployed water solutions. • Access to safe and context appropriate drinking water and sanitation. • Responsible and efficient use of water, reuse and recycling. • Mature water industry as a meaningful player in the economy • Changes in the fertiliser market • Offering opportunities for energy generation off the water grids thereby contributing to increased options for independent power production and grid • Creating new high value products thereby strengthening the chemical industry in SA • Contributing to low carbon/circular economy
3. Results – Alignment and scope	

Alignment with NDP vision
To what extent is the Thrust aligned with the vision of the NDP? Please specify:
• Fully aligned
• Mostly aligned
• Partially aligned
• Poorly aligned
 	
Please explain your choice.
 	
In other words, how will the Thrust contribute, both directly and indirectly, towards eliminating poverty,
	Fully aligned
	
	From the NDP 2030:
	• Economy infrastructure – The foundation of social and economic development
	    ○ Access to basic electricity, water and sanitation (direct)
	    ○ The energy sector: empowering south Africa (direct – off grid solutions independent of main electrical grid)
	• Environmental sustainability - An equitable transition to a low-carbon economy
	    ○ Responding effectively to climate change (direct – more mobile, rapid, flexible, scale able solutions)
	• An integrated and inclusive rural economy

reducing inequality and increasing employment? Please distinguish clearly between direct and indirect contributions.	◦ Food security and basic services (indirect – nexus potential of decentralised solutions • Transforming human settlements ◦ Recognising differences and inequalities within rural areas (indirect – more responsive, niche, customisable local solutions)
Scope of the benefits What is the scope of the benefits of the results which the Thrust is likely to have, by 2030? Please specify: • Very broad scope • Broad scope • Medium scope • Narrow scope Please explain your choice. Who will benefit? How many people will benefit (order of magnitude estimate)? In what way will they benefit?	Narrow scope Decentralised solutions, using smart scalable revenue models, inherently focus on a particular user or group of users – they thus have a narrower scope. There is however potential to massify the application of the approach to larger parts of South Africa.
4. High-level implementation	
High-level steps What are the high-level interim objectives or milestones which need to be achieved? What are the high-level activities/steps/ stages needed to achieve the objectives/milestones? In other words, what are the high-level steps required to deliver on the outputs, outcomes and impact mentioned above?	• Buy in from all role players and stakeholders, including all levels of government (water sector, RDI sector, housing, Planning, finance, energy) • Research and Innovation project/initiative prioritization process ◦ Research gaps, including societal and governance needs ◦ High end skills interventions ◦ Tech and solution demonstrators that can be scaled up in different locations in communities – these must focus not just on technology but also the enabling governance, planning and capacity processes to scale up and local acceptability • Requires a framework to be developed that clearly states who is involved and what exactly their roles are. • Co-learning platforms to bring together researchers, implementers, planners, funders, users, etc
Resources required What are the resources which are required to achieve the outputs, outcomes and impact? Examples of such resources can include: • Knowledge and expertise • Technologies • Technical infrastructure • Institutional infrastructure • Research results	Resources: • Knowledge and expertise: investment into research opportunities, smart consolidation of the different research nodes around SA to maximise on the innovation capacity in the sector, ongoing investment in skills and expertise, clear understanding of water sector skills demand and jobs of the future (reorientation of universities and training providers around this; networking funding to integrate efforts across universities and ensure units are not working in silos) • Technologies: local technologies need to be supported through well-coordinated sectoral demonstrations and engagement with end-users to ensure that designs are context relevant, standardised (where possible); business

• Partnerships established • Funding • Etc	development support; processes for handling incoming tech localisation • Institutional infrastructure: more formal links between the research community, DWS and water sector implementing agencies, as well as relevant related functions (energy, agriculture, housing, etc) • Research results: focus on knowledge dissemination, consolidation of knowledge outputs, access and deployment issues, with appropriate stakeholder engagement and communication management • Partnerships established • Funding: R&D and early stage testing funding is key to building a diverse pipeline of solutions, water sector finance issues need to be looked at carefully (including water price) to drive more investment into the sector • Private sector market development
Resources to be established Which of the required resources are already established? Which need to be established, and what will be needed to establish them? For example, what STI-related research will be needed to achieve the intended results of the Thrust?	Existing: • Water RDI Roadmap and Implementation Unit housed at WRC, supported by DST • Water Technologies Demonstration Programme (WADER) housed at WRC, supported by DST • South African Sanitation Demonstration Programme – DST, WRC, BMGF • Water Research Commission to support the implementation of Water RDI Priorities Nationally • A variety of tertiary institution research units across the country dedicated to water-related research Going forward: • WADER will need to be resourced (funds, personal) to support more engagement and demonstrations; multi-partner funding model for demos will be key • More standard national technology validation approaches • Consolidated national network of municipal and utility test bed/ learning facilities ('living laboratories' and demonstration sites) • Well-resourced new water and sanitation R&D programme (will need to extend beyond just the water levy and needs multi-sectoral support and collaboration) • Close partnerships and collaborative spaces between Research and implementation communities (advisory service platforms, communities of practise, etc) • Plan partnerships into the SADC and the wider African region to ensure opportunities for regional solution deployment and collaboration.
Policy and regulatory environment What changes are required, if any, to the current STI policy and regulatory environment? What new policy and regulatory provisions, if any, will the Thrust require?	• Synergise the National Water RDI Roadmap, National Water and Sanitation Master Plan and water components of the Industrial Policy Action Plan – Water Phakisa could be part of the process of undertaking this task. • Synergise and work with all municipalities, regardless of political affiliations • Better coordination of institutions engaged in water research, innovation and solution deployment. • Strengthen public private partnerships

<table>
<tr><th colspan="2">5. Risk</th></tr>
<tr><td>Risk of not achieving results
Explain the level of difficulty involved in achieving the intended results. Please specify:
• Straightforward to achieve
• Fairly difficult to achieve
• Moderately difficult to achieve
• Very difficult to achieve.
Please explain your choice.

What are the anticipated obstacles and challenges, and what is the likelihood of their being overcome?

What are the risks associated with not achieving the intended results of the Thrust?</td><td>Fairly difficult to achieve
Obstacles:
• There are deeply institutionalised ways of doing and approaching water sector management that will need to be challenged and redeveloped
• Not a mature water tech industry to deploy solutions; where expertise exists, it is difficult to engage with leading water technologists
• Low levels of water sector investment
• Low levels of trust in the ability of government to make decisions on behalf of its people

Risks:
• Large scale infrastructure ceases to be effective before it has paid back its loan
• Service delivery backlogs due to delays in building large scale infrastructure projects
• Dependence on the public sector for service delivery.</td></tr>
<tr><td>Social and ethical acceptability
How ethically and socially acceptable is the Thrust? Specify:
• Highly acceptable
• Mostly acceptable
• Fairly unacceptable
• Mostly unacceptable
Please explain your choice.</td><td>Mostly acceptable.

In principle the proposed approach is acceptable but,
- Decentralised & off-grid solutions, if mainstreamed sufficiently, will cut into municipal revenue streams. This is in itself an underlying problem that needs to be addressed before necessary changes can be made.

- Heightened role of private sector can also challenge established public sector roles and the basic rights of citizens as set out in the Constitution. These issues will need to be re-thought.

- Any new approach needs to come with carefully considered governance incentives, and a sensitively managed approach to behavioural complexities and reasons for resistance. Detailed and long-term research is needed on social acceptability before interventions are rolled out.</td></tr>
<tr><td>Unintended consequences
Are there unintended consequences that may result from the Thrust? Explain the level of risk of these possible consequences.</td><td>Stronger possible role for private sector in supporting service delivery which has implications for how municipalities manage their service delivery approaches and responsibilities.</td></tr>
<tr><th colspan="2">6. Other</th></tr>
<tr><td>Other information
Is there any other information which you wish to provide to support this Proposal for a Thrust?</td><td>The new water and sanitation management paradigm can only thrive if supported by an innovation synergised water industry that is able to deploy new solutions through efficient manufacturing support and effective water sector businesses.</td></tr>
</table>

Annexure G: Summary Inputs from Stakeholder Interviews

Set out below are the summary inputs to the foresight exercise from the stakeholder interviews conducted by Sci STIP.

1 Agriculture

1.1 General

1.1.1 Markets – Strength/Opportunity

Opportunities include, but are not limited to: i) New markets becoming available for South African agriculture products (China, rest of African continent, etc);

1.2 Infrastructure

Required: That this organisation has the infrastructure to support research, this includes buildings, library services, financial support, security and maintenance.

1.2.1 Horticulture

Required: Convert present mega and successful farming operations into supply centres for the new farmers (the out growing concept). Such supply centres of basic farming business knowledge, technology introduction, agricultural hardware infrastructure and resource supply, product processing and marketing guidance and assistance. Supply centres created, developed and advanced by presently successful farming enterprises with the mission to share essential expertise and necessary hardware.

1.2.2 Testing facilities

Problem: Increase our export of agricultural products; but then Government needs to be able to fulfil their role as designated authority (see for e.g. the closing of the meat exports due to Govt not being able to do residue tests).

1.3 Innovation

1.3.1 General

Required: Five research areas were defined to deliver solutions to the agricultural sector across the value chain… ARC priority: Quality of life (Research focus: Anticipation and mitigation of agricultural risks)

Five research areas were defined to deliver solutions to the agricultural sector across the value chain… ARC priority: Agriculture and skills development (Research focus: Solutions, processes and technologies to enhance agri value chain)

1.3.2 Coordination between various stakeholders

Problem: Lack of leadership among the participants and coordinators of agriculture sector along with lack of a unified approach to key issues impacting on all the relevant stakeholders.

1.3.3 Industry research/technology divide

Recommendation: Opportunities: the top farmers in the private sector are keen to work together with research institutions; maybe a tax break for those that do? More programs such as THRIP (but then the bureaucracy within needs to be lowered).

Create fundamentally sound operational plans continuously updated. Innovation happens at speed globally and locally but the translation of ever changing innovations in understandable terminologies for the new farmers will be the difference between winning and losing in South African agriculture.

1.3.4 R&D funding

Strength/Opportunity: Opportunities include, but are not limited to: iii) Positive sentiments for collaboration with South African scientists throughout the world – inclusive of possible opportunities for funding at international level (e.g. EU Framework Programme Horizon 2020, African Union Research Grants, Bill and Melinda Gates Foundation, Bilateral agreements, International Atomic Energy Agency etc).

Required: I have a simple formula for what enables a sustainable research program. The first is that there needs to be funding from a local industry, there needs to be at least matching government funding and then there needs to be funding from a changing series of granting agencies (national and international).

1.3.5 Agro-processing

Required: Agro processing and value chain addition

1.3.6 Disease and pests

Required technology: …identification of water and disease stress, etc...

1.3.7 Emerging farmers/new entrants

Required: We should be taking technology to our far-flung areas to facilitate the access of these areas to solutions to their problems.

1.3.8 Environment

Problem: Climate change in the absence of rapid scientific solutions from local institutions to enable adaptation and innovation for market access;

Required: Development of high intensive climate-smart farming systems as pressures for food increases with population increase and climate change.

Five research areas were defined to deliver solutions to the agricultural sector across the value chain… ARC priority: Natural conservation; Research focus: Promotion of ecosystem sustainability

1.3.9 Climate smart agriculture

Required technology: Whilst it is difficult to give an accurate picture of what agriculture will look like in the next 20 to 35 years, one thing is clear: as the global population continues to grow, more food will be needed to feed an estimated 9 billion people globally in 2050. Agriculture productivity will be negatively influenced, amongst others, by climate change, and soil and water degradation. New agricultural technologies will be needed to ensure that sufficient food is produced to feed the population. Bold decisions will have to be taken today to secure the future.

1.3.10 Food security

Required: Food security should be a key focus area. Increasing productivity with innovative approaches and ongoing outreach, especially to rural communities will be important.

Required technology: Five research areas were defined to deliver solutions to the agricultural sector across the value chain… ARC priority: National food security; Research focus: Genetic improvement of crops and livestock

1.3.11 Livestock

Problem: We should be moving away from using antibiotics and growth hormones in the rearing of animals.

Many diseases do jump species barriers and etiological factors often know no species differences.

Required: …herd management...

Required technology: We should be accelerating our use of genomics in animal breeding to quickly improve the quality of our herds and flocks. Embrace the concept of one health rather that the old approach of working in animal health, human health, environmental health, etc silos.

1.3.12 Nutrition

Required: Agriculture with nutrition outcomes

1.3.13 New crop/animal varieties

Required technology: Research into especially drought-resistant breeds and production methods.

1.3.14 Small holders

Required: Five research areas were defined to deliver solutions to the agricultural sector across the value chain… ARC priority: Equitable participation in sector; Research focus: inclusive market-oriented development (Small holder farmers and others)

1.3.15 Precision/"smart farming"

Required: Big data – internet of things, more advances in remote and satellite technology – as it applied to combating theft...

Required technology: The advance in aviation and computer technologies provider great opportunities for modernising agricultural production. One of these opportunities is the use of aerial drones for surveying fields, mapping weeds, yields and soil variation. This technology also enables precise application of inputs.

The other expected advance is in the use of fleets of agribots which are a herd of specialised agribots (or agricultural robots) which are used for tending crops, weeding, fertilising and harvesting. The other new technology is the use of smart tractors which use GPS controlled steering and optimised route planning which reduces soil damage and saves fuel costs.

The other is the use of texting cows whereby sensors are attached to livestock allowing monitoring of animal health and wellbeing. The sensors can send text to alert farmers when a cow goes into labour or develops infection which in the end increases head survival and milk yields.

1.3.16 Water utilization

Problem: Challenges: water footprint.

1.3.17 Technology – general

Strength/Opportunity: Opportunities include, but are not limited to: ii) Technologies have enabled use of new production methods (e.g. hydroponics, aquaponics, vertical farming, precision agriculture etc);

1.4 Role of government

1.4.1 Policy/legislation/strategy

Problem: Changing land use and regulatory systems…

Required: Minimise Bureaucracy.

1.4.2 Politicians and governmental officials

Problem: National expectations on land and agrarian reform, inclusive of experiences to date since 1994;

1.4.3 Subsidies

Problem: Rising input costs in an environment where agriculture enterprises are competing with products imported from countries where farmers are subsidized – difficult economic environment…

1.4.4 Schools

Required: The major demand is educating and skills development that commence at school level. Abundant raw South African talent is begging to be developed. Create education centres manned by the competent tutors should urgently be attended to and executed.

1.4.5 Graduates and trained professionals

Problem: Ageing cohort of primary producer with insignificant infusion of diverse participants (extremely inadequate transformation throughout the value chain);

1.4.6 Centres of Excellence

Required: We need more universities and more research in every sector. While we wait for this to happen the NRF should be making sure that the centres of excellence that do exist can continue doing what they are already doing. The only way to grow any sector is to support those that are excellent and with time these will grow and train the next generation. The analogy I have is that of golf, the only reason that South Africa features internationally with regards to golf is Gary Player, with his leadership and golf excellence he has produced and inspired a cohort of excellent golfers. Research is no different. We need to grow and support what is already excellent internationally. There are always new and exciting areas to develop, research centres of excellence will grow those as part of what they do. I know of no centre of excellence in the country which does not support many different projects and young researchers focused on projects of national relevance yet most often also using cutting edge research. At the “edges” of all the centres of excellence that the NRF funds are many fledgling research programs that would not have existed without the centres of excellence - this is the next generation and through the centres of excellence we can support these researchers.

Ten years ago I sequenced the first fungal genome in Africa. I could never have predicted that we would now (ten years on) be faced with the tsunami of genomes sequence data that we have. I do not have crystal ball clear enough to predict the future but I do know that if funding is given the centres of excellence in the country they will train the next generation and these researchers will be our future leaders in science.

1.4.7 Researchers

Required: The second is that the researchers need to have full time permanent employment at a University/Research organization.

Recommendation: Training workers to be more efficient in utilising technology (e.g. needs to know how to use a GPS, or a drone).

2 Education

2.1 Innovation

Required: Measuring learning, analytics…

Required technology: 3D environments, augmented reality (e.g., for teaching physics, biology), simulated learning (perhaps more in professional education and teacher education than in schools)

Teacherbots!

3 Energy

3.1 Infrastructure

3.1.1 Independent power producers

Required: Better support and access of independent power producers to the grid.

3.2 Innovation

3.2.1 General

Required: Integrated water-energy-food systems that work at a local, city, community or settlement level.

3.2.2 Biofuels

Required: Biomass is multi-functional and multi-purpose – considering energy as the primary product from available plant biomass is not sensible, as this overlooks high-value speciality products, which could offer much better economics than low value commodities like energy. Energy from biomass should be a secondary product in a biorefinery that co-produces high value specialities, typically with energy from biomass residues.

3.2.3 Fossil fuels

Required: Cleaning fossil fuels and integrating REs

3.2.4 The grid/smart grids

Required: Integrated smart grid for electricity

Storage and grid integration as mentioned above.

Smart grids and also technologies for rural electrification i.e. mini-grids.

3.2.5 Renewables

Required: Clarity on how to integrate REs into the energy economy

Solar, Wave and Bioenergy.

3.2.6 Transportation

Europe and the East is going the electric car route and is phasing out all petrol and diesel cars. What are we doing about this?

3.2.7 Technology – general

Required: Advanced materials applications in the Energy Value chain

3.2.8 Researchers

Required: Developing qualified and experienced researchers.

4 Environment

4.1 Innovation

4.1.1 Coordination between various stakeholders

Required: The challenge is in engaging in a non-trivial, credible and useful way with other disciplines (and eventually other epistemologies; starting with the human sciences, but going ever further from the comfort zone of biophysical research - the humanities and arts, non-western belief systems...)

4.1.2 Energy

Problem: Extensive roll out of de-centralised energy grid

4.1.3 Mining

Problem: Effective mine rehabilitation techniques that do not require high levels of maintenance

4.1.4 Waste

Required: Waste management and urgent recycling

Food waste

4.1.5 Water

Problem: Water saving devices

4.1.6 Technology – general

Required: The opportunities include the increasing policy awareness and relevance of the sector, brought about by a growing number and severity of environmental problems, occurring at the same time when great advances are being made in a number to technical fields: AI and pattern recognition applied to unprecedented quantity and richness of data sources, a lot of it remotely or automatically collected; metagenomics.

4.2 Role of government

4.2.1 Policy/legislation/strategy

Required: Ocean resources and ocean integrity (ie ensuring that ocean resources are not stolen).

5 Health

5.1 General

Information dissemination

Required

Widespread packaging and dissemination of trusted evidence-based health education information to the public, through IT, radio, TV and print media.

5.2 Innovation

5.2.1 General

The Global Burden of Disease study has published very recently in the Lancet that given SA's level of development, our health outcomes are extremely poor and much much lower than would be expected. We need to improve this significantly. Now is the time to invest in this.

Required: Programs to develop country-specific initiatives for health promotion

Much better collection, analysis and feedback of routine information to inform planning and management of resources

5.2.2 Evaluation

Required: Skills to assess effectiveness/appropriateness of health policies

5.2.3 Mental health

Required: Seeing that mental health is emerging as a significant factor in morbidity and mortality, evidence-based programs for this area of health should be developed, with plans for assessments

5.2.4 HIV/TB

Technology required: As mentioned earlier - hopefully the HIV vaccine trial that is ongoing will give successful results. This is urgently needed.

5.2.5 Precision medicine/diagnoses

Technology required: Precision public health care is essential in SA as developing country. We need investment in much better big data collection and surveillance. A good description can be found here: https://www.nature.com/news/four-steps-to-precision-public-health-1.21089

With global funding agencies such as the Bill & Melinda Gates Foundation investing in this, SA may gain significantly by joining forces and take centre stage leading such initiatives.

5.2.6 Technology – general

Required:

- Digital Health
- Personalised healthcare
- Medical imaging
- Scale up of 3D Printing and Bioprinting in health care
- Virtual reality in interventional medicine.
- Integrating bioinformatics at the point-of-care.

6 Manufacturing

6.1 Innovation

6.1.1 Partnerships

Partnerships eg local and overseas universities

6.1.2 Advanced/smart manufacturing

QC methods

Streamlining manufacturing processes

6.1.3 Computational mechanics (computational fluid dynamics)

Computational Mechanics or computational fluid dynamics is going to be a key and critical area. But it cannot be simply open source or available commercial codes as everybody has access to this. Needs to be a world class CFD technology (bringing together the latest in mathematics, computer science and engineering innovation via a dedicated experienced team with their own niche code).

6.1.4 Environmentally friendly

Greening the sector eg biodegradable materials etc

6.1.5 Utilize local strengths/opportunities

South Africa should focus more on what they could do with their local resources - specifically conversion of raw materials into products for local use and for export. To be quite honest, I think that this should really be the priority. Analyze our resources, determine the need and see what we can do from there.

6.2 Role of government

6.2.1 Policy/legislation/strategy

The government seems keen on pushing the Ocean Economy and the latest buzzword is Industry 4.0. I believe that we need to keep abreast of trends and rather than looking to follow, possible identify opportunities unique to South Africa that we can take advantage of. So in terms of alignment, I would imagine that it would be prudent to develop a strategy within the Ocean Economy.

7 Water

7.1 Innovation

7.1.1 Measurement & management

Monitoring and measurement

7.1.2 Wastewater

South Africa has the real opportunity to become a world leader in wastewater beneficiation as well as a manufacturing centre for new sanitation

Water as an economic enabler centred on beneficiation of waste stream and the creation of New Water to fill the shortages that currently constrain the economy.

Optimization of wastewater treatment plants in urban centres

Strong emphasis on wastewater reuse and beneficiation using technology adapted for local application.

7.1.3 Water reuse

Water scarce country we need to look at water reuse. Sustainable treatment systems that does not use electricity or harmful chemicals

Development of technologies that are capable of resource recovery, e.g. desalination, ‘waste’ water, algae, sludge, urine, etc.

7.1.4 Water quality/supply

Managed Aquifer Recharge is a strategic priority that is under-funded and researched.

Treatment of water quality and the use of ‘fit for purpose’ water for reuse

Protection of our surface and ground water using technology to adequately treat industrial effluents

7.2 Role of government

7.2.1 Government establishment

The creation of a dedicated Water Board that focusses only on desalination and the creation of New Water from either waste or the sea.

7.2.2 Enforcement/management

Education of the consumer and promoting effective demand side management

7.2.3 Increase participation in innovation value chain

The emergence of a business model that enables a PPP approach to the investment of both capital and technology into the 824 waste water treatment plant that is mostly dysfunctional.

7.2.4 Policy/legislation/strategy

Water resources management is very important… South Africa is a water scarce country… Otherwise we will run out of water… we have to know how to manage wastewater… and to convince people even how they can drink that water…

Annexure H: Big Data Analytics for South African National STI Foresight 2030

Contents

Big Data Analytics for South African National STI Foresight 2030

Institute for Statistical Studies and Economics of Knowledge (ISSEK)
National Research University Higher School of Economics (HSE)
Moscow, 2019

CONTENTS

INTRODUCTION

Foresight studies have been undertaken for the purpose of investigating in the future of Science, Technology and Innovation (STI) and how these can serve for the improvement of quality of life and creation of wealth, while achieving the goals for sustainable development. A National Foresight exercise has been undertaken for South Africa for identifying STI priorities and strategies towards 2030. The South African National STI Foresight 2030 study aimed at contributing to the following STI objectives of the country:

- advancing the capacity of the national innovation system to contribute to socio-economic development;
- enhancing South Africa's capacity for generating knowledge to produce world class research outputs, as well as innovative products and processes thereafter;
- developing appropriate human capital in the STI sector to meet the needs of society;
- building a world class infrastructure in the STI sector; and
- positioning South Africa as a strategic international R&D and innovation partner and destination.

The Foresight study was commissioned by the Department of Science and Technology (DST) of the Republic of South Africa, and was implemented in cooperation with Non-Zero-Sum Development and the Institute for Statistical Studies and Economics of Knowledge (ISSEK) of the National Research University Higher School of Economics (HSE), Moscow, Russian Federation during 2018 and 2019.

This report presents the results of the Big Data Analysis (BDA) undertaken by the ISSEK HSE. Providing a new evidence-base, Big Data makes precious contributions for Foresight exercises. The types of analyses involved in this study are:

1. Bibliometric analysis of the scientific outputs produced by South Africa. The bibliometric analysis helped to understand South Africa's competences in research with key STI areas focused, scientific capacity within the country and key collaborators across the world and in Africa. The temporal analysis of scientific outputs indicate the mature and emerging areas in South African research landscape
2. Semantic analysis of large document sets was undertaken through the "intelligent Foresight Analytics (iFORA)" system, which is a proprietary tool developed by ISSEK HSE. iFORA uses advanced semantic analysis, machine learning and AI algorithms to integrate diverse information sources including scientific articles, patents, news, grants, analytical reports among the others with the aim of exploring new knowledge on emerging and evolving trends. The iFORA system generated semantic maps for the domain areas and thrusts identified in the South African National STI Foresight exercise. Detailed analyses of maps are provided to describe emerging issues and topics in each domain and the thrusts under them. These are provided in the report with detailed interpretations.

Presenting the results of the analyses, the report begins with a description of the South African research landscape with current trends in research outputs, thematic areas of specialization and scientific partners of South Africa across the world and in the African continent. Dynamic analysis of publications in research outputs indicates the trends in STI related work in South Africa. Following the description of the research landscape and capacity, the next chapter takes a detailed look at each of the STI domains identified by the National STI Foresight 2030 study. The semantic maps generated clearly illustrate the thrusts under each domain and identify emerging topics and issues related to them. This helps to set a development agenda and strategies under the STI domains. Further bibliometric analysis under each domain indicates the research capacity of

South Africa, which helps to assess the country's ability to respond to the emerging trends and issues. The study is rounded off with overall conclusions and a detailed description of the methodology in the annex.

Acknowledgements

The core team members of ISSEK HSE involved in the South African National STI Foresight 2030 study are: Prof. Ozcan Saritas and Prof. Alexander Sokolov. Mr. Maxim Kotsemir made contributions to the study with bibliometric analysis of the South African scientific landscape through the analysis of South African scientific output. Mr. Pavel Bakhtin of the iFORA Team contributed to the study with the semantic analysis of thousands of documents to identify emerging trends and key topics for South Africa. The present report was co-authored by Prof. Ozcan Saritas, Prof. Alexander Sokolov and Mr. Maxim Kotsemir.

We are grateful to the DST Team, including Dr. Mlungisi Cele, Dr. Petrus Letaba, Mr. Benny Nhlapo, Ms. Thato Dube and other members of the team for their invaluable support, teamwork and hospitality. Collaboration with Mr. Peter Greenwood and Ms. Tina James during the workshops in South Africa was instrumental for the successful completion of this work. We also appreciate the dedication and efforts of the all participants of the Foresight working panels in South Africa. The administrative support provided by Ms. Elena Nasybulina and the DST administrative team is greatly valued by us.

1. RESEARCH LANDSCAPE OF SOUTH AFRICA: CURRENT TRENDS IN RESEARCH OUTPUTS, THEMATIC FOCUS, AND SCIENTIFIC PARTNERSHIPS

This chapter provides a comprehensive analysis of research landscape in South Africa in terms of: level of the country's publication activity and its contribution to the global process of knowledge generation; thematic structure of publications, their scientific specializations; quality of articles measured by citation indicators; similarity of thematic structures of publications; international research collaboration profiles; and finally closeness and relative influence of each country in collaboration with other countries. *The findings presented here should be considered in conjunction with the outputs of the "South Africa Science and Technology Foresight for 2030", which identified seven science and technology domains and thrusts (priorities) associated to them. Matches and mismatches between the priorities and scientific capacity should be assessed in order to develop strategies for supporting some of the critical science and technology areas in order to achieve 2030 visions of the country*.

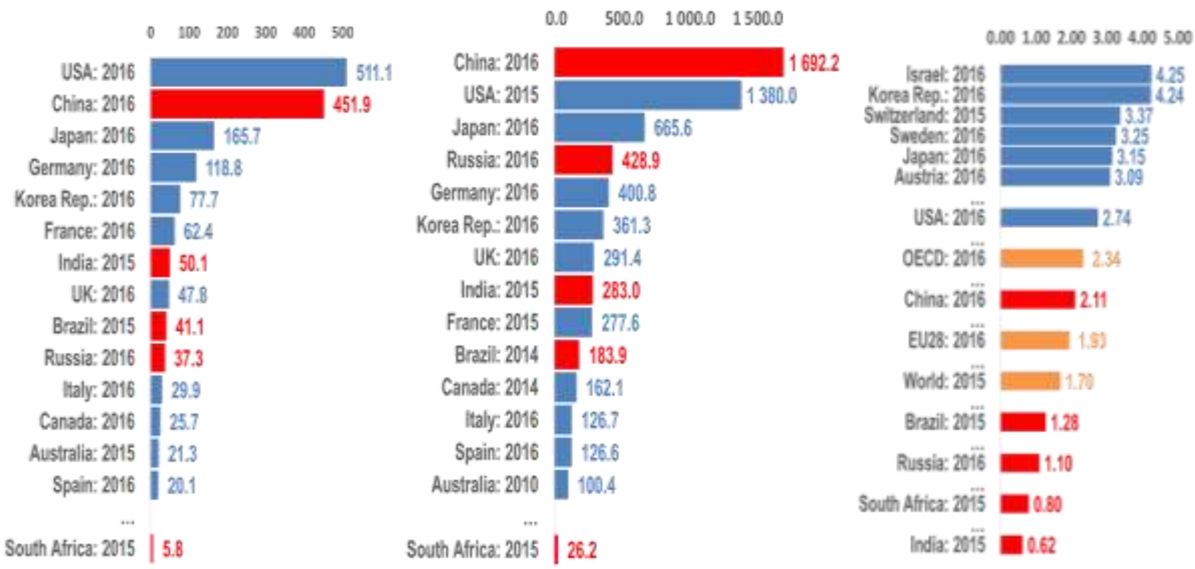
Scopus database was used for analysis with the timespan of 2001-2017[1] that allows demonstrating some of the key trends in the development of research landscape in South Africa. A wide range of bibliometric indicators was used for analysis including citation indicators; indices of structural difference; indicators of scientific collaboration. Among the key outputs produced are:

- publication activity of South Africa, the country's contribution to the global process of knowledge generation;
- thematic structure of publications of South Africa, its scientific specialization, and the quality of articles in the country's specialization areas;
- the similarity of the thematic structure of publications; and
- research collaboration profiles, collaboration closeness, and the dominance level of South Africa in comparison with other countries including BRICS, the United States and the European Union (EU) 28.

Different approaches are used to visualize data in form of illustrative tables and charts. In the analysis, the following types of documents are considered (unless otherwise indicated): articles, conference proceedings, and reviews. A publication is considered to belong to a certain country if at least one of its authors is affiliated with this country.

When South Africa's overall scientific and technological potentials assessed, it is seen that the country still has considerable progress to make. There is an urgent need to increase the R&D intensity of the country. One of the ways of doing this is to increase investments in R&D and the number of active researchers with higher number of publications. On the R&D funding side Figure 1.1 illustrates that South Africa's "Gross Expenditure on Research and Development – GERD" as percentage of GDP is quite low – 0.80.

[1] The year 2018 is not yet complete in scientific databases.



GERD, USD bln PPP Researchers (Full time equivalent, '000) GERD as % of GDP

Figure 1.1 Key R&D expenditures and R&D personnel indicators for BRICS countries in comparison with best benchmark countries in 2016 or last year with available data

Note: Calculated by authors using OECD MSTI (Main Science and technology Indicators database); UNESCO Institute of Statistic database (section "Science, technology and innovation").

The figure above shows that South Africa is far behind leading countries in this respect (EU28 average for this indicator is 1.96 as of year 2015). Regarding publication activity, Figure 1.2 shows number of publications in different countries.

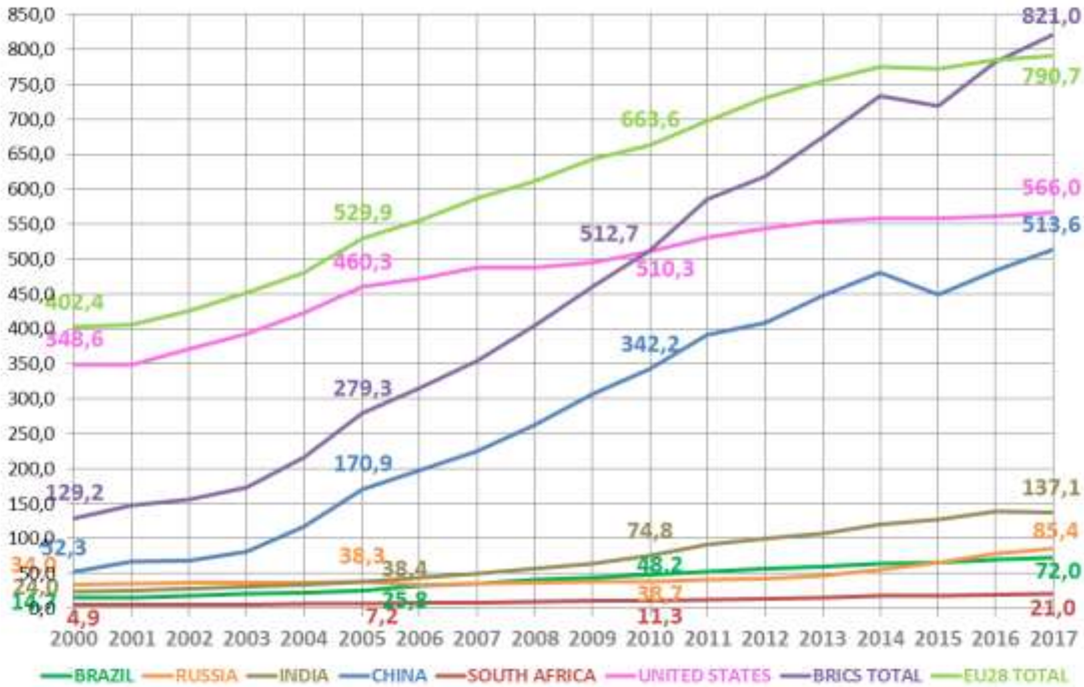


Figure 1.2. Dynamics of publications in Scopus (2000-2017) – (vertical axis indicates 1000 publications)

Note: Data for calculations derived from Scopus SciVal "Benchmarking" Toolbox. Types of publications include articles, reviews, and conference papers.

It is seen that China has made a significant progress in terms of number of publications, whereas increase in the number of publications from South Africa remained rather modest. Further details are shown on Table 1.1, which, in addition, illustrates the share of South Africa in global scientific publication output. In the global ranking on the total number of publications, South Africa is in the top 50 countries.

Table 1.1. Key indicators of publication activity in Scopus in 2000, 2005, 2010 and 2017

Country/ Country group	2000	2005	2010	2017	2000	2005	2010	2017	Growth for 2000-2017, times
	Total no. of publications in Scopus ('000)				Share in global publication output in Scopus				
Brazil	14,7	25,8	48,2	72,0	1,2%	1,5%	2,3%	2,8%	4,90
Russia	34,0	38,3	38,7	85,4	2,8%	2,3%	1,8%	3,3%	2,52
India	24,0	38,4	74,8	137,1	2,0%	2,3%	3,5%	5,3%	5,70
China	52,3	170,9	342,2	513,6	4,3%	10,3%	16,0%	19,9%	9,81
South Africa	4,9	7,2	11,3	21,0	0,40%	0,43%	0,53%	0,81%	4,30
BRICS	129,2	279,3	512,7	821,0	10,7%	16,8%	24,0%	31,8%	6,35
United States	348,6	460,3	510,3	566,0	28,8%	27,6%	23,9%	21,9%	1,62
EU28	402,4	529,9	663,6	790,7	33,2%	31,8%	31,0%	30,6%	1,97
World	**1 210,2**	**1 666,8**	**2 138,9**	**2 582,3**	**100,0%**	**100,0%**	**100,0%**	**100,0%**	**2,13**

Note: Data for calculations derived from Scopus SciVal “Benchmarking” Toolbox. Types of publications include articles, reviews, and conference papers.

Besides the number of publications, it is also important to understand the key areas of competence in scientific work. These are demonstrated by the key subject areas of Scopus (Table 1.2).

Table 1.2. South Africa publication activity by Scopus subject area in 2017

Subjarea	Scopus subject area	Number of SA publications in subject area in 2017	Position of SA in global ranking of countries by number of publications in subject area in 2017	% of SA to Country-leader by number of publications in 2017	Country-leader by number of publications in 2017
AGRI	Agricultural and Biological Sciences	3 197	22	7,0%	USA
ARTS	Arts and Humanities	1 498	13	5,7%	USA
BIOC	Biochemistry, Genetics & Molec. Bio.	1 915	36	2,3%	USA
BUSI	Business, Management and Accounting	964	21	6,8%	USA
CENG	Chemical Engineering	689	36	1,6%	China (since 2009)
CHEM	Chemistry	1 292	35	1,8%	China (since 2007)
COMP	Computer Science	2 063	41	2,6%	China (since 2006)
DECI	Decision Sciences	379	33	4,3%	USA
DENT	Dentistry	28	53	1,0%	USA
EART	Earth and Planetary Sciences	1 397	26	4,2%	China (since 2015)
ECON	Economics, Econometrics and Finance	580	22	5,1%	USA
ENER	Energy	800	34	2,4%	China (since 2005)
ENGI	Engineering	2 513	42	1,6%	China (since 2007)
ENVI	Environmental Science	1 948	25	5,5%	USA
HEAL	Health Professions	353	29	2,7%	USA
IMMU	Immunology and Microbiology	852	24	4,2%	USA
MATE	Materials Science	1 484	38	1,5%	China (since 2007)
MATH	Mathematics	1 212	41	2,3%	China (since 2012)
MEDI	Medicine	6 010	28	2,8%	USA
MULT	Multidisciplinary	238	38	2,0%	China (since 2015)
NEUR	Neuroscience	302	40	1,2%	USA
NURS	Nursing	375	26	2,7%	USA
PHAR	Pharmacology, Toxicology & Pharma.	593	32	3,3%	USA
PHYS	Physics and Astronomy	2 159	38	2,6%	China (since 2013)
PSYC	Psychology	570	29	2,2%	USA
SOCI	Social Sciences	3 666	16	5,9%	USA
VETE	Veterinary	65	24	6,3%	USA
Total	**All publications**	**22 051**	**29**	**3,7%**	**USA**

Note: Authors’ calculations from SCImago journal and country rank database (based on Scopus). Types of publications include articles, reviews, and conference papers. SCImago Data was updated at June 2018.

Analysis of Table 1.2 indicates that South Africa lags behind other BRIC countries in global ranking on number of publications in Scopus. The country is placed usually below 20th in 27 Scopus subject areas. Among the “strongest” subject areas for South Africa are: “Agricultural and Biological Sciences” (22nd position and 7.0% of the global leader); “Business, Management and Accounting” (21st and 6.8%); “Veterinary” (24th and 6.3%); “Social sciences” (16th and 5.9%); “Arts and humanities” (13th and 5.7%).

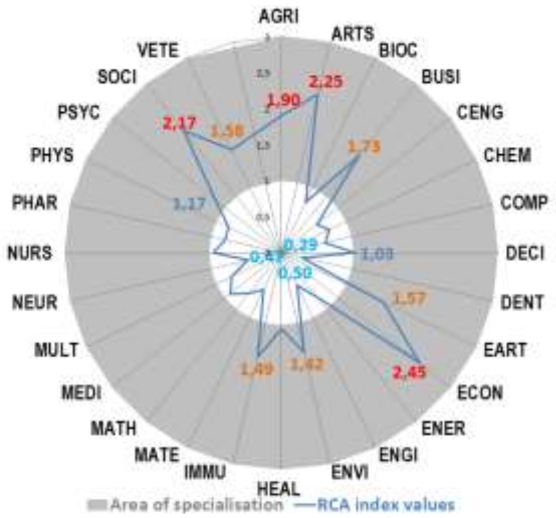


Figure 1.3. Specialization areas of South Africa by Scopus subject areas for 2013 - 2017[2]

Note: Data for calculations derived from the Scopus database. Types of publications include articles, reviews, and conference papers.

In order to better illustrate the key areas of specializations, a further analysis was undertaken using Relative Comparative Advantage, or Revealed Comparative Advantage (RCA) index, which is used to measure the degree of scientific specialization of a country in a given subject area. Subject areas where RCA index value is higher than 1.00 are areas of the research specialization of a given country. Subject areas where the value of the RCA index is significantly higher than 1.00 (i.e. above 1.50 or 2.00) can be attributed to the key areas of the scientific specialization of the country.[3] Figure 1.3 illustrates the specialization areas of South Africa in Scopus subject areas.

The figure illustrates that South Africa has significant specialization in the areas of "ECON - Economics, Econometrics and Finance" (RCA: 2.45); "ARTS - Arts and Humanities" (RCA: 2.25); "SOCI - Social Sciences" (RCA: 2.17); and "AGRI - Agricultural and Biological Sciences" (RCA: 1.90). Further scientific specialization is also observed in "BUSI – Business, Management and Accounting"; "VETE – Veterinary"; "EART – Earth and Planetary Sciences"; "IMMU – Immunology and Microbiology"; "ENVI – Environmental Science"; and "DECI – Decision Sciences" (1.0<RCA<1.80). Low specialization is observed in some of the key areas like "ENGI – Engineering"; "NEUR – Neuroscience"; and "COMP – Computer Science" (RCA<1.0). Considering the science and technology priority domains and priorities for South Africa, particularly Engineering and Computer Sciences areas need immediate attention for the development of the scientific capacity.

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[2] 27 Scopus subject areas are abbreviated as follows: AGRI – Agricultural and Biological Sciences; ARTS – Arts and Humanities; BIOC – Biochemistry, Genetics and Molecular Biology; BUSI – Business, Management and Accounting; CENG – Chemical Engineering; CHEM – Chemistry; COMP – Computer Science; DECI – Decision Sciences; DENT – Dentistry; EART – Earth and Planetary Sciences; ECON – Economics, Econometrics and Finance; ENER – Energy; ENGI – Engineering; ENVI – Environmental Science; HEAL – Health Professions; IMMU – Immunology and Microbiology; MATE – Materials Science; MATH – Mathematics; MEDI – Medicine; MULT – Multidisciplinary; NEUR – Neuroscience; NURS – Nursing; PHAR – Pharmacology, Toxicology and Pharmaceutics; PHYS – Physics and Astronomy; PSYC – Psychology; SOCI – Social Sciences; VETE – Veterinary.

Source: Authors' calculations from data taken from the Scopus database. Types of publications include articles, reviews, and conference papers. Data is current as of September 2016.

[3] For a given country (j) and a given subject area (i) Revealed comparative advantages index (RCA) index is calculated as follows: $RCA_{subjarea\ i\ country\ j} = \frac{Share_{subjarea\ i\ country\ j}}{Share_{subjarea\ i\ world}}$

where $Share_{subjarea\ i\ country\ j}$ – is the share of publications on subject area i (i = 1, … , 27) in the total number of publications of a specific country j in the Scopus database; - $Share_{subjarea\ i\ world}$ - is the share of publications on subject area i (i = 1, … , 27) in the global number of publications in the Scopus database.

Figure 1.4 shows the thematic structure of publications in South Africa based on the shares of publications in 27 Scopus subject areas in the total number of publications of South Africa in Scopus. Key areas of research of South Africa in Scopus are Medicine; Social sciences; and Agricultural and biological sciences.

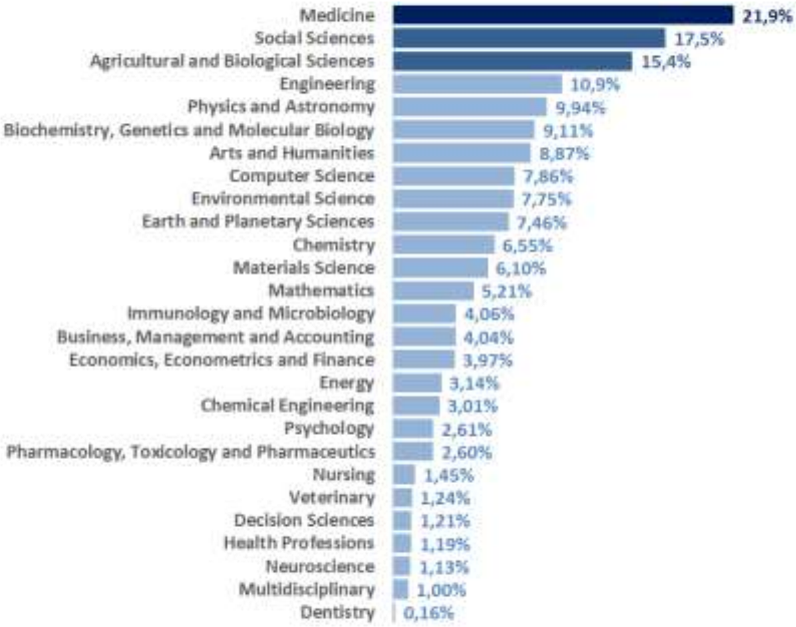

Figure 1.4. Subject structure of publications of South Africa in Scopus for 2013 – 2017

Note: Data for calculations derived from the Scopus database. Types of publications include articles, reviews, and conference papers.

Figure 1.5 further analyses the subject areas by considering the quality of publications in those areas.

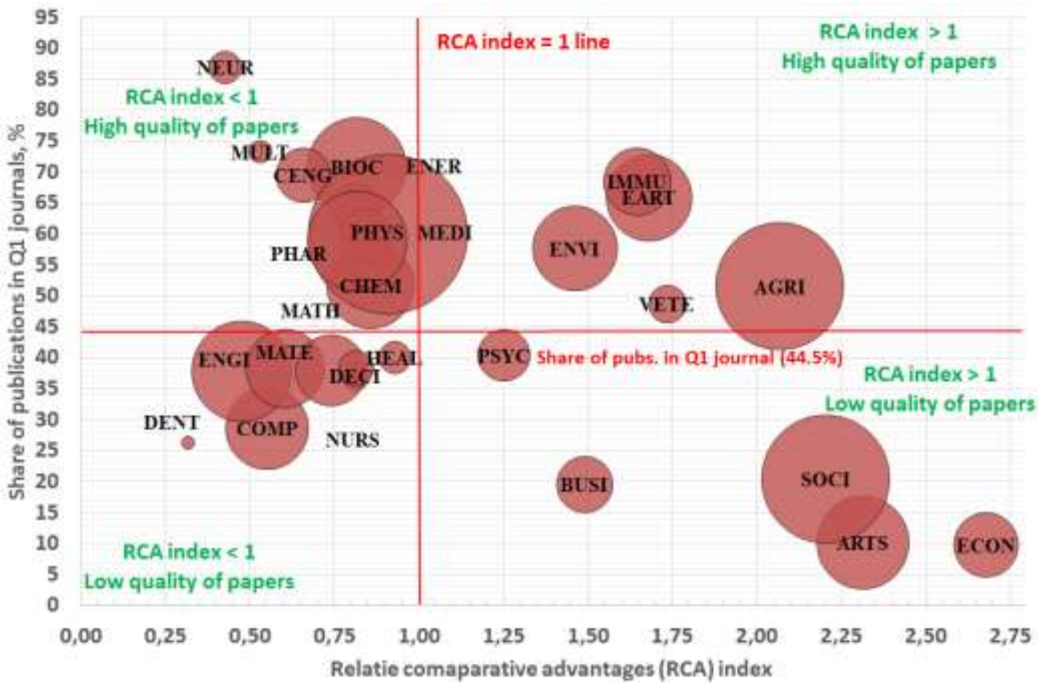

Figure 1.5. Areas of specialization vs. quality of publications of South Africa in Scopus in 2011 – 2015

Notes: Bubble size (square) is set as the number of publications for 2011 – 2015 in a given subject area. Data for calculations derived from Scopus SciVal "Benchmarking" Toolbox. Types of publications include articles, reviews, and conference papers.

In Figure 1.5, the quality of publications is measured based on whether they are published in Q1 journals. The subject areas with 45% or more of total such publications are considered to be 'high quality'. The degree of specialization is indicated with the RCA scores. If the RCA score is higher than 1.0, there is a high degree of specialization. In the figure, the bubble size is determined by the number of publications from 2011 to 2017 in a given subject area. Overall, it is seen that the subject areas related to Agriculture, Environment, Immunology, and Earth sciences produce high quality output with high degree of specialization. These are clearly among the strengths of South Africa. Medicine is the next area, where South Africa indicates strong potentials if further invested. As noted earlier, areas related to Mathematics, Engineering and Computer science are rather poor and need strong support, if the country is to address Grand Challenges, where these scientific areas are the key enablers of development. Research in Business, Economy, and Social sciences clearly is in need for higher quality output to be competitive nationally and globally. Figure 1.6 shows the dynamics of growth of South African publications in common for BRICS STI priority areas from year 2000 to 2017.

As the figure illustrates, South Africa makes some progress in almost all scientific areas. However, considering the low number of publications, the figures are far from ideal for a significant progress at the national and global levels. The biggest improvement is observed in "Renewable energy sources" (24 times since year 2000), which is meaningful considering the climate change and growing demand for sustainable energy. Similarly, the emphasis on "Information and Communication Technologies" is also growing. Despite of this growth, the earlier analysis showed that there still remains a substantial progress to be made in this area. "Transport" is an area, which appears to be receiving more attention with 10 times of growth. However, the number of publications is extremely low in order to interpret this progress as significant. In terms of the share of scientific work in South Africa as percentage of total work in the world, "Food security and sustainable agriculture" area represents over 1%, like other areas including "Climate change, environmental protection and disaster management", and "Water resources". Considering the priority areas in the S&T Foresight 2030, these advancements are certainly crucial. It is also noteworthy that "Space systems and astronomical observations" represent over 1% of the global scientific output as of 2017. This area is also a key for achieving 2030 visions.

Area	South Africa				
	N. of publications		Growth, times	Share in the world	
	2000	2017		2000	2017
1. Information and communication technologies	167	2 053	12,29	0,21%	0,57%
2. Nanotechnology and new materials	304	1 470	4,84	0,24%	0,48%
3. Advanced manufacturing and robotics	300	1 701	5,67	0,20%	0,44%
4. Space systems and astronomical observations	105	448	4,27	0,51%	1,06%
5. Transport systems	7	74	10,57	0,12%	0,35%
6. Energy efficiency and energy saving	39	457	11,72	0,16%	0,64%
7. Nuclear energy	8	32	4,00	0,18%	0,24%
8. Renewable energy resources	18	444	24,67	0,45%	0,99%
9. Search, exploration, development and mining of minerals	219	556	2,54	0,68%	0,97%
10. Climate change, environmental protection and disaster management	502	1 994	3,97	0,85%	1,13%
11. Water resources	252	586	2,33	0,91%	1,04%
12. Food security and sustainable agriculture	560	1 315	2,35	1,27%	1,30%
13. Healthcare and medicine	1 075	4 583	4,26	0,32%	0,77%
14. Biotechnology	331	951	2,87	0,33%	0,59%
Total (all publications in Scopus)	**4 842**	**21 120**	**4,36**	**0,40%**	**0,80%**

Figure 1.6. Research potentials of South Africa in Scopus in common for BRICS countries STI priority areas in 2000 and 2017

Note: Correspondence between priority areas and Scopus subject Areas is shown in in Table A.1 in Appendix. Data for calculations derived from the Scopus database. Types of publications include articles, reviews, and conference papers.

Another important aspect of scientific work is 'international collaboration', which represents joint research and knowledge exchange between countries. Table 1.3 illustrates the global scientific partners of South Africa. As the table illustrates, the United States, Australia, and five leading European countries (incl. United Kingdom, Germany, France and the Netherlands) are among the top scientific partners of South Africa. These partners indicate leading positions in internationally collaborated publications. India and China are among the BRICS countries, which South Africa is intensively collaborating in top 10 partner countries. Among the others South Africa's partnerships with other African countries including Nigeria, Kenya and Zimbabwe are noteworthy. Figure 1.8 illustrates the dynamics of these partnerships across time. Although the top 5 collaborators remained the same since 2000, new scientific partners are emerging for South Africa. For instance, the share of BRICS counties as percentage of total partnerships has increased significantly from 7.84% in 2000 to 12.88% in 2010, and finally 23.54% in 2017. Meanwhile, new partnerships have been established with countries like Chile, Mexico and Turkey. Finally, Table 1.4 presents the thematic structure of internationally collaborated publications of South Africa in years 2000, 2010 and 2017 by Scopus subject area. It is seen that subject areas like Business, Management and Accounting; Health Professions; Decision Sciences; Nursing; and Arts and Humanities are gaining momentum in terms of the growth of their share in total number of publications.

Table 1.3. Scientific partners of South Africa in South Africa in Scopus in 2017

Country	Number of joint publications with a country			Growth of joint papers 2017 to 2010, times	Share of a country in all internationally collaborated punblications (ICPs) of SAR		
	2000	2010	2017		2000	2010	2017
All ICPs of SAR	**1518**	**4906**	**10 729**	**7,07**	**100,0%**	**100,0%**	**100,0%**
1. United States	488	1560	3235	6,63	32,15%	31,80%	30,15%
2. United Kingdom	369	1122	2383	6,46	24,31%	22,87%	22,21%
3. Germany	190	557	1341	7,06	12,52%	11,35%	12,50%
4. Australia	150	506	1314	8,76	9,88%	10,31%	12,25%
5. France	109	465	1037	9,51	7,18%	9,48%	9,67%
6. Netherlands	81	337	970	11,98	5,34%	6,87%	9,04%
7. India	34	213	895	26,32	2,24%	4,34%	8,34%
8. Canada	102	367	893	8,75	6,72%	7,48%	8,32%
9. China	29	185	733	25,28	1,91%	3,77%	6,83%
10. Switzerland	55	247	728	13,24	3,62%	5,03%	6,79%
11. Italy	49	259	726	14,82	3,23%	5,28%	6,77%
12. Nigeria	12	176	692	57,67	0,79%	3,59%	6,45%
13. Spain	31	216	668	21,55	2,04%	4,40%	6,23%
14. Sweden	38	240	627	16,50	2,50%	4,89%	5,84%
15. Belgium	56	214	529	9,45	3,69%	4,36%	4,93%
16. Brazil	22	137	502	22,82	1,45%	2,79%	4,68%
17. Japan	48	168	443	9,23	3,16%	3,42%	4,13%
18. Norway	20	162	405	20,25	1,32%	3,30%	3,77%
19. Russian Federation	34	97	396	11,65	2,24%	1,98%	3,69%
20. Denmark	26	159	385	14,81	1,71%	3,24%	3,59%
21. Poland	26	108	372	14,31	1,71%	2,20%	3,47%
22. Austria	28	116	355	12,68	1,84%	2,36%	3,31%
23. Kenya	19	111	343	18,05	1,25%	2,26%	3,20%
24. Chile	13	70	316	24,31	0,86%	1,43%	2,95%
25. Turkey	10	60	308	30,80	0,66%	1,22%	2,87%
26. Portugal	4	68	305	76,25	0,26%	1,39%	2,84%
27. Zimbabwe	27	72	291	10,78	1,78%	1,47%	2,71%
28. Finland	16	67	281	17,56	1,05%	1,37%	2,62%
29. Czech Republic	8	74	276	34,50	0,53%	1,51%	2,57%
29. New Zealand	49	104	276	5,63	3,23%	2,12%	2,57%
31. Argentina	9	83	254	28,22	0,59%	1,69%	2,37%

Note: Data for calculations derived from the Scopus database. Types of publications include articles, reviews, and conference papers.

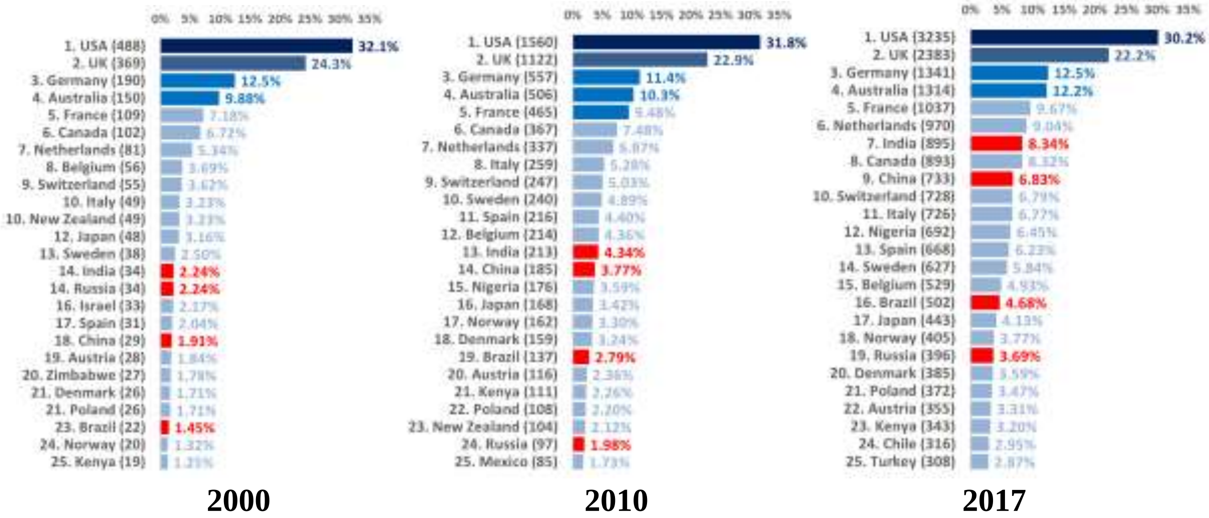

Figure 1.8. Top 25 scientific partners of South Africa in Scopus in years 2000, 2010 and 2017

Note: Data for calculations derived from the Scopus database. Types of publications include articles, reviews, and conference papers.

Table 1.4. Thematic structure of internationally collaborated publications of South Africa in years 2000, 2010 and 2017 by Scopus subject area

Scopus Subject area	Number of internationally collaborated publications (ICPs) in subject area			Growth of ICPs 2017 to 2010, times	Share of a subject area in all ICPs of SAR			Growth of share of subject area 2017 to 2010, times
	2000	2010	2017		2000	2010	2017	
	1515	4903	10 776		100.0%	100.0%	100.0%	
Medicine	329	1354	2822	8.58	21.72%	27.62%	26.19%	1.21
Agricultural and Biological Sciences	336	1069	1881	5.60	22.18%	21.80%	17.46%	0.79
Physics and Astronomy	216	566	1465	6.78	14.26%	11.54%	13.60%	0.95
Social Sciences	122	490	1218	9.98	8.05%	9.99%	11.30%	1.40
Engineering	124	449	1151	9.28	8.18%	9.16%	10.68%	1.30
Biochemistry, Genetics and Molecular Biology	207	551	1111	5.37	13.66%	11.24%	10.31%	0.75
Environmental Science	114	416	1058	9.28	7.52%	8.48%	9.82%	1.30
Earth and Planetary Sciences	218	511	936	4.29	14.39%	10.42%	8.69%	0.60
Materials Science	101	291	791	7.83	6.67%	5.94%	7.34%	1.10
Chemistry	115	369	693	6.03	7.59%	7.53%	6.43%	0.85
Computer Science	60	248	683	11.38	3.96%	5.06%	6.34%	1.60
Mathematics	100	272	640	6.40	6.60%	5.55%	5.94%	0.90
Immunology and Microbiology	88	374	562	6.39	5.81%	7.63%	5.22%	0.90
Arts and Humanities	23	180	387	16.83	1.52%	3.67%	3.59%	2.37
Energy	28	98	382	13.64	1.85%	2.00%	3.54%	1.92
Chemical Engineering	34	169	329	9.68	2.24%	3.45%	3.05%	1.36
Business, Management and Accounting	11	82	313	28.45	0.73%	1.67%	2.90%	4.00
Psychology	18	122	311	17.28	1.19%	2.49%	2.89%	2.43
Pharmacology, Toxicology and Pharmaceutics	47	143	290	6.17	3.10%	2.92%	2.69%	0.87
Economics, Econometrics and Finance	33	69	238	7.21	2.18%	1.41%	2.21%	1.01
Neuroscience	24	62	177	7.38	1.58%	1.26%	1.64%	1.04
Multidisciplinary	15	47	175	11.67	0.99%	0.96%	1.62%	1.64
Health Professions	8	50	174	21.75	0.53%	1.02%	1.61%	3.06
Nursing	10	79	171	17.10	0.66%	1.61%	1.59%	2.40
Veterinary	33	80	146	4.42	2.18%	1.63%	1.35%	0.62
Decision Sciences	7	32	131	18.71	0.46%	0.65%	1.22%	2.63
Dentistry	7	11	8	1.14	0.46%	0.22%	0.07%	0.16

Note: Data for calculations derived from the Scopus database. Types of publications include articles, reviews, and conference papers.

2. SEMANTIC ANALYSIS OF STI DOMAINS AND THRUSTS

The National STI Foresight 2030 study identified seven STI domains and thrusts associated to them. STI domains are defined as fairly broad but bounded areas, related to STI as well as to a societal need or issue. The Foresight study identified several thrusts for each of the STI domains. Thrusts are considered as STI-related priority areas, which indicate what South Africa wishes to achieve with the time horizon of 2030. Throughout the Foresight process, a number of STI areas were identified. These were prioritized using a set of criteria related to their (i) potentials for new impact, (ii) association to global and STI trends, and (iii) contribution to socio-economic development. As a result of online and offline consultations with the stakeholders of the STI system in South Africa, first, eight STI domains were selected. The number was then reduced to seven as two of the domains were merged. Then thrusts were determined through the following stages of the Foresight study. First, a long list of thrusts was proposed through a Foresight workshop. Then, these were shortlisted using a new set of prioritization criteria by considering their importance and feasibility. The importance criteria included the (i) socio-economic impact; (ii) new impact; and (iii) strategic value of each thrust. The feasibility criteria included (i) availability of required knowledge and expertise; (ii) availability of institutional capacity; (iii) availability of infrastructure; (iv) required policy and regulatory environment in place; (v) social and ethical acceptability; (vi) amount of relevant funding currently allocated and; (vii) ease of addressing barriers and obstacles. In total of 25 thrusts were identified under seven STI domains. These are:

1. CIRCULAR ECONOMY
    a. CE1: Reduce, reuse and recycle waste
    b. CE2: Ensuring sustainable water, energy and food (agriculture) security
    c. CE3: Low-carbon and climate-resilient economy
    d. CE4: Smart connectivity and mobility in communities

2. HIGH-TECH INDUSTRY
    a. HT1: Enabling small business to adopt high tech
    b. HT3: New thinking for new industries
    c. HT4: New thinking for old industries

3. NUTRITION SECURITY FOR A HEALTHY POPULATION
    a. NU1: Zero impact agriculture
    b. NU2: Use and acceptance of modern biotechnology
    c. NU3: Personalized information for healthy nutrition for all
    d. NU4: Precision and big data in agri-businesses

4. THE OPPORTUNITIES, THREATS AND IMPACT OF ICTs, INCLUDING SMART SYSTEMS, ON SOCIETY
    a. IT1: Checks and balances for a digital future
    b. IT2: ICT infrastructure and Internet access
    c. IT3: Big data, data analytics and decision support
    d. IT4: Smart and sustainable municipal service delivery

5. HEALTH TECHNOLOGY TO PREVENT AND TREAT ILL-HEALTH, AND ADVANCE WELL-BEING FOR THOSE WHO ARE MARGINALIZED
    a. HE1: Optimization of health systems
    b. HE2: Improving the quality of healthcare
    c. HE3: Digitization of health systems

6. SUSTAINABLE ENERGY TECHNOLOGIES FOR THE MARGINALIZED
    a. EN1: Clean, affordable and sustainable energy for all
    b. EN2: Renewable energy sources and technologies
    c. EN3: Energy efficiency solutions for industry plus household use
    d. EN4: Distributed energy generation and storage

7. EDUCATION FOR THE FUTURE
    a. ED1: Skills for the 4th Industrial Revolution
    b. ED2: Inclusive innovation and development
    c. ED3: Curriculum development 2030

The following sections present the results of the semantic analysis with the iFORA system for each domain areas. Detailed analyses of maps are provided to describe emerging issues and topics in each domain and the thrusts under them.

2.1. CIRCULAR ECONOMY DOMAIN

Overall description of the domain

The Circular Economy domain is concerned with the generation of products which are restorative and regenerative by design, and which circulate through the economy repeatedly, thereby minimizing waste. This includes the conversion of biological and non-biological waste into new resources and materials as well as the restoration and protection of biodiversity with further implications for rural areas.

Overview of research potential of South Africa in “Circular economy” domain

Figure 2.1.1 shows that there is a growing scientific emphasis on the Circular Economy domain in South Africa. The number of publications has been growing steadily as well as the share of South Africa in the global scientific output in this domain.

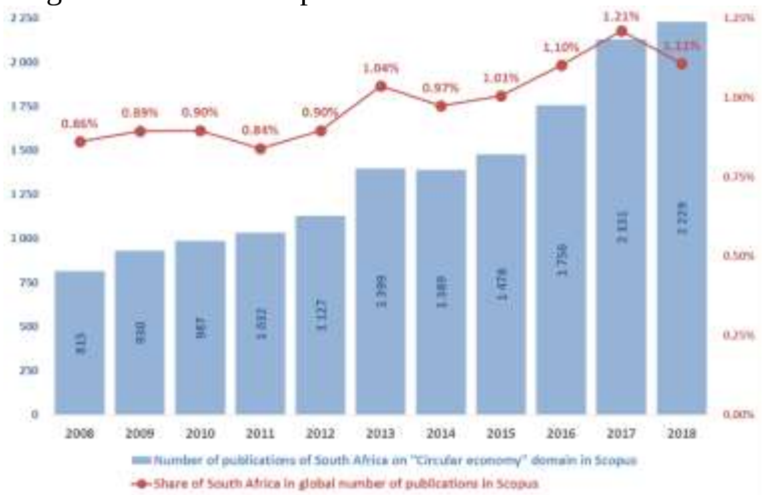

Figure 2.1.1. Dynamics of publications of South Africa in “Circular economy” domain in Scopus in 2008 – 2018

Note: all types of documents except of technical documents, indexed in Scopus are included in the analysis.

Figure 2.1.2 shows the leading countries in the Circular Economy domain.

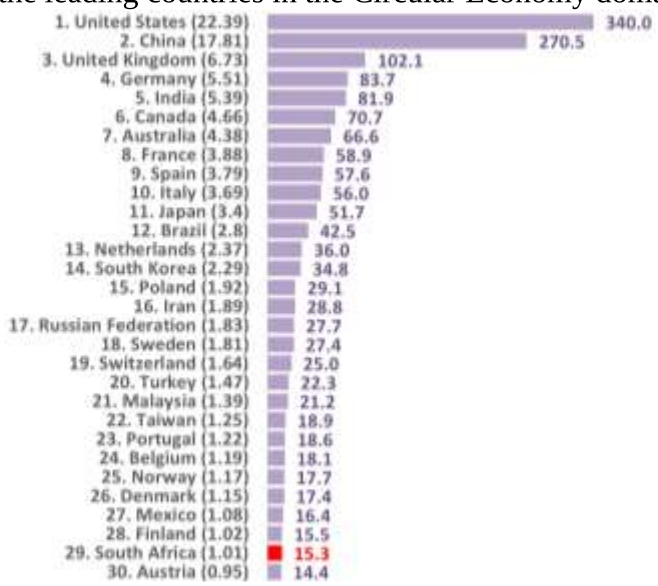

Figure 2.1.2. Leading countries by number of publications (‘000) in “Circular economy” domain in Scopus for 2008 – 2018

Note: 1. All types of documents except of technical documents, indexed in Scopus are included in the analysis. 2. Share of a country in global number of publications is shown in parenthesis.

Among those countries, the key partners of South Africa are the United States, the United Kingdom, Australia, Germany and France (Table 2.1.1). Nigeria, Zimbabwe, Kenya, Namibia and Ethiopia are among the African scientific partners of South Africa.

Table 2.1.1. Key partner countries of South Africa in internationally collaborated publications in "Circular economy" domain in Scopus for 2008 - 2018

Country	Number of Joint papers with South Africa	Share of a country in all ICPs of South Africa
United States	2058	25.98%
United Kingdom	1730	21.84%
Australia	1126	14.22%
Germany	845	10.67%
France	753	9.51%
Netherlands	613	7.74%
Canada	548	6.92%
Sweden	476	6.01%
India	437	5.52%
Nigeria	433	5.47%
Spain	358	4.52%
China	352	4.44%
Italy	349	4.41%
Switzerland	329	4.15%
Norway	311	3.93%
Zimbabwe	292	3.69%
Belgium	281	3.55%
New Zealand	260	3.28%
Kenya	240	3.03%
Japan	237	2.99%
Brazil	200	2.53%
Denmark	199	2.51%
Austria	187	2.36%
Portugal	174	2.20%
Finland	162	2.05%
Namibia	157	1.98%
Ethiopia	139	1.76%
Czech Republic	132	1.67%
Botswana	127	1.60%
Tanzania	123	1.55%
Ghana	111	1.40%
Poland	111	1.40%
Argentina	102	1.29%
Mexico	95	1.20%
Iran	94	1.19%
Malaysia	92	1.16%
Uganda	91	1.15%
Chile	88	1.11%
Russian Federation	88	1.11%
Thailand	80	1.01%
Malawi	72	0.91%
Zambia	71	0.90%
Cameroon	67	0.85%
Saudi Arabia	67	0.85%
Mozambique	65	0.82%
Israel	64	0.81%
Ireland	61	0.77%
Turkey	59	0.74%
Hungary	55	0.69%
Egypt	54	0.68%

Indonesia	52	0.66%
South Korea	50	0.63%

Note: 1. All types of documents except of technical documents, indexed in Scopus are included in the analysis.

Table 2.1.2 shows the leading organizations in South Africa publishing in the domain of Circular Economy with the total number of publications they produced in the last 10 years, as well as the percentage of their contribution in the total scientific output.

Table 2.1.2. Leading organizations of South Africa by number of publications in "Circular economy" domain in Scopus for 2008 – 2018

Affiliation	Number of publications	Share in all South Africa publications
University of Cape Town	2127	8.89%
University of KwaZulu-Natal	1808	7.56%
Universiteit Stellenbosch	1775	7.42%
Universiteit van Pretoria	1731	7.24%
University of Witwatersrand	1271	5.31%
North-West University	910	3.80%
The Council for Scientific and Industrial Research	874	3.65%
University of Johannesburg	867	3.62%
Rhodes University	862	3.60%
University of the Free State	624	2.61%
Nelson Mandela Metropolitan University	536	2.24%
Tshwane University of Technology	495	2.07%
University of South Africa	414	1.73%
University of the Western Cape	403	1.68%
Agricultural Research Council, Pretoria	309	1.29%
University of Fort Hare	300	1.25%
University of Venda for Science and Technology	285	1.19%
South African National Biodiversity Institute	278	1.16%
Cape Peninsula University of Technology	258	1.08%
South African National Parks	219	0.92%
Marine and Coastal Management	214	0.89%
Durban University of Technology	207	0.87%
University of Limpopo	199	0.83%
South African Institute for Aquatic Biodiversity	181	0.76%
South African Environmental Observation Network	141	0.59%
South African Medical Research Council	135	0.56%
University of Zululand	116	0.48%
Vaal University of Technology	113	0.47%
International Water Management Institute, Pretoria	111	0.46%
Human Sciences Research Council of South Africa	95	0.40%
Plant Protection Research Institute, Pretoria	90	0.38%
Council for Geoscience	80	0.33%
University of Witwatersrand, School of Chemical and Metallurgical Engineering	76	0.32%
Kruger National Park	72	0.30%
Ezemvelo KZN Wildlife	68	0.28%
Endangered Wildlife Trust	64	0.27%
South African Water Research Commission	55	0.23%
National Research Foundation	54	0.23%
Central University of Technology, Free State	53	0.22%
South African Weather Service	53	0.22%

Note: 1. All types of documents except of technical documents, indexed in Scopus are included in the analysis. 2. Organization names are presented as they are spelled in Scopus database.

Semantic analysis of “Circular economy” domain

This section describes the “Circular Economy” STI domain and its thrusts based on the results of the semantic analysis produced by the iFORA system. First, the full domain is described with a domain map including all of the topics covered. Figure 2.1.3 shows the entire domain of the Circular Economy (CE) with its clusters and interrelations to each other. A detailed analysis of Figure 2.1.3 provides an overview of CE thrusts and a number of existing and emerging topics for consideration under each of them. These are presented in Table 2.1.3. In the following sections network maps are given to illustrate these thrusts and further issues emerging under each of them.

Table 2.1.3. “Circular Economy” thrusts and topics

Circular Economy Thrusts	Topics emerging under each thrust
CE1: Reduce, reuse and recycle waste	Waste reduction (Fig. 2.1.4)
	Waste recycling and sustainable strategy (Fig. 2.1.5)
CE2: Ensuring sustainable water, energy and food (agriculture) security	Water resources (Fig. 2.1.6)
	‘Water management’ and ‘flood risk and extreme weather’ (Fig. 2.1.7)
	Agricultural water use (Fig. 2.1.8)
	‘Water security’ and ‘Food security’ (Fig. 2.1.9)
	Precision framing and farm efficiency (Fig. 2.1.10)
	Agricultural policy (Fig. 2.1.11)
CE3: Low-carbon and climate resilient economy	Economic impact of sustainability (Fig. 2.1.12)
	‘Energy efficiency’ and ‘Renewable energy’ (Fig. 2.1.13)
	Low carbon and low emissions (Fig. 2.1.14)
	Climate change (Fig. 2.1.15)
	‘Biodiversity conservation’ and ‘Land use’ (Fig. 2.1.16)
	African environmental policy (Fig. 2.1.17)
CE4: Smart connectivity and mobility in communities, supporting the circular economy	Green transport (Fig. 2.1.18)

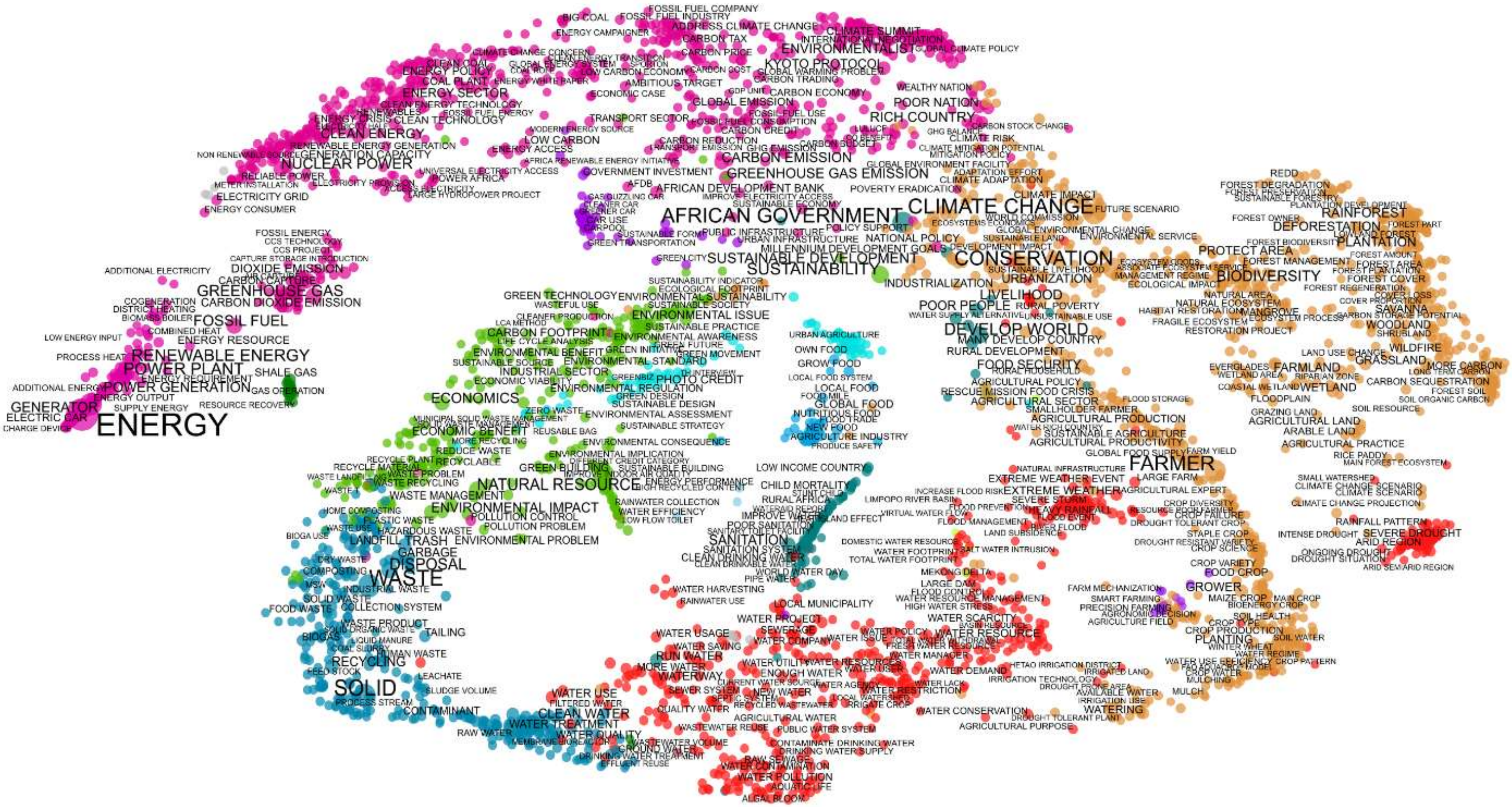

Figure 2.1.3. “Circular economy” domain full semantic map for 2014-2018

CE1: Reduce, reuse and recycle waste

This thrust is concerned with the development and deployment of performance improvements in "waste management". It is considered that development of efficient and effective waste management systems will make a significant contribution for strengthening the sustainable use of resources and thus reducing the environmental impact of waste. The analysis of the thrust through the iFORA system yielded two important action points. The first one is related to "waste reduction" and the second is "waste recycling and sustainable strategy". Issues around both action points are shown in the maps below (Figures 2.1.4. and 2.1.5).

Figure 2.1.4. "Waste reduction"

The first step in achieving breakthrough progress in CE is waste reduction. This covers the issues of garbage disposal, waste collection system, landfills and recycling solid waste. Points also arise regarding different types of waste such as food waste, industrial waste, human waste, organic waste, dry waste and hazardous waste, all of which need to be treated and recycled in a certain way. Energy generation through Biogas production appears to be a promising solution in terms of using waste.

Indeed, besides reducing waste and recycling and reusing them, it is also important to develop strategies for sustainable waste recycling.

Figure 2.1.5. "Waste recycling and sustainable strategy"

Figure 3 shows the whole set of issues for the development of sustainable waste recycling strategies. There are a number of areas, which require action under this category. These include strategies for increasing efficiency such as making buildings greener and making them more sustainable, as well as collecting rainwater and using low flow toilets for increased water efficiency. Better management of different waste categories such as solid, plastic and hazardous, through waste reduction and recycling are also mentioned under this thrust.

CE2: Ensuring sustainable water, energy and food (agriculture) security

iFORA analysis yielded six important areas under this thrust:

1. Water resources
2. 'Water management' and 'Flood risk and extreme weather'
3. Agricultural water use
4. 'Water security' and 'Food security'
5. Precision framing and farm efficiency

6. Agricultural policy

The water resources category represents issues around water usage, operation of water resources and their management by municipalities, water pollution and water treatment through techniques like membranes and filtration (Figure 2.1.6). Water harvesting and rainwater use also come as important areas under this cluster.

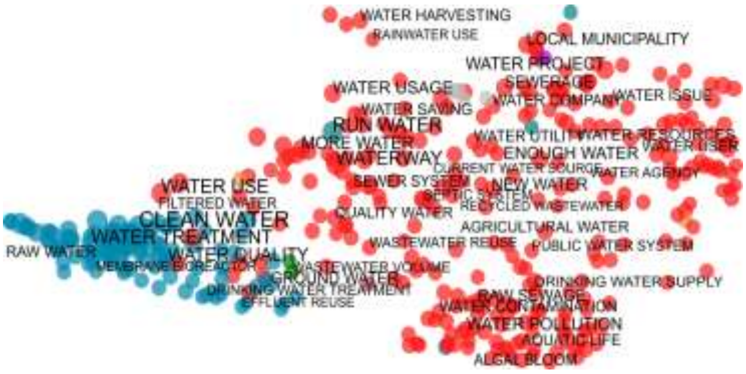

Figure 2.1.6. "Water resources"

Management of water resources is strongly linked to the weather conditions and flood (Figure 2.1.7). Extreme weather events, rainfalls and floods directly affect the availability of water. Unbalanced supply of water makes water management critical. There is a need to manage water when it is abundant as well as when it is not available. Therefore, besides introducing water flood management systems, there is a need to develop irrigation technologies for agricultural water use, as well as research and development on drought resistant plants.

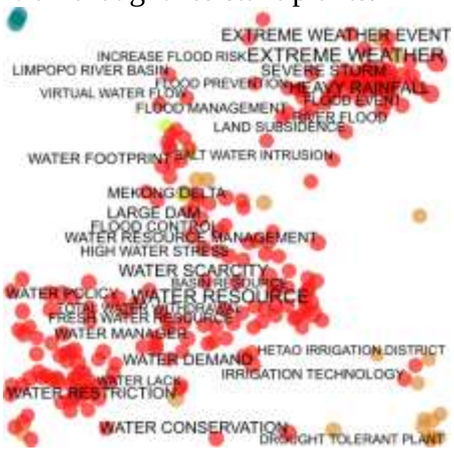

Figure 2.1.7. "Water management" and "flood risk and extreme weather"

Under water security thrusts a particular emphasis emerges on agricultural water use. Here a number of issues arise regarding planting, crop water and water use efficiency as well as development of irrigation technologies and efficient watering (Figure 2.1.8).

Figure 2.1.8. "Agricultural water use"

The water and food nexus emerge as an important issue. Under water security, the use of water for sanitation is highlighted with all other issues related that such as poor sanitation, sanitation systems, and sanitary toilet facilities. Water security in terms of accessing clean drinkable water is also mentioned in this category and linked further to sanitation and low water access in rural Africa and associated child mortality (Figure 2.1.9). Also in the right side of the figure, food security is mentioned in association to issues like growing food, local and urban food production systems as well as increasing nutrition and development of the agriculture industry with safe food production.

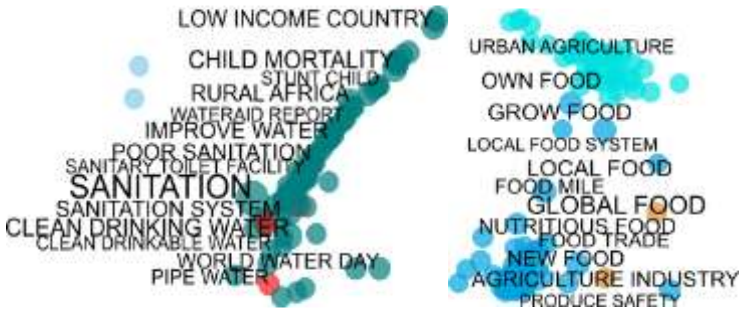

Figure 2.1.9. "Water security" (left) and "Food security" (right)

Among the technologies emerging with potential contributions to sustainable water, energy and food (agriculture) security is precision farming and other technologies for increasing farm efficiency. Smart farming and farm mechanization technologies also emerge as important areas for technological development. Increasing crop diversity, developing drought tolerant crops, and further research in crop type and production appear to be areas for improving farm efficiency. Besides crops, soil health is also addressed as an important topic in this category (Figure 2.1.10).

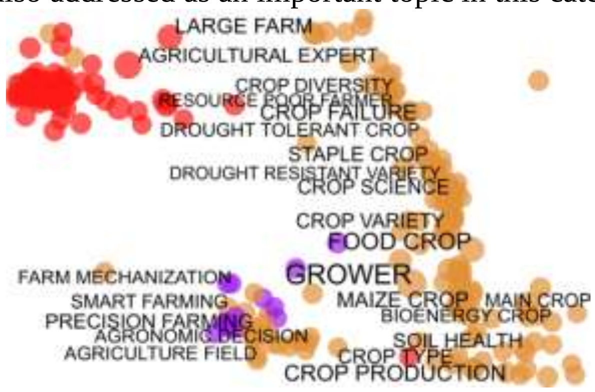

Figure 2.1.10. "Precision farming and farm efficiency"

Indeed, technologies are not solely enough for achieving sustainable water, energy and food security. There should be necessary agricultural policy in place for managing agricultural practices, providing food security, and a more balanced development. Industrialization and urbanization also emerge as important and associate areas to the agricultural policy topic (Figure 2.1.11).

Figure 2.1.11. "Agricultural policy"

CE3: Low-carbon and climate resilient economy

The third thrust under CE domain is concerned with the low-carbon and climate resilient economy. The iFORA system identified six important topics under this thrust, including:

1. Economic impact of sustainability
2. ‘Energy efficiency’ and ‘Renewable energy’
3. Low carbon and low emissions
4. Climate change
5. ‘Biodiversity conservation’ and ‘Land use’
6. African environmental policy

Economy plays a critical role for shifting to a low-carbon society and creating a more resilient economy under the effects of climate change. Reduction or carbon footprint, implementing greener initiatives and technologies, introduction of life cycle analysis and cleaner production are the key principles of this new economy. In order to achieve these, businesses need to be ‘greener’ with more sustainable design of products, processes and services, and zero waste. Reusable bag emerges as a specific issue in this category, as high amount of plastic bag use appears to be an important problem (Figure 2.1.12).

Figure 2.1.12. “Economic impact of sustainability”

Efficient energy use and increasing use of renewables are also detected as important topics under low carbon and climate resistant economy. Under energy efficiency, the reduction of fossil fuel use, and greenhouse gas emissions appear to be the key challenges for South Africa. Development of low energy input technologies, cogeneration, district heating and introduction of electric cars and necessary infrastructure for charging them appear to be important areas. Nuclear power is still on the agenda for South Africa together with coal power plants. The role and share of these in the energy mix should be determined towards the goals for higher energy efficiency and renewables (Figure 2.1.13).

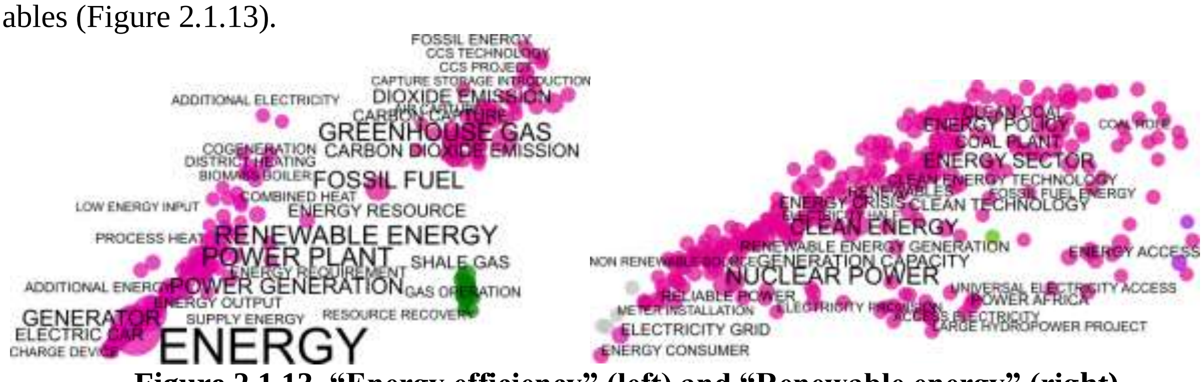

Figure 2.1.13. “Energy efficiency” (left) and “Renewable energy” (right)

In addition to achieving energy efficiency, low carbon and low emissions are important concerns. All the issues related to these topics are indicated in Figure 2.1.14 including setting targets, introducing necessary taxation systems, reducing fossil fuel use and associated emissions, and taking policy measures to mitigate climate change while increasing the wealth of the country.

Figure 2.1.14. "Low carbon and low emissions"

Climate change mitigation and environmental conservation also need to be considered not only at the local level, but also at the regional and global levels, as these are among the key grand challenges for humanity. Synchronizing national policies, setting up carbon stock exchange systems, developing global systems for climate adaptation are among the important issues under this topic (Figure 2.1.15).

Figure 2.1.15. "Climate change"

Besides global, policy, economic and low carbon aspects, the conservation of biodiversity and more sustainable use of land also emerge as important aspects leading to a low-carbon and climate resilient economy. Issues arising under these topics are indicated in Figure 2.1.16. Regarding biodiversity conservation, a number of issues around forests emerge, including deforestation, plantation, the protection of woodland and rainforest. Habitat restoration, protection and management are important for biodiversity conservation. Indeed, the challenge of land use is closely associated to biodiversity conservation. At the intersection of both topics is the crop use with issues related to agricultural land use practices, and management of arable land, wetland, grazing land, and farmland.

Figure 2.1.16. "Biodiversity conservation" (left) and "Land use" (right)

In order to achieve a low-carbon and climate resistant economy, there are policy actions to be taken at the continental level in Africa. African governments and institutions need to develop joint and national policies for sustainable development, greener economy and cities with better infrastructures. These need to comply with the international and global sustainable development goals (Figure 2.1.17).

Figure 2.1.17. "African environmental policy"

CE4: Smart connectivity and mobility in communities, supporting the circular economy

For the final thrust in this category regarding smart connectivity and mobility, the iFORA system detected topics clustering around greener transport systems. These include use of greener and cleaner cars as well as setting up necessary urban infrastructures to develop greener cities and livelihoods. This also includes introduction of electric cars and improving electricity access (Figure 2.1.18).

Figure 2.1.18. "Green transport"

Dynamics of circular economy thrusts

In this section, the dynamics of the circular economy thrusts are shown based on their frequency of occurrence in the documents indexed in the iFORA database. Among the thrusts CE2 (Ensuring sustainable water, energy and food security) appears to be the highest on the agenda (Figure 2.1.19). However, the progress with smart connectivity and mobility are extremely low (CE4). This thrust certainly needs more research for the achievement of the goals related to circular economy.

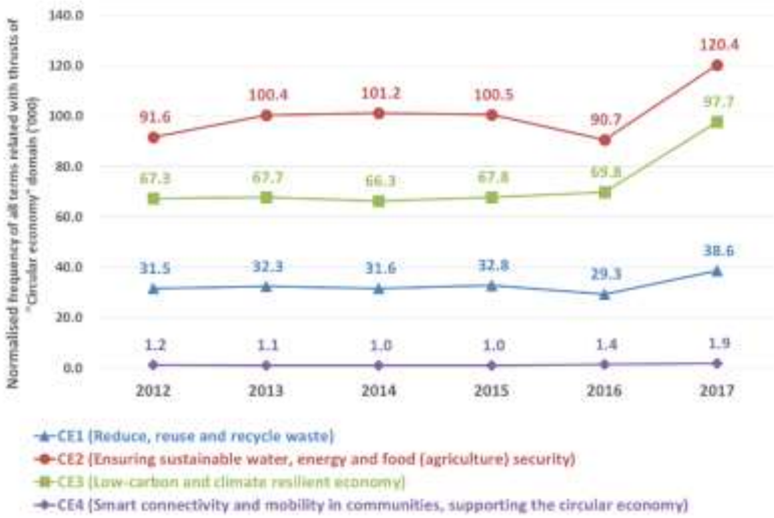

Figure 2.1.19. Normalized frequency of all terms related with thrusts of "Circular economy" domain ('000) in 2012 – 2017

Note: "Normalized frequency" for a specific thrust – is a total normalized number of mentions (in thousands) of all terms (that are shown on a semantic map) related with this specific thrust in documents indexed in IFORA for a given year.

Furthermore, Table 2.1.4 illustrates to what extent the Circular Economy domain thrusts address the challenges. The table indicates that most of the thrusts in the CE domain are associated to population growth (except CE4). CE4 appears to be linked with job creation though at a lesser extent compared to CE1 and CE2.

Table 2.1.4. Impacts of all thrusts of "Circular Economy" domain on challenges

Challenges	Circular Economy			
	CE1	CE2	CE3	CE4
Affordable Education	1.0	0.0	0.0	0.0
Affordable Energy	3.0	15.5	4.2	0.0
Affordable Food	1.0	3.0	2.3	0.0
Carbon Emission Reduction	0.0	10.0	15.9	0.0
Clean Water Access	1.0	2.0	1.0	0.0
Crime Prevention	1.0	2.0	1.0	0.0
Crime Reduction	0.0	0.0	0.0	0.0
Economy Growth	0.0	4.0	1.3	0.0
Employment Growth	0.0	2.8	2.4	0.0
Export Growth	0.0	9.0	3.2	0.0
High Living Standard	2.0	1.0	1.0	0.0
High Quality Health Care Service	0.0	0.0	0.0	0.0
Income Growth	1.0	9.7	4.4	0.0
Job Creation	16.5	19.1	8.5	2.0
Low Greenhouse Gas Emission	2.3	3.3	2.0	0.0
Low Mortality	0.0	0.0	1.3	0.0
Population Growth	7.0	25.6	47.9	0.0
Poverty Alleviation	9.0	2.0	4.8	0.0
Reduce Water Demand	0.0	3.0	1.0	0.0
Renewable Energy Growth	0.0	3.0	2.0	0.0
Rural Community	7.3	14.4	3.9	0.0
Secure Water Supply	1.0	1.0	1.0	0.0
Skill Improvement	0.0	0.0	0.0	0.0
Universal Broadband Access	0.0	0.0	0.0	0.0

Notes: 1. Value in each specific cell of this table is a normalised number of co-occurrences of all terms (that are shown on a semantic map) related with a specific thrust (e.g. Thrust CE1) and a specific challenge (e.g. "Low Mortality") in documents indexed in iFORA database for 2012 – 2017. This value is treated as an impact of a specific thrust onto a specific challenge. 2. Cells are colored by bars as follows: within a column of a specific thrust the biggest green bar means the challenge for which this specific thrust has the highest impact.

2.2 HIGH-TECH INDUSTRY DOMAIN

Overall description of the domain

Industry 4.0 is expected to transform products, processes and services in a revolutionary way through the application of smart and connected systems. Following these lines, the High-tech Industry domain focuses on the implementation of advanced manufacturing in South Africa by utilizing the technologies like Robotics, Artificial Intelligence (AI), Internet of Things (IoT), and Additive manufacturing among the others. Progress towards the High-tech Industry will transform old industries and will give rise to the emergence of new industries. Industrial actors including SMEs will need to equip themselves with necessary skills, infrastructure and capacity for a successful transition.

Overview of research potential of South Africa in "High-tech Industry" domain

Figure 2.2.1 shows that there is a fast growing scientific emphasis on the High-tech Industry domain in South Africa. The number of publications has been growing steadily as well as the share of South Africa in the global scientific output in this domain especially in last 3 years.

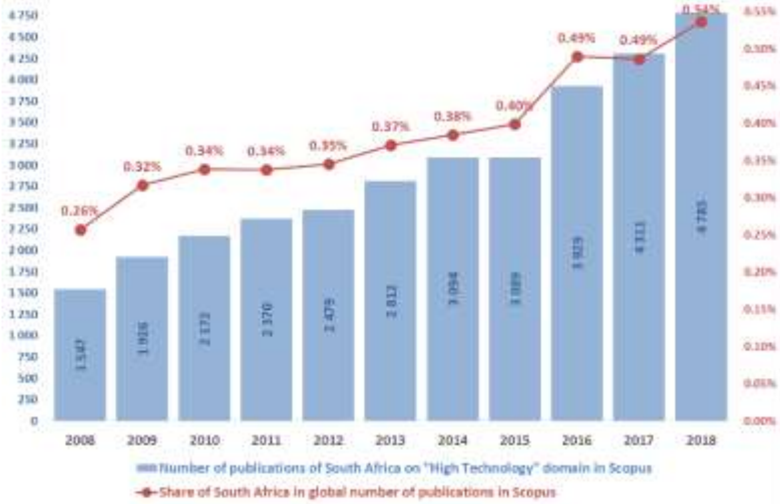

Figure 2.2.1. Dynamics of publications of South Africa in "High-tech Industry" domain in Scopus in 2008 – 2018

Note: all types of documents except of technical documents, indexed in Scopus are included in the analysis.

Figure 2.2.2 shows the leading countries in the high-tech industry domain. South Africa's scientific position in High-tech Industry is poor with the 41st place in the world. Top five key collaborators of the country in this domain are the US, the UK, India, Germany and China. Other African countries rank also very low both in scientific capacity and level of collaboration (Table 2.2.1).

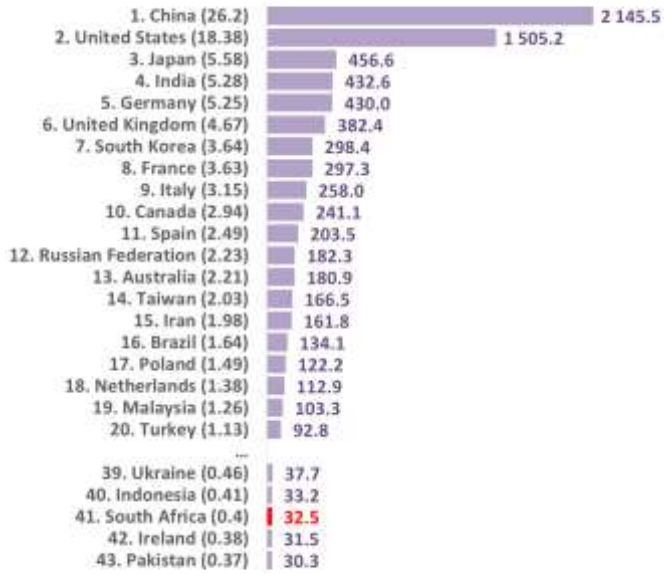

Figure 2.2.2. Leading countries by number of publications in "High-tech Industry" domain in Scopus for 2008 – 2018

Note: 1. All types of documents except of technical documents, indexed in Scopus are included in the analysis. 2. Share of a country in global number of publications is shown in parenthesis.

Table 2.2.1. Key partner countries of South Africa in internationally collaborated publications in "High-tech Industry" domain in Scopus for 2008 - 2018

Country	Number of Joint papers with South Africa	Share of a country in all ICPs of South Africa
United States	2665	19.10%
United Kingdom	1982	14.20%
India	1724	12.36%
Germany	1451	10.40%
China	1330	9.53%
France	1246	8.93%
Australia	1071	7.68%
Nigeria	932	6.68%
Canada	893	6.40%
Netherlands	879	6.30%
Italy	717	5.14%
Sweden	681	4.88%
Spain	611	4.38%
Switzerland	559	4.01%
Turkey	505	3.62%
Japan	503	3.60%
Saudi Arabia	503	3.60%
Brazil	467	3.35%
Poland	435	3.12%
Iran	421	3.02%
Russian Federation	414	2.97%
Norway	403	2.89%
Denmark	399	2.86%
Belgium	395	2.83%
Austria	368	2.64%
Czech Republic	341	2.44%
Greece	314	2.25%
Portugal	301	2.16%
Chile	300	2.15%
Taiwan	296	2.12%
Hungary	290	2.08%

Romania	290	2.08%
Israel	284	2.04%
Malaysia	282	2.02%
Argentina	278	1.99%
Slovakia	277	1.99%
South Korea	262	1.88%
Serbia	234	1.68%
Armenia	226	1.62%
Morocco	226	1.62%
Finland	225	1.61%
Slovenia	224	1.61%
Colombia	220	1.58%
Hong Kong	213	1.53%
Belarus	205	1.47%
Azerbaijan	204	1.46%
Kenya	201	1.44%
Zimbabwe	199	1.43%
New Zealand	195	1.40%
Pakistan	194	1.39%
Georgia	190	1.36%
Botswana	179	1.28%
Qatar	156	1.12%
Egypt	152	1.09%
Mexico	143	1.02%
Algeria	141	1.01%
Namibia	131	0.94%
Ghana	103	0.74%
Ethiopia	100	0.72%
Thailand	100	0.72%

Table 2.2.2 shows the leading organizations in South Africa publishing in the domain of High-tech Industry with the total number of publications they produced in the last 10 years, as well as the percentage of their contribution in the total scientific output.

Table 2.2.2. Leading organizations of South Africa by number of publications in "High-tech Industry" domain in Scopus for 2008 – 2018

Affiliation	**Number of publications**	**Share in all South Africa publications**
Universiteit van Pretoria	4036	12.41%
University of Cape Town	3925	12.07%
Universiteit Stellenbosch	3591	11.04%
University of KwaZulu-Natal	3493	10.74%
University of Johannesburg	3436	10.57%
University of Witwatersrand	3166	9.74%
The Council for Scientific and Industrial Research	2226	6.85%
Tshwane University of Technology	1756	5.40%
North-West University	1293	3.98%
University of South Africa	1192	3.67%
University of the Free State	1063	3.27%
Rhodes University	872	2.68%
Nelson Mandela Metropolitan University	717	2.21%
University of the Western Cape	702	2.16%
Cape Peninsula University of Technology	685	2.11%
Durban University of Technology	609	1.87%
Vaal University of Technology	380	1.17%
University of Fort Hare	333	1.02%
University of Witwatersrand, School of Chemical and Metallurgical Engineering	299	0.92%

Central University of Technology, Free State	277	0.85%
South African Medical Research Council	275	0.85%
University of Zululand	249	0.77%
University of Venda for Science and Technology	222	0.68%
Meraka Institute	213	0.66%
National Research Foundation	210	0.65%
University of KwaZulu-Natal School of Chemical Engineering	203	0.62%
Mintek	201	0.62%
Sasol Technology Pty Ltd	194	0.60%
Agricultural Research Council, Pretoria	184	0.57%
University of Cape Town, Faculty of Health Sciences	160	0.49%
University of Limpopo	160	0.49%
Eskom	152	0.47%
Mangosuthu University of Technology	122	0.38%
National Health Laboratory Services	122	0.38%
NECSA	106	0.33%
Walter Sisulu University	105	0.32%

Note: 1. All types of documents except of technical documents, indexed in Scopus are included in the analysis. 2. Organization names are presented as they are spelled in Scopus database.

Semantic analysis of “High-tech Industry” domain

This section describes the “High Technology Industry” STI domain and its thrusts based on the results produced by the iFORA system. First, the full domain is described with a domain map including all of the topics covered. Then each of the thrusts is described by the emerging topics identified by iFORA. The next section presents topic clusters under each thrust with more detailed network maps with descriptions of emerging issues under them. Figure 2.3.3 shows the entire domain of the High-tech Industry (HT) with its clusters and interrelations to each other. A detailed analysis of Figure 2.2.3 provides an overview of CE thrusts and a number of existing and emerging topics for consideration under each of them. These are presented in Table 2.2.3. In the following section network maps are given to illustrate these maps and further issues emerging under each of them.

Table 2.2.3. “High-tech Industry (HT)” thrusts and topics

HT Thrusts		Topics emerging under each thrust
HT1: Enabling small business to adopt high tech		“IT adoption” and “High tech start-ups” (Fig. 2.2.4)
		“Skills development” (Fig. 2.2.5)
HT2: New thinking for new industries		“Artificial intelligence”; “Virtual reality” and “Gaming” (Fig. 2.2.6)
		“Cryptocurrency”; and “Biometry” (Fig. 2.2.7)
		“New technologies”; “Aerospace”; “Biotech-nology” (Fig. 2.2.8)
HT3: New thinking for old industries		“Economy” and “Productivity” (Fig. 2.2.9)
		“Clean transport” and “Energy efficiency” (Fig. 2.2.10)
		“Sustainability” and “Environmental policy” (Fig. 2.2.11)
		“Climate change” and “Chemistry” (Fig. 2.2.12)

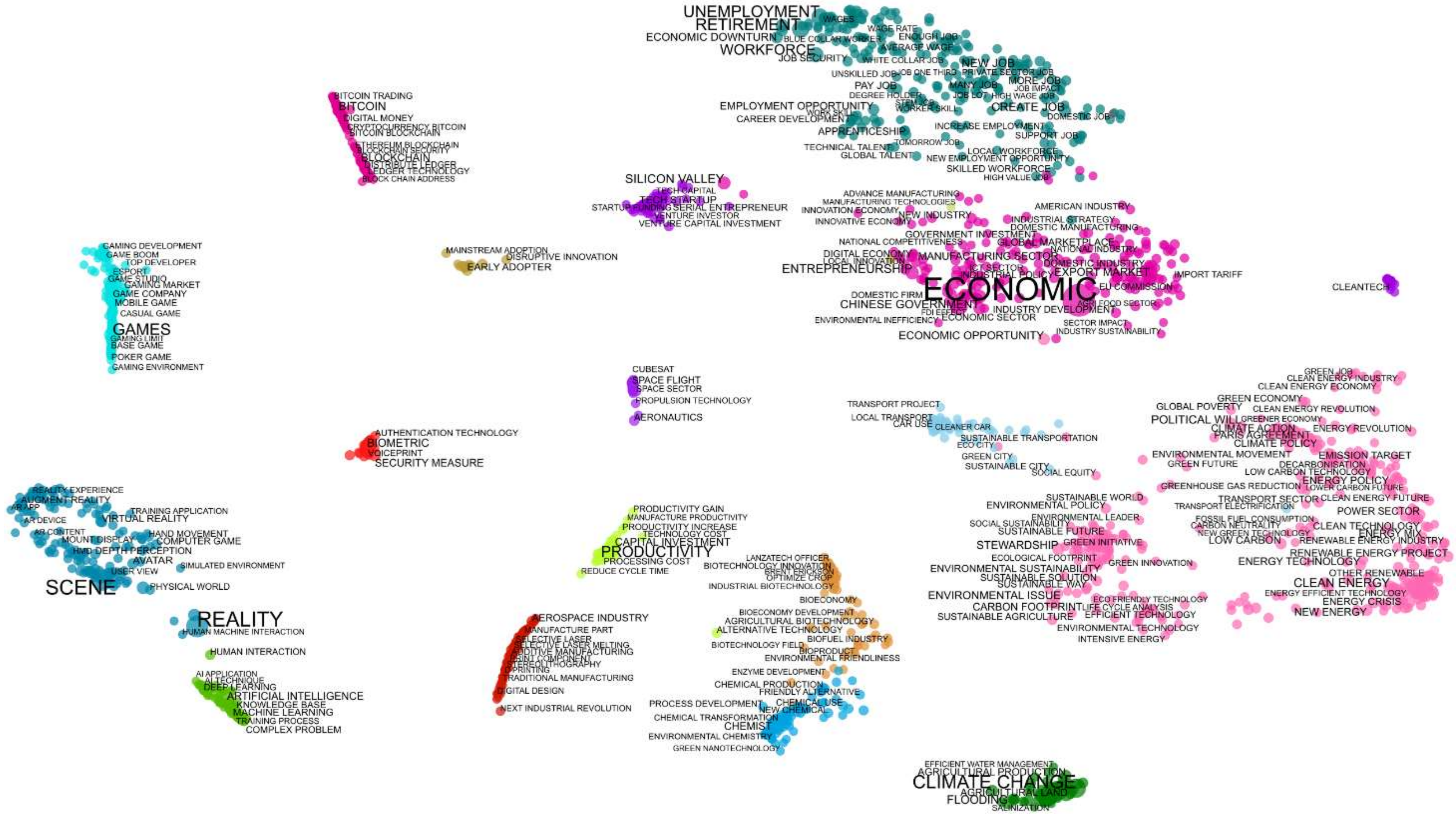

Figure 2.2.3. "High-tech industry" domain full semantic map for 2014-2018

“High-tech Industry” Thrusts

HT1: Enabling small business to adopt high tech

The iFORA system revealed two topics for the adoption of high technology in small businesses. The first one is related to mainstream IT adoption, which is necessary for all small businesses. Early adopters will gain competitive advantage to the others. Besides making existing small businesses more IT based, it is undoubtedly crucial to have high tech start-ups for a more STI based economy and society. Entrepreneurship and venture capital investment are two important drivers for setting up high tech small businesses (Figure 2.2.4).

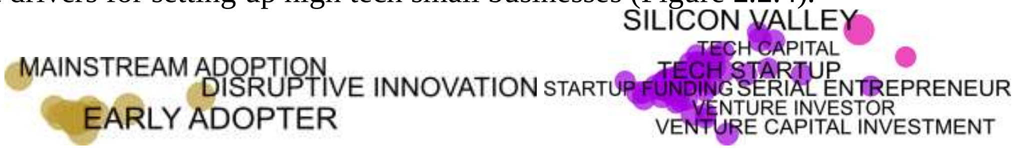

Figure 2.2.4. “IT adoption” (left) and “High tech start-ups” (right)

IT adoption by small businesses is not only about a technological issue. Skills development for high tech adoption is also an important aspect. Figure 2.2.5 demonstrates the issues related to skills development including job creation and markets, wage levels, skill requirements as well as job security and further career development. These factors combined with technical skills will have impacts on widespread IT adoption in small businesses.

Figure 2.2.5. “Skills development”

HT2: New thinking for new industries

High-tech Industry will certainly have impacts on new and old industries. Therefore, there is a need to shift in the thinking for new industries. The iFORA system identified three technological topics, which can be the drives for a breakthrough development of new industries, including Artificial Intelligence (AI), Virtual Reality (VR) and gaming. AI appears to be important for all sorts of industries and businesses. Necessary technologies and skills need to be developed for the implementation of AI systems, such as machine learning and deep learning systems. In conjunction with AI, VR systems provide larger application areas for new industries. Particularly human-machine interaction systems will transform the way products, production processes, and provision of services. Gaming has also emerged as a new and growing market, not only for entertainment, but also for simulation and decision-making (Figure 2.2.6).

Figure 2.2.6. “Artificial intelligence” (left); “Virtual reality” (center); “Gaming” (right)

The new high technology business and industrial systems will also need to transform in terms of new economic and security systems. Cryptocurrencies are revolutionary in terms of creating more stable, secure and speedy financial transactions. Bitcoin is being experimented for several years now, and is expected to be more widespread along with all other cryptocurrencies being continuously introduced into the financial market, such as Ethereum and others. In association of cryptocurrencies, the Blockchain concept is also developing fast. Actually, cryptocurrency is only one application for Blockchain as a distributed ledger system. It has potentials to transform all sorts of industries and businesses such as energy and agriculture, which are among the key drivers of South African social and economic systems. In parallel to the emergence of digital financial systems, increasing security issues need to be addressed. These include the development of biometric systems and authentication technologies with increasing security measures (Figure 2.2.7).

Figure 2.2.7. "Cryptocurrency" (left); "Biometry" (center); "Cleantech" (right)

Among the technologies for high-tech development are additive manufacturing, 3D printing and digital design. Aerospace and biotechnology emerge as two application areas for high tech industries in South Africa. Particularly space technologies are considered to benefit from developments in this domain. Regarding biotechnology, the main areas for development are transformation into bioeconomy, development of industrial biotechnology, and biofuel industry. Without any doubt, environmental, social and ethical concerns need to be addressed regarding the implementation of biotechnologies (Figure 2.2.8).

Figure 2.2.8. "New technologies" (left); "Aerospace" (center); "Biotechnology" (right)

HT3: New thinking for old industries

Besides setting up new industries with new technologies, it is also important to upgrade the old industries, which are the main backbones of development. Economic and productivity improvements are needed to make sure that old industries remain competitive. These include the development of the manufacturing industry at the national and domestic levels, supporting innovation, upgrading technologies and expanding export markets. Regarding productivity, technological and capital investments, as well as reducing cycle times and processing costs appear to be areas for action in all industries (Figure 2.2.9).

Figure 2.2.9. "Economy" (left) and "Productivity" (right)

Transport is one of the old, but rapidly developing sectors of the South African economy. Actions for the improvements of the transport systems begin with making the industry cleaner and more sustainable. Sustainable transport systems need to be developed with a balanced use of personal cars and local transport. Vehicles on the road should be clean and energy efficient. In order to increase energy efficiency, there is a need to introduce cleaner technologies for all sectors, including energy. Renewable and low carbon energy technologies should be developed, fossil fuel use should be reduced and power sector should be upgraded (Figure 2.2.10).

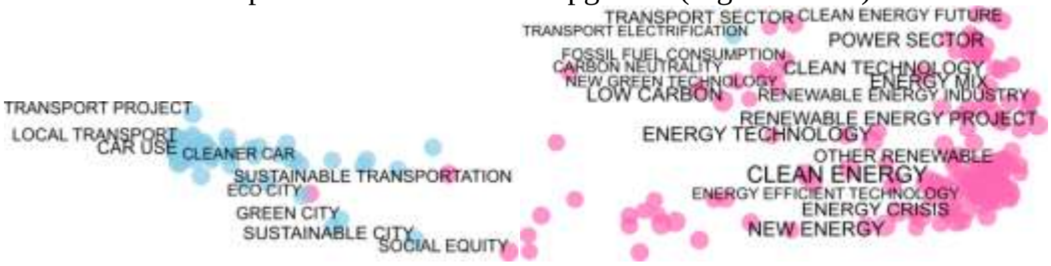

Figure 2.2.10. "Clean transport" (left) and "Energy efficiency" (right)

In line with energy efficiency, overall improvements in sustainability are needed. Green innovation and initiatives should be in place with reduced ecological footprint and decarbonization. Besides environmental sustainability, social sustainability is also important for a more sustainable future. This requires political will, leadership and stewardship with environmental policies in place (Figure 2.2.11).

Figure 2.2.11. "Sustainability" (left) and "Environmental policy" (right)

Old industries like agriculture and chemistry should also be considered with new thinking. Climate change effects like flooding should be observed with mitigation policies and actions, such as through more efficient water management and agricultural production systems. Similarly, the chemistry industry needs to be development to make it greener and more environmentally friendly with advanced processes and production systems (Figure 10).

Figure 2.2.12. "Climate change" (left) and "Chemistry" (right) fragments

Dynamics of "High-tech industry" domain thrusts

In this section, the dynamics of "high-tech industry" thrusts are shown based on their frequency of occurrence in the documents indexed in the iFORA database. Among the thrusts HT3 (New thinking for new industries) appears to the highest on the agenda with an increasing growth rate (Figure 2.2.13). This is certainly promising as the research trends support the agenda of the 4th industrial revolution. However, research on small businesses to adopt high-tech is relatively low without a significant progress across years.

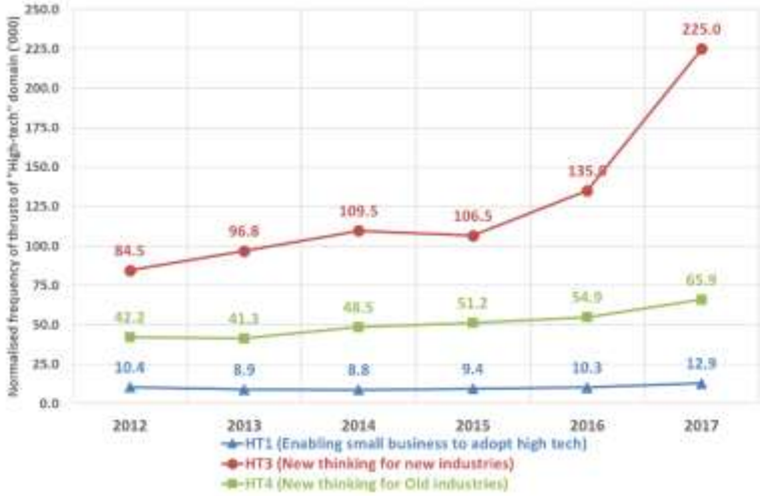

Figure 2.2.13. Normalised frequency of all terms related with thrusts of "High-tech industry" domain ('000) in 2012 – 2017

Notes. 1. "Normalized frequency" for a specific thrust is a total normalized number of mentions (in thousands) of all terms (that are shown on a semantic map) related with this specific thrust in documents indexed in IFORA for a given year. 2. The HT2 thrust has been moved to "Education" domain and became ED1 "Skills for the 4th Industrial Revolution" thrust.

Furthermore, Table 2.2.4 illustrates to what extent the "High-tech industry" domain thrusts address the challenges. HT4 is extremely linked to job creation. HT3 has also a strong linkage with the same challenge along with population growth. HT1 is the only thrust, which appears to be linked with income growth.

Table 2.2.4. Impacts of all thrusts of "High-tech industry" domain on challenges

Challenges	High-tech		
	HT1	HT3	HT4
Affordable Education	0.0	5.0	1.5
Affordable Energy	0.0	0.0	9.0
Affordable Food	0.0	0.0	0.0
Carbon Emission Reduction	0.0	1.5	2.0
Clean Water Access	0.0	0.0	1.0
Crime Prevention	0.0	1.0	1.0
Crime Reduction	0.0	2.0	0.0
Economy Growth	0.0	1.0	1.0
Employment Growth	0.0	3.0	23.0
Export Growth	0.0	1.0	3.0
High Living Standard	0.0	5.5	4.0
High Quality Health Care Service	0.0	0.0	0.0
Income Growth	1.0	1.3	6.0
Job Creation	0.0	36.6	133.1
Low Greenhouse Gas Emission	0.0	0.0	2.0
Low Mortality	0.0	0.0	0.0
Population Growth	0.0	53.8	24.0
Poverty Alleviation	0.0	2.0	11.8
Reduce Water Demand	0.0	0.0	1.0
Renewable Energy Growth	0.0	1.0	0.0
Rural Community	0.0	13.0	26.6
Secure Water Supply	0.0	0.0	0.0
Skill Improvement	0.0	0.0	0.0
Universal Broadband Access	0.0	1.0	1.5

Notes: 1. Value in each specific cell of this table is a normalised number of co-occurrences of all terms (that are shown on a semantic map) related with a specific thrust (e.g. Thrust HT1) and a specific challenge (e.g. "Low Mortality") in documents indexed in iFORA database for 2012 – 2017. This value is treated as an impact of a specific thrust onto a specific challenge. 2. Cells are colored by bars as follows: within a column of a specific thrust the biggest green bar means the challenge for which this specific thrust has the highest impact.

2.3. NUTRITION SECURITY FOR A HEALTHY POPULATION (NUTRITION) DOMAIN

Overall description of the domain

Good nutrition is essential for a health population. There are currently serious issues around malnutrition and stunting in South Africa. Particularly women and children are in a disadvantaged position. There are economic (low income, unemployment etc.) and environmental (climate change) drivers of the health and nutrition related problems. Technologies like precision farming are considered to create opportunities for advancing farming in South Africa and making efficient use of arable land by reducing pressures due to climate change, waste and pollution. Hence, the nutrition security domain focuses on zero impact agriculture as well as the application of advanced technologies like biotechnologies, precision agriculture as well as big data.

Overview of research potential of South Africa in "Nutrition" domain

Figure 2.3.1 shows that there is a growing scientific emphasis on the Nutrition security domain in South Africa. The number of publications has growing gradually as well as the share of South Africa in the global scientific output in this domain.

Figure 2.3.1. Dynamics of publications of South Africa in "Nutrition" domain in Scopus in 2008 – 2018

Note: all types of documents except of technical documents, indexed in Scopus are included in the analysis.

Figure 2.3.2 shows the leading countries in the Nutrition security domain. As the most advanced country in Africa, South Africa has the 25th position in the world in this domain.

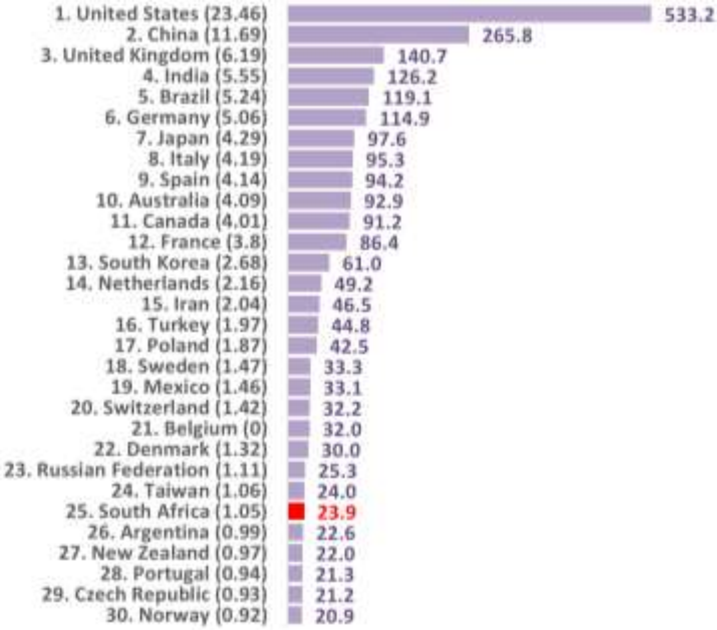

Figure 2.3.2. Leading countries by number of publications (‘000) in “Nutrition” domain in Scopus for 2008 – 2018

Note: 1. All types of documents except of technical documents, indexed in Scopus are included in the analysis. 2. Share of a country in global number of publications is shown in parenthesis.

Among those countries, the key partners of South Africa in the Nutrition security domain are the United States, the United Kingdom, Australia, Germany and France. African countries like Nigeria and Zimbabwe are among the top collaborators in the Africa continent (Table 2.3.1).
/*

Table 2.3.1. Key partner countries of South Africa in internationally collaborated publications in “Nutrition” domain in Scopus for 2008 - 2018

Country	Number of Joint papers with South Africa	Share of a country in all ICPs of South Africa
United States	3357	27.77%
United Kingdom	2244	18.56%
Australia	1457	12.05%
Germany	1106	9.15%
France	1060	8.77%
Netherlands	938	7.76%
Canada	829	6.86%
Nigeria	674	5.58%
Belgium	644	5.33%
Switzerland	594	4.91%
India	563	4.66%
Kenya	563	4.66%
Spain	556	4.60%
Italy	533	4.41%
China	532	4.40%
Sweden	501	4.14%
Brazil	457	3.78%
Zimbabwe	416	3.44%
Norway	383	3.17%
Portugal	373	3.09%
Denmark	356	2.95%
New Zealand	305	2.52%
Cameroon	293	2.42%
Japan	293	2.42%
Russian Federation	268	2.22%

Ethiopia	264	2.18%
Tanzania	262	2.17%
Czech Republic	239	1.98%
Argentina	237	1.96%
Finland	236	1.95%
Ghana	226	1.87%
Uganda	211	1.75%

Note: 1. All types of documents except of technical documents, indexed in Scopus are included in the analysis.

Table 2.3.2 shows the leading organizations in South Africa publishing in the domain of Nutrition security with the total number of publications they produced in the last 10 years. Top four universities publish more than half of research in this domain.

Table 2.3.2. Leading organizations of South Africa by number of publications in "Nutrition" domain in Scopus for 2008 – 2018

Affiliation	Number of publications	Share in all South Africa publications
Universiteit van Pretoria	3969	16.59%
Universiteit Stellenbosch	3422	14.31%
University of KwaZulu-Natal	3167	13.24%
University of Cape Town	2968	12.41%
University of Witwatersrand	1679	7.02%
North-West University	1262	5.28%
Rhodes University	1202	5.03%
University of the Free State	1115	4.66%
Agricultural Research Council, Pretoria	1108	4.63%
South African Medical Research Council	1038	4.34%
University of Johannesburg	816	3.41%
South African National Biodiversity Institute	693	2.90%
University of the Western Cape	677	2.83%
University of Fort Hare	605	2.53%
Nelson Mandela Metropolitan University	570	2.38%
University of Limpopo	516	2.16%
Tshwane University of Technology	503	2.10%
The Council for Scientific and Industrial Research	396	1.66%
South African Institute for Aquatic Biodiversity	390	1.63%
Cape Peninsula University of Technology	351	1.47%
University of South Africa	347	1.45%
University of KwaZulu-Natal, Pietermaritzburg Campus	330	1.38%
Plant Protection Research Institute, Pretoria	328	1.37%
ARC Infruitec-Nietvoorbij	321	1.34%
University of Venda for Science and Technology	317	1.33%
National Health Laboratory Services	262	1.10%
Onderstepoort Veterinary Institute	243	1.02%
Groote Schuur Hospital	232	0.97%
South African Sugarcane Research Institute	220	0.92%
Compton Herbarium	210	0.88%
Human Sciences Research Council of South Africa	195	0.82%
Citrus Research International Pty Ltd, South Africa	192	0.80%
University of Zululand	174	0.73%
Marine and Coastal Management	174	0.73%
University of Cape Town, Faculty of Health Sciences	169	0.71%
National Institute for Communicable Diseases	163	0.68%
Durban University of Technology	146	0.61%
Walter Sisulu University	145	0.61%
The Nelson R. Mandela Medical School	141	0.59%
Sefako Makgatho Health Sciences University SMU	131	0.55%
South African Environmental Observation Network	121	0.51%

Tygerberg Hospital	102	0.43%

Note: 1. All types of documents except of technical documents, indexed in Scopus are included in the analysis. 2. Organization names are presented as they are spelled in Scopus database.

Semantic analysis of "Nutrition" domain

This section describes the "Nutrition Security for a Healthy Population" STI domain and its thrusts based on the results produced by the iFORA system. First, the full domain is described with a domain map including all of the topics covered. Then each of the thrusts is described by the emerging topics identified by iFORA. The next section presents topic clusters under each thrust with more detailed network maps with descriptions of emerging issues under them. Figure 2.3.3 shows the entire domain of the Nutrition Security for a Healthy Population (NU) with its clusters and interrelations to each other. A detailed analysis of Figure 2.3.3 provides an overview of NU thrusts and a number of existing and emerging topics for consideration under each of them. These are presented in Table 2.3.3. In the following section network maps are given to illustrate these maps and further issues emerging under each of them.

Table 2.3.3. "Nutrition Security for a Healthy Population" thrusts and topics

Nutrition Security Thrusts	Topics emerging under each thrust
NU1: Zero Impact Agriculture	"Waste problems" and "Agricultural water management" (Fig. 2.3.4)
	"Organic and ecological farming" and "Food labeling" (Fig. 2.3.5)
	"Entrepreneurship" and "Small agriculture" (Fig. 2.3.6)
	"Agricultural policy" and "Sustainability" (Fig. 2.3.7)
NU2: Use and acceptance of modern biotechnology	"Crop GMO" and "Plant genomics" (Fig. 2.3.8)
	"Plant gene engineering" and "Pest resistant crops" (Fig. 2.3.9)
	"Crop yield management" and "Crop science" (Fig. 2.3.10)
NU3: Personalized information for healthy nutrition for all	"Malnutrition" and "Nutrition diseases" (Fig. 2.3.11)
	"Eating behavior" and "Dieting problems" (Fig. 2.3.12)
	"Sugar food" and "Junk food" (Fig. 2.3.13)
	"Healthy eating behavior" and "Health food policy" (Fig. 2.3.14)
NU4: Precision & big data in agri-businesses	"Precision agriculture" (Fig. 2.3.15)

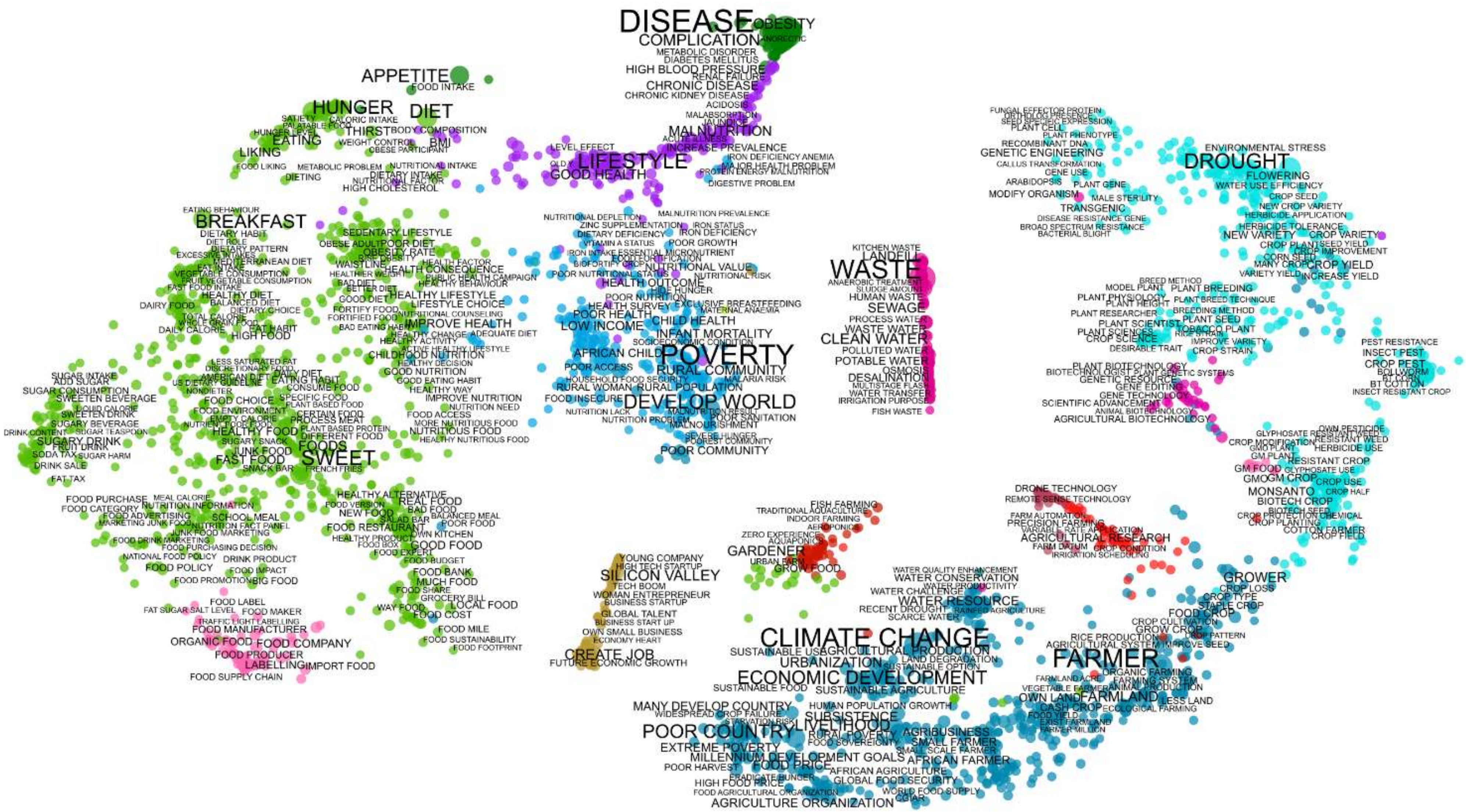

Figure 2.3.3. “Nutrition Security for a Healthy Population” domain full semantic map for 2014-2018

“Nutrition Security for a Healthy Population” Thrusts

NU1: Zero Impact Agriculture

One of key steps for achieving zero impact agriculture is reducing waste. The iFORA analysis revealed that the biggest problem related to waste in Agriculture concerns water related issues. Besides polluted and wastewater, sewage and treatment, other types of waste such as food and kitchen waste and fish waste emerge as related issues. In order to reduce water waste and make use of limited water resources efficiently, managing agricultural water emerges as an important topic. There is a need to increase water productivity and develop water quality (Figure 2.3.4).

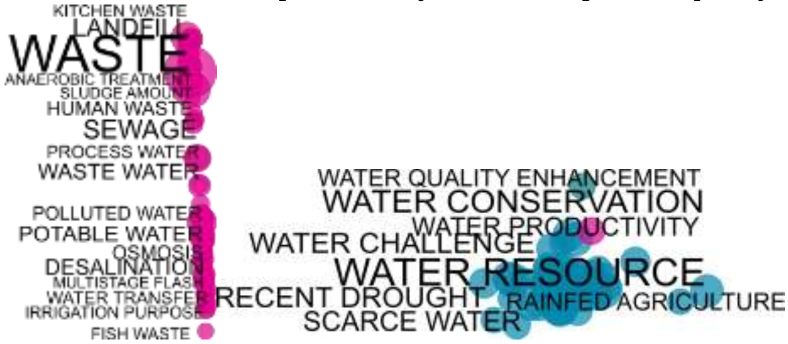

Figure 2.3.4. “Waste problems” (left) and “Agricultural water management” (right)

Zero impact agriculture and providing healthy nutrition population require organic and ecological farming and food labeling in order to protect consumer health in terms of food safety and nutrition. Organic and ecological farming covers a range of issues from the quality and quantity of the farmland and crops to cultivation and eventual food yield. Food labeling is an important and direct way of communicating information about food and its ingredients to the consumer. Food labels include any written or pictorial information attached to a food package or a container. Labels include information on ingredients, quality and nutritional value of the food. Especially fat and sugar information and salt level of food are frequently looked at besides the other nutritional values. Food manufacturers/producers play an important role in indicating food labels accurately and in a visible and accessible way to consumers (Figure 2.3.5).

Figure 2.3.5. “Organic and ecological farming” (left) and “Food labeling” (right)

Entrepreneurship and small agriculture emerge as two other issues under zero impact agriculture thrust. Entrepreneurship in this regard is concerned with start-ups and small businesses, which are crucial in employment and future economic growth in the country. Small agriculture also provides food for a large amount of population, especially for the ones, which have no economic means of accessing food markets and supermarkets. Besides these, small farming and growing own food is becoming popular in urban and peri-urban areas through urban farming and indoor farming, where food is produced nearby where it is consumed (Figure 2.3.6).

Figure 2.3.6. "Entrepreneurship" (left) and "Small agriculture" (right)

Zero impact agriculture and moving towards a society with healthy nutrition also require strong agricultural policies and measures for sustainability. There are a number of issues on the agenda of the agricultural policy, ranging from macro to micro level issues. These include policies for meeting sustainable/millennium development goals, world food supply and food security at the global level. Developing the state of the African farmers, dealing with extreme poverty and high food prices are also on the agenda. Besides providing food for population, policy issues should also address the sustainability concerns, which cover achieving economic development and urbanization while mitigating the impacts of climate change, and making agriculture and food more sustainable (Figure 2.3.7).

Figure 2.3.7. "Agricultural policy" (left) and "Sustainability" (right)

NU2: Use and acceptance of modern biotechnology

Evolving and emerging technologies provide plenty of opportunities for tackling grand challenges. Similarly biotechnologies are increasingly used for the agriculture and food sector. Genetically modified crops have been considered as a way to produce resistant and nutritious crops through genetic modification. Although this appears beneficial, in principle, a number of concerns have been raised about the health and environmental impacts of GMOs. Issues around the GMO crops are related to crop modification, pesticide use and resistant weeds among the others. Regarding plant genomics, the key issues are clustered around gene technology, plant and animal biotechnology as well as gene editing, which are the scientific fields with rapid technological development in the world and in South Africa (Figure 2.3.8).

Figure 2.3.8. "Crop GMO" (left) and "Plant genomics" (right)

Among the technologies used for plant gene engineering in South Africa the iFORA analysis revealed several application areas in plant cells, phenotypes, callus transformation, transgenic and bacterial blights. Among the key aims of plant gene engineering are developing pest resistant crops against insects and other pests (Figure 2.3.9).

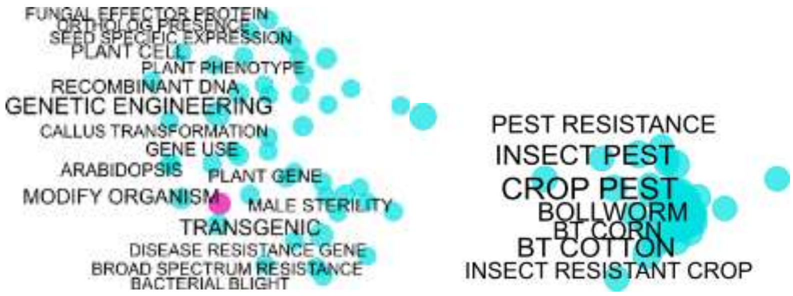

Figure 2.3.9. "Plant gene engineering" (left) and "Pest resistant crops" (right)

Modern technologies in agriculture are also used to improve crop yield to increase crop variety, improve herbicide tolerance as well as providing water use efficiency with lower environmental stress. Crop science related to breeding also appears as an important area of research in South Africa (Figure 2.3.10).

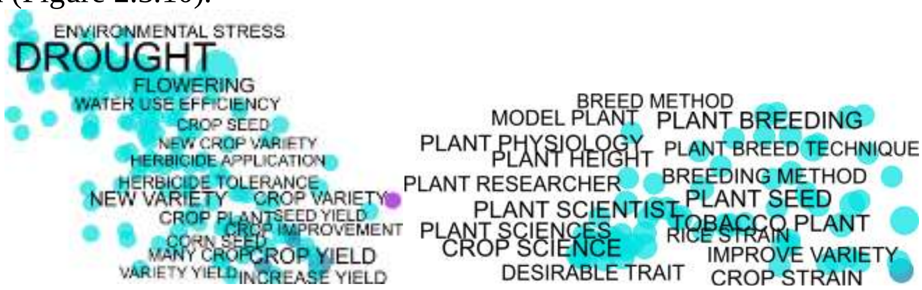

Figure 2.3.10. "Crop yield management" (left) and "Crop science" (right)

NU3: Personalized information for healthy nutrition for all

Healthy nutrition for all is a challenge for multiple aspects including, agriculture, food, health, economic condition, environment, lifestyle as well as urban-rural issues. Malnutrition is a key problem in many developing countries in the world as well as in South Africa. Among the main drivers for malnutrition are low income and poverty, poor access to food, food insecurity and resultant poor health, infant mortality and other dietary deficiency related to the lack of iron, zinc and other nutrients. These give rise to a number of diseases and major health problems such as high blood pressure, metabolic disorders, diabetes, obesity, anemia, kidney disorders among the others, which are commonly seen in Africa (Figure 2.3.11).

Figure 2.3.11. "Malnutrition" (left) and "Nutrition diseases" (right)

Eating behaviors are closely related to dietary problems. In today's world, large amount of populations in developed, developing or under-developed countries suffer from unhealthy diets. These are related to issues regarding daily calorie intake, balanced diet, vegetable and fruit consumption, and consumption of whole grain food. Failure in providing healthy diet results with hunger, thirst, high cholesterol, obesity and other metabolic dieting problems (Figure 2.3.12).

Figure 2.3.12. "Eating behavior" (left) and "Dieting problems" (right)

In particular, sugar and junk food consumption emerge as two important problems in dietary problems. Sugar intake in the world has increased dramatically with sugary/sweetened drinks and food. Especially the use of unhealthy sugars in diet causes serious health problems. Taxes on fat soda are proposed in order to reduce the unhealthy consumption, which gives rise to higher levels of obesity. Junk food is one of the main causes of dieting problems due to the high level of sugar they contain. Changing lifestyles and food choices make people to consume more unhealthy food like processed meat, French fries and sugary snacks (Figure 2.3.13).

Figure 2.3.13. "Sugar food" (left) and "Junk food" (right)

Healthy eating behavior includes not only consuming healthy products and maintaining balanced meal. Ensuring food sustainability and reducing food print should also be among the main concerns. Proper health policies should be formulated for improving health, encouraging a healthy lifestyle, provide access to nutritious food by the larger groups of society while reducing bad diet and obesity (Figure 2.3.14).

Figure 2.3.14. "Healthy eating behaviour" (left) and "Health food policy" (right)

NU4: Precision & big data in agri-businesses

Besides bio- and crop technologies, other technologies are emerging to improve farming practice, and in turn producing more nutritious and sustainable food. Among these are precision farming, farm automation technologies and remote sensing technologies. Development and implementation of these technologies require close collaboration between scientists, industry and policy makers to make sure that these technologies are available and accessible by the farmers in daily agricultural practices (Figure 2.3.15).

Figure 2.3.15. "Precision agriculture"

Dynamics of "Nutrition" domain thrusts

In this section, the dynamics of the "Nutrition" domain thrusts are shown based on their frequency of occurrence in the documents indexed in the iFORA database. Among the thrusts NU3 (Personalized information for healthy nutrition for all) appears to be the highest on the agenda (Figure 2.3.16).

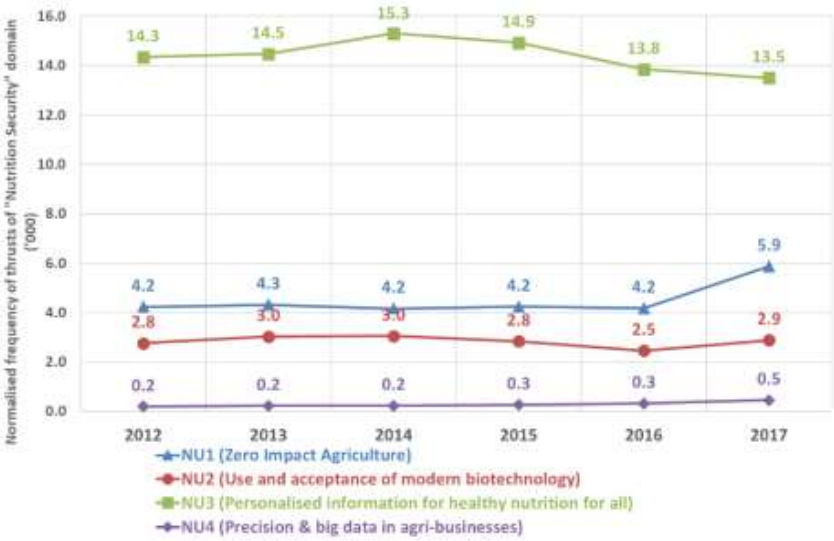

Figure 2.3.16. Normalised frequency of all terms related with thrusts of "Nutrition" domain ('000) in 2012 – 2017

Note: "Normalised frequency …" for a specific thrust – is a total normalised number of mentions (in thousands) of all terms (that are shown on a semantic map) related with this specific thrust in documents indexed in IFORA for a given year.

Table 2.3.4 illustrates to what extent the "Nutrition security" domain thrusts address the challenges. The use and acceptance of modern biotechnology (NU2) is strongly linked to affordable food. Personalized information for healthy nutrition for all (NU3) is instrumental in addressing low mortality and population growth. Finally zero impact agriculture (NU1) shows a considerable association to rural communities.

Table 2.3.4. Impacts of all thrusts of "Nutrition" domain on challenges

Challenges	Nutrition Security			
	NU1	NU2	NU3	NU4
Affordable Education	0.0	0.0	1.0	0.0
Affordable Energy	5.5	0.0	4.3	0.0
Affordable Food	2.5	103.0	20.7	0.0
Carbon Emission Reduction	0.0	0.0	1.0	0.0
Clean Water Access	2.5	1.0	1.0	0.0
Crime Prevention	4.0	0.0	5.0	0.0
Crime Reduction	0.0	0.0	1.0	0.0
Economy Growth	0.0	0.0	0.0	0.0
Employment Growth	0.0	0.0	4.5	0.0
Export Growth	0.0	2.0	3.0	0.0
High Living Standard	3.0	3.0	2.0	0.0
High Quality Health Care Service	0.0	0.0	2.0	0.0
Income Growth	14.5	5.0	12.0	2.0
Job Creation	11.3	4.7	9.0	1.0
Low Greenhouse Gas Emission	2.0	2.0	2.7	0.0
Low Mortality	1.0	10.0	49.3	0.0
Population Growth	9.7	18.0	47.0	0.0
Poverty Alleviation	10.0	8.0	13.0	0.0
Reduce Water Demand	8.0	8.0	0.0	0.0
Renewable Energy Growth	0.0	0.0	1.0	0.0
Rural Community	28.0	9.8	21.3	5.0
Secure Water Supply	9.0	0.0	0.0	0.0
Skill Improvement	0.0	0.0	0.0	0.0
Universal Broadband Access	0.0	0.0	0.0	0.0

Notes: 1. Value in each specific cell of this table is a normalised number of co-occurrences of all terms (that are shown on a semantic map) related with a specific thrust (e.g. Thrust NU1) and a specific challenge (e.g. "Low Mortality") in documents indexed in iFORA database for 2012 – 2017. This value is treated as an impact of a specific thrust onto a specific challenge. 2. Cells are colored by bars as follows: within a column of a specific thrust the biggest green bar means the challenge for which this specific thrust has the highest impact.

2.4. INFORMATION AND COMMUNICATION TECHNOLOGIES: OPPORTUNITIES, THREATS AND IMPACTS (ICT) DOMAIN

Overall description of the domain

Information and Communication Technologies (ICTs) are one of the key enablers of development in all domains from agriculture to health, industry to governance and service delivery. There are a number of technologies under the umbrella of ICTs. The Internet of Things (IoT) promises a hyper-connected and ultra-digitally responsive society that supports human, societal and environmental developments. Artificial intelligence offers unique opportunities to improve human lives and to address major societal challenges. Blockchain technology is expected to disrupt several markets by ensuring trustworthy transactions without the necessity of a third party. All these technologies bring opportunities and threats for socio-economic systems. Therefore, their development needs to be regulated by addressing the concerns regarding security, privacy, equity and integrity.

Overview of research potential of South Africa in “ICT” domain

Figure 2.4.1 shows that there is a growing scientific emphasis on the ICT domain in South Africa. However, the number of publications and the share of South Africa in the global scientific output in this domain remain still very low. Clearly more research in this domain is critical for the achievement of the 2030 goals and targets, as the ICTs are key drivers of development almost in all of the domains covered by the National Foresight 2030 study.

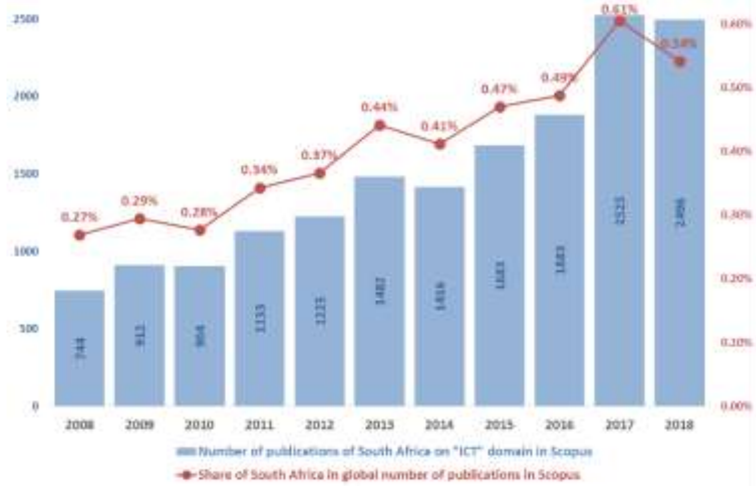

Figure 2.4.1. Dynamics of publications of South Africa in “ICT” domain in Scopus in 2008 – 2018

Note: all types of documents except of technical documents, indexed in Scopus are included in the analysis.

Figure 2.4.2 shows the leading countries in the ICT domain. South Africa’s position in ICTs is extremely low (45th place in the world). Top collaborators in this domain are similar to other domains (Table 2.3.1).

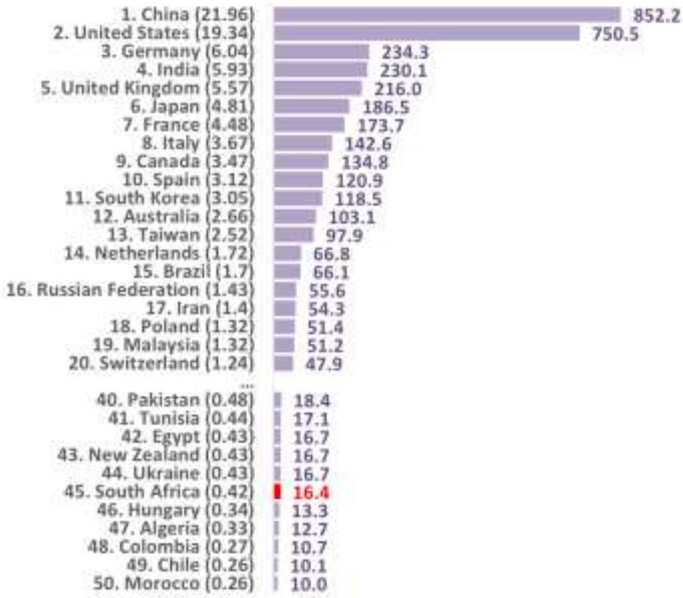

Figure 2.4.2. Leading countries by number of publications on "ICT" domain in Scopus for 2008 – 2018

Note: 1. All types of documents except of technical documents, indexed in Scopus are included in the analysis. 2. Share of a country in global number of publications is shown in parenthesis.

Table 2.4.1. Key partner countries of South Africa in internationally collaborated publications in "ICT" domain in Scopus for 2008 - 2018

Country	Number of Joint papers with SAR	Share of a country in all ICPs of South Africa
United States	1181	20.82%
United Kingdom	902	15.90%
Germany	627	11.05%
France	481	8.48%
China	433	7.63%
Australia	430	7.58%
Canada	392	6.91%
Netherlands	368	6.49%
India	341	6.01%
Italy	284	5.01%
Nigeria	273	4.81%
Sweden	206	3.63%
Belgium	155	2.73%
Switzerland	155	2.73%
Spain	152	2.68%
Finland	134	2.36%
Namibia	132	2.33%
Austria	124	2.19%
Brazil	115	2.03%
Zimbabwe	110	1.94%
Denmark	99	1.75%
Japan	99	1.75%
Norway	97	1.71%
Kenya	94	1.66%
Botswana	93	1.64%
Turkey	89	1.57%
New Zealand	87	1.53%
Saudi Arabia	84	1.48%
Poland	76	1.34%
South Korea	71	1.25%

Singapore	64	1.13%
Ghana	63	1.11%
Ireland	63	1.11%
Hong Kong	61	1.08%
Russian Federation	60	1.06%
Portugal	59	1.04%
Mexico	55	0.97%
Iran	53	0.93%
Malaysia	53	0.93%
Greece	51	0.90%
Argentina	50	0.88%

Table 2.4.2 shows the leading organizations in South Africa publishing in the domain of ICT with the total number of publications they produced in the last 10 years, as well as the percentage of their contribution in the total scientific output. The number of publications is considerably low considering the importance of the ICT domain.

Table 2.4.2. Leading organizations of South Africa by number of publications in "ICT" domain in Scopus for 2008 – 2018

Affiliation	Number of publications	Share in all South Africa publications
Universiteit van Pretoria	2349	14.32%
University of Cape Town	2224	13.56%
University of Johannesburg	1863	11.36%
University of KwaZulu-Natal	1567	9.55%
The Council for Scientific and Industrial Research	1551	9.46%
Universiteit Stellenbosch	1370	8.35%
University of Witwatersrand	1179	7.19%
University of South Africa	1053	6.42%
Tshwane University of Technology	914	5.57%
North-West University	627	3.82%
Meraka Institute	558	3.40%
Nelson Mandela Metropolitan University	456	2.78%
Rhodes University	410	2.50%
University of the Western Cape	337	2.05%
Cape Peninsula University of Technology	336	2.05%
Durban University of Technology	252	1.54%
University of the Free State	224	1.37%
University of Fort Hare	169	1.03%
Central University of Technology, Free State	160	0.98%
University of Zululand	154	0.94%
Vaal University of Technology	150	0.91%
University of Limpopo	106	0.65%
South African Medical Research Council	102	0.62%
South African Astronomical Observatory	93	0.57%
University of Venda for Science and Technology	79	0.48%
Eskom	57	0.35%
Walter Sisulu University	51	0.31%
African Institute for Mathematical Sciences	50	0.30%
Square Kilometre Array, South Africa	49	0.30%
Mangosuthu University of Technology	45	0.27%
Nelson Mandela University	37	0.23%
University of Witwatersrand, School of Chemical and Metallurgical Engineering	33	0.20%
South African National Space Agency	31	0.19%
Groote Schuur Hospital	27	0.16%
University of Cape Town, Faculty of Health Sciences	26	0.16%
Agricultural Research Council, Pretoria	25	0.15%

Stellenbosch Institute for Advanced Study	25	0.15%

Note: 1. All types of documents except of technical documents, indexed in Scopus are included in the analysis. 2. Organization names are presented as they are spelled in Scopus database.

Semantic analysis of the “ICT” domain

This section describes the “The Opportunities, Threats and Impact of ICTs (including Smart Systems, on Society)” STI domain its thrusts based on the results produced by the iFORA system. First, the full domain is described with a domain map including all of the topics covered. Then each of the thrusts is described by the emerging topics identified by iFORA. The second section presents topic clusters under each thrust with more detailed network maps with descriptions of emerging issues under them. Figure 2.3.3 shows the entire domain of the Opportunities, Threats and Impact of ICTs, including Smart Systems, on Society (IT) with its clusters and interrelations to each other. A detailed analysis of Figure 2.4.3 provides an overview of IT thrusts and a number of existing and emerging topics for consideration under each of them. These are presented in Table 2.4.3. In the following section network maps are given to illustrate these maps and further issues emerging under each of them.

Table 2.4.3. “The Opportunities, Threats and Impact of ICTs, including Smart Systems, on Society” thrusts and topics

IT Thrusts	Topics emerging under each thrust
IT1: Checks and balances for a digital future	“Identity security” and “Cybersecurity” (Fig. 2.4.4)
	“Privacy issues” (Fig. 2.4.5)
	“Ethical issues of ICT” and “Media, news and trust” (Fig. 2.4.6)
IT2: Internet Access & the Network & Information Infrastructure	“Broadband access promotion” and “Cloud based systems” (Fig. 2.4.7)
IT3: Big Data, Data Analytics and Decision Support	“Sensor networks and wireless infrastructure” and “Real time data” (Fig. 2.4.8)
	“Big data analytics” and “Decision support” (Fig. 2.4.9)
	“IT in education” (Fig. 2.4.10)
IT4: Smart and sustainable Municipal Service delivery	“Smart systems (city, energy, transport)” (Fig. 2.4.11)
	“Energy, electricity and utilities” (Fig. 2.4.12)
	“Smart governance” and “Cryptocurrency” (Fig. 2.4.13)

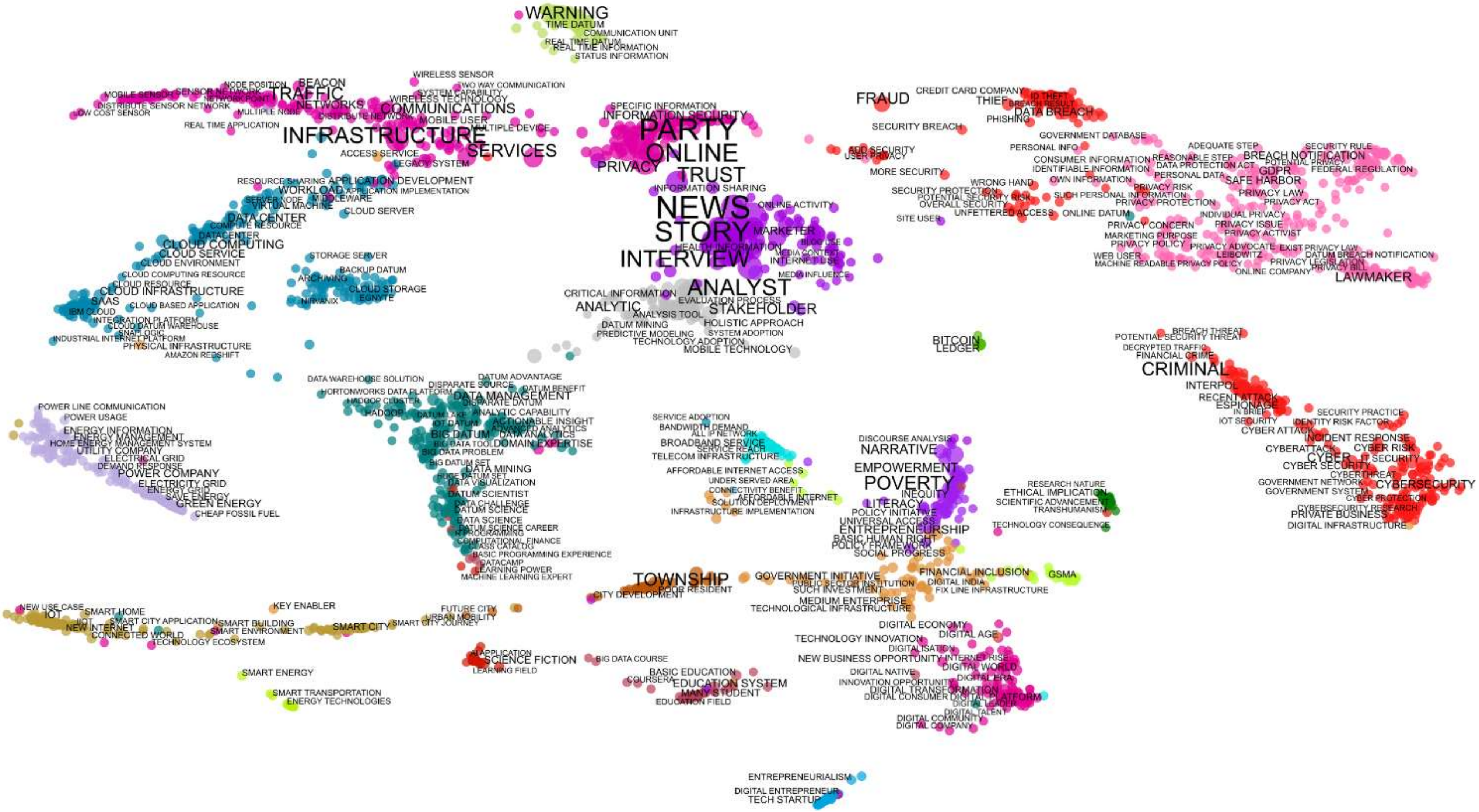

Figure 2.4.3. “The Opportunities, Threats and Impact of ICTs, including Smart Systems, on Society” domain full semantic map for 2014-2018

"The Opportunities, Threats and Impact of ICTs, including Smart Systems, on Society" Thrusts

IT1: Checks and balances for a digital future

The first thrust of the IT domain is concerned with the societal impacts of the rapidly developing Information and Communication Technologies (ICTs). Many intended and unintended consequences are emerging with significant impacts. The analysis with the iFORA system revealed five important points, which are concerned with security and privacy as well as ethical and trust issues. These are presented respectively from Figures 2.4.4. to 2.4.6. Identity theft and fraud are emerging as important concerns in parallel to the more widespread use of the ICTs. Personal information is collected through online systems by a wide variety of parties including the governmental agencies, internet operators, applications, online marketing and retail sites among the others. Therefore, strict protection and regulations are needed to make sure that this sensitive information does not go into wrong hands, which may result with ID theft. Today the worldwide information security spending has almost reached 124 billion USD[4]. This large amount is an indicator of how crucial the issue is. Setting up a safe and secure digital infrastructure is the first step for cyber protection. Particularly governmental systems and networks may be vulnerable. However, private businesses are also under risk of cyber-attacks. There is a need to establish systems for identifying risk factors and developing incident response systems for increased security (Figure 2.4.4).

Figure 2.4.4. "Identity security" (left) and "Cybersecurity" (right)

In parallel to security issues, privacy issues emerge as important concerns in the widespread use of ICTs. Most of the topics related to privacy issues addresses policy measures, regulations and law in relation to privacy (Figure 2.4.5).

Figure 2.4.5. "Privacy issues"

Developments in ICTs create ethical dilemmas, and appropriate social and technological responses to be developed to tackle with them in terms of processes, policy initiatives and frameworks, data access and information sharing, technology solutions and legislation. Another aspect of the ethics concerns publication and sharing of information through media. With the widespread sharing of information through online and social media channels, it is getting more and more difficult to distinguish real news and stories from the fake ones. These create mixed social reactions to developments, which are shared by reliable as well as unreliable sources of information. There-

[4] https://www.gartner.com/en/newsroom/press-releases/2018-08-15-gartner-forecasts-worldwide-information-security-spending-to-exceed-124-billion-in-2019

fore, trust factor plays an important role in media and raises concerns about preventing the dissemination of fake news and information over ICT networks, for which there is no clear solution so far (Figure 2.4.6).

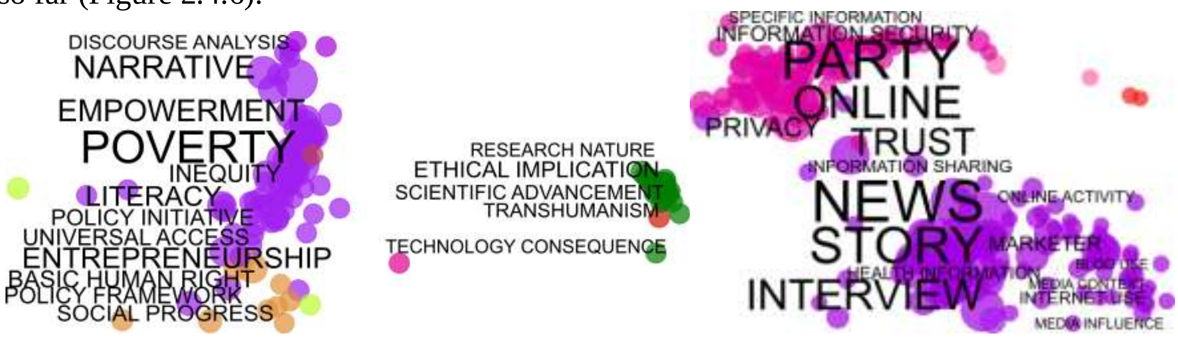

Figure 2.4.6. "Ethical issues of ICT" (left) and "Media, news and trust" (right)

IT2: Internet Access & the Network & Information Infrastructure

Accessing to the Internet and information infrastructure is crucial to exploit the opportunities offered by the digitalization process and digital economy. Two topics emerging related to this thrust are broadband access and cloud based systems. Broadband access is important to make sure that large groups of the population both in urban and rural areas have access to the Internet in a fast, secure and affordable way. There is a need to develop necessary telecom infrastructure, and provide broadband services for all. In addition to the Internet access, the storage of information is also an important issue. Cloud systems have been developed for making applications, services and resources available to large amount of users on demand via the Internet from a cloud computing providers' servers. Cloud services also require investments in infrastructures with servers, data centers and applications (Figure 2.4.7).

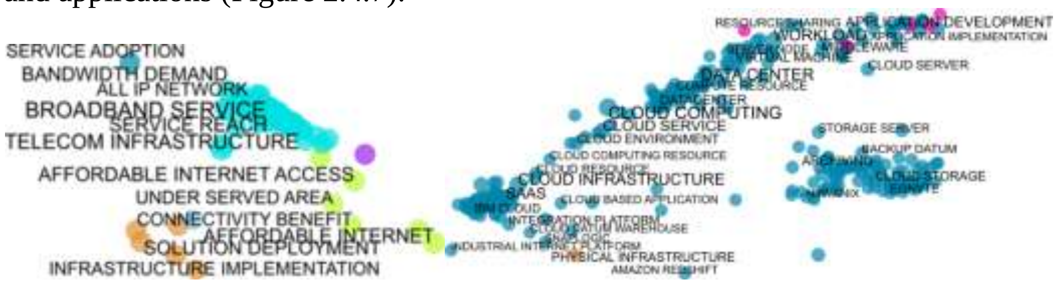

Figure 2.4.7. "Broadband access promotion" (left) and "Cloud based systems" (right)

IT3: Big Data, Data Analytics and Decision Support

Increased amount of data and advancements in data analytics made the use of big data as a new source of evidence for decision-making. Two points related to this thrust are concerned with the collection of data. With the reduced cost of sensors and widespread implementation of wireless networks, large amount of information are collected related to climate, transportation, agriculture, health and all other sectors of the social and economic life. Besides collection of the historical data, there is now an increasing need and possibilities for collecting information real time to enable real time decision-making. A real time data collection system will require infrastructure for networks and communication systems, wireless networks as well as systems for processing data (Figure 2.4.8).

Figure 2.4.8. "Sensor networks and wireless infrastructure" (left) and "Real time data" (right)

Data collected and processed need to be analyzed through the big data analytics systems. This is certainly an area where South Africa, like many other countries in the world, should develop necessary skills, capacity and infrastructure. Systems to be developed include data collection, storage, processing, analytics, visualization, and interpretation. A number of new skills will be required for the big data analytics systems including machine learning expert, data scientist, analyst, domain experts, and programmers (Figure 2.4.9).

Figure 2.4.9. "Big data analytics" (left) and "Decision support" (right)

In order to build necessary skills and capacity for a digital future, ICTs should be increasingly integrated into education systems. For instance coding and big data analytics can be included in the curricula of tertiary schools, if not primary and secondary (Figure 2.4.10).

Figure 2.4.10. "IT in education"

IT4: Smart and sustainable municipal service delivery

Information and Communication Technologies are also instrumental in terms of implementing smart cities, energy, transport and public services. A smart city refers to the use of ICTs to increase operational efficiency, information sharing and use, and service delivery to improve quality of life of citizens and provide sustainable systems with smart solutions. Smart energy use and transportation systems are two out of many other application areas for smart cities. Besides them, there are also technologies and applications for smart homes and buildings. The key enabling technology of these smart systems is the Internet of Things (IoT). It is expected that these technologies will find application areas not only in cities but also to improve quality of life in rural areas with better access to products, services and clean energy and efficient transport systems with smart and integrated solutions (Figure 2.4.11).

Figure 2.4.11. "Smart systems (city, energy, transport)"

Regarding smart energy systems, a number of topics arise around use of green energy sources, energy saving solutions, smart grid systems and energy information and management systems. Policy structures, energy infrastructure, and utility companies need to be upgraded in order to implement smart energy solutions (Figure 2.4.12).

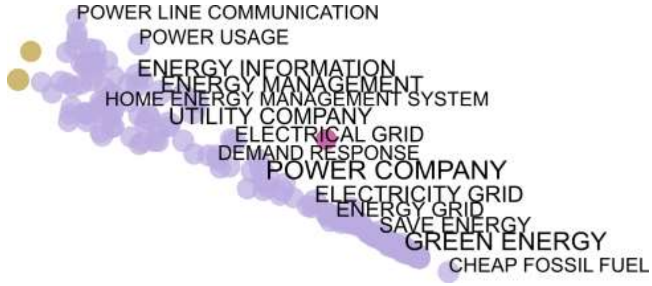

Figure 2.4.12. "Energy, electricity and utilities"

Implementing individual smart solutions certainly is not sufficient for setting up 'smart systems'. Smart governance is also needed for integrating and operating those components. Governance at the national, regional and local levels should be adapted to smart systems with the development of necessary public sector institutions, raising investments, and involving enterprises in the process. The iFORA system also picked up the development of smart payment methods and digital currencies associated to the development of smart and sustainable municipal service delivery thrust (Figure 2.4.13).

Figure 2.4.13. "Smart governance" (left) and "Cryptocurrency" (right)

Dynamics of "ICT" domain thrusts

Dynamics of the "ICT" domain thrusts are shown based on their frequency of occurrence in the documents indexed in the iFORA database. Among the thrusts IT1 (Checks and balances for a digital future) appears to be the highest on the agenda (Figure 2.4.14). The emphasis on big data, analytics and decision support (IT3) is growing, however, this growth is still insignificant. Use of ICTs for smart and sustainable municipal service delivery (IT4) is considerably low.

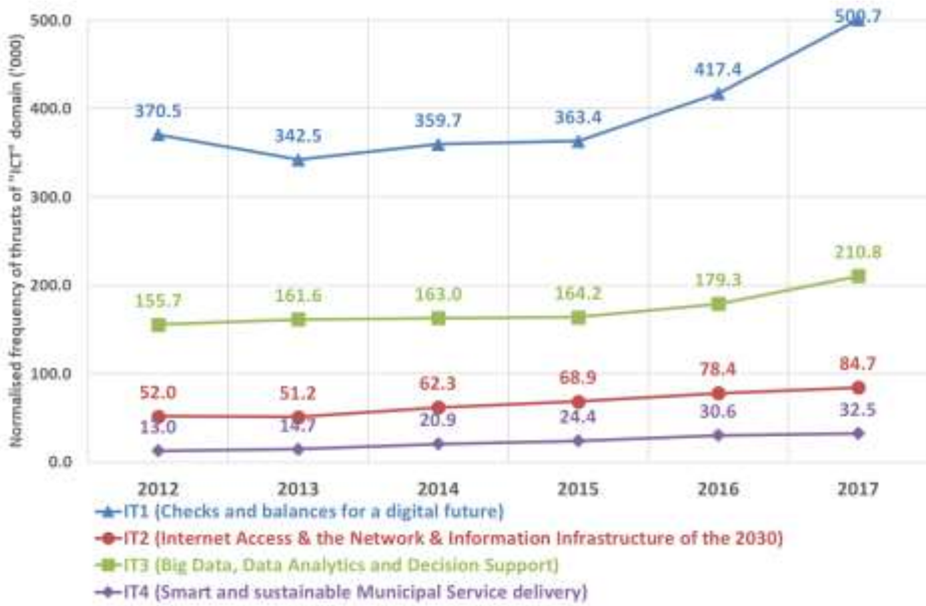

Figure 2.4.14. Normalized frequency of all terms related with thrusts of "ICT" domain ('000) in 2012 – 2017

Note: "Normalized frequency" for a specific thrust is a total normalized number of mentions (in thousands) of all terms (that are shown on a semantic map) related with this specific thrust in documents indexed in IFORA for a given year.

Furthermore, Table 2.4.4 illustrates to what extent the "ICT" domain thrusts address the challenges. Job creation, population growth and rural communities appear to be challenges linked to ICT thrusts.

Table 2.4.4. Impacts of all thrusts of "ICT" domain on challenges

Challenges	ICT			
	IT1	IT2	IT3	IT4
Affordable Education	0.0	0.0	1.0	0.0
Affordable Energy	1.0	0.0	0.0	0.0
Affordable Food	7.0	0.0	2.0	0.0
Carbon Emission Reduction	2.0	4.0	0.0	8.0
Clean Water Access	0.0	2.0	0.0	0.0
Crime Prevention	3.4	0.0	1.5	0.0
Crime Reduction	13.0	0.0	0.0	0.0
Economy Growth	0.0	0.0	0.0	1.0
Employment Growth	7.0	1.0	3.0	1.5
Export Growth	2.0	0.0	0.0	2.0
High Living Standard	1.0	0.0	0.0	1.0
High Quality Health Care Service	3.0	0.0	0.0	0.0
Income Growth	2.5	0.0	0.0	0.0
Job Creation	35.5	14.7	31.0	61.0
Low Greenhouse Gas Emission	0.0	0.0	0.0	0.0
Low Mortality	7.0	5.0	1.0	0.0
Population Growth	37.7	14.0	7.0	18.5
Poverty Alleviation	4.0	1.0	1.5	26.0
Reduce Water Demand	0.0	0.0	0.0	0.0
Renewable Energy Growth	0.0	0.0	0.0	2.0
Rural Community	16.0	28.7	9.0	21.0
Secure Water Supply	0.0	0.0	0.0	1.0
Skill Improvement	1.0	0.0	1.0	0.0
Universal Broadband Access	1.0	1.5	0.0	0.0

Notes: 1. Value in each specific cell of this table is a normalized number of co-occurrences of all terms (that are shown on a semantic map) related with a specific thrust (e.g. Thrust IT1) and a specific challenge (e.g. "Low Mortality") in documents indexed in iFORA database for 2012 – 2017. This value is treated as an impact of a specific thrust onto a specific challenge. 2. Cells are colored by bars as follows: within a column of a specific thrust the biggest green bar means the challenge for which this specific thrust has the highest impact.

2.5. HEALTH TECHNOLOGY TO PREVENT ILL-HEALTH, AND ADVANCE WELL-BEING FOR MARGINALIZED (HEALTH)

Overall description of the domain

Within the scope of the South African National STI Foresight 2030, the Health domain refers to technologies and strategies to prevent and treat ill health while advancing well-being for marginalized. Overall, the health system needs to be optimized in order to deliver better diagnostic and treatment services and for the overall improvement of the healthcare system as well as drug development. An understanding needs to be developed in the society that prevention is cheaper than cure, so that people have better control over their own health. There is also need to develop current health infrastructure and administration, which are inadequate, particularly in the rural areas of South Africa. Like in other domains, emerging technologies including mobile technologies, AI and Big Data will bring enormous opportunities for the development of the healthcare service delivery for all.

Overview of research potential of South Africa in "Health" domain

Figure 2.5.1 shows that there is a growing scientific emphasis on the Health domain in South Africa. The number of publications in this domain the Health domain is considerably high compared to other STI domains identified in the National STI Foresight 2030 study. The number of publications has been growing continuously as well as the share of South Africa in the global scientific output in this domain.

Profile of South Africa in "Health" domain in Scopus

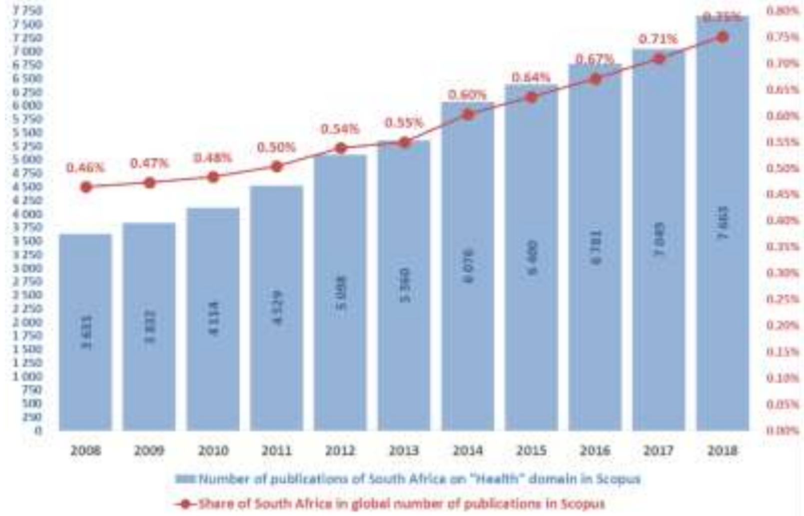

Figure 2.5.1. Dynamics of publications of South Africa on "Health" domain in Scopus in 2008 – 2018

Note: all types of documents except of technical documents, indexed in Scopus are included in the analysis.

Figure 2.5.2 shows the leading countries in the Health domain. Although in terms of number of publications this domain appears to be one of the leading STI areas in South Africa, compared to the rest of the world, there is still a considerable progress the country needs to make. The country is currently positioned at the 31st place in the world.

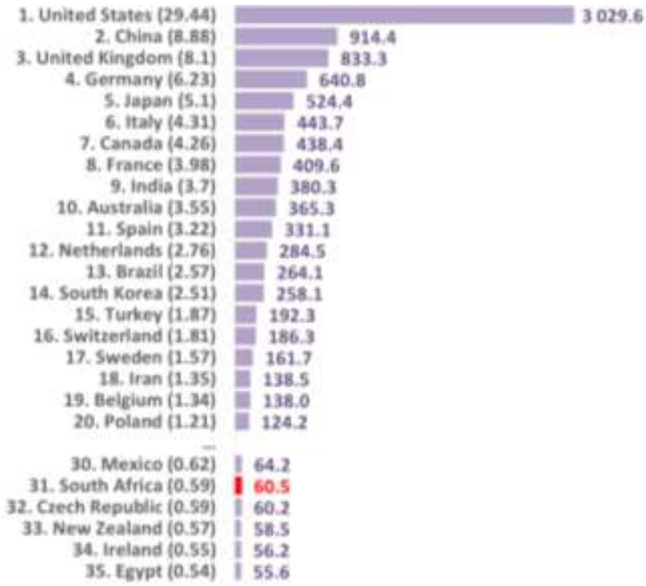

Figure 2.5.2. Leading countries by number of publications in "Health" domain in Scopus for 2008 – 2018

Note: 1. All types of documents except of technical documents, indexed in Scopus are included in the analysis. 2. Share of a country in global number of publications is shown in parenthesis.

Among those countries, the key partners of South Africa are the United States, the United Kingdom, Australia, the Netherlands and Canada (Table 2.5.1). Nigeria, Kenya, Uganda, Ghana and Zimbabwe are among the key African scientific collaborators.

Table 2.5.1. Key partner countries of South Africa in internationally collaborated publications in "Health" domain in Scopus for 2008 - 2018

Country	Number of Joint papers with South Africa	Share of a country in all ICPs of South Africa
United States	13593	42.39%
United Kingdom	9168	28.59%
Australia	3895	12.15%
Netherlands	3343	10.42%
Canada	3156	9.84%
Germany	3022	9.42%
Switzerland	2750	8.58%
France	2475	7.72%
Belgium	2146	6.69%
India	1897	5.92%
Italy	1790	5.58%
Sweden	1780	5.55%
Nigeria	1681	5.24%
Spain	1617	5.04%
Brazil	1436	4.48%
Kenya	1305	4.07%
China	1120	3.49%
Norway	1101	3.43%
Uganda	1041	3.25%
Denmark	1020	3.18%
Japan	879	2.74%
Ghana	846	2.64%
New Zealand	822	2.56%
Zimbabwe	777	2.42%
Thailand	766	2.39%
Cameroon	700	2.18%
Argentina	668	2.08%

Tanzania	660	2.06%
Malawi	641	2.00%
Austria	598	1.86%
Zambia	590	1.84%
Mexico	581	1.81%
Poland	577	1.80%
Ireland	571	1.78%
Finland	570	1.78%
Israel	559	1.74%
Saudi Arabia	522	1.63%
Portugal	501	1.56%

Note: 1. All types of documents except of technical documents, indexed in Scopus are included in the analysis.

Table 2.5.2 shows the leading organizations in South Africa publishing in the domain of Health with the total number of publications they produced in the last 10 years, as well as the percentage of their contribution in the total scientific output. University of Cape Town appears to have a significant capacity in publishing in the Health domain.

Table 2.5.2. Leading organizations of South Africa by number of publications in "Health" domain in Scopus for 2008 – 2018

Affiliation	Number of pub-lications	Share in all South Africa publications
University of Cape Town	13636	22.53%
University of Witwatersrand	9766	16.13%
Universiteit Stellenbosch	8345	13.79%
University of KwaZulu-Natal	7148	11.81%
Universiteit van Pretoria	6177	10.20%
South African Medical Research Council	4988	8.24%
North-West University	2952	4.88%
Groote Schuur Hospital	2427	4.01%
National Health Laboratory Services	2424	4.00%
University of the Western Cape	2081	3.44%
University of the Free State	1717	2.84%
University of Cape Town, Faculty of Health Sciences	1677	2.77%
The Nelson R. Mandela Medical School	1536	2.54%
University of Johannesburg	1529	2.53%
Tygerberg Hospital	1262	2.08%
National Institute for Communicable Diseases	1190	1.97%
Red Cross War Memorial Children's Hospital	1183	1.95%
University of South Africa	1153	1.90%
University of Limpopo	1019	1.68%
Human Sciences Research Council of South Africa	927	1.53%
Sefako Makgatho Health Sciences University SMU	861	1.42%
University of Fort Hare	843	1.39%
Rhodes University	826	1.36%
Baragwanath Hospital	715	1.18%
Tshwane University of Technology	644	1.06%
The Council for Scientific and Industrial Research	553	0.91%
University of the Witwatersrand, Faculty of Health Sciences, School of Pathology	551	0.91%
Nelson Mandela Metropolitan University	533	0.88%
Cape Peninsula University of Technology	523	0.86%
Centre for the AIDS Programme of Research in South Africa	521	0.86%
University of Venda for Science and Technology	464	0.77%
Walter Sisulu University	454	0.75%
Durban University of Technology	441	0.73%
National Research Foundation	424	0.70%
Africa Centre for Health and Population Studies	423	0.70%

Agricultural Research Council, Pretoria	400	0.66%
Inkosi Albert Luthuli Central Hospital	365	0.60%
Onderstepoort Veterinary Institute	279	0.46%
University of Cape Town Lung Institute	268	0.44%
University of the Witwatersrand, Faculty of Health Sciences, School of Clinical Medicine	248	0.41%
University of the Free State, School of Medicine	227	0.38%
University of Zululand	227	0.38%
University of the Witwatersrand, Faculty of Health Sciences	207	0.34%

Note: 1. All types of documents except of technical documents, indexed in Scopus are included in the analysis. 2. Organization names are presented as they are spelled in Scopus database.

Semantic analysis of "Health" domain

This section describes the "Health Technology to Prevent and Treat Ill-Health, and Advanced Well-Being, for Marginalized (HE)" domain and analysis of its thrusts based on the results produced by the iFORA system. First, the full domain is described with a domain map including all of the topics covered. Figure 2.3.3 shows the Health domain with its clusters and interrelations to each other. A detailed analysis of Figure 2.5.3 provides an overview of HE thrusts and a number of existing and emerging topics for consideration under each of them. These are presented in Table 2.5.3. In the following section network maps are given to illustrate these maps and further issues emerging under each of them.

Table 2.5.3. "Health Technology to Prevent and Treat Ill-Health, and Advance Well-Being, for Marginalized (HE)" thrusts and topics

HE Thrusts	Topics emerging under each thrust
HE1: Optimization of health systems	"Rapid diagnostic" and "Diagnostic tools" (Fig. 2.5.4)
	"Medical treatment" and "Patient treatment" (Fig. 2.5.5)
	"Healthcare system" and "Drug development" (Fig. 2.5.6)
HE2: Improving the quality of health care	"Birth care and child care" (Fig. 2.5.7)
	"Intensive care" (Fig. 2.5.8)
	"Healthcare organization management" (Fig. 2.5.9)
	"Healthcare staff issues" (Fig. 2.5.10)
	"Healthcare policy" (Fig. 2.5.11)
	"Health care economics" (Fig. 2.5.12)
	"Health care access" (Fig. 2.5.13)
	"Health care quality" and "Management of clinics" (Fig. 2.5.14)
	"Personalized medicine" and "Cancer treatment" (Fig. 2.5.15)
HE3: Digitization of health systems	"Hospital records" and "Patient records" (Fig. 2.5.16)
	"Heath information system" and "Health database" (Fig. 2.5.17)
	"Telemedicine", "Mobile medicine", and "Robotics" (Fig. 2.5.18)

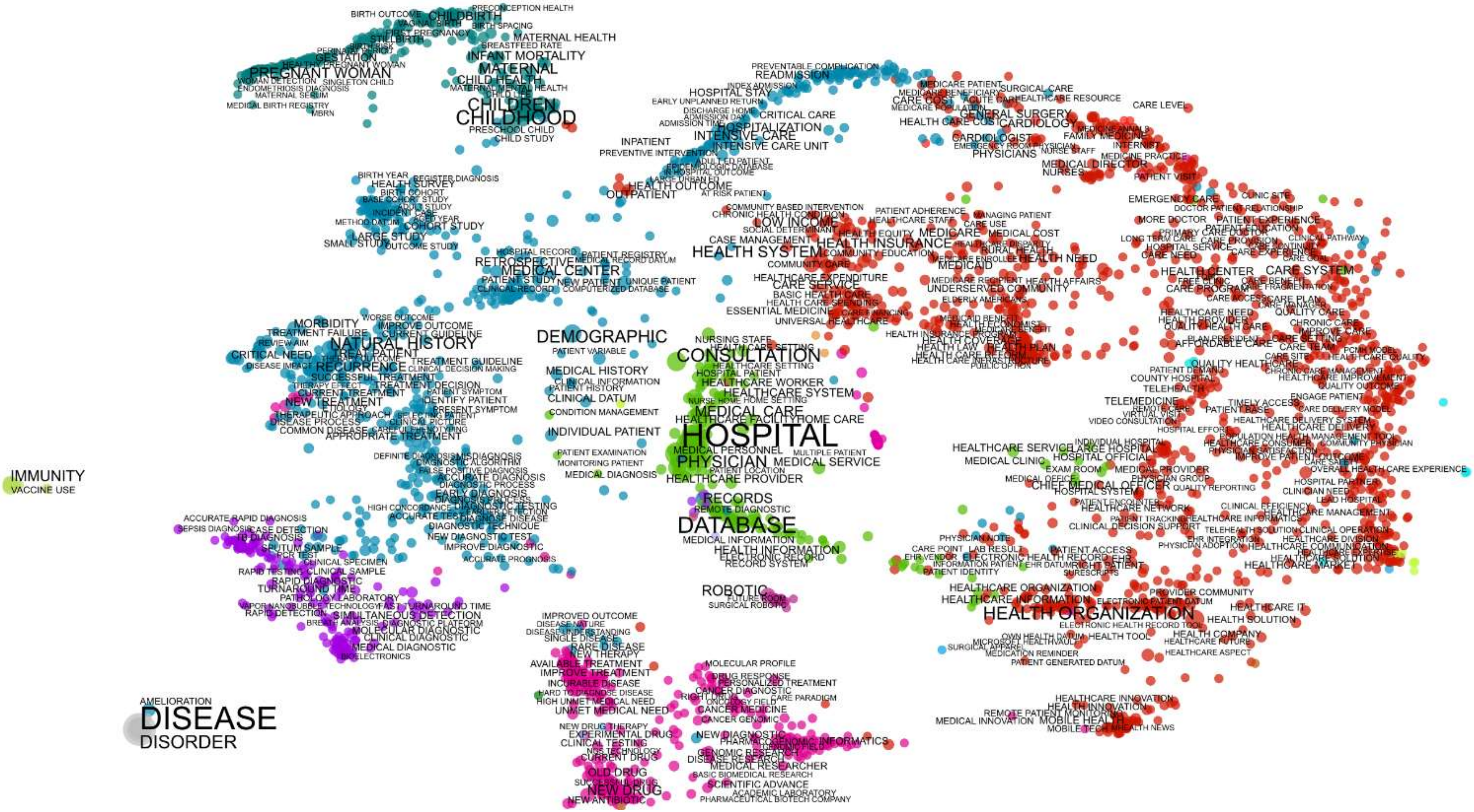

Figure 2.5.3. "Health Technology to Prevent and Treat Ill-Health, and Advance Well-Being, for Marginalized" domain full semantic map for 2014-2018

“Health Technology to Prevent and Treat Ill-Health, and Advance Well-Being, for Marginalized” Thrusts

HE1: Optimization of health systems

The analysis of the “optimization of health systems” thrust revealed six topics regarding diagnostic, treatment, and overall improvement of the healthcare system as well as drug development. In terms of diagnostics, rapid diagnostic systems are gaining importance. The cluster on this topic includes issues on different levels of diagnostics (clinical, medical or molecular), development of diagnostic platforms, sample collection methods and various technologies to be used for this purpose (including Bioelectronics and vapor nanobubble technologies (Figure 2.5.4 left). In relation to that, Figure 2.5.4. (right) presents various issues concerning diagnostics tools, and new methods and techniques for increasing accuracy.

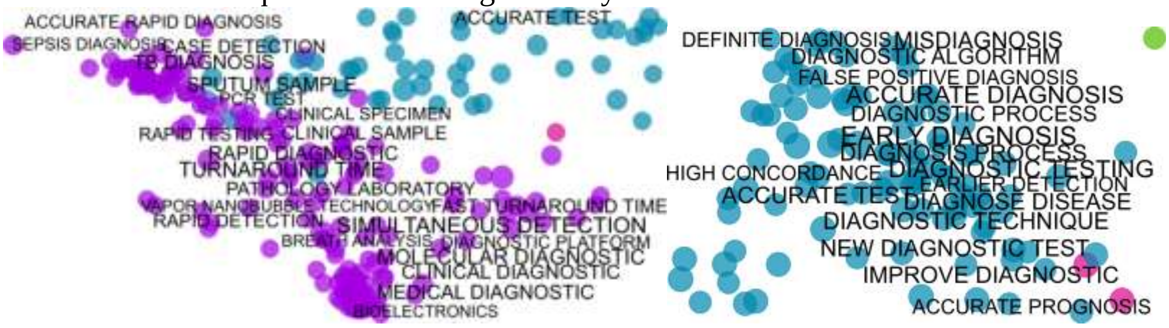

Figure 2.5.4. “Rapid diagnostic” (left) and “Diagnostic tools” (right)

Following the diagnosis, treatment comes as an important topic for the optimization of the health systems. The advancement of new technologies brings new methods and approaches for treatment. There is a need to improve patient examination methods, keep clinical information and patient history, with the help of the ICT systems, and monitor patients’ health conditions regularly (Figure 2.5.5.).

Figure 2.5.5. “Medical treatment” (left) and “Patient treatment” (right)

Besides improvements in diagnostics and treatment, the optimization of the health systems also requires its upgrading. These upgrades require substantial improvements in the hospitals and healthcare facilities, skills of the healthcare personnel, and the quality of the medical services. Home care also appears to be an important point for the development as a part of the healthcare system (Figure 2.5.6 left). Drugs are vital components of the healthcare. Development and use of new drugs will certainly have transformative effects on the healthcare system. The issues around the new drugs are populated around experiments and clinical testing of drugs and their successful use in therapy. The antibiotic use in the world is also a big debate in health circles. Development of new antibiotics also appears as a branch in new drug development activities (Figure 2.5.6 right).

Figure 2.5.6. “Healthcare system” (left) and “Drug development” (right)

HE2: Improving the quality of healthcare

In addition to the optimization of the healthcare services, the second thrust of the HE domain is concerned with the improvement of the quality of the healthcare. A number of topics emerge regarding to this thrust ranging from the development of care from the birth to a comprehensive overhaul of the healthcare system from the way it is organized, staff employed, its economic aspects, quality, efficiency and access. These are described in the consecutive maps presented below. Children health is immensely important for a health population. Most of the diseases can be prevented already from the pregnancy stages of mothers. Reduced infant mortality is an important indicator of development. Therefore necessary healthcare should be provided for women and parents from the pregnancy and maternity stage to early and late childhood (Figure 2.5.7).

Figure 2.5.7. “Birth care and child care”

Another aspect of healthcare to be developed is intensive care. There are a range of issues to be considered starting from the admission to intervention, hospital stay and discharge (Figure 2.5.8).

Figure 2.5.8. “Intensive care”

Besides the issues related to care, the improvement of healthcare requires transformations in the healthcare systems, which require action at multiple aspects. Beginning with the management of healthcare organizations, there are possibilities of using ICTs to implement and widespread use of electronic health records and patient data. These technologies, along with the application of personal health systems, are expected to make revolutionary changes in the way healthcare services are organized and delivered (Figure 2.5.9).

Figure 2.5.9. “Healthcare organization management”

Healthcare staff, including physicians, surgeons, cardiologists and nurses among the others, needs necessary skills and capabilities to keep up with the developments in the healthcare system. Particularly skills related to the use of ICTs and health data as well as new technologies for diagnosis, treatment, surgery etc. seem to be important (Figure 2.5.10).

Figure 2.5.10. "Healthcare staff issues"

Healthcare system also needs to be regulated with appropriate policy measures in order to be improved. Among the important aspects for regulation are access to the healthcare system and equity, management of healthcare costs, making healthcare more affordable for low income populations, health insurance, and community care among the others illustrated in Figure 2.5.11.

Figure 2.5.11. "Healthcare policy"

As mentioned in the policy aspect, the availability and accessibility of healthcare services from the economic point of view come out as an important issue for the improvement of the healthcare systems. Reduction of the healthcare expenditures is a first step for accessing to basic healthcare services for the marginalized parts of the society. Meanwhile, it is important to reduce the burden of the healthcare spending on the economic system. This requires a more systemic approach, which relates to other STI domains, such as nutrition. With better nutrition of the population, the society will be healthier with less health problems. This is also related to education systems, economic systems and access to information and technology systems. Therefore, there is a need to have a systemic perspective when economic and policy aspects of healthcare are dealt with (Figure 2.5.12).

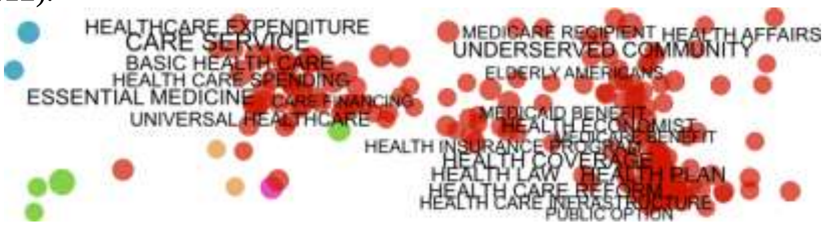

Figure 2.5.12. "Health care economics"

Improved healthcare systems also mean accessible healthcare services for all layers of the society. There are a number of issues to be considered in terms of access, including income levels, medical costs, community care, disparity in healthcare and equity. Necessary insurance systems should be in place also for the marginalized to access healthcare services (Figure 2.5.13).

Figure 2.5.13. "Health care access"

While delivering healthcare services, besides their economy, the quality aspect should also be considered. Availability of medical personnel, improved infrastructure and services, patient experience are among the important determinants of the quality in healthcare. There is also a need for the efficient management of the clinics in order to maintain the quality of services (Figure 2.5.14).

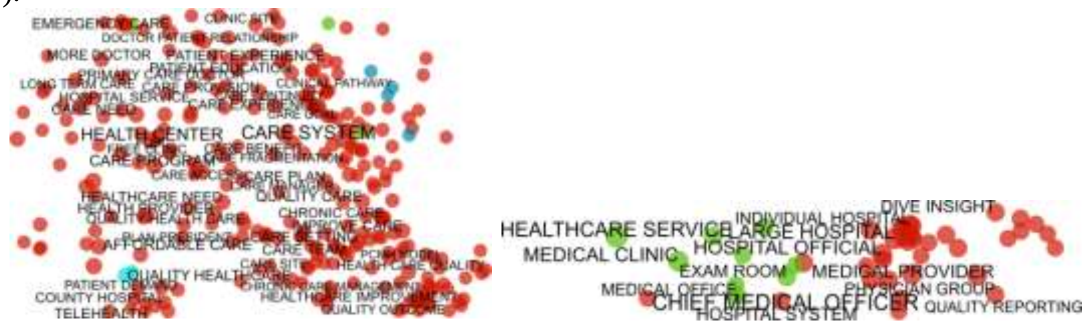

Figure 2.5.14. “Health care quality” (left) and “Management of clinics” (right)

Improving healthcare quality is also directly related to the development of personalized medicine, where medical services, practices, interventions and products are tailored to the individual patients based on their characteristics. Research in areas like genomics and pharmagenomics plays important role for personalized medicine. One of the areas where personalized medicine can play a significant role is cancer research, where personalized treatment is needed from the diagnostic stages to drug response (Figure 2.5.15).

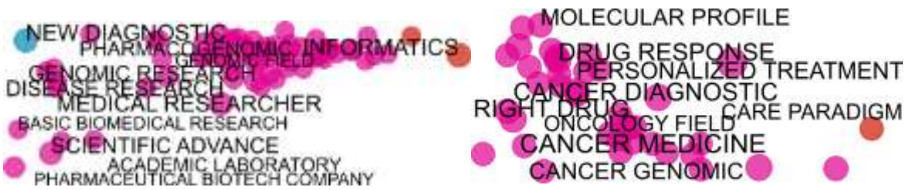

Figure 2.5.15. “Personalized medicine” (left) and “Cancer treatment” (right)

HE3: Digitization of health systems

The digitalization of health systems provides enormous opportunities for the optimization of healthcare services and increasing their quality. Electronic health records are one of the major application areas for the digitalization of health systems. Clinical records should be collected in a database in safe and secure ways by considering the privacy and ethical aspects. Necessary computer infrastructures need to be established with ICT skills in place (Figures 2.5.16 and 2.5.17).

Figure 2.5.16. “Hospital records” (left) and “Patient records” (right)

Figure 2.5.17. “Heath information system” (left) and “Health database” (right)

Recent years have also seen increasing possibilities for telemedicine, which allows caring for patients remotely when the healthcare provider and patient are not physically present with each other. Video consultations and virtual visits are technological alternatives as they enable remote care. Associated to the telemedicine concept is mobile medicine, which also serves for the remote delivery of healthcare services. The use of robotics in recent years moved telemedicine to a new dimension enlarging the services delivered from mere consultations to remote surgeries (Figure 2.5.18).

Figure 2.5.18. "Telemedicine" (left), "Mobile medicine" (center), and "Robotics" (right)

Dynamics of "Health" domain thrusts

In this section, the dynamics of the "Health" domain thrusts are shown based on their frequency of occurrence in the documents indexed in the iFORA database. Among the thrusts HE1 (Optimization of health systems) and HE2 (Improving the quality of health care) appear to the highest on the agenda (Figure 2.5.19). Digitization of health systems (HE3) is still not given sufficient attention in the Health domain.

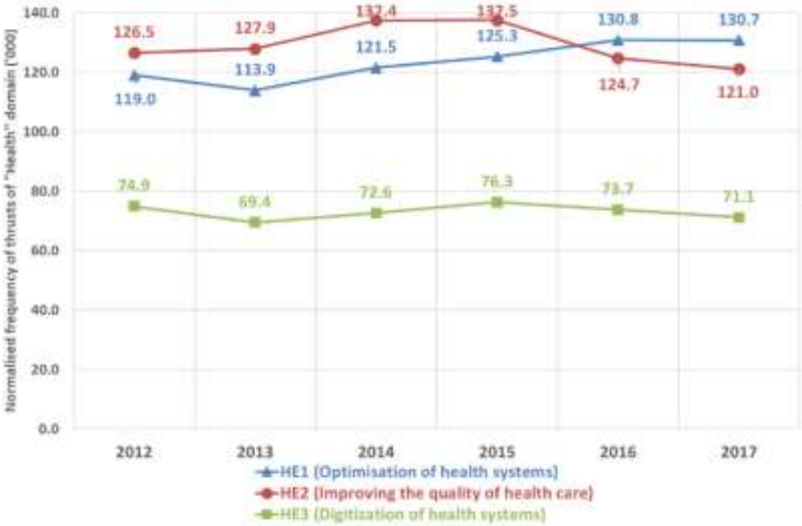

Figure 2.5.19. Normalised frequency of all terms related with thrusts of "Health" domain ('000) in 2012 – 2017

Note: "Normalised frequency …" for a specific thrust – is a total normalised number of mentions (in thousands) of all terms (that are shown on a semantic map) related with this specific thrust in documents indexed in IFORA for a given year

Furthermore, Table 2.5.4 illustrates to what extent the "Health" domain thrusts address the challenges. In parallel to the other STI domains, the thrusts of the Health domain are strongly linked to rural community, job creation and population growth.

Table 2.5.4. Impacts of all thrusts of "Health" domain on challenges

Challenges	Health		
	HE1	HE2	HE3
Affordable Education	1.0	0.0	0.0
Affordable Energy	0.0	1.5	0.0
Affordable Food	1.0	4.5	0.0
Carbon Emission Reduction	0.0	0.0	0.0
Clean Water Access	1.0	1.0	0.0
Crime Prevention	1.0	2.0	1.0
Crime Reduction	2.5	1.0	0.0
Economy Growth	1.0	0.0	0.0
Employment Growth	4.5	1.0	1.0
Export Growth	0.0	1.0	1.0
High Living Standard	4.0	2.0	1.5
High Quality Health Care Service	3.5	2.0	1.0
Income Growth	0.0	2.0	0.0
Job Creation	14.2	15.2	26.0
Low Greenhouse Gas Emission	0.0	1.0	0.0
Low Mortality	3.3	9.8	6.0
Population Growth	17.8	28.7	1.3
Poverty Alleviation	2.0	1.0	3.0
Reduce Water Demand	0.0	0.0	0.0
Renewable Energy Growth	0.0	0.0	0.0
Rural Community	34.3	13.0	73.6
Secure Water Supply	0.0	0.0	0.0
Skill Improvement	0.0	0.0	0.0
Universal Broadband Access	0.0	0.0	1.0

Notes: 1. Value in each specific cell of this table is a normalized number of co-occurrences of all terms (that are shown on a semantic map) related with a specific thrust (e.g. Thrust HE1) and a specific challenge (e.g. "Low Mortality") in documents indexed in iFORA database for 2012 – 2017. This value is treated as an impact of a specific thrust onto a specific challenge. 2. Cells are colored by bars as follows: within a column of a specific thrust the biggest green bar means the challenge for which this specific thrust has the highest impact.

2.6. SUSTAINABLE ENERGY TECHNOLOGIES FOR THE MARGINALIZED (ENERGY) DOMAIN

Overall description of the domain

With the advancement of societies, energy has become one of the basic human needs for a sustained and uninterrupted life. Although large cities in South Africa has a relatively stable energy supply, both rural and peri-urban marginalized communities suffer from accessing energy. Clean and affordable energy sources such as the harvesting of solar, wind and bio energy provide opportunities for marginalized communities to adopt these new technologies, as there is no overhead due to the replacement of old technologies. Sustainable energy technologies can leapfrog old technologies and their many limitations. Possibilities for local sustainable energy production will give communities independence, self-sufficiency and cooperation towards a common good. Decentralized local energy sources will reduce dependence on the national grid and create economic opportunities for the marginalized across South Africa. Thus, the Energy domain focuses on clean, affordable and renewable energy solutions, energy efficiency and distributed generation.

Overview of research potential of South Africa in "Energy" domain

Figure 2.6.1 shows that there is a growing scientific emphasis on the Energy domain in South Africa. The number of publications has been growing rather faster compared to other STI domains. However, the share of South Africa's contribution in the global scientific output is still relatively low (under 1%).

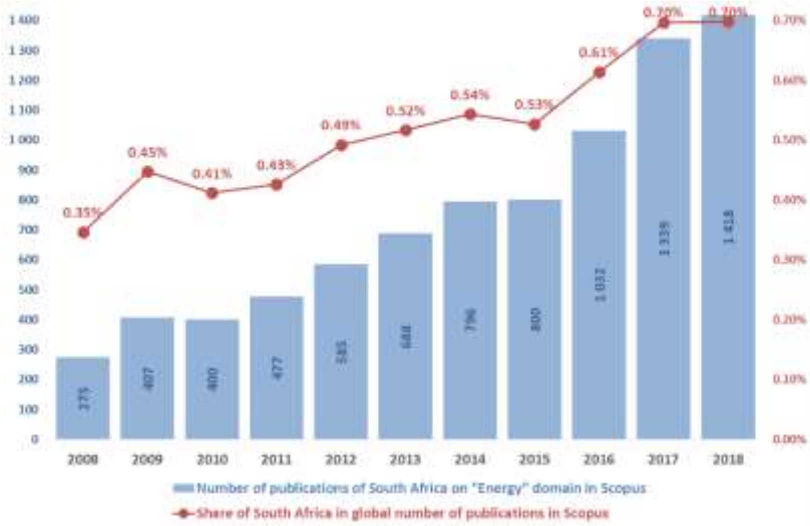

Figure 2.6.1. Dynamics of publications of South Africa in "Energy" domain in Scopus in 2008 – 2018

Note: all types of documents except of technical documents, indexed in Scopus are included in the analysis.

Figure 2.6.2 shows the leading countries in the Energy domain.

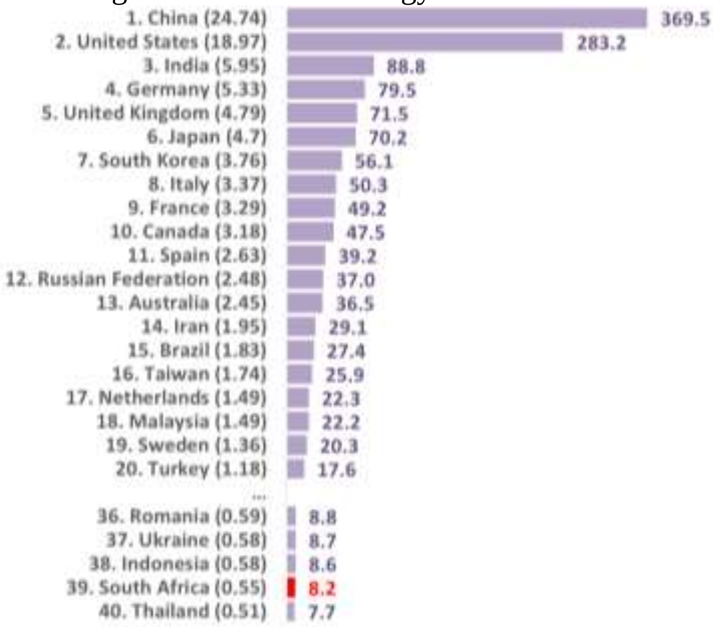

Figure 2.6.2. Leading countries by number of publications ('000) in "Energy" domain in Scopus for 2008 – 2018

Note: 1. All types of documents except of technical documents, indexed in Scopus are included in the analysis. 2. Share of a country in global number of publications is shown in parenthesis.

Among those countries, the key partners of South Africa are the United States, the United Kingdom, Germany, India and France. Collaboration with Nigeria is relatively high with the 7th position among the top collaborators (Table 2.6.1).

Table 2.6.1. Key partner countries of South Africa in internationally collaborated publications in "Energy" domain in Scopus for 2008 - 2018

Country	Number of Joint papers with South Africa	Share of a country in all ICPs of South Africa
United States	756	21.97%
United Kingdom	519	15.08%
Germany	397	11.54%
India	396	11.51%
France	328	9.53%
Australia	287	8.34%
Nigeria	277	8.05%
China	259	7.53%
Italy	240	6.97%
Canada	224	6.51%
Netherlands	195	5.67%
Iran	129	3.75%
Sweden	129	3.75%
Norway	107	3.11%
Spain	105	3.05%
Denmark	103	2.99%
Brazil	98	2.85%
Japan	97	2.82%
Poland	95	2.76%
Switzerland	85	2.47%
Austria	82	2.38%
Belgium	80	2.32%
Russian Federation	78	2.27%
Chile	75	2.18%

Finland	73	2.12%
New Zealand	68	1.98%
Saudi Arabia	63	1.83%
Malaysia	59	1.71%
Ireland	58	1.69%
Kenya	52	1.51%
Turkey	52	1.51%
Namibia	50	1.45%
Zimbabwe	50	1.45%

Note: 1. All types of documents except of technical documents, indexed in Scopus are included in the analysis.

Table 2.6.2 shows the leading organizations in South Africa publishing in the domain of Energy with the total number of publications they produced in the last 10 years, as well as the percentage of their contribution in the total scientific output.

Table 2.6.2. Leading organizations of South Africa by number of publications in “Energy” domain in Scopus for 2008 – 2018

Affiliation	Number of pub-lications	Share in all South Africa publications
University of Cape Town	954	11.61%
Universiteit van Pretoria	916	11.15%
University of KwaZulu-Natal	816	9.93%
University of Johannesburg	778	9.47%
North-West University	758	9.22%
Universiteit Stellenbosch	733	8.92%
University of Witwatersrand	553	6.73%
Tshwane University of Technology	463	5.63%
The Council for Scientific and Industrial Research	426	5.18%
University of the Western Cape	289	3.52%
University of South Africa	271	3.30%
Cape Peninsula University of Technology	251	3.05%
Durban University of Technology	161	1.96%
University of the Free State	161	1.96%
Eskom	149	1.81%
Nelson Mandela Metropolitan University	120	1.46%
Central University of Technology, Free State	108	1.31%
University of Fort Hare	107	1.30%
Vaal University of Technology	107	1.30%
Rhodes University	103	1.25%
University of Witwatersrand, School of Chemical and Metallurgical Engineering	98	1.19%
Sasol Technology Pty Ltd	87	1.06%
Pebble Bed Modular Reactor Pty Limited	74	0.90%
NECSA	63	0.77%
University of Venda for Science and Technology	58	0.71%
University of Limpopo	55	0.67%
Meraka Institute	54	0.66%
National Research Foundation	50	0.61%
Ithemba Laboratory for Accelerator-Based Sciences	47	0.57%
Mangosuthu University of Technology	41	0.50%
University of Zululand	38	0.46%
University of KwaZulu-Natal School of Chemical Engineering	36	0.44%
South African Astronomical Observatory	34	0.41%
Mintek	27	0.33%
Agricultural Research Council, Pretoria	26	0.32%

Note: 1. All types of documents except of technical documents, indexed in Scopus are included in the analysis. 2. Organization names are presented as they are spelled in Scopus database.

Semantic analysis of "Energy" domain

This chapter describes the "Sustainable Energy Technologies for the Marginalized" domain and analysis of its thrusts based on the results produced by the iFORA system. First, the full domain is described with a domain map including all of the topics covered. Then each of the thrusts is described by the emerging topics identified by iFORA. The second section presents topic clusters under each thrust with more detailed network maps with descriptions of emerging issues under them. Figure 2.6.3 shows the entire domain of "Sustainable Energy Technologies for the Marginalized (EN)" with its clusters and interrelations to each other. A detailed analysis of Figure 2.6.3 provides an overview of EN thrusts and a number of existing and emerging topics for consideration under each of them. These are presented in Table 2.6.3. In the following section network maps are given to illustrate these maps and further issues emerging under each of them.

Table 2.6.3. "Sustainable Energy Technologies for the Marginalized" thrusts and topics

EN Thrusts	Topics emerging under each thrust
EN1: Clean, affordable and sustainable energy for all	"Conventional energy sources" (Fig. 2.6.4)
	"Clean and renewable energy" (Fig. 2.6.5)
	"Bioenergy" (Fig. 2.6.6)
	"Energy policy" (Fig. 2.6.7)
	"Carbon emissions policy" (Fig. 2.6.8)
	"Energy costs and tariffs" (Fig. 2.6.9)
EN2: Renewable Energy sources and technologies	"Solar energy" (Fig. 2.6.10)
	"Wind energy" (Fig. 2.6.11)
EN3: Energy efficiency solutions for industry plus household use	"Energy efficiency" (Fig. 2.6.12)
	"Energy system" (Fig. 2.6.13)
EN4: Distributed energy generation and storage	"Distributed energy generation" (Fig. 2.6.14)
	"Grid energy generation" (Fig. 2.6.15)

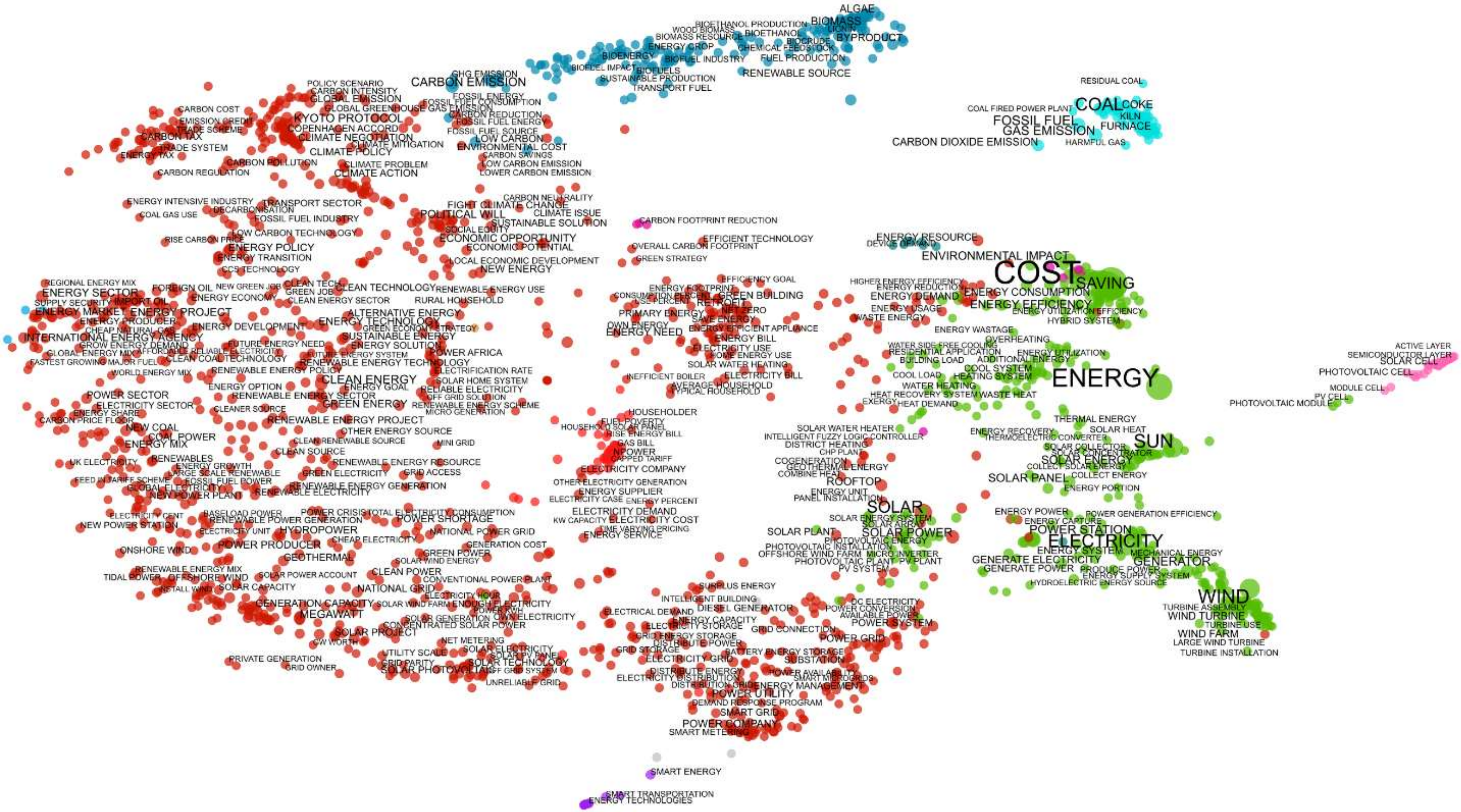

Figure 2.6.3. "Sustainable Energy Technologies for the Marginalized" domain full semantic map for 2014-2018

"Sustainable Energy Technologies for the Marginalized" Thrusts

EN1: Clean, affordable and sustainable energy for all

Although renewable energy sources are used increasingly, it is expected that the conventional sources of energy will still have a considerable proportion in the energy mix in the next few decades to come. However, scientific and technological innovations should be introduced for the sustainable use of the conventional energy sources. South Africa is rich in coal reserves and the dependency of the country on fossil fuels is still high. In order to use these conventional sources in a more sustainable way, carbon dioxide emissions generated by them should be reduced, especially generated by the coal-fired power plants (Figure 2.6.4).

Figure 2.6.4. "Conventional energy sources"

Meanwhile, rich potentials of South Africa on clean and renewable energy sources also need to be exploited. Particularly, the potentials for solar energy are high in the country. There is a need to develop a more holistic and integrated approach for renewables in South Africa, including, the technologies for providing clean and renewable energy sources; solutions for urban and rural areas, such as smart grids in cities and micro energy generation in rural and remote areas; setting up energy storage systems; as well as building necessary technological and skills capacity in the country along with green jobs (Figure 2.6.5).

Figure 2.6.5. "Clean and renewable energy"

Besides solar energy, South Africa also has great potentials on Bioenergy. Energy and fuel production from biomass, bioethanol and algae appear to be promising areas for development. A modern biofuel industry with sustainable production principles can be among the main suppliers of the transport fuel in the country (Figure 2.6.6).

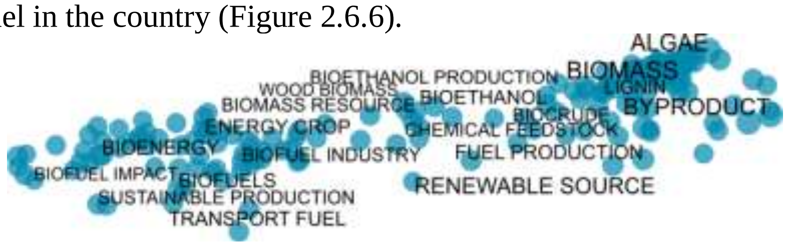

Figure 2.6.6. "Bioenergy"

Providing clean, affordable and sustainable energy for all requires efficient energy policies. Green principles should be at the backbone for the energy policy with an overall aim of providing low cost and low carbon footprint energy for all in the county. Necessary political will should be in place in order to make sure that long term commitment for climate change mitigation, carbon neutrality and social equity targets can be achieved (Figure 2.6.7).

Figure 2.6.7. "Energy policy"

Within energy policy, carbon emissions policy appears to have a special emphasis. Reduction of emissions from fossil fuels is the main global, regional and national priority. There are climate targets and commitments agreed in Kyoto protocol and in other international agreements. There is always a question on how to fund carbon reduction efforts. Carbon regulations and taxation schemes have been implemented to reduce emissions and generate income for scientific and technological innovations to meet emission targets. There is a need for widespread implementation of policy measures at all levels of governance from macro to micro levels – e.g. individual carbon credit/taxation systems (Figure 2.6.8).

Figure 2.6.8. "Carbon emissions policy"

While innovating for new and renewable energy sources, and reducing carbon emission levels, there are expectations by the society for affordable energy. Costs and tariffs need to be balanced to make sure that society, particularly the marginalized, has access to sustainable energy supply. Among alternative ways of energy generation, household solar panel appears to be a technological solution. However, at present this has a limited use. Necessary solutions should be developed for balancing energy demand and supply, tariffs and services (Figure 2.6.9).

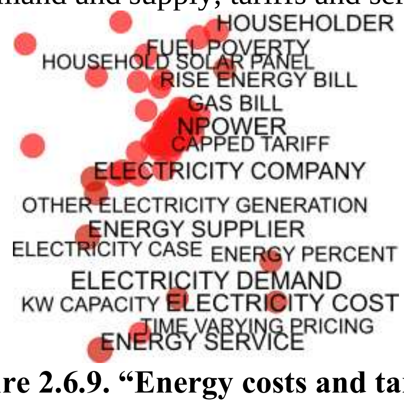

Figure 2.6.9. "Energy costs and tariffs"

EN2: Renewable Energy sources and technologies

Regarding renewable energy sources and technologies, the analysis revealed that solar and wind energy should be high on the agenda in South Africa. As mentioned earlier, the country has considerable potentials for solar energy. This solution is particularly useful for the marginalized to meet their energy demand at an affordable price. Similarly, large-scale solar farms have been implemented in a number of countries for generating large amounts of energy. Widespread implementation of solar energy solutions requires overcoming several technological and technical challenges such as solar energy collection, conversion and combination (Figure 2.6.10).

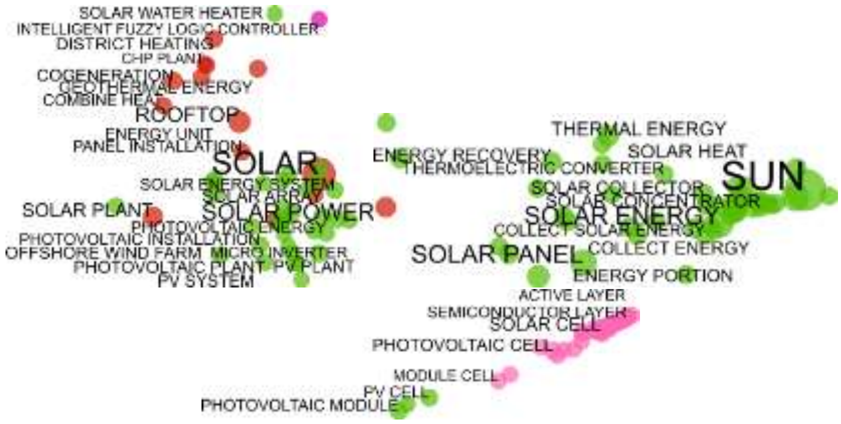

Figure 2.6.10 “Solar energy”

Besides solar energy, South Africa has considerable potentials for wind energy. Issues around the wind energy include the installation of wind turbines and setting up wind farms both on the land and offshore (Figure 2.6.11).

Figure 2.6.11. “Wind energy”

EN3: Energy efficiency solutions for industry plus household use

In addition to energy generation concerns, the consumption aspect should also be at the forefront. Energy costs and expenses can be reduced through the energy efficiency solutions both at the industrial and household levels. Heating and cooling systems should be efficient with lesser demand. Besides devices, building design and technologies should be developed for reduced energy consumption and energy waste (Figure 2.6.12).

Figure 2.6.12. “Energy efficiency”

Recent years have seen advancements in developing smart energy systems with greater power generation efficiency, better energy capture, and lesser grid loss. Besides smart energy, smart transport systems should have a higher priority on the South African development agenda (Figure 2.6.13).

Figure 2.6.13. “Energy system”

EN4: Distributed energy generation and storage

Generating energy near the points of consumption is crucial for achieving greater efficiencies, lesser loses and reduced costs, particularly for the marginalized, who live in far and remote areas of the country. Energy generation, transfer and storage are among the areas for innovation in distributed energy. Furthermore, any use of advanced energy technologies will require setting up smart technologies like smart grids and metering systems (Figure 2.6.14).

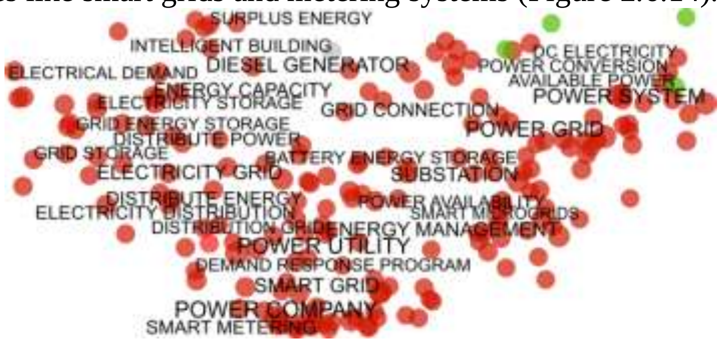

Figure 2.6.14. "Distributed energy generation"

Figure 2.6.15 elaborates the issues around grid energy generation for aforementioned high technology and renewable energy systems. Transition into new energy systems may require an initial investment, however, in the medium to long term they will pay off with cheaper, cleaner and more sustainable solutions.

Figure 2.6.15. "Grid energy generation"

Dynamics of “Energy” domain thrusts

In this section, the dynamics of the “Energy” domain thrusts are shown based on their frequency of occurrence in the documents indexed in the iFORA database. Among the thrusts EN3 (Energy efficiency solutions for industry plus household use) appears to be the highest on the agenda (Figure 2.6.16).

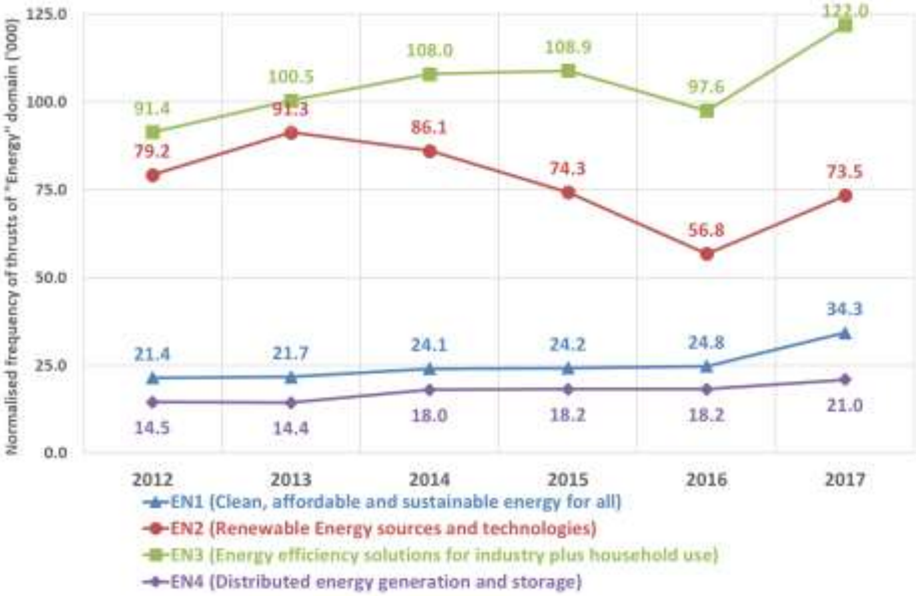

Figure 2.6.16. Normalized frequency of all terms related with thrusts of “Sustainable Energy Technologies for the Marginalized” (Energy) domain ('000) in 2012 – 2017

Note: “Normalized frequency” for a specific thrust is a total normalized number of mentions (in thousands) of all terms (that are shown on a semantic map) related with this specific thrust in documents indexed in IFORA for a given year.

Table 2.6.4 illustrates to what extent the "Energy" domain thrusts address the challenges. Naturally, most of the thrusts in this domain are strongly linked to affordable energy (EN1, EN2 and EN3). EN4 appears to be highly linked with job creation. EN1 is also addressing the carbon emission reduction challenge.

Table 2.6.4. Impacts of all thrusts of "Energy" domain on challenges

Challenges	Energy			
	EN1	EN2	EN3	EN4
Affordable Education	0.0	0.0	0.0	0.0
Affordable Energy	553.7	103.8	117.0	3.0
Affordable Food	4.0	2.0	0.0	1.0
Carbon Emission Reduction	94.0	17.0	3.0	2.0
Clean Water Access	1.0	0.0	0.0	0.0
Crime Prevention	1.0	4.5	11.0	0.0
Crime Reduction	0.0	0.0	0.0	1.0
Economy Growth	5.0	1.0	0.0	1.0
Employment Growth	25.0	3.8	2.0	1.0
Export Growth	4.0	3.5	0.0	1.0
High Living Standard	1.0	2.0	0.0	3.0
High Quality Health Care Service	0.0	0.0	0.0	0.0
Income Growth	6.0	16.3	19.0	1.0
Job Creation	49.0	36.0	5.0	50.5
Low Greenhouse Gas Emission	12.3	35.0	64.0	1.0
Low Mortality	0.0	1.0	0.0	0.0
Population Growth	129.0	22.4	1.0	4.7
Poverty Alleviation	9.0	5.5	0.0	4.0
Reduce Water Demand	1.0	3.0	4.0	0.0
Renewable Energy Growth	44.0	7.3	0.0	0.0
Rural Community	10.5	22.3	2.0	26.0
Secure Water Supply	1.0	1.0	4.0	0.0
Skill Improvement	0.0	0.0	0.0	0.0
Universal Broadband Access	0.0	0.0	0.0	0.0

Notes: 1. Value in each specific cell of this table is a normalised number of co-occurrences of all terms (that are shown on a semantic map) related with a specific thrust (e.g. Thrust EN1) and a specific challenge (e.g. "Low Mortality") in documents indexed in iFORA database for 2012 – 2017. This value is treated as an impact of a specific thrust onto a specific challenge. 2. Cells are colored by bars as follows: within a column of a specific thrust the biggest green bar means the challenge for which this specific thrust has the highest impact.

2.7. EDUCATION FOR THE FUTURE (EDUCATION) DOMAIN

Overall description of the domain

Education is a foundation of a fair society and successful economy. Towards the 2030s, South Africa wishes to provide all its citizens with quality education as a human right. Currently the public education system suffers from the problems of effectiveness of mathematics and science. Citizens of the country, particularly in rural areas, have expectations for accessing quality learning opportunities. Technology provides an ever-growing range of opportunities to provide this access. New and alternative learning technologies will not only give people basic education, but will also equip them with necessary skills for the future, while reducing divides in the society. Besides implementing new technologies, curriculum should also be developed in line to enable people to be more creative with skills for idea generation and problem solving.

Overview of research potential of South Africa in “Education” domain

Figure 2.7.1 shows that there is a growing scientific emphasis on the “Education” domain in South Africa. Although the number of publications is relatively low compared to other STI domains, some growth has been observed, particularly in year 2014. In recent years, share of South Africa’s contribution to total scientific pool has accessed 1.22% with the high of 1.44% in 2014.

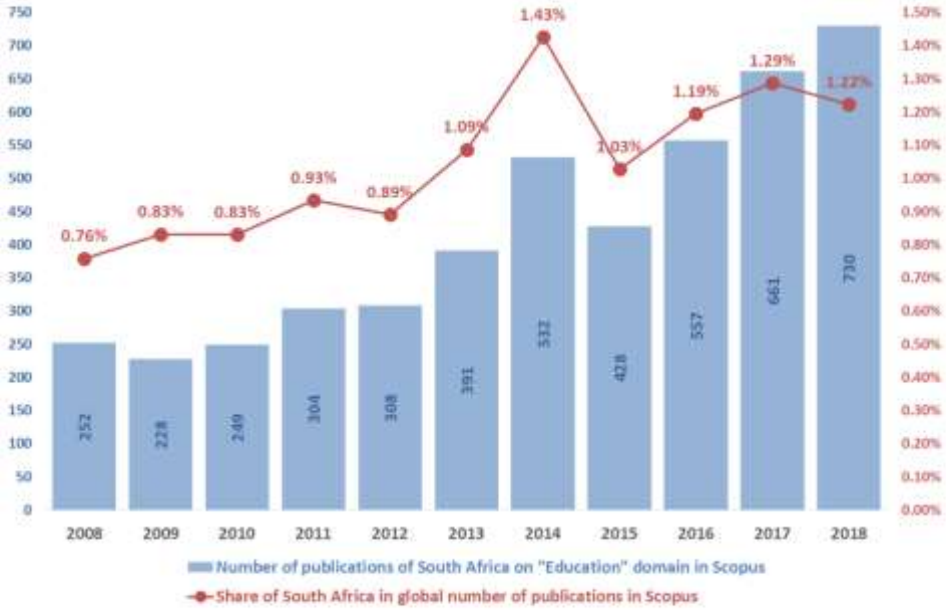

Figure 2.7.1. Dynamics of publications of South Africa in “Education” domain in Scopus in 2008 – 2018

Note: all types of documents except of technical documents, indexed in Scopus are included in the analysis.

Figure 2.7.2 shows the leading countries in the Education domain. Compared to other domains South Africa is positioned high in this domain with the 16th place.

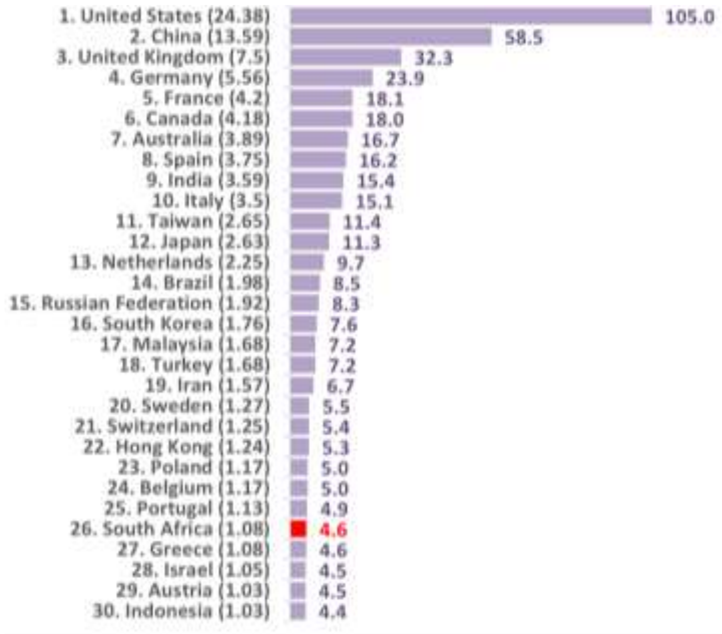

Figure 2.7.2. Leading countries by number of publications ('000) on "Education" domain in Scopus for 2008 – 2018

Note: 1. All types of documents except of technical documents, indexed in Scopus are included in the analysis. 2. Share of a country in global number of publications is shown in parenthesis.

Among the key partner countries of South Africa are the United States, the United Kingdom, Germany, Australia and Canada. Nigeria comes as the first African collaborator with the 9th place among the top collaborators (Table 2.7.1).

Table 2.7.1. Key partner countries of South Africa in internationally collaborated publications in "Education" domain in Scopus for 2008 - 2018

Country	Number of Joint papers with South Africa	Share of a country in all ICPs of South Africa
United States	300	21.60%
United Kingdom	265	19.08%
Germany	122	8.78%
Australia	111	7.99%
Canada	108	7.78%
Netherlands	84	6.05%
China	81	5.83%
Sweden	63	4.54%
Nigeria	56	4.03%
India	55	3.96%
France	53	3.82%
Belgium	51	3.67%
Zimbabwe	48	3.46%
Italy	40	2.88%
Spain	38	2.74%
Switzerland	38	2.74%
Greece	34	2.45%
Russian Federation	32	2.30%
South Korea	31	2.23%
Finland	30	2.16%
Norway	30	2.16%
Pakistan	29	2.09%
Ghana	24	1.73%
Austria	23	1.66%
Botswana	22	1.58%

Kenya	22	1.58%
Denmark	21	1.51%
Turkey	21	1.51%
Brazil	20	1.44%
Czech Republic	20	1.44%

Note: 1. All types of documents except of technical documents, indexed in Scopus are included in the analysis.

Table 2.7.2 shows the leading organizations in South Africa publishing in the domain of Education with the total number of publications they produced in the last 10 years, as well as the percentage of their contribution in the total scientific output.

Table 2.7.2. Leading organizations of South Africa by number of publications in "Education" domain in Scopus for 2008 – 2018

Affiliation	Number of publications	Share in all South Africa publications
University of South Africa	536	11.55%
Universiteit van Pretoria	518	11.16%
University of Witwatersrand	463	9.98%
University of Cape Town	455	9.81%
University of KwaZulu-Natal	418	9.01%
University of Johannesburg	387	8.34%
North-West University	358	7.72%
Universiteit Stellenbosch	327	7.05%
University of the Free State	195	4.20%
University of the Western Cape	170	3.66%
Tshwane University of Technology	139	3.00%
Cape Peninsula University of Technology	125	2.69%
Rhodes University	117	2.52%
The Council for Scientific and Industrial Research	89	1.92%
Nelson Mandela Metropolitan University	83	1.79%
South African Medical Research Council	65	1.40%
Durban University of Technology	64	1.38%
Central University of Technology, Free State	64	1.38%
University of Fort Hare	56	1.21%
University of Limpopo	55	1.19%
Human Sciences Research Council of South Africa	54	1.16%
Meraka Institute	47	1.01%
Vaal University of Technology	39	0.84%
Walter Sisulu University	38	0.82%
University of Zululand	37	0.80%
University of Venda for Science and Technology	37	0.80%
Mangosuthu University of Technology	15	0.32%
University of Cape Town, Faculty of Health Sciences	11	0.24%
The Nelson R. Mandela Medical School	10	0.22%

Note: 1. All types of documents except of technical documents, indexed in Scopus are included in the analysis. 2. Organization names are presented as they are spelled in Scopus database.

Semantic analysis of "Education" domain

This section describes the "Education for the Future" domain and analysis of its thrusts based on the results produced by the iFORA system. First, the full domain is described with a domain map including all of the topics covered. Then each of the thrusts is described by the emerging topics identified by iFORA. The next section presents topic clusters under each thrust with more detailed network maps with descriptions of emerging issues under them. Figure 2.7.3 shows the entire domain of "Education for the Future (ED)" with its clusters and interrelations to each other. A detailed analysis of Figure 1 provides an overview of ED thrusts and a number of existing emerging topics for consideration under each of them. These are presented in Table 2.7.3. In the following section network maps are given to illustrate these maps and further issues emerging under each of them.

Table 2.7.3. "Education for the Future" thrusts and topics

ED Thrusts	Topics emerging under each thrust
ED1: Skills for the 4th Industrial Revolution	"Technology development" and "Digitalization (Fig. 2.7.4)
	"Innovation and entrepreneurship" and "Creativity, problem solving and idea generation" (Fig. 2.7.5)
ED2: Inclusive innovation & development	"Inclusive development" and "Employment and job search" (Fig. 2.7.6)
	"Student career development" and "preschool learning" (Fig. 2.7.7)
ED3: Curriculum development 2030	"Curriculum development" (Fig. 2.7.8)
	"Skill development" and "Basic skills" (Fig. 2.7.9)
	"Primary and secondary school" (Fig. 2.7.10)
	"Higher education system" (Fig. 2.7.11)
	"Engineering education" (Fig. 2.7.12)
	"Online education" (Fig. 2.7.13)
	"Education policy" (Fig. 2.7.14)

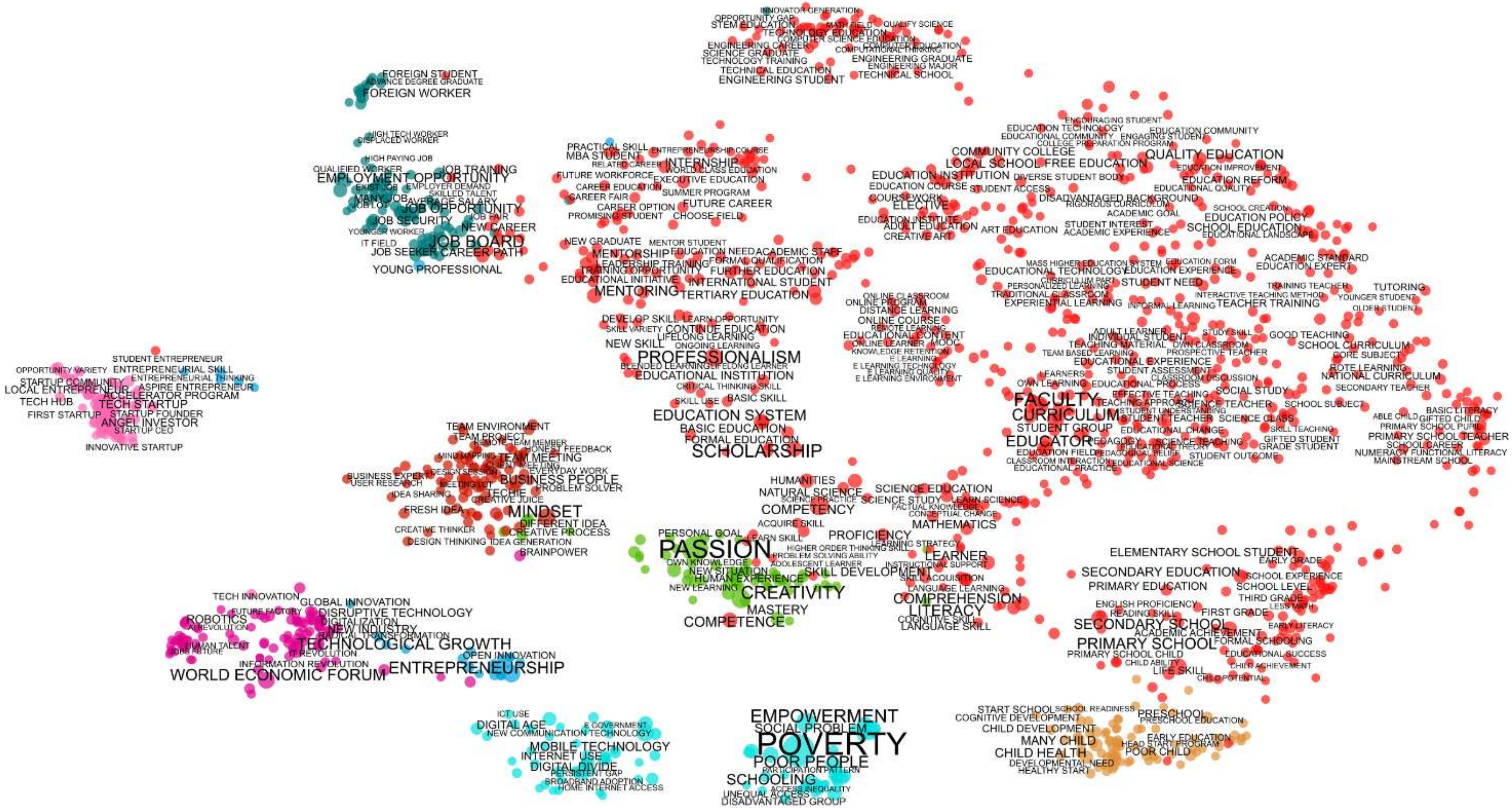

Figure 2.7.3. "Education for the Future" domain full semantic map for 2014-2018

“Education for the Future” Thrusts

ED1: Skills for the 4th Industrial Revolution

Innovations and transformations always require new skills and capabilities. The 4th Industrial Revolution is not an exception. Two of the main drivers of the 4th Industrial Revolution are technology development and digitalization. There are a number of technologies, which are likely to bring disruptions. Among them are robotics, Artificial Intelligence and new methods for production. The digitalization trend itself transforms economy, energy, health, communication and all other industries. In the age of digitalization, it is important for society to be a part of the process. At the very basic level most of the students, if not all, need to have Internet access with higher broadband adoption rates. Failing in providing Internet access to the society and marginalized may increase the digital divide in society (Figure 2.7.4).

Figure 2.7.4. “Technology development” (left) and “Digitalization (right)

New technological developments and new jobs to be created will require development of new skills and capabilities. These include innovation and entrepreneurship skills. Particularly innovative start-ups are likely to make social, economic and technological contributions, while generating highly qualified and skilled employment. In order to start such initiatives, it is important to create a culture of entrepreneurial thinking, skills and programs for supporting young entrepreneurs. Furthermore, new industrial revolution will also require skills like creativity, problem solving and idea generation, which are the keys for innovation. Design thinking, teamwork, and critical thinking appear to be other important skills, which will make a difference for humans in the age of smart technologies and machines (Figure 2.7.5).

Figure 2.7.5. “Innovation and entrepreneurship” (left) and “Creativity, problem solving and idea generation” (right)

ED2: Inclusive innovation & development

Inclusive innovation and development require empowerment of poor people and disadvantaged groups into the process of innovation. Education and schooling are certainly the first steps in generating awareness and achieving greater inclusivity. Education should be supported with a continuous empowerment through the generation of new and highly qualified jobs for younger people. Regular and higher income jobs with clear career paths will help to create a healthier society with a more sustainable economic system and greater possibilities for the marginalized (Figure 2.7.6).

Figure 2.7.6. "Inclusive development" (left) and "Employment and job search" (right)

Career development should be started from the earlier levels of education even starting at the pre-school level. At the school level students should be provided necessary mentorship and guidance. Future career options should be shown to them. Promising students should be directed towards future careers where they may indicate higher potentials in tertiary and higher education. The process can actually begin at the preschool stage. Child development, readiness for school, and cognitive development are among the most important factors for a healthy start to school and future careers. Poor children also need to be considered at this stage for their successful integration into inclusive innovation and development processes (Figure 2.7.7.).

Figure 2.7.7. "Student career development" (left) and "preschool learning" (right)

ED3: Curriculum development 2030

Continuous curriculum development is a must for the education system to prepare students for the future. This holds true for all levels of education from pre-/primary school to higher education. New curriculum to be developed should allow up-to-date teaching materials and effective teaching methods, and should allow an interactive process with students actively involved in classroom discussions and working in teams where possible. Good teaching practices should be developed and should be made widespread across schools. Continuous education of educators is also a must for adapting teachers into new teaching methods with relevant teaching materials (Figure 2.7.8).

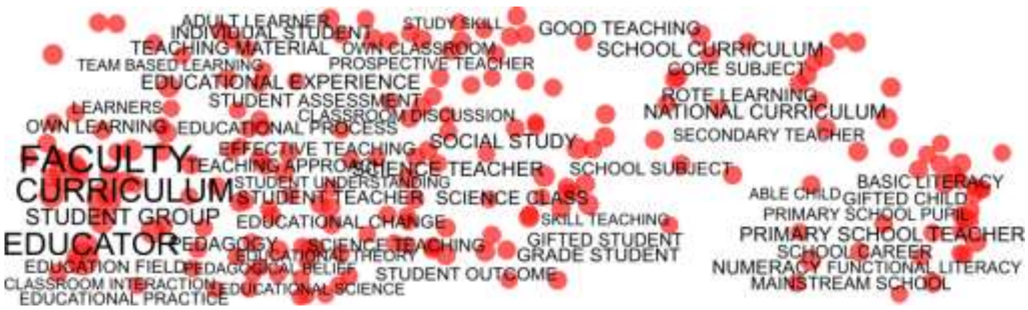

Figure 2.7.8. "Curriculum development"

Curriculum development should help to develop skills for the new industrial developments discussed earlier. As mentioned earlier, new curriculum to be developed should contribute to cognitive and critical thinking skills, as well as creativity and problem solving abilities. For sure, the knowledge society enabled by new technologies require a solid science education, mathematics and language learning as basic skills (Figure 2.7.9).

Figure 2.7.9. “Skill development” (left) and “Basic skills” (right)

Starting from the primary school, reading and language seem to be important skills to be gained. Understanding children’s potentials from the early ages is important for future educational success (Figure 2.7.10).

Figure 2.7.10 “Primary and secondary school”

Similarly, at the level of higher education, it is important to increase academic and educational standards. Newest educational technologies should be exploited to enable experiential and personalized learning with interactive teaching methods (Figure 2.7.11).

Figure 2.7.11. “Higher education system”

In relation the new industrial revolution and curriculum development to address the emerging scientific and technological needs, an overhaul in the engineering education is crucial. Science, computer, mathematics and technical education will remain at the core of the engineering curriculum (Figure 2.7.12).

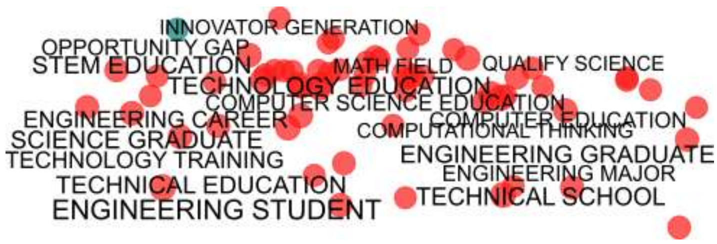

Figure 2.7.12. “Engineering education”

The increasing use of Information and Communication Technologies will also have implications on the way education is delivered. There is an increasing trend for delivering courses online. This will enable possibilities for distant learning, which would also help the marginalized and remote layers of the society to access the education systems. For instance, MOOC courses enable accessing online courses not at the national level, but also at the global level from all centers of excellence in the world. Necessary e-learning technologies, infrastructure and ecosystem need to be set up to enable online education (Figure 2.7.13).

Figure 2.7.13. "Online education"

In order to implement the aforementioned transformations in the education system, there is a need for efficient education policies. There are a wide variety of issues to be addressed. Overall, the quality of the education should be increased at all levels. Particularly for the marginalized and disadvantaged parts of the society education should be delivered for free or at least at minimal costs for increased access. Besides student education, adult education should also be given emphasis so that there will not be educational, social or technological divides in the society. Scientific and technical skills are important, however, necessary education for creativity and arts should also be delivered in a balanced way. Community colleges and local schools should be empowered (Figure 2.7.14).

Figure 2.7.14. "Education policy"

Dynamics of "Education" domain thrusts

In this section, the dynamics of the "Education" domain thrusts are shown based on their frequency of occurrence in the documents indexed in the iFORA database. Among the thrusts ED1 (Skills for the 4th Industrial Revolution) and ED3 (Curriculum development 2030) appear to be the highest on the agenda. ED2 remains largely insignificant (Figure 2.7.15).

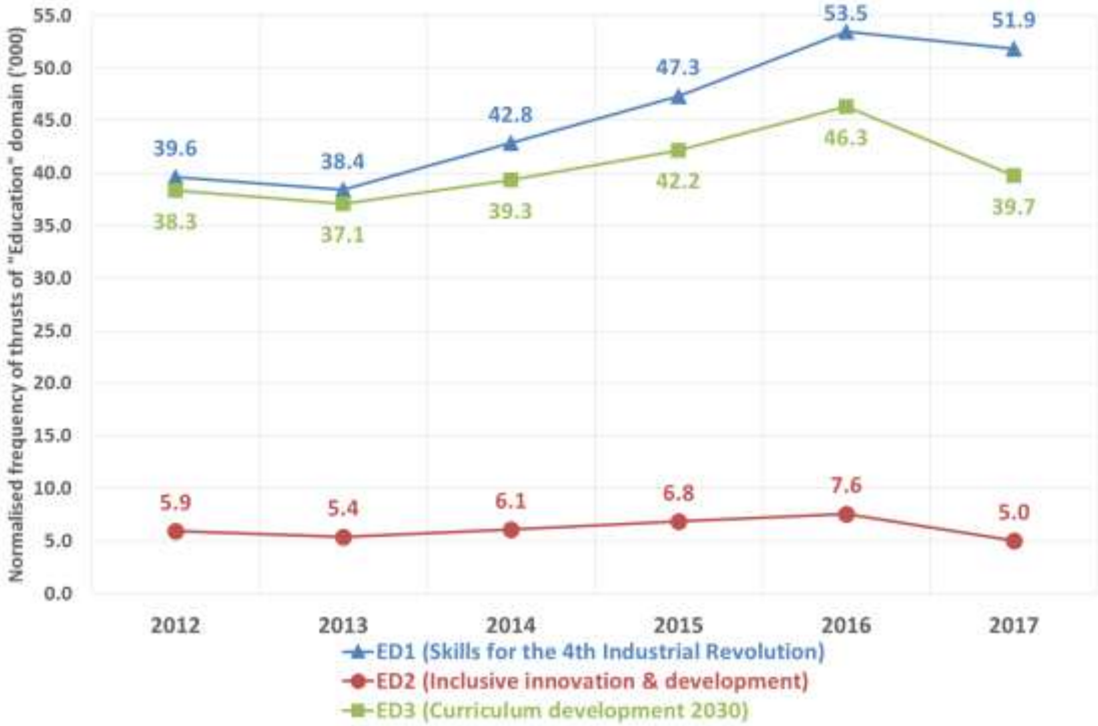

Figure 2.7.15. Normalized frequency of all terms related with thrusts of "Education" domain ('000) in 2012 – 2017

Note: "Normalized frequency" for a specific thrust is a total normalized number of mentions (in thousands) of all terms (that are shown on a semantic map) related with this specific thrust in documents indexed in IFORA for a given year.

Furthermore, Table 2.7.4 illustrates to what extent the "Education" domain thrusts address the challenges. Education thrusts are linked to job creation and employment growth with contributions in addressing rural community, population growth and skill improvement.

Table 2.7.4. Impacts of all thrusts of "Education" domain on challenges

Challenges	Education		
	ED1	ED2	ED3
Affordable Education	0.0	0.0	14.0
Affordable Energy	0.0	0.0	3.3
Affordable Food	0.0	0.0	0.0
Carbon Emission Reduction	1.5	0.0	0.0
Clean Water Access	0.0	0.0	0.0
Crime Prevention	1.0	0.0	4.0
Crime Reduction	1.0	0.0	1.0
Economy Growth	0.0	0.0	0.0
Employment Growth	6.0	2.0	2.5
Export Growth	3.0	0.0	2.0
High Living Standard	1.0	0.0	9.0
High Quality Health Care Service	0.0	0.0	0.0
Income Growth	0.0	0.0	9.5
Job Creation	7.0	1.0	71.3
Low Greenhouse Gas Emission	0.0	0.0	1.0
Low Mortality	0.0	0.0	0.0
Population Growth	4.3	0.0	3.3
Poverty Alleviation	1.0	0.0	6.0
Reduce Water Demand	0.0	0.0	0.0
Renewable Energy Growth	0.0	0.0	0.0
Rural Community	3.7	0.0	32.0
Secure Water Supply	0.0	0.0	0.0
Skill Improvement	3.5	0.0	0.0
Universal Broadband Access	0.0	0.0	0.0

Notes: 1. Value in each specific cell of this table is a normalized number of co-occurrences of all terms (that are shown on a semantic map) related with a specific thrust (e.g. Thrust ED1) and a specific challenge (e.g. "Low Mortality") in documents indexed in iFORA database for 2012 – 2017. This value is treated as an impact of a specific thrust onto a specific challenge 2. Cells are colored by bars as follows: within a column of a specific thrust the biggest green bar means the challenge for which this specific thrust has the highest impact.

3. CONCLUSIONS

Development of internationally competitive science and technology is able to contribute to the creation of national wealth and societal progress is among the key prerequisite of success for any big nation including South Africa. Selection of promising fields of research and relevant areas of practical applications of scientific findings is one of major issues for national science and technology policy. The “South Africa Science, Technology and Innovation (STI) Foresight for 2030” identifies seven STI domains and related priorities (thrusts) to be addressed by national innovation strategies in the decade to come.

The review of current state and prospects of national capacities in these domains and thrusts presented in the report is based on a comprehensive semantic analysis of big data as well as on the analysis of publication activities. The country’s research landscape, its strengths and weaknesses, benchmark vis-à-vis global leaders and leading research institutions, scientific specializations and international partners: one can find a lot of detailed information on all this issues in the report. A big number of visual presentations, graphs and tables provide a broad picture of the national science and technology capacities and, on the other hand, show key economic and societal problems to be resolved with the use of these capacities.

New technologies have to serve needs of society and society is changed by new technologies. The analysis of STI domains and thrusts shows how important is co-evolutionary development of science and technology and society. Comparing the scientific output with the priority STI domains and thrusts, the present report indicate that in some areas of STI, such as ICTs, South Africa’s position is research is relatively low, despite the fact that almost all seven STI domains are closely linked to the development of ICTs. In this way, the report shows somewhat the feasibility of the STI goals and targets. Strategies need to be developed to implement a balanced development of research, capacities, skills and infrastructures.

Being one of the first examples of using big data for setting STI priorities, the present report can also help to derive new ideas for researchers, setting agendas and promoting systematic planning among policy-makers and better use of new technologies by industries, it might also help all of them and ordinary citizens to be better prepared for the future.

ANNEX: Methodological Notes

We built the present study on the "Intelligent Foresight Analytics System" (iFORA), which was developed by the National Research University Higher School of Economics (HSE). The documents fed into the system were collected from open data sources: scientific articles from CrossRef database[5], United States Patent and Trademark Office (USPTO) patents[6], National Science Foundation (NSF) grant awards[7], news feed and media publications of influential media and sectoral organizations (e.g. MIT Technology Review, CNN), analytical reports of international organizations (e.g. Food and Agriculture Organization of United Nations, FAO). Metadata, such as titles, publication dates, lists of authors, organizations, were processed by the PostgreSQL[8] database for further statistical analysis.

Figure 4.1 describes iFORA's main data sources, architecture and main technologies applied:

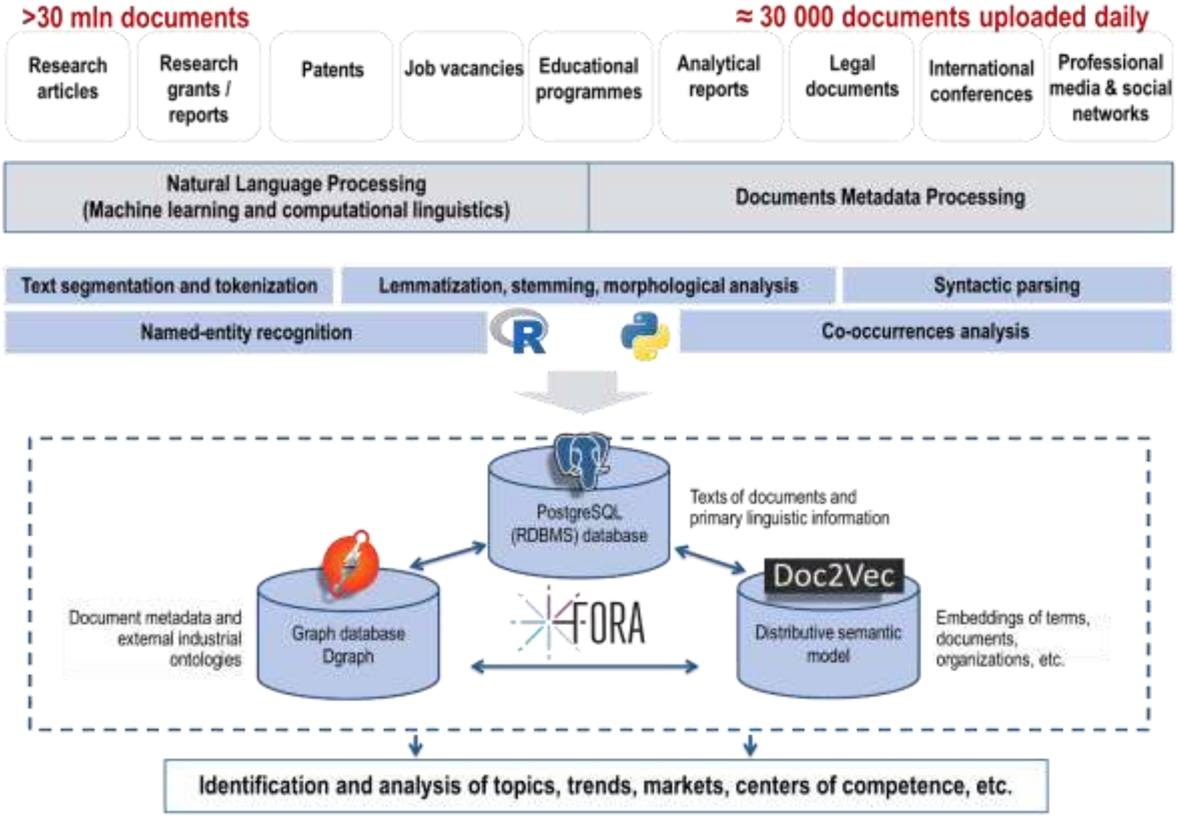

Figure 4.1. iFORA: sources, architecture and technologies

The analysed texts (including titles, abstracts, patent claims, etc.) were split into separate sentences, words, lemmas and stems with all morphological characteristics for natural language processing with Python's open software package Spacy[9]. Syntactic analysis of dependencies between words, particularly adjective modifiers and compounds of Universal Dependencies[10], helped to identify key phrases for each sentence. Figure 4.2 shows schematically how the process was done:

[5] https://www.crossref.org/
[6] https://www.uspto.gov/
[7] https://www.nsf.gov/awardsearch/
[8] https://www.postgresql.org/
[9] https://spacy.io/
[10] http://universaldependencies.org/u/dep/index.html

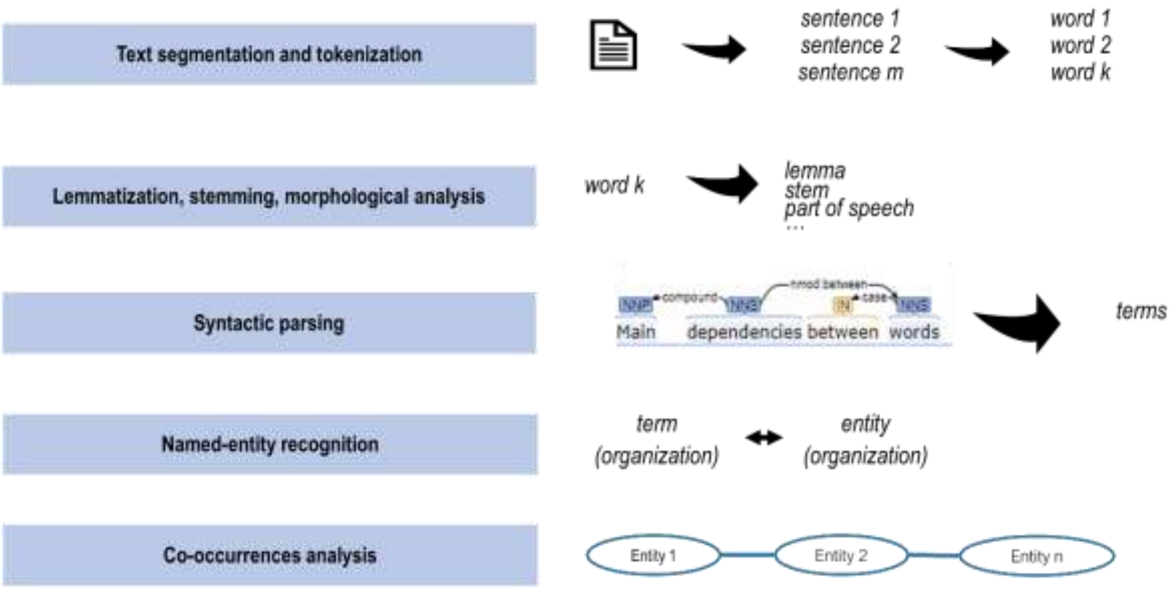

Figure 4.2. iFORA's NLP pipeline

The system follows best practices of words' semantic meaning identification (Mikolov, et al., 2013; Pennington, et al., 2014; Bojanowski, et al., 2017) to strengthen natural language processing with word embeddings. These word embeddings build numeric n-dimensional vector representation in the same vector space for each term in iFORA's 30 million documents. The distributed semantic skip-gram model was trained using neural network technology called word2vec/doc2vec as part of the Python package gensim[11]. The model used 200 parameters for building vector spaces with a minimal occurrence of 5 terms, window size of 6 terms and hierarchical SoftMax optimization of neural network hidden layer weights for each term. Figure 4.3 demonstrates the process of training iFORA's distributed semantic model:

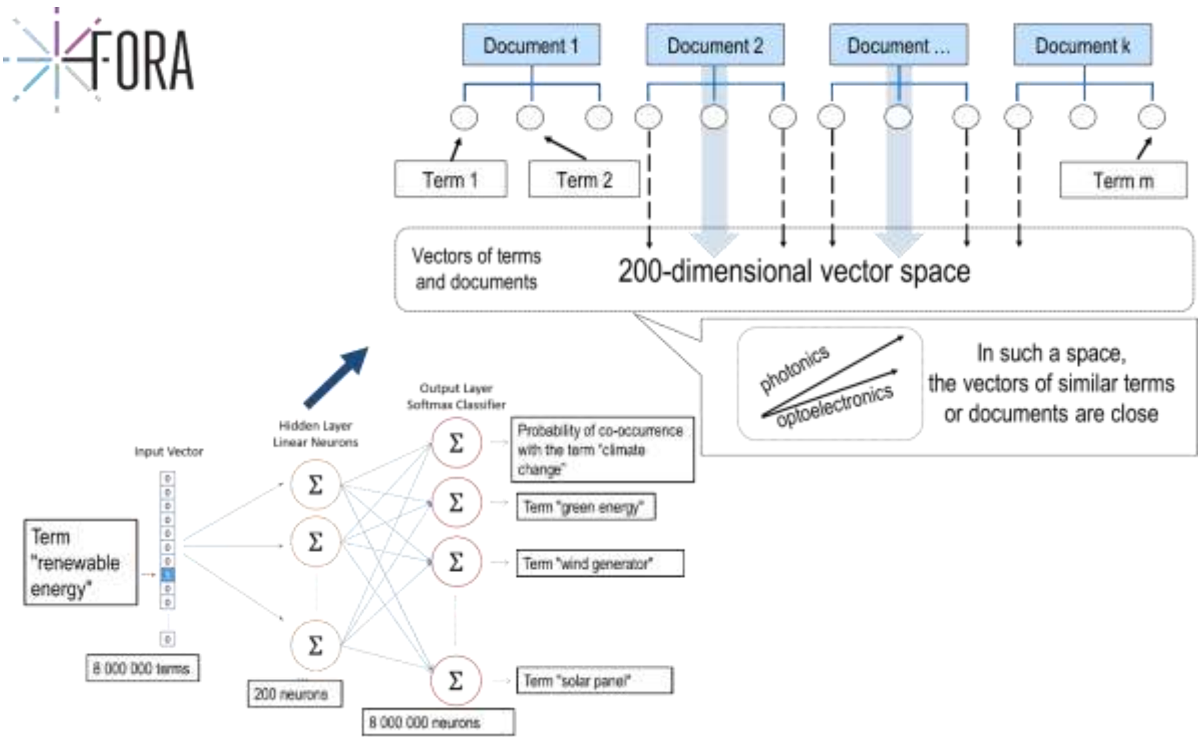

Figure 4.3. Training of iFORA's distributed semantic model

[11] https://radimrehurek.com/gensim/models/word2vec.html

The initial keywords were extracted from domain and thrust descriptions made by South African experts.

The system searched for all related terms in thematic proximity. For each keyword, the top-100 terms with the cosine similarity not less than 0.6 were identified. The metric of similarity in the 200-dimensional vector space is further described by following formula (1):

$$CosSim_{A,B} = \frac{\sum_{i=1}^{n=200}(A_i * B_i)}{\sqrt{\sum_{i=1}^{n=200}(A_i^{\,2})} * \sqrt{\sum_{i=1}^{n=200}(B_i^{\,2})}} \quad (1)$$

A, B – two terms being compared,

A_i – i^{th} value of the term A in 200-dimensional vector representation,

B_i – i^{th} value of the term B in 200-dimensional vector representation.

The clustering of terms for each domain into groups (or, in semantic meaning *topics*) was based on the following algorithm:

1. *principal component analysis (PCA)* reduced the dimensionality of terms from 200 dimensions to 50 based on Python's open software package sklearn.decomposition[12];
2. *t-distributed stochastic neighbor embedding (t-sne)* calculated coordinates of each term in 2-dimensional space from 50 pca parameters using Python's open software package sklearn.manifold[13];
3. the clustering of terms based on *average cosine similarity hierarchical clustering.*

Further to expand the corpus of keywords that are searched within iFORA framework the tool multiplier of scientific and technical search terms that provides a deep search for specific information and minimizes the work of analysts on the selection of the relevant keywords. Figure 4.4 shows the result of application of multiplier of scientific and technical terms for the search queries "aviation" and "aircraft". They analysis of this figure shows how multiplier of scientific and technical terms works. The initial search query, containing two terms "aviation" and "aircraft", were expanded ("multiplied") to 500 terms in databases of professional media information sources (proxy for markets), to 400 terms in databases of scientific publications (proxy for science) and to over 600 terms in patent databases (proxy for technology). The words that are most commonly associated with given search terms are more prominently highlighted. Such an analysis is carried out is much faster than a similar work of a general analyst on reaching and selection of the relevant terms that are related with "aviation" and "aircraft".

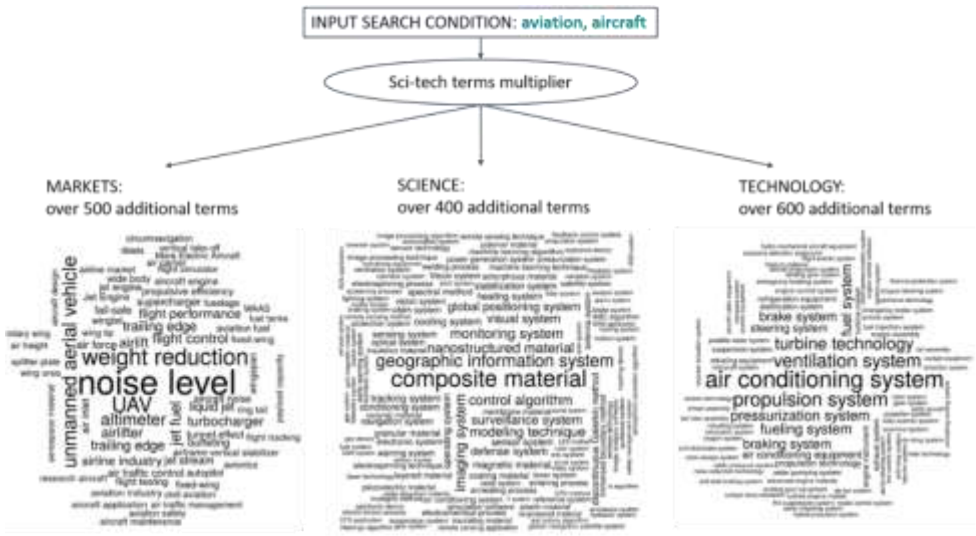

Figure 4.4. Multiplier of scientific and technical terms in global aircraft industry

Source: HSE ISSEK iFORA.

[12] http://scikit-learn.org/stable/modules/generated/sklearn.decomposition.PCA.html

[13] http://scikit-learn.org/stable/modules/generated/sklearn.manifold.TSNE.html

Table 4.1 presents as example the list of keywords related with four thrusts of (Nutrition) domain.

Table 4.1. Initial List of keywords related with thrusts of “Nutrition Security for a Healthy Population” (Nutrition) domain that were uploaded to multiplier of scientific and technical search terms

Thrusts of “Nutrition” domain	Terms uploaded to multiplier of scientific and technical search terms
NU1 (Zero Impact Agriculture)	aquaponic; aquaponics; desalination; drought tolerance; food basket; food security; healthy meal; local agriculture; nutritional improvement; smallholder farmer; small-scale farming; sustainable agriculture; sustainable food production; water quality enhancement; water scarcity
NU2 (Use and acceptance of modern biotechnology)	biotech crop; disease resistant crop; food shortage; food waste; genetically modified crop; genetically modified organism; genome edited crop; healthy food; herbicide tolerance; insect resistance; micronutrient deficiency; modern biotechnology; pathogen resistant plant; pest resistant crop; plant biotechnology; plant genetic engineering; plant genomics
NU3 (Personalised information for healthy nutrition for all)	balanced nutrition; fast food; food choice; food insecurity; food labelling; food policy; good food choice; healthy diet; healthy food choice; healthy nutrition; hunger; malnourishment; malnutrition; nutrition information; nutrition outcome; nutrition policy; nutrition security; nutrition status; nutritional status; nutritious food; obesity; poor diet; poor dietary habit; stunting; sugary drink
NU4 (Precision & big data in agri-businesses)	precision agriculture; precision farming

For each South Africa domain a semantic map based on list of initial keywords (that were further extended via) related with thrust was made. This semantic map is segmented on different clusters of keywords related with different thematic topic. On each semantic map colors represent topics and position representing similarity of terms towards each other. Clusters were then manually tagged to display their impact on any of thrusts within the domain. Size of a specific bubble represents impact of this specific term for South Africa (based on co-occurrence of this specific term with the word “South Africa” in documents). Based on the obtained visualizations, we can quickly draw conclusions about which scientific and technical trends related with South Africa thrusts and domains receive the most attention in various information sources. Fragments of semantic map for “Nutrition Security for a Healthy Population” (Nutrition) domain are presented on Figure 4.6.

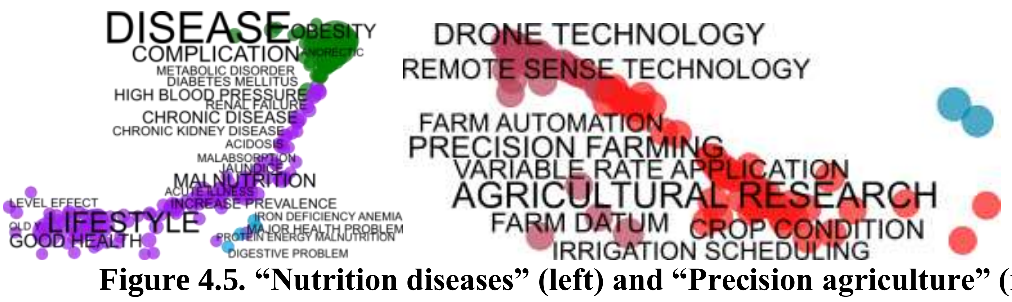

Figure 4.5. “Nutrition diseases” (left) and “Precision agriculture” (right) fragments of semantic map for “Nutrition” domain

Dynamics of thrusts and their impact onto challenges

To identify trends in the dynamic of thrusts we estimated the annual frequency of all terms related with thrusts in iFORA indexed documents collected for each year. Figure 4.6 shows the total normalized number of mentions (in thousands) of all terms (that are shown on a semantic map) related with four thrusts of “Nutrition” domains in documents indexed in IFORA for a given year. Among the thrusts NU3 (Personalized information for healthy nutrition for all) appears to be the highest on the agenda.

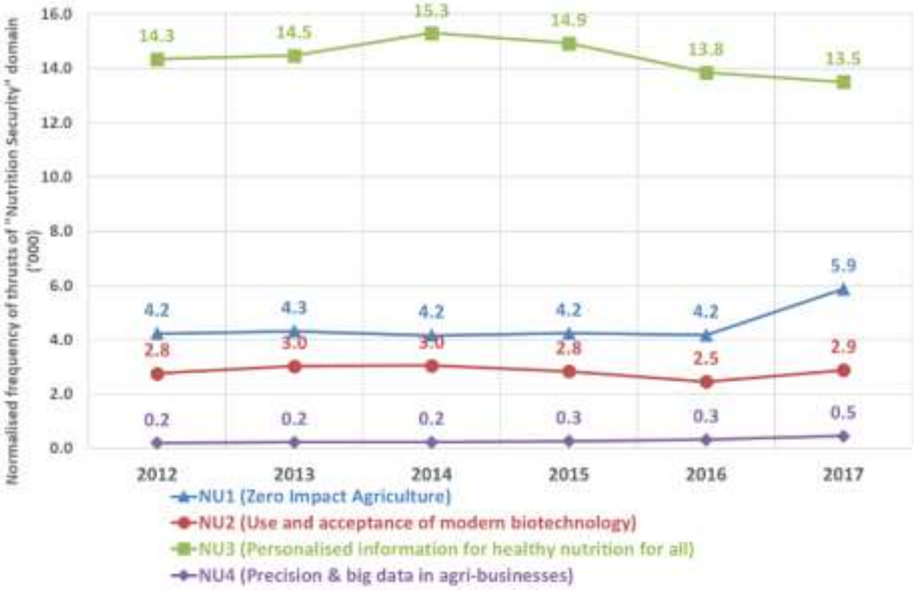

Figure 4.6. Normalized frequency of all terms related with thrusts of "Nutrition" domain ('000) in 2012 – 2017

The impact of thrust onto South Africa challenges was calculated as follows. The 26 terms listed as challenges (see Table 4.2) – are the terms that were extracted from the text describing the domains of South Africa and identified as special tasks and challenges for South Africa development. The impact of thrusts onto challenges was calculated based on co-occurrence of terms related with a specific thrust and terms that are identified as challenges.

Table 4.2. Impacts of all thrusts of "Nutrition" domain on challenges

Challenges	Nutrition Security			
	NU1	NU2	NU3	NU4
Affordable Education	0.0	0.0	1.0	0.0
Affordable Energy	5.5	0.0	4.3	0.0
Affordable Food	2.5	103.0	20.7	0.0
Carbon Emission Reduction	0.0	0.0	1.0	0.0
Clean Water Access	2.5	1.0	1.0	0.0
Crime Prevention	4.0	0.0	5.0	0.0
Crime Reduction	0.0	0.0	1.0	0.0
Economy Growth	0.0	0.0	0.0	0.0
Employment Growth	0.0	0.0	4.5	0.0
Export Growth	0.0	2.0	3.0	0.0
High Living Standard	3.0	3.0	2.0	0.0
High Quality Health Care Service	0.0	0.0	2.0	0.0
Income Growth	14.5	5.0	12.0	2.0
Job Creation	11.3	4.7	9.0	1.0
Low Greenhouse Gas Emission	2.0	2.0	2.7	0.0
Low Mortality	1.0	10.0	49.3	0.0
Population Growth	9.7	18.0	47.0	0.0
Poverty Alleviation	10.0	8.0	13.0	0.0
Reduce Water Demand	8.0	8.0	0.0	0.0
Renewable Energy Growth	0.0	0.0	1.0	0.0
Rural Community	28.0	9.8	21.3	5.0
Secure Water Supply	9.0	0.0	0.0	0.0
Skill Improvement	0.0	0.0	0.0	0.0
Universal Broadband Access	0.0	0.0	0.0	0.0

Table 4.2 provides the measures of the impact of thrusts of "Nutrition" domain onto challenges. Value in each specific cell of this table is a normalized number of co-occurrences of all terms (shown on a semantic map) related with a specific thrust (e.g. thrust NU1) and a specific

challenge (e.g. "Low Mortality") in documents indexed in iFORA database for 2012 – 2017. This value is treated as an impact of a specific thrust onto a specific challenge 2. Cells are colored by bars as follows: within a column of a specific thrust the biggest green bar means the challenge for which this specific thrust has the highest impact. Cells of table 4.2 are colored by bars as follows: within a column of a specific thrust the biggest green bar means the challenge for which this specific thrust has the highest impact. In the case of thrusts of "Nutrition" domain the highest impact refers to "affordable food", "low mortality"; "population growth" and "rural community" challenges.

Research potential of South Africa in the studied domains

Research potential of South Africa in seven domains was assessed via basic publication activity indicators of South Africa and other countries in Scopus database. Scopus database was founded by publishing corporation Elsevier in 2004. Scopus is one of the two largest international database of scientific publications (the other database in this aspect is web of Science). As of April 2019, 74.5 mln scientific documents (journal articles, reviews, conference papers, books, book chapters etc.) were indexed in Scopus database. Among them almost 356 thousand documents (0.48% of global publication output) – are publications of South Africa –(i.e. publications where at least one author from South Africa[14] is automatically identified).

The time span of our analysis covers the period of 2008- 2018 to take into account the latest trends in publication activity of South Africa. We also restrict the corpus of documents indexed in Scopus by those documents that can be treated as scientific publication[15]: scientific article; scientific article in press; review; conference paper; book, book chapter; letter; note; editorial. Publications related with a specific domain were searched in Scopus via running in titles and/or abstracts and/or keyword lists of publications the query search that contains terms that related with thrusts of a specific domain. Here in Scopus we searched those terms that were search in iFORA database plus some additional terms that were found in the text describing South Africa domains. Terms related with thrusts of "Nutrition" domain that were searched in titles and/or abstracts and/or keyword lists of publications indexed in Scopus are provided in Table 4.3.

Table 4.3. List of terms related with thrusts of "Nutrition Security for a Healthy Population" (Nutrition) that were used in Scopus query search

Thrusts of "Nutrition" domain	Terms included in Scopus query search
NU1 (Zero Impact Agriculture)	aquaponic*; closed irrigation; desalinat*; drought tolera*; fish* farm*; food basket*; food security; healthy meal; local agricultur*; marginal soil*; nutrition* improvement*; saltwater conversion; saltwater evaporation; secure agricultural productivity; small agri-business; smallholder farm*; small-scale farm*; sustainable agriculture*; sustainable food production; urban farm*; water quality enhancement*; water saving; water scarcity
NU2 (Use and acceptance of modern biotechnology)	animal health; biotech* crop*; crops yield; disease resistant animal*; disease resistant crop*; fertiliser*; fertilizer*; food shortage*; food waste*; gen* edited crop*; gene* modif* crop*; gene* modif* organism*; GM crop*; healthy food; herbicide tolera*; insect resist*; micronutri* defici*; modern biotechnology*; pathogen* resist* plant*; pest resist* crop*; pest resistant livestock*; pest tracking; pesticide*; plant biotechnology*; plant gen* engineer*; plant genome editing; plant genomic*; yield of crops;

[14] If a specific author has several affiliations and one of this affiliations is affiliation with South Africa – this author will be identified as author from South Africa.

[15] **Article-in-Press** is accepted article made available online before official publication. Review is a significant review of original research, also includes conference papers. **Letter** is a format of correspondence with the editor. Letters are individual letters or replies. Each individual letter or reply is processed as a single item. **Note -** Notes are short items that are not readily suited to other item types. They may or may not share characteristics of other item types, such as author, affiliation and references. **Editorial** – is a summary of several articles or provides editorial opinions or news. See more details at: https://www.elsevier.com/__data/assets/pdf_file/0007/69451/0597-Scopus-Content-Coverage-Guide-US-LETTER-v4-HI-singles-no-ticks.pdf

NU3 (Personalised information for healthy nutrition for all)	balanced nutrition; cheap food; Climate adapt* crop*; Climate adapt* livestock*; climate controlled greenhouse; diabete*; enhanced nutrition; fast food*; food choice*; food insecurity; food label*; food labelling; food polic*; food price; food processing; food production; good food choice*; health* diet*; health* food choice*; health* nutrition; healthy food choice; hunger; malnourishment*; malnutrition; nutrient content; nutriti* food; nutrition need*; nutrition shortage*; nutrition* information; nutrition* outcome*; nutrition* polic*; nutrition* security; nutrition* status*; nutritious food; obesities; obesity; poor diet*; poor dietary habit*; poor soil*; price of food; stunting; sugary drink*
NU4 (Precision & big data in agri-businesses)	agriculture big data; precis* agriculture*; precis* farm*

Note: to search for different word forms in Scopus we set "*" note at the end of terms. For example "food polic*" term runs the search for all word forms like food policy, food policies, food policymaker etc.

Scopus query search included also Scopus subject areas and Scopus subject categories (second level of classification within subject areas[16]) related to relevant thrusts of a specific domain. For example in the above given case, "Veterinary" subject area and also "Agronomy and Crop Science"; "Aquatic Science"; "Food Science"; "Horticulture"; "Insect Science"; "Plant Science"; "Soil Science" subject categories within "Agricultural and Biological Sciences" subject area were selected.

References

- Bojanowski, P., Grave, E., Joulin, A., & Mikolov, T. (2017). Enriching word vectors with subword information. *Transactions of the Association for Computational Linguistics*, *5*, 135-146.
- Mikolov, T., Chen, K., Corrado, G., & Dean, J. (2013). Efficient estimation of word representations in vector space. *arXiv preprint arXiv:1301.3781*.
- Pennington, J., Socher, R., & Manning, C. (2014). Glove: Global vectors for word representation. In *Proceedings of the 2014 conference on empirical methods in natural language processing (EMNLP)* (pp. 1532-1543).

[16] Scopus classification is based on All Science Journal Classification Codes (ASJC). Scopus classification covers 27 subject areas and 313 subject categories. See in a more details on: https://service.elsevier.com/app/answers/detail/a_id/15181/supporthub/scopus/

Appendix 1: Figures and tables for the Future of Society domain

FUTURE OF SOCIETY DOMAIN

Overview of research potential of South Africa in "Future of Society" domain

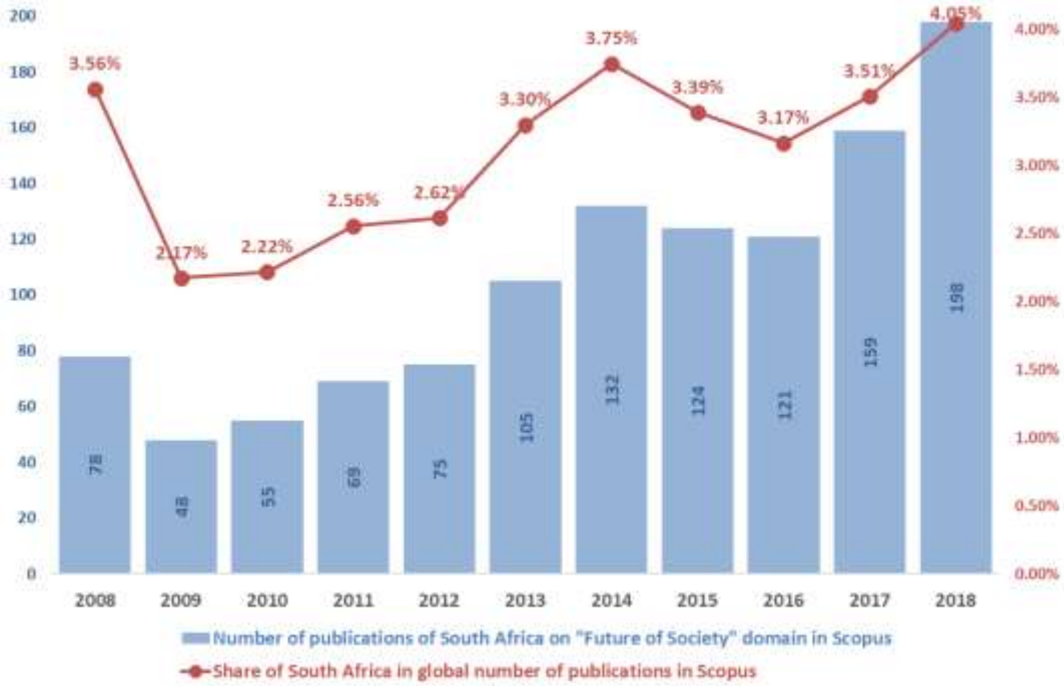

Figure 1. Dynamics of publications of South Africa on "The Future of Society" domain in Scopus in 2008 – 2018

Note: all types of documents except of technical documents, indexed in Scopus are included in the analysis.

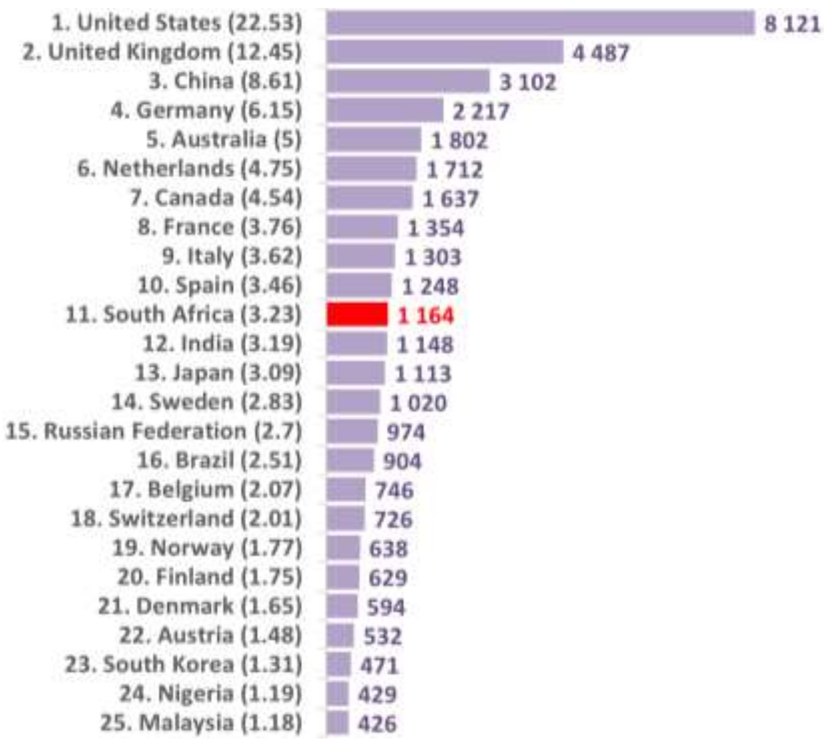

Figure 2. Leading countries by number of publications on "The Future of Society" domain in Scopus for 2008 – 2018

Note: 1. All types of documents except of technical documents, indexed in Scopus are included in the analysis. 2. Share of a country in global number of publications is shown in parenthesis.

Table 1. Leading organisations of South Africa by number of publications on "The Future of Society" domain in Scopus for 2008 – 2018

Affiliation	Number of publications	Share in all SAR publications
University of Cape Town	201	17.27%
Universiteit Stellenbosch	153	13.14%
Universiteit van Pretoria	136	11.68%
University of Witwatersrand	134	11.51%
University of KwaZulu-Natal	91	7.82%
University of South Africa	71	6.10%
University of Johannesburg	69	5.93%
North-West University	60	5.15%
University of the Western Cape	51	4.38%
South African Medical Research Council	36	3.09%
Human Sciences Research Council of South Africa	34	2.92%
The Council for Scientific and Industrial Research	33	2.84%
University of the Free State	29	2.49%
Rhodes University	28	2.41%
University of Fort Hare	24	2.06%
Tshwane University of Technology	23	1.98%
University of Cape Town, Faculty of Health Sciences	23	1.98%
Nelson Mandela Metropolitan University	21	1.80%
Groote Schuur Hospital	19	1.63%
Council for Geoscience	16	1.37%
University of Limpopo	16	1.37%
University of Cape Town, Graduate School of Business	15	1.29%
South African National Biodiversity Institute	12	1.03%
Cape Peninsula University of Technology	11	0.95%

Note: 1. All types of documents except of technical documents, indexed in Scopus are included in the analysis. 2. Organisation names are presented as they are spelled in Scopus database.

Table 2. Key country-partners of South Africa in internationally collaborated publications (ICPs) on "The Future of Society" domain in Scopus for 2008 - 2018

Country	Number of Joint papers with SAR	Share of a country in all ICPs of SAR
United Kingdom	173	32.58%
United States	135	25.42%
Australia	83	15.63%
Germany	73	13.75%
Netherlands	65	12.24%
Canada	59	11.11%
Nigeria	53	9.98%
France	39	7.34%
Switzerland	37	6.97%
Kenya	36	6.78%
Sweden	35	6.59%
Ghana	33	6.21%
Cameroon	32	6.03%
Norway	31	5.84%
Denmark	30	5.65%
Uganda	29	5.46%
Belgium	28	5.27%
Italy	23	4.33%
Ethiopia	21	3.95%
Malawi	21	3.95%

Country	Number of Joint papers with SAR	Share of a country in all ICPs of SAR
Namibia	20	3.77%
India	19	3.58%
Japan	18	3.39%
Brazil	17	3.20%
Mozambique	17	3.20%
New Zealand	16	3.01%
Spain	16	3.01%
Sudan	16	3.01%
Tanzania	16	3.01%
Senegal	15	2.82%
Finland	14	2.64%
Ireland	14	2.64%
Zimbabwe	14	2.64%
China	12	2.26%
Botswana	11	2.07%
Mexico	11	2.07%
Zambia	11	2.07%
Czech Republic	10	1.88%
Egypt	10	1.88%
Tunisia	10	1.88%

Note: 1. All types of documents except of technical documents, indexed in Scopus are included in the analysis.

Semantic analysis of "Circular economy" domain

Semantic analysis of "The Future of Society" domain (full semantic map)

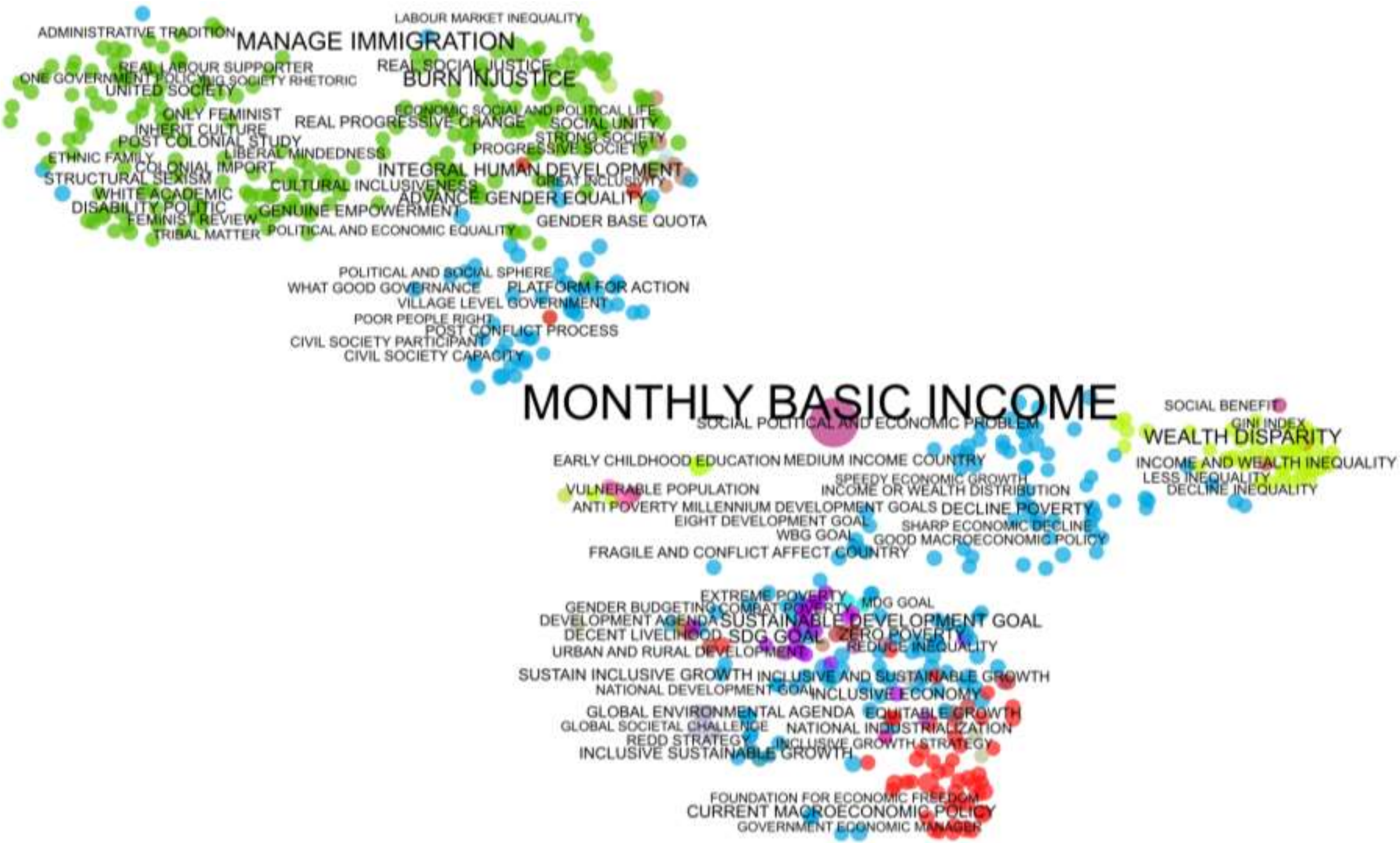

Figure 3. "The Future of Society" domain full semantic map for 2014-2018

Semantic analysis of "The Future of Society" domain (fragments of full semantic map)

Figure 4. "Economic growth and wealth distribution" (left) and "Wealth disparity" (right) fragments

Figure 5. "Sustainable development goal –zero poverty" fragment

Figure 6. "Economic policy" fragment

Figure 7. "Inclusive growth" fragment

Figure 8. "Equality and inequality" fragment

Figure 9. "Governance and Civil Society" fragment

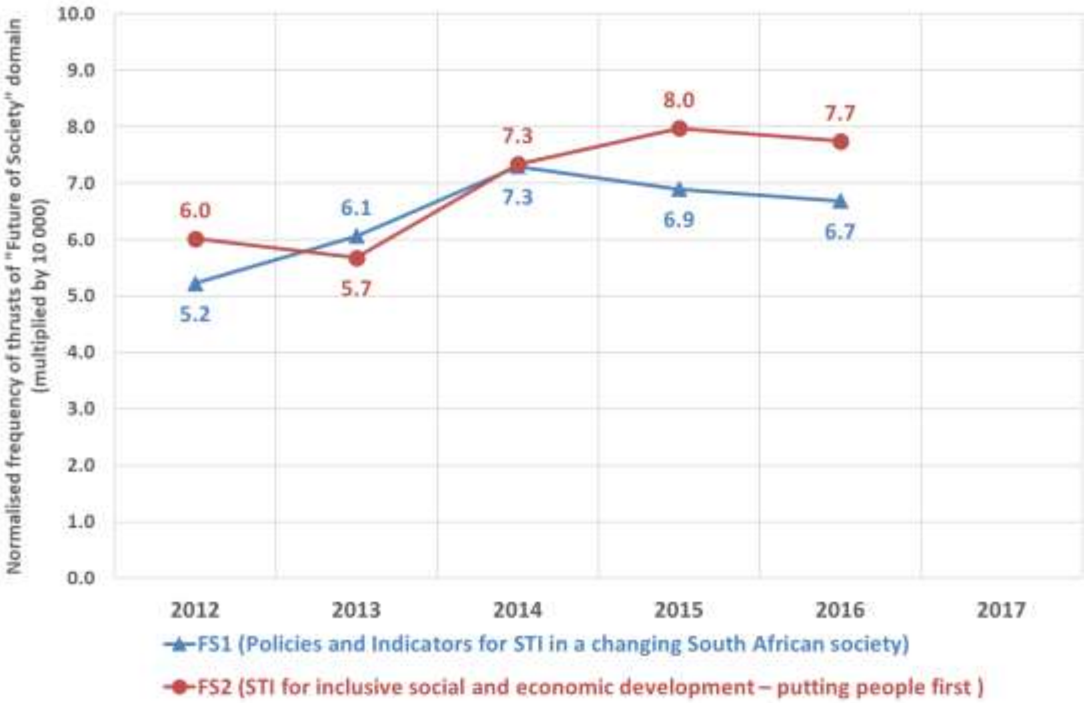

Figure 10. Normalized frequency of all terms related with thrusts of "The Future of Society" domain (multiplied by 10 000) in 2012 – 2017

Note: "Normalized frequency …" for a specific thrust – is a total normalized number of mentions (multiplied by 10 000) of all terms (that are shown on a semantic map) related with this specific thrust in documents indexed in iFORA for a given year.

Appendix 2: Figures and tables for the Water Security domain

WATER SECURITY DOMAIN

Overview of research potential of South Africa in "Water Security" domain

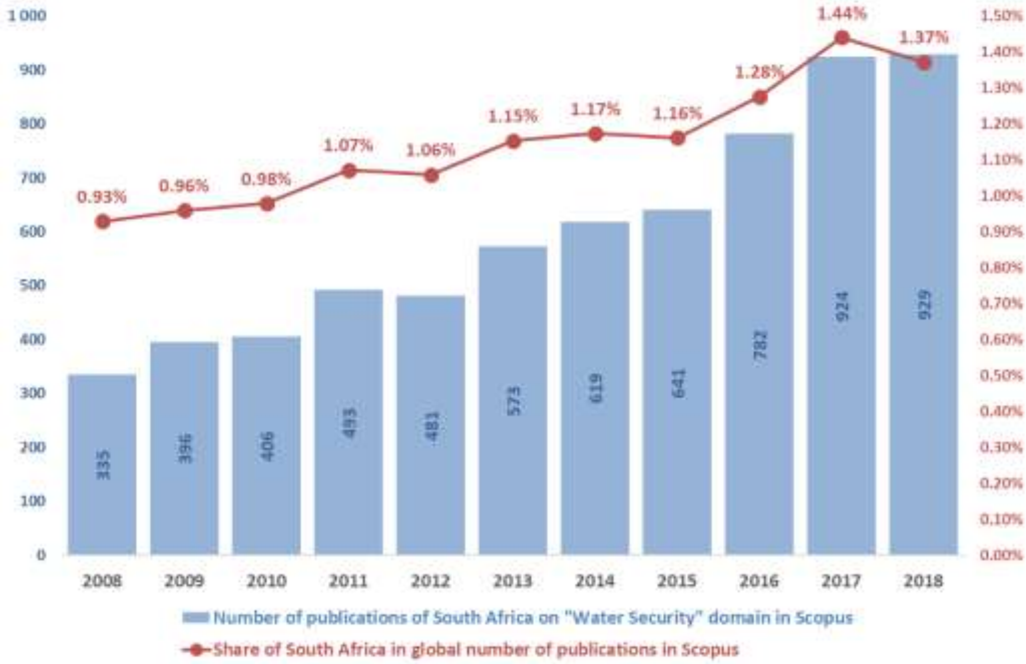

Figure 1. Dynamics of publications of South Africa on "Water Security" domain in Scopus in 2008 – 2018

Note: all types of documents except of technical documents, indexed in Scopus are included in the analysis.

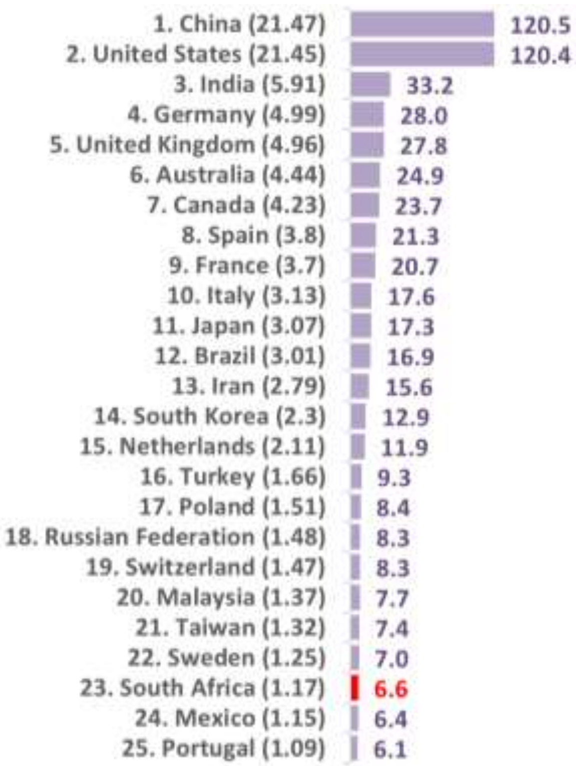

Figure 2. Leading countries by number of publications ('000) on "Water Security" domain in Scopus for 2008 – 2018

Note: 1. All types of documents except of technical documents, indexed in Scopus are included in the analysis. 2. Share of a country in global number of publications is shown in parenthesis.

Table 1. Leading organisations of South Africa by number of publications on "Water Security" domain in Scopus for 2008 – 2018

Affiliation	Number of publications	Share in all SAR publications
University of KwaZulu-Natal	827	12.57%
University of Cape Town	642	9.76%
Universiteit Stellenbosch	636	9.67%
Universiteit van Pretoria	616	9.36%
University of Johannesburg	577	8.77%
The Council for Scientific and Industrial Research	574	8.72%
University of Witwatersrand	555	8.44%
Rhodes University	388	5.90%
Tshwane University of Technology	355	5.40%
North-West University	299	4.54%
University of South Africa	260	3.95%
University of the Free State	242	3.68%
University of the Western Cape	224	3.40%
Durban University of Technology	175	2.66%
University of Fort Hare	166	2.52%
University of Venda	157	2.39%
Cape Peninsula University of Technology	152	2.31%
Nelson Mandela Metropolitan University	146	2.22%
Vaal University of Technology	117	1.78%
International Water Management Institute, Pretoria	109	1.66%
Agricultural Research Council, Pretoria	99	1.50%
University of Limpopo	87	1.32%
South African National Biodiversity Institute	72	1.09%
South African National Parks	64	0.97%
South African Water Research Commission	60	0.91%
Marine and Coastal Management	57	0.87%
University of Witwatersrand, School of Chemical and Metallurgical Engineering	56	0.85%
Council for Geoscience	55	0.84%
South African Institute for Aquatic Biodiversity	45	0.68%
University of Zululand	45	0.68%
South African Medical Research Council	42	0.64%
South African Environmental Observation Network	42	0.64%
Rand Water	41	0.62%
South African National Space Agency	36	0.55%
Central University of Technology, Free State	34	0.52%
University of KwaZulu-Natal School of Chemical Engineering	30	0.46%
Mintek	30	0.46%
Mangosuthu University of Technology	29	0.44%
Department of Water Affairs and Forestry, South Africa	28	0.43%
South African Weather Service	28	0.43%
ARC Infruitec-Nietvoorbij	25	0.38%
South African Sugarcane Research Institute	24	0.36%
University of KwaZulu-Natal, Westville Campus	24	0.36%
Plant Protection Research Institute, Pretoria	22	0.33%
Department of Water Affairs and Forestry Republic of South Africa	22	0.33%
University of KwaZulu-Natal, Pietermaritzburg Campus	20	0.30%

Note: 1. All types of documents except of technical documents, indexed in Scopus are included in the analysis. 2. Organisation names are presented as they are spelled in Scopus database.

Table 2. Key country-partners of South Africa in internationally collaborated publications (ICPs) on "Water Security" domain in Scopus for 2008 - 2018

Country	Number of Joint papers with SAR	Share of a country in all ICPs of SAR
United States	588	21.43%
United Kingdom	455	16.58%
Australia	283	10.31%
Germany	254	9.26%
Nigeria	209	7.62%
France	206	7.51%
Netherlands	203	7.40%
India	192	7.00%
Zimbabwe	142	5.17%
Canada	133	4.85%
China	126	4.59%
Sweden	124	4.52%
Belgium	111	4.05%
Norway	101	3.68%
Italy	99	3.61%
Switzerland	96	3.50%
Kenya	86	3.13%
Spain	79	2.88%
New Zealand	76	2.77%
Ethiopia	69	2.51%
Japan	67	2.44%
Iran	61	2.22%
Denmark	54	1.97%
Brazil	51	1.86%
Czech Republic	49	1.79%
Finland	48	1.75%
Austria	47	1.71%
Botswana	45	1.64%
Namibia	43	1.57%
Saudi Arabia	42	1.53%
Ghana	38	1.38%
Uganda	37	1.35%
Malaysia	36	1.31%
Tanzania	36	1.31%
Sri Lanka	33	1.20%
Egypt	32	1.17%
Thailand	32	1.17%
Israel	31	1.13%
South Korea	30	1.09%
Portugal	29	1.06%
Russian Federation	27	0.98%
Hungary	26	0.95%
Argentina	23	0.84%
Chile	23	0.84%
Ireland	23	0.84%
Malawi	22	0.80%
Swaziland	20	0.73%

Note: 1. All types of documents except of technical documents, indexed in Scopus are included in the analysis.

Semantic analysis of “Integrated Solutions for Water Security” domain (full semantic map)

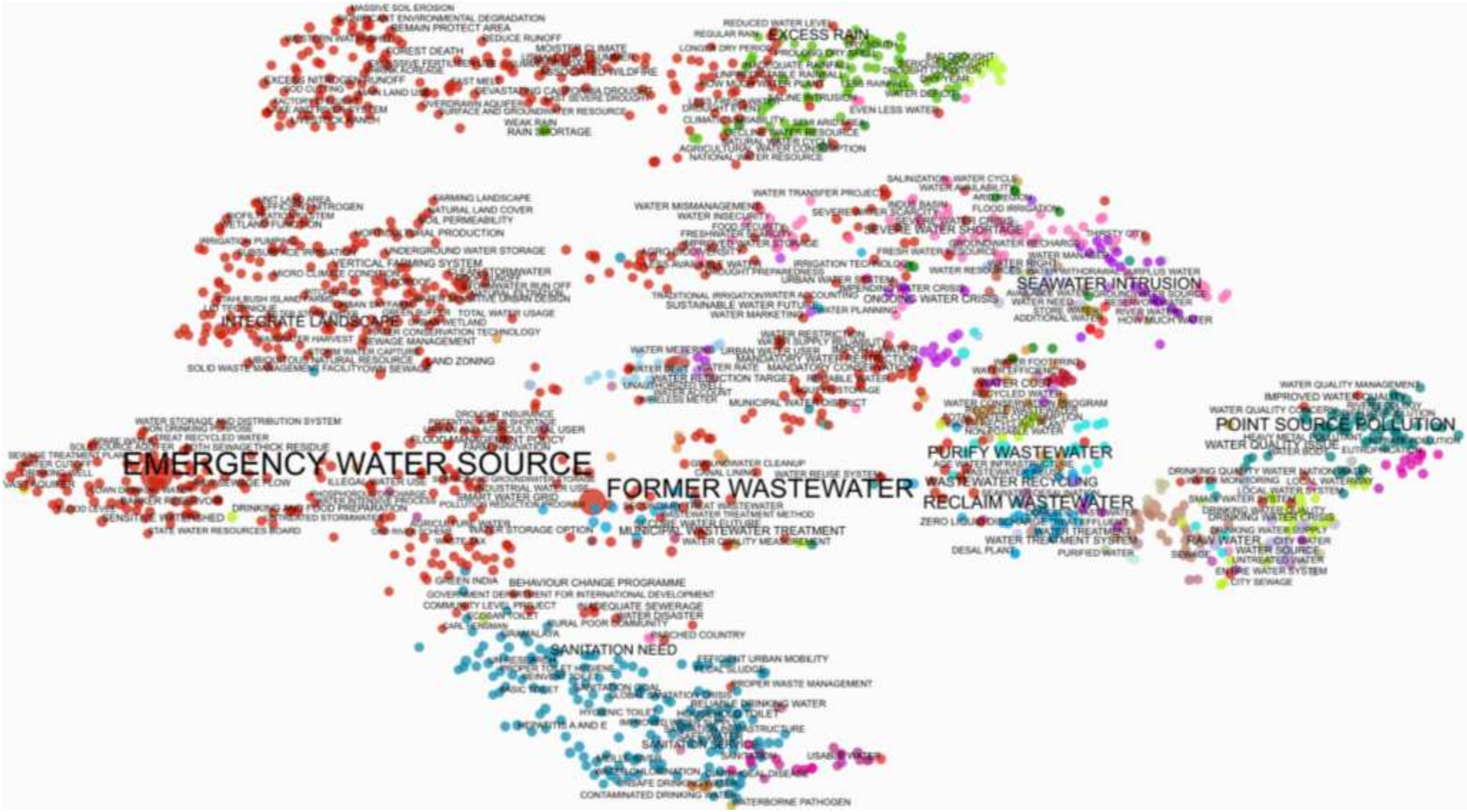

Figure 3. “Integrated Solutions for Water Security” domain full semantic map for 2014-2018

Semantic analysis of "Integrated Solutions for Water Security" domain (fragments of full semantic map)

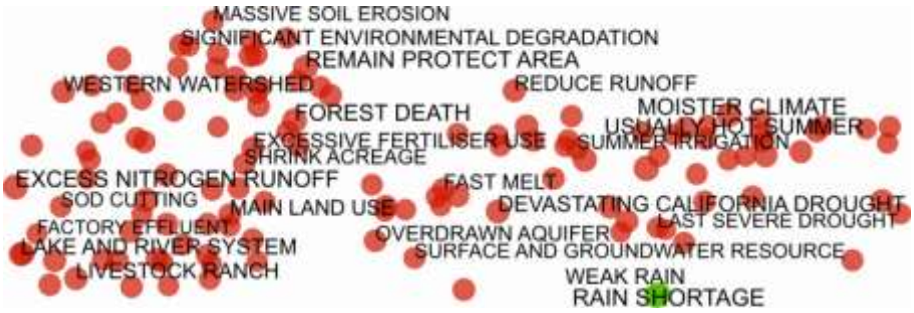

Figure 4. "Environmental impact" fragment

Figure 5. "Rainfall and drought" fragment

Figure 6. "Water conservation" fragment

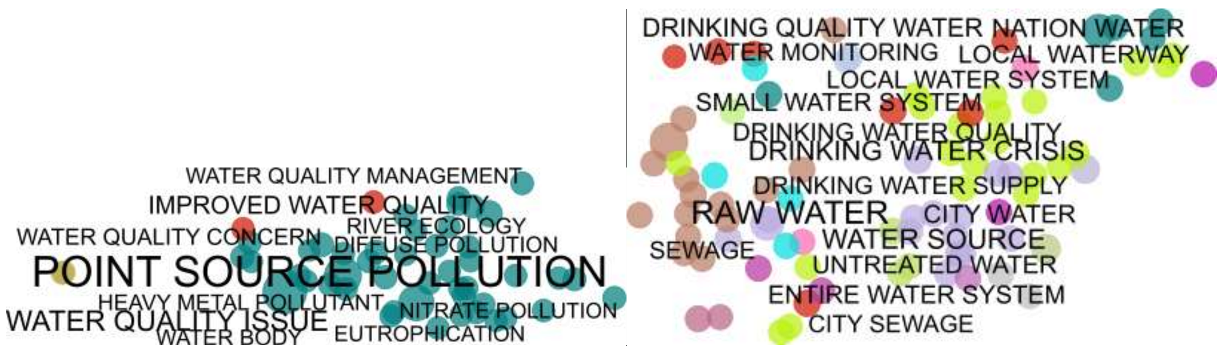

Figure 7. "Water quality" (left) and "Drinking water issues" (right) fragments

Figure 8. “Irrigation and water availability issues” fragment

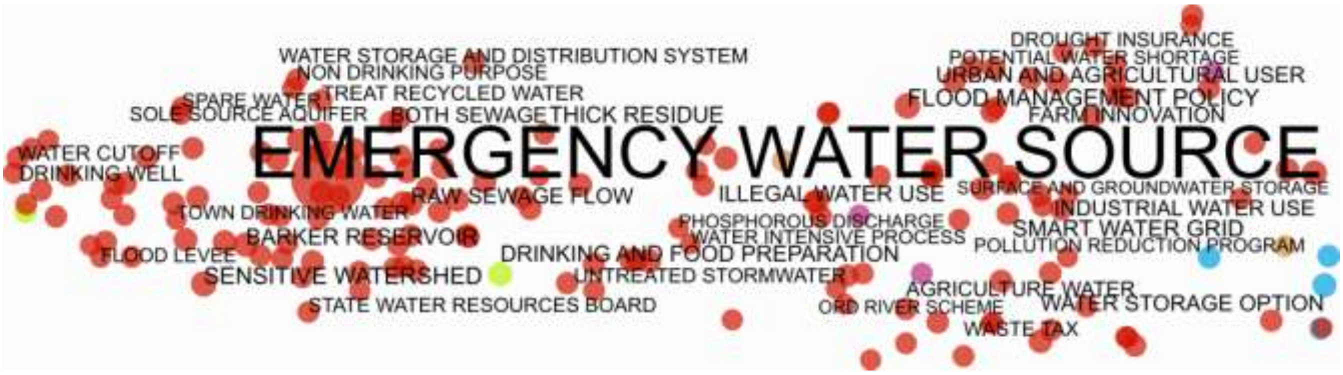

Figure 9. “Underground water and water use” fragment

Figure 10. “Water treatment” (left) and “Wastewater” (right) fragments

Figure 11. “Water supply” (left) and “Water recycling” (right) fragments

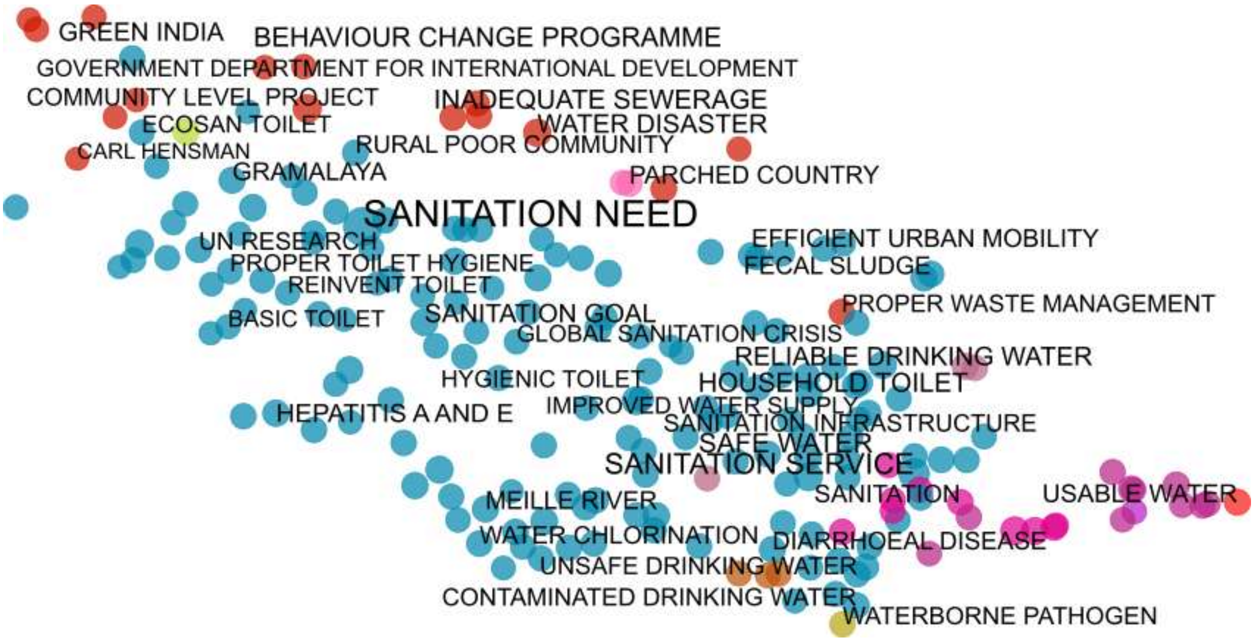

Figure 12. Sanitation fragment

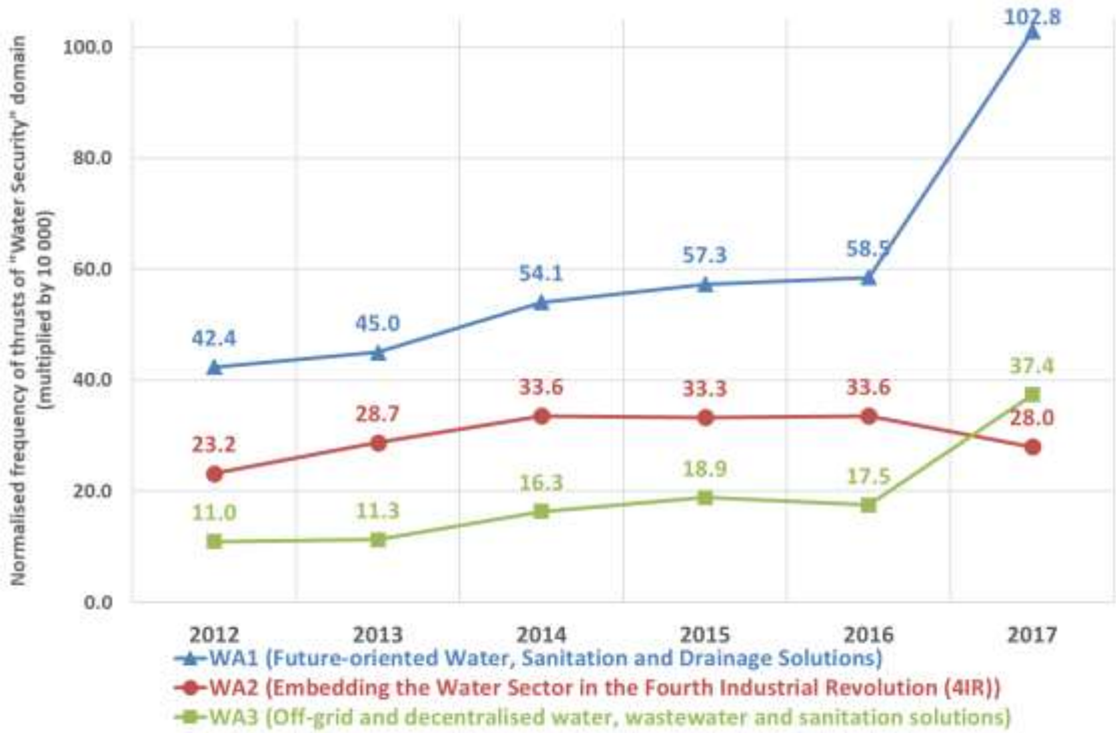

Figure 13. Normalized frequency of all terms related with thrusts of "Integrated Solutions for Water Security" domain (multiplied by 10 000) in 2012 – 2017

Note: "Normalized frequency …" for a specific thrust – is a total normalized number of mentions (multiplied by 10 000) of all terms (that are shown on a semantic map) related with this specific thrust in documents indexed in iFORA for a given year.

Annexure I: Publication Quality: Areas of Specialisation

Code	Full name of subject area
Agric	Agricultural and Biological Sciences
Arts	Arts and Humanities
Biochem	Biochemistry, Genetics and Molecular Biology
Business	Business, Management and Accounting
ChemEng	Chemical Engineering
Chem	Chemistry
CompSci	Computer Science
DecisionSci	Decision Sciences
Dentistry	Dentistry
EarthSci	Earth and Planetary Sciences
Economics	Economics, Econometrics and Finance
Energy	Energy
Engineering	Engineering
Environ	Environmental Science
Health	Health Professions
Immunology	Immunology and Microbiology
MaterialSci	Materials Science
Maths	Mathematics
Medicine	Medicine
MultDisc	Multidisciplinary
NeuroSci	Neuroscience
Nurse	Nursing
Pharm	Pharmacology, Toxicology and Pharmaceutics
Physics	Physics and Astronomy
Psych	Psychology
SocSci	Social Sciences
Veterinary	Veterinary