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THE FOURTH INDUSTRIAL REVOLUTION: SYNOPSES AND IMPLICATIONS FOR STI POLICY DEVELOPMENT

Article

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Abstract

The Forth Industrial Revolution (4IR) is still in its infancy. Typically, this offers a potential opportunity to shape its trajectory and mass-base its benefits from a South African perspective, in the context of its peculiarities. Relatedly, the focal aim in this article is to provide synopses of the 4IR and draw significant insights for Science, Technology and Innovation (STI) policy development in relation to Local Economic Development (LED).

Key words: Fourth industrial revolution, industrial re-organization, science technology and innovation policy, advanced engineering, engineering design, advanced manufacturing, broad-basing, offshoring, reshoring, technological upgrading, competence building.

1. Introduction

Our knowledge of industrial organization and global industrial systems often influence our understanding of industrial revolution. Industrial revolutions are characterized by 'exponential change' and unstoppability of that change, which renders tried and tested solutions obsolete or ineffective. The 4IR is characterized by a fusion of technologies resulting in the blurring of lines between the physical, digital and biological spheres.

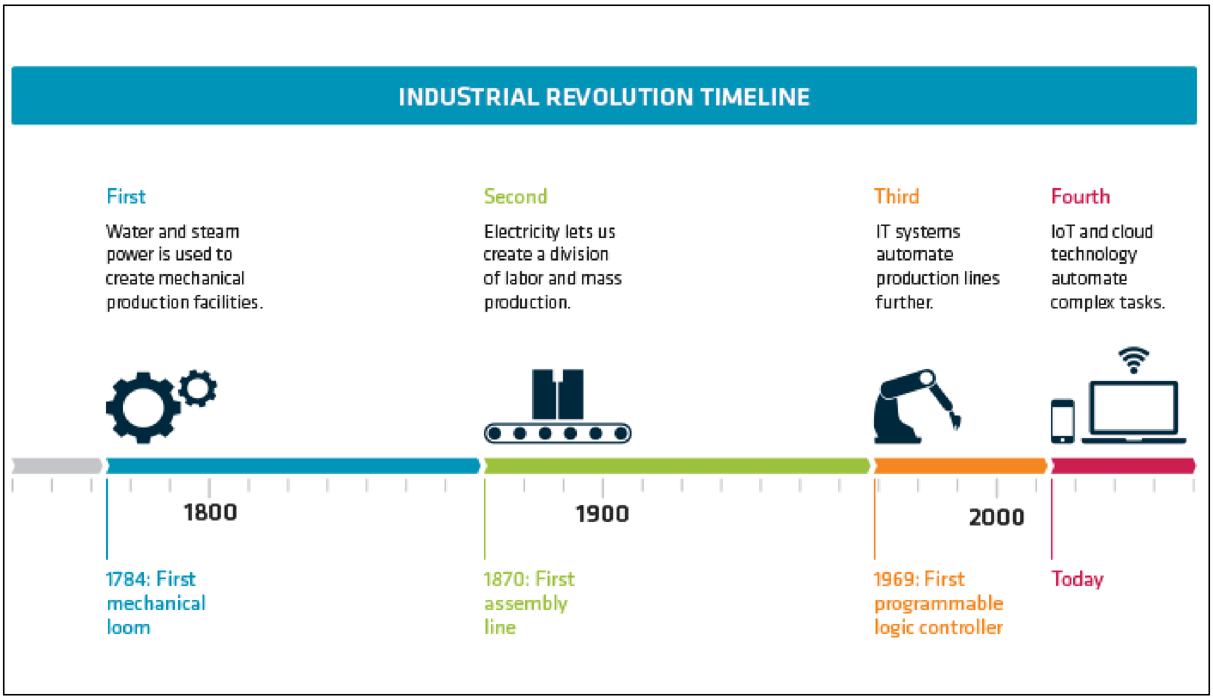
Klaus Schwab, the founder of the World Economic Forum who came up with concept of the 4IR, argues that the speed of current breakthroughs as a result mainly of this fusion, has no historical precedent. The United Nations Social and Economic Council cautions that this rapid and unprecedented technological change may also disrupt the UN development goals, particularly those concerning the inclusive development agenda aimed at benefiting the developing world. Younus (2017) contends that the 4IR marginalises those who are illiterate and reside in less developed regions.

The aim of this article is to provide synopses of the 4IR. The analyses provide significant insights which are used to frame the conclusions and implications for STI policy development in the context of LED.

2. Historical Overview of The First Three Industrial Revolutions

This section presents a historical context of the 4IR by providing an analysis of the first three industrial revolutions as highlighted in Figure 1.

Figure 1: Timeline of the various revolutions leading up to the fourth industrial revolution



Source: https://cdn.mjolner.dk/wpcontent/uploads/2015/01/mjolner_industrial_revolution_ timeline.png

The first industrial revolution began in 1784. During this period, production was largely mechanical and relied on steam and water to function. The First Industrial Revolution shifted reliance from biomass as primary source of energy to the use of fossil fuels and this enabled the use of mechanical power.[1] The availability of mechanical power enabled the use of machines and less reliance on animals.[2] This mechanisation led to the development of industrial towns[3] such as Oldham, Northampton and South Shields in Britain.[4] The three towns were sectorally diverse in their development. Oldham thrived in the cotton industry particularly from the 1790s.[5] By contrast, Northampton specialised in shoe manufacturing and used villagers as a source of cheap labour during the 1820s and 1830s.[6] Equally, South Shields merged the shipping and mining industries and emerged with a strong militant industry.[7] Manufacturing cloth in large quantities helped sustain the economy of England at the time, ultimately enabling the country's commerce sector to thrive.[8] With England's leading commerce sector there was an increased demand for the manufacturing of goods in the area.[9]

The rush to manufacture goods led to a need (by producers) to produce goods in large quantities but at minimum costs (often unregulated).[10] The first industrial revolution made way for innovations in alternative modes of transportation. In the early 19th century; these modes of transportation allowed for easier transportation of goods from the factory to the market.[11]

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[1] What is the fourth industrial revolution?". *World Economic Forum*. Retrieved 2016-12-12. https://www.weforum.org/agenda/2016/01/what-is-the-fourth-industrial-revolution/ (ACCESSED, 11 February 2018)
[2] Younus, U.M., 2017. Fourth industrial revolution.
[3] Hackett, L., 1992. Industrialization: The first phase.
[4] Foster, J., 2003. *Class struggle and the industrial revolution: early industrial capitalism in three English towns*. Routledge.
[5] Foster, J., 2003. *Class struggle and the industrial revolution: early industrial capitalism in three English towns*. Routledge.
[6] Foster, J., 2003. *Class struggle and the industrial revolution: early industrial capitalism in three English towns*. Routledge.
[7] Foster, J., 2003. *Class struggle and the industrial revolution: early industrial capitalism in three English towns*. Routledge.
[8] Hackett, L., 1992. Industrialization: The first phase.
[9] Hackett, L., 1992. Industrialization: The first phase.
[10] Hackett, L., 1992. Industrialization: The first phase.
[11] Hackett, L., 1992. Industrialization: The first phase.

The period between the late 19th century and the beginning of the 20th century saw the rise of the second industrial revolution which was founded by processes that produce goods in large quantities (this includes the production of steel, fertiliser and electricity).[12] This type of production put emphasis on the use of conveyor belts, giving birth to 'Fordism' which remains embedded in our history.[13] Major technological advances during this period included the telephone, light bulb, phonograph and the internal combustion engine. The 2nd revolution introduced new systems for electricity, power generation and the division of labour which facilitated the mass production of industrial products.[14] Electric power was more prominent in this revolution. This enhanced production as goods could be produced cheaper and faster.[15] The industrial significance of the second industrial revolution is that there was increased use of technology and close attention to the organization of production to create economies of scale.[16] During the second industrial revolution, progress was made in the areas of automation and diesel engines enabled increased use of railways[17]. This period saw shifts in the way automobiles worked, from Otto's gas engine to Benz's electrical induction coil engines; technological advances also advanced in the form of exploring the air which led to the innovation of the airplane.[18]

In sum, according to Perkin (1969)[5] the 1st industrial revolution began in Great Britain in the textile, cottage / clothing industry. Prior to the 1st industrial revolution, clothes were made in a domestic system – that is a system where manufacturing was done in homes or cottages by families[5]. This form of domestic system was not very efficient, and it could not meet the increasing demands for cloth due to low speed. In 1764, James Hargreaves invented a machine called 'the spinning jenny'. This machine spin more than one ball of yarn or thread at a time, making it easier and faster to make

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[12] Mokyr, J., 1998. The second industrial revolution, 1870-1914. *Storia dell'economia Mondiale*, pp.219-45.
[13] Bloem, J., Van Doorn, M., Duivestein, S., Excoffier, D., Maas, R. and Van Ommeren, E., 2014. The Fourth Industrial Revolution. *Things Tighten*.
[14] Younus, U.M., 2017. Fourth industrial revolution.
[15] Hackett, L., 1992. Industrialization: The first phase.
[16] Mokyr, J., 1998. The second industrial revolution, 1870-1914. *Storia dell'economia Mondiale*, pp.219-45.
[17] [17] Mokyr, J., 1998. The second industrial revolution, 1870-1914. *Storia dell'economia Mondiale*, pp.219-45.
[18] [18] Mokyr, J., 1998. The second industrial revolution, 1870-1914. *Storia dell'economia Mondiale*, pp.219-45.

clothes. This new invention assisted in producing more textiles to meet the increasing demand which was due to increasing population as a result of the discovery of the steam energy. It led the way for a systematic shift from the domestic system and a factory system was created[5]. According to Perkin (1969)[6] factory systems developed during the 1st industry revolution in the 1700s and early 1800s in Great Britain and quickly spread throughout the world with emerging big market. From 1750 – 1800, Europe was reaching stage 2 of the demographic transition model due to high birth rate, declining death rate and medical advances after the black death event. The increase in population and the increase in demand for food led to agricultural revolution which was facilitated by the creation of capitalism.

The second industrial revolution largely influenced standards of living of those living in industrial towns. The 2nd revolution led to a shift in technological leadership from the British to the Germans.[19] The 2nd revolution especially 1960s and 1970s further saw the emergence of the green revolution which increased crop yields in the agricultural sector by utilising technologies such as tractors, fertilizer and genetically modified[20] New farming techniques increased food production to meet the demands of the growing populations[21].

Capitalism according to Berger et al (1980)[10] was referred to as the 2nd industrial revolution which originated from America between the 1820s and 1870s. The 2nd industrial revolution saw the mechanization of agriculture, textile manufacturing and a revolution of the steam energy system. The improvement of the steam engine due to a more efficient designs was made possible by James Watt. This improved steam engine system helped power the first trains, steamboats, and factories. It also helped to improve transport networks, which gave birth to the mass production of iron for steam ships, railroads and later cars, that effected social, cultural and economic transitions. These periods also witnessed an increased migration of people – mostly

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[19] Mokyr, J., 1998. The second industrial revolution, 1870-1914. *Storia dell'economia Mondiale*, pp.219-45.
[20] Peng, Jet al., 1999. 'Green revolution'genes encode mutant gibberellin response modulators. *Nature*, *400*(6741), p.256.
[21] Peng, J., et al., 1999. 'Green revolution'genes encode mutant gibberellin response modulators. *Nature*, *400*(6741), p.256.

the movement of people from the rural to the urban area due to the demand for a large workforce for the growing industries. This resulted to rural unemployment, a concentration of threshold population and an increase of urban population[10].

According to Hall, et al (2001)[22], this era can be accredited to people like James Hargreaves – the change of the cotton industry, James Watts – the development of an improved version of steam engine; George Stephenson – who constructed the first twin rail track for faster transport and later Henry Ford for Fordism. The 2nd industrial revolution was referred to the age of economic increase, massive production and urbanization as a result of rural -urban migration for employment purpose[8]. According to Perkin (1996)[9], the 2nd industrial revolution lacked flexible specialisation and customized product due to mass production across various large economic geographic region. The need for a customized iconic production and the need to meet an increasing population figure with various geographical configuration, location and demand gave rise to the 3rd industrial revolution[9].

The third industrial revolution according to Perkin (1996)[9] disrupted the regular economic processes and democratized manufacturing with specific geographical configuration, new communication technologies converge and new energy systems. Berger, et al (1980)[10] point out that the 3rd industrial revolution involved new energy uprisings that made more integrated and expansive trading possible. The new energy flows were also accompanied by various communication revolutions that can manage the new complex commercial activities[23]. It combined new energy infrastructure such as micro-power plants to collect renewable energies on-site with various evolving internet communication technologies[24]. Today, Internet technology and renewable energies are beginning to merge to create a new infrastructure for a Fourth Industrial Revolution (4IR) that will change the way economic activities takes place in the 21st century.

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[22] Hall, Peter A. and David Soskice, Eds. (2001). Varieties of Capitalism: The Institutional Foundations of Comparative Advantage. Oxford, Oxford University Press.

[23] Berger, Suzanne and the MIT Industrial Performance Centre (2005). How We Compete: What Companies Around the World Are Doing to Make it in Today's Global Economy. New York, Currency Doubleday.

The third industrial revolution began in 1969 and it essentially digitized production by using information technology and electronics to aid production processes.[25] The 3rd Industrial Revolution, or the Digital Revolution, refers to the advancement of technology from analog electronic and mechanical devices to the digital technology available today. Advancements during the Third Industrial Revolution include the personal computer, the Internet, and information and communications technology (ICT). Modern communications, digital systems, smartphones, social media and the modern computer are products of this revolution.[26] The third industrial revolution also introduced the concept of robotics (where robots undertake the production process with precision. These improvements do not discredit the intellectual capacity of man but rather vouches for the collaboration of man and robot to produce quality products.[27]

The growth in information technology alienated those who lack the necessary skills. It has also affected labour force in varied sectors such as agriculture as machines started to replace workers[28]. These factors have widened income inequality on a global scale[29].

3. The fourth Industrial Revolution

The Fourth Industrial Revolution builds on the Digital Revolution, representing new ways in which technology becomes embedded within societies and even the human body.[30] The present-day form of industrial revolution is influenced by 'cyber-physical systems' and incorporates in it production processes. This revolution (unlike its former

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[25] Bloem, J et al. 2014. The Fourth Industrial Revolution. *Things Tighten*.
[26] Younus, U.M., 2017. Fourth industrial revolution.
[27] Bloem, J., Van Doorn, M., Duivestein, S., Excoffier, D., Maas, R. and Van Ommeren, E., 2014. The Fourth Industrial Revolution. *Things Tighten*.
[28] Greenwood, J., 1997. *The third industrial revolution: technology, productivity, and income inequality* (No. 435). American Enterprise Institute.7
[29] Greenwood, J., 1997. *The third industrial revolution: technology, productivity, and income inequality* (No. 435). American Enterprise Institute.
[30] What is the fourth industrial revolution?". *World Economic Forum*. Retrieved 2016-12-12. https://www.weforum.org/agenda/2016/01/what-is-the-fourth-industrial-revolution/ (ACCESSED, 11 February 2018).

revolutions) integrates the physical, digital and biological dimensions; it does so exponentially which intensifies its impact thus causing a need for the transformation of systems of governance, management and production[31]. It is characterised by a fusion of technologies that are blurring the lines between the physical, digital, and biological spheres. It is marked by emerging technology breakthroughs in a number of fields, including robotics, artificial intelligence, nanotechnology, quantum computing, biotechnology, The Internet of Things, 3D printing and autonomous vehicles.[32]

The fourth industrial revolution signifies a change in the way development takes place from industries being in small-scale workshops to being in craft studios. The term 'Cyber-Physical-Systems' is used to describe this revolution. The specific features that define the FIR include:

a. The rate of change is considerably faster than in preceding industrial revolutions.

b. There are ongoing developments in new and emerging technologies including: nanotechnology, 3-D printing, biotechnology, quantum computing and renewable energy and energy storage.

c. The emergence of "smart manufacturing" and "smart factories" – that is manufacturing processes based on the integration of physical production with digital technologies collecting data on plant operations and the supply chain, which are able to analyse this data and contribute to real-time improvements in production, procurement and supply chain management.

d. The replacement and augmentation of certain kinds of labour using automation technologies, including robotics and machine learning. This also opens up the possibility of automation of certain kinds of knowledge work.

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[31]Klaus Schwab. (2016). *The Fourth Industrial Revolution: what it means, how to respond.* (online)
[32] What is the fourth industrial revolution?". *World Economic Forum*. Retrieved 2016-12-12. https://www.weforum.org/agenda/2016/01/what-is-the-fourth-industrial-revolution/ (ACCESSED, 11 February 2018).

e. In the IoT, everyday objects are connected to the internet able to identify themselves to other devices to collect and exchange data. Some applications for IoT technologies include:

   i. *Consumer and residential*—IoT applications in these market sectors include domestic and home automation tools, such as remote monitoring and control of appliances, lighting, heating and air conditioning, water usage, entertainment systems and premises security.

   ii. *Health and healthcare*—These markets include personal health and fitness devices that monitor physical activity, such as wrist bands and other wearable devices. They also include m-Health technologies that monitor and record vital patient data in real time, or that enable healthcare professionals to retrieve and update patient medical records from any location.

   iii. *Transportation*—IoT applications in the transportation sector include smart cars and smart roadways that can help manage the flow of traffic and minimize congestion, and applications that identify vacant parking spaces.

   iv. *Energy infrastructure and distribution*— Smart grid technologies are transforming the way in which energy is produced and distributed, enabling utility operators to more accurately estimate usage and to source energy from the most cost-effective suppliers.

   v. *Public safety*—Cities and towns are quickly adopting IoT technologies to improve public safety and services. In some cases, these efforts leverage the transportation applications noted previously to help reduce city congestion. These are also part of the smart city technologies.

   vi. *Industrial and manufacturing*—IoT technologies, such as so-called machine-to-machine (M2M) applications, are being widely adopted in support of industrial automation to increase productive efficiency and flexibility.

vii. *The environment*—Finally, IoT technologies are being used to monitor environmental conditions that could affect human, animal or plant life. IoT-equipped sensors are used to detect rising water levels in rivers and streams that could lead to flooding; increases in air pollution levels due to automobiles or industrial activity; localized atmospheric conditions that could portend an increased risk of forest fires; and, even vibration patterns that could signal risk of an earthquake, landslide or avalanche. [33]

Overall, the rise of the 'Internet of Things' – (sometimes also referred to as the "Internet of Everything," or IoE) generally referring to the multiple networks of devices or technology platforms ("things") that communicate with each other via wireless protocols without direct human interaction.[34]

Indeed, the internet has been prioritised and is used to improve security, efficiency and quality of production processes and services it is more flexible and adaptable to these processes.[35] For example, Table 1 illustrates this point.

Box 1: Future Possibilities

The supermarket of tomorrow will have sensors that send real time inventory information to suppliers of products. Bakeries will deliver bread before the last loaf is sold out, with networked bakery ovens and mixers on standby 24 hours to start on pre-determined inventory thresholds. New apps will provide data to small scale farmers to harvest recommended quantities of fresh produce to their supermarket clients. Supermarket shelves will indicate stock availability to shoppers, thus reducing the need for shop floor enquiries. In the city, cars will reflect real time data about availability of fuel at closest fuel stations. Such data will be accompanied by service quality ratings, numbers of cars currently in the queue; and motorists will choose the best service provider in their proximity. With the internet of things, big

[33] Mick Conley (2016). An Introduction to the Internet of Things. UL
[34] Mick Conley (2016). An Introduction to the Internet of Things. UL
[35] Bloem, J., Van Doorn, M., Duivestein, S., Excoffier, D., Maas, R. and Van Ommeren, E., 2014. The Fourth Industrial Revolution. Things Tighten.

data and mass customization, wearables and virtual cameras shall send biometric data directly to clothing factories, get customized suits designed, tailored, packed and delivered to the door via drones.

4. Some Challenges And Opportunities

The capitalist system under which the 4IR and the three preceding revolutions took place has never been an egalitarian system. The capitalist system is premised on the values of a free 'market' system driven and regulated by market forces of demand and supply. The global access to information made possible by the internet exposes the vulnerability of some global market players in terms of their readiness to meaningfully participate in in these global developments in ways that are inclusive.

At the centre of all industrial revolutions is the notion of production (production for the market) that is informed and influenced by market opportunities where players must compete for a limited market share (see Ibata-Arens, 2008). To achieve this, organisations must maximize a number of efficiencies to remain competitive; and this happens within a volatile and unpredictable globalized market. Fierce competition for markets is most likely to continue. Similarly, information shall continue to be at the centre of the economy and increasingly available to all but via the 'cloud', the key differentiating factor between winners losers shall be each player's astuteness in analyzing it, making sense of it and appropriately and timeously responding as the market opportunities suggest (SAS, 2018). Eearly adopters of the emerging technologies shall emerge as global industrial market leaders.

The notion of catch-up by the developing world has its challenges because target is constantly in motion. Indeed, one big challenge is that the future is not easily predictable and so the challenges are only partially known. Forecasts from the current trends need to accommodate shocks that may come from anytime and anywhere in the world. Finally, levels of readiness for the adoption of 4IR technologies is much higher in developed countries than in the developing world.

Permanence does not characterize the current realities. Planned development interventions therefore, should be conceptualized within the current reality of constant change. Advance 4IR technologies such as big data, augmented reality, Internet of Things (IoT), Artificial Intelligence, etc. bring futures that are accompanied by varied surprises.

The unequal global economic relations between the industrialized and the developing world cannot be over-emphasized. The concentration of wealth in fewer hands disadvantages the developing world in terms of financial resources to drive innovation and promote access to ubiquitous technologies thus closing the digital divide between the rich and the poor remains a challenge (see Thatcher and Ndabeni, 2011).

On the positive side, it is argued that 4IR will increase income levels globally and improve people's quality of life.[36] One great opportunity relates to the use of both social and technological innovations to improve the provision of goods and services[37]. The mass use of these emerging technologies can also enhance inclusive economies.[38] For example, the rural economy has massive supply of labour in handcrafts and farming and they represent a critical component of future production. However, they require government investments in the form of required infrastructure[39]. The vast use of technologies mainly by those who can afford them remain a critical concern[40]. Indeed the 4IR is not only about the economy and employment opportunities but also about a whole range of factors whose final outcome is the wellbeing of people and the environments within which they live. The centrality of the economy in discussing the broader 4IR and its technologies is its power to drive technological innovations (through challenges that must be solved with technology) and to support the diffusion of those innovations through the markets.

The rest of this section summarizes the global economic conditions preceding the fourth industrial revolution and key responses from the industrialized countries. More

[36]Klaus Schwab. (2016). *The Fourth Industrial Revolution: what it means, how to respond.* (online)
[37] Klaus Schwab. (2016). *The Fourth Industrial Revolution: what it means, how to respond.* (online)
[38] Klaus Schwab. (2016). *The Fourth Industrial Revolution: what it means, how to respond.* (online)
[39] Klaus Schwab. (2016). *The Fourth Industrial Revolution: what it means, how to respond.* (online)
[40]Klaus Schwab. (2016). *The Fourth Industrial Revolution: what it means, how to respond.* (online)

importantly are the efforts of industrialized countries and their levels of preparedness to adopt the 4IR. Against this backdrop, the analyses highlight preconditions for South Africa to play a meaningful role in this revolution. This section concludes by citing practical examples on the use of some 4IR technologies in Sub-Saharan Africa by looking specifically at selected documented cases of South Africa and Rwanda.

5. Rapid Technological Changes

At the centre of each industrial revolution (IR) – from the first to the emerging one, is the notion of production and particularly, manufacturing (Lars et. al 2015). It is worth noting that all the preceding industrial revolutions as well as the envisaged one, have taken place within one economic system – the capitalist economic system. That said, it is important to acknowledge the market conditions which gave rise to the previous IRs. It is also important to note that the pace and scope of industrialization have hinged on technology of the time as a key enabling factor; with each new technology tool enabling more innovations than were ever imagined when it first emerged. The computer and cell phone technologies are typical examples with their newly-discovered and increased capabilities enabling a wide range of game changing innovations in manufacturing, logistics, delivery of services, etc.

Innovations in cell phones have brought further innovations and increased innovative capabilities and solutions that created new market opportunities. For example, Uber and Taxify built their innovations on existing technological platforms of interactive maps and smart phones supported by high speed telephone and data networks.

When 3D printing was first introduced in the late 1950s, it was mainly for prototyping, as a cost saving measure to create prototypes for mass production. However, nowadays sport apparel companies like Nike and Adidas are using additive manufacturing as one of their key manufacturing technologies on an industrial scale. It is this dynamic interaction between markets and rapid technological change that characterized the latter half of the 20^{th} century as a period of turbulence with the only constant aspect of everything – including in global politics – being **‘change’.** The current pace of technological change, deemed exponential, suggests that technology has now become both a significant enabling and a disruptive force. Equally, rapid change infers that everything is in a constant state of transition.

6. Some Foundations For The 4IR

The post Second World War political and market stability made long-term future forecasting possible. Predictable market behavior and growth of world markets for domestic consumption and exports stimulated mass production of goods and services. Further, new technologies were designed to facilitate and to benefit from the post-war boom. This historical period further influenced specific management and organisational thinking such as the division of labour, bureaucratic management), industrial design characterized by assembly lines.

As more competition increases however, as seen in the third industrial revolution, the market becomes saturated, choices widen and new ways of competing and responding to market challenges become necessary. Once this stage was reached in the 3^{rd} Industrial Revolution technologies that made mass production (Just in Case Production) possible were soon criticized for being rigid, leading to waste and unable to respond to dynamic market changes. Newer computer based production systems brought in some relief and made Just In Time (JIT) and lean production methods possible leading to a reduction in unwanted inventory and unnecessary losses as a result of over-production and over supply. New manufacturing technologies like 3D or additive manufacturing are solutions that the market has long been yearning for (see Enke et. al. 2018). Indeed, some of the challenges in the latter half of the third IR paved way for the emergence of the fourth industrial revolution. The combined and interactive effects of the most recent innovations have inspired even larger scale or grand innovations mostly made possible by information and communication technologies. What started as isolated innovations like networked computers in the form of the internet, intelligent cars, computer based diagnostic systems, virtual data storage servers have been creatively combined to give rise to complex innovations that drive the fourth industrial revolution.

Market players in the form of organisations also respond to market dynamics (both those that are anticipated and those that cannot be anticipated – in other words *‘market shocks’* - in various ways. The emergence of lean production systems brought new ways of work organisation and resulted in more flexible and flatter organisations (flatter in terms of fewer bureaucratic levels). As a consequence, organisations have been becoming smaller and smaller and with even shorter lifespans than used to be the case during the 2nd and initial years of the third IR (Williams, 2013).

7. The 4IR And The Developed World

This section provide an analyses of how Germany, Japan and the United States of America (USA) have responded to the 4IR. The review of three country-specific responses provide insights for policy development.

7.1 The Case of Germany

Rising labour costs in developed countries have always been among key reasons behind multi-national corporations’ (MNCs) decisions to invest offshore. A plethora of documented evidence mainly in labour and industrial sociology research suggests that MNCs would continue operating in foreign countries for as long as labour costs in those countries remained low (UNCTAD, 2016). The availability of cheap labour in many Asian countries, and mainly in China, have benefitted these countries in terms of foreign direct investment with many European and North American companies preferring to locate their manufacturing firms in these countries. Labour costs have been rising in the developing world with recent studies estimating that production costs in the USA were only about 5% above China (Saxter, 2017). Conversely, evidence suggests that real wages in the developed world, particularly the United States, have stagnated and productivity levels dropped. These dynamics immediately imply an expected change in relationship between capital and politics in the industrial world to balance the need for profit by capital on the one hand; and incomes of the home market population on the other.

The report raises these points to contextualize the developed world's response to the 4IR. The current reorganization of industry as a result of the 4IR could not have come at a better time for some industrialized countries given their challenges. One of the 4IR implications on north-south economic and investment relations is a likelihood of capital flight back to the industrialized world in the form of a newly coined concept of 'reshoring'. Other possible reasons for reshoring however, are not as clear-cut but are linked to the imperatives of market efficiencies. For example, mass customization as a result of additive manufacturing (3D) will significantly change the dynamics between production, logistics and markets. More importantly, if the developed world remains the market for high quality customized consumer goods, then mass customization, due to its emphasis on producing as little as is possibly required, shall justify the location of production next to the home market. The digital literacy skills of the developing world's labour markets and its readiness to be absorbed by smart factories could also be an additional reason for the reshoring trend.

In a recent paper published by the United Nations Industrial Development Organisation (Santago, 2018) Germany is poised to be a pioneer and a leader in Industry 4.0 solutions mainly as a response to its recent challenges of rising labour and energy costs. This industrial leadership suggests years of behind-the-scenes work premised on a long-term, forward-looking industrial policy that is informed by internal and global market dynamics and emerging trends in industrial manufacturing. In discussing conditions for the adoption of I4.0 in industrialized countries Santiago (2018) further highlights that Germany's Industry 4.0 policy is particularly defensive as it aims to ensure home-based production and also offensive in seeking to retain skills and know-how to support an export-led economic growth model. Indeed digital literacy skills shall be the new comparative advantage in the 4IR.

Germany's Industry 4.0 leadership also places it at the top of Global value chain in as far as industrial production trends are concerned. Consistent with this argument Lopez-Gomez et.al (2017 in Santiago 2018) points out that countries may capture Industry 4.0 value by:

- Adopting I4.0 systems to capitalize on the gains in efficiency, flexibility, speed/responsiveness, precision and customization they offer;

- Becoming a manufacturer/supplier of key I4.0 technologies;
- Providing knowledge management and analysis tools or services via IoT and other I4.0 technologies;
- Building key I4.0 enabling infrastructures to underpin the expansion if I4.0.

The emergence of the 4IR and reshoring highlight a form of political economy where the industrialized countries have to deal with political pressure resulting from stagnant economic growth rates and suppressed incomes.

7.2 The United States

The world's largest economy (the USA) and Japan have grappled with rather distinct challenges towards the latter part of the 20th century and both are pinning their hopes on the fourth industrial revolution technologies to change their fortunes. These global super powers are boasting not only strong and innovation-driven economies but also strong science and technology sectors. However, even with such advancements in science and technology in both countries the 3IR technologies of mainly digitization and automation did not offer many desired solutions. Instead, as was the case with Germany, the 3IR technologies and their influence on global labour market relations were partly to blame for the challenges these countries, specifically the USA, experienced – the offshoring of production facilities providing employment opportunities to foreign countries.

Most recently, one of the key challenges facing the USA has been the rise in unemployment and falling productivity levels. Lars et. al (2015) argue that business-driven productivity goals in the USA, which first influenced foreign investment to take advantage of low labour costs in foreign markets are now behind the reshoring initiatives as 4IR technologies (mainly in the form of robotics in the USA) have made it possible to profitably produce in the USA again. As a result, Reshoring Initiative (a non-profit organization that analyses data on the scope and reasons behind reshoring) estimates that with the advent of flexible 4IR technologies the USA has, through reshoring initiatives to date, managed to create more than 260, 000 jobs (Saxer, 2017).

In the case studies of companies whose activities have been relocated back to the USA, the main reasons cited range from high prices of producing abroad (the case of Chrysler reshored from Italy); product quality and freight costs (Motorola Solutions reshored from China); to government incentives to produce locally (Tesla jeans manufacturing reshored from China). In anticipating this trend the USA has developed policy interventions to boost the growth of the manufacturing sector with the enactment of legislation more specifically the Revitalize American Manufacturing Innovation Act of 2014 and the Manufacturing Universities Act of 2014; the latter designed to place specifically designated universities at the centre of manufacturing innovations (Lars, et. al. 2015). The enactment of both of these Acts in one year signifies the urgency with which the interventions are expected to effect action and yield desired results. The timing also highlights the level of coordination among universities and the ministry responsible for industrial development and/or innovation.

Against this backdrop of reshoring, developing countries have some questions to explore:

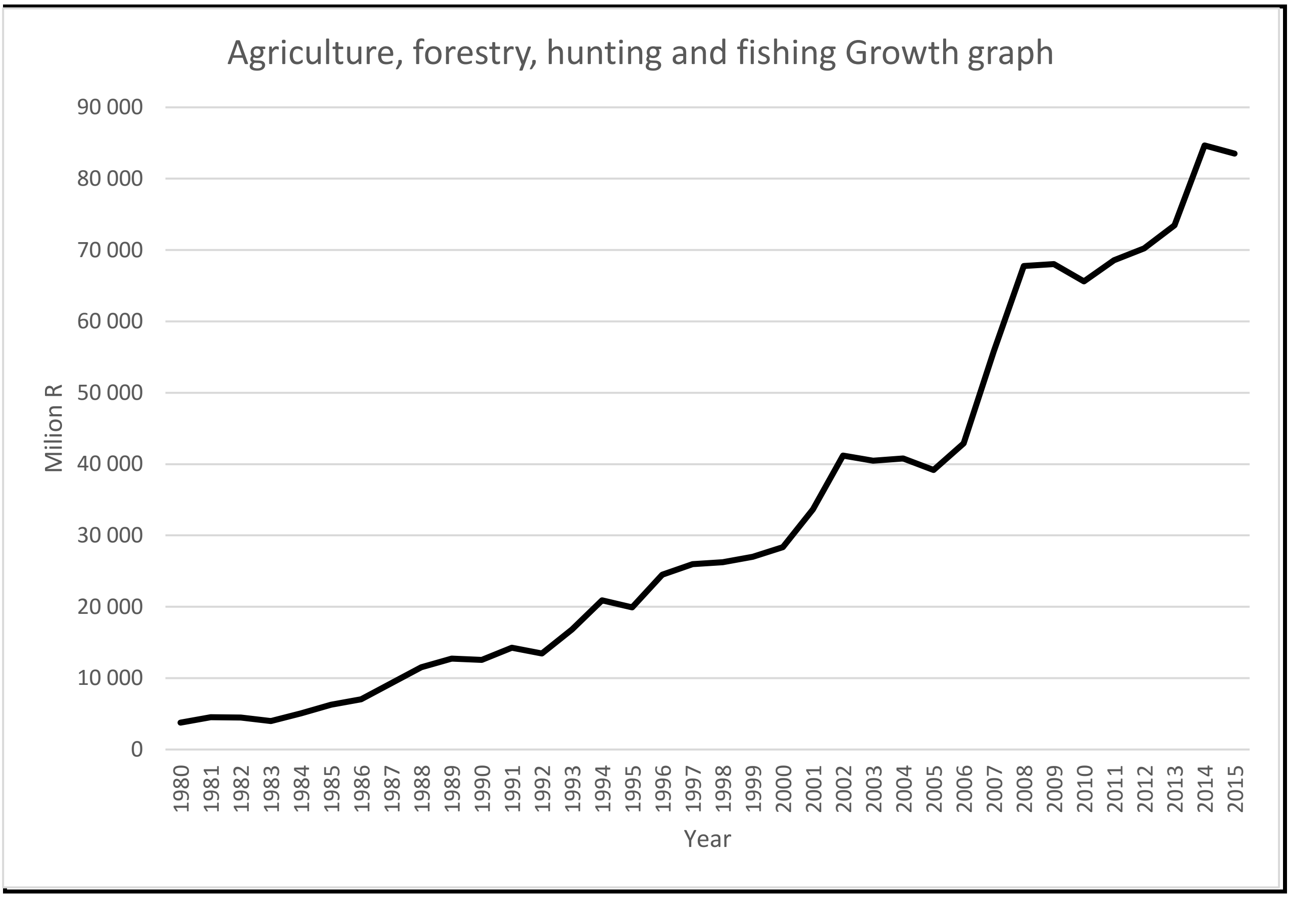
- The potential outcomes of deindustrialization.
- How can South Africa discharge 4IR technologies to achieve her socio-economic policy objectives?

8. Some Pre-conditions for the Adoption of 4IR

Santiago (2018) argues that when it comes to crafting strategies and policies for industry 4.0 there is no one size fits all as each country must carefully look at its uniqueness its role in the global market. However, this needs to be balanced with the socio-economic development objectives of the country. In South Africa, rural economic development is mainly constrained by under-developed infrastructure in the form of roads network and energy supply and slow levels of competencies. For the adoption of 4IR and its reliance on advanced information and communication technologies, South Africa's network penetration especially outside the metros, is rather low.

The importance of the agricultural sector in the economy requires some consideration as highlighted in Figures 1, 2 and 3.

Figure 2: Agricultural Growth from 1980-2015



Source: Adapted from Abstract of agricultural statistics 2016, Namibia is included until 1983

Figure 3: Employment Trends in Agriculture

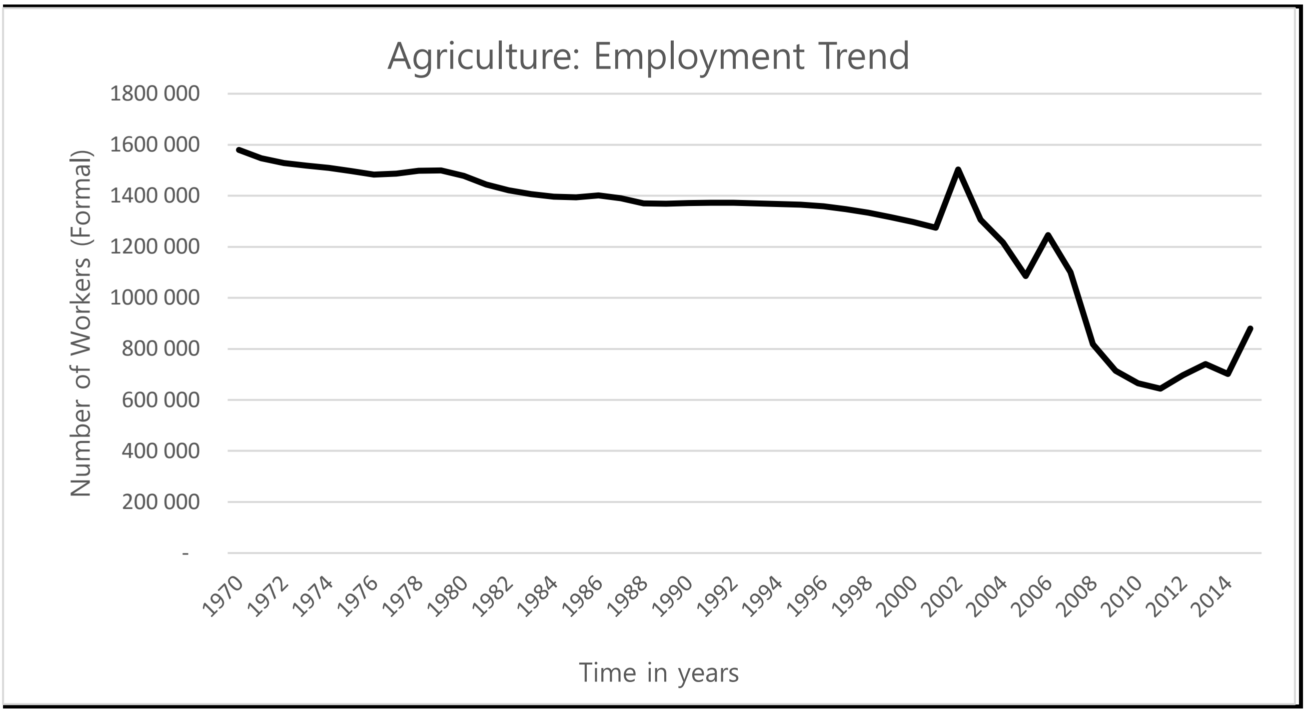
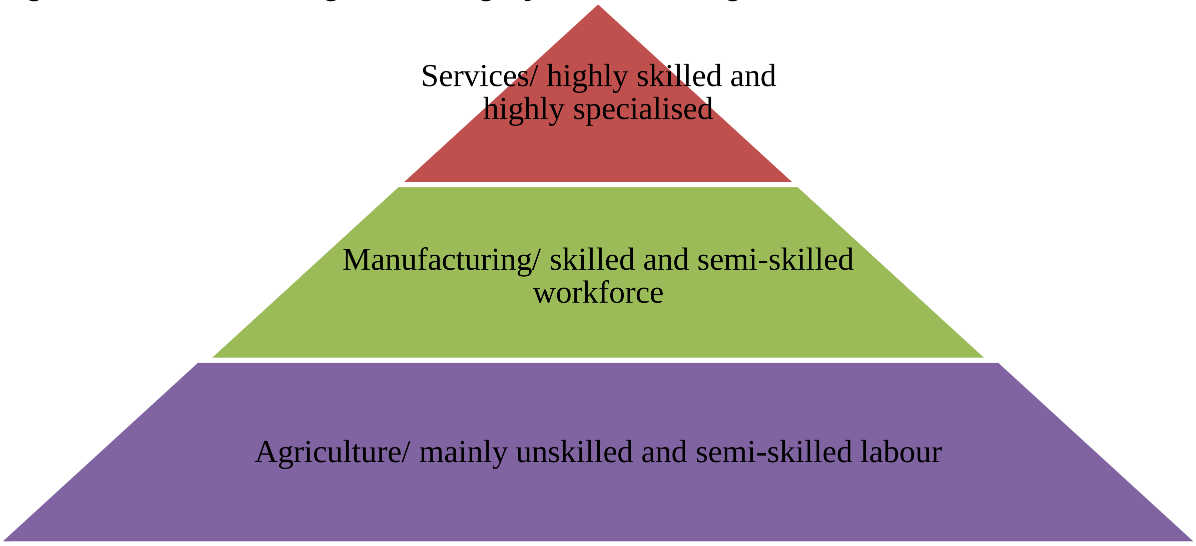


Figure 1: Employment Trend. Source adapted from: Easydata. The data was converted from an excel spreadsheet. Accessed on 6/12/2017 available on: http://quanis1.easydata.co.za/ReportFolders/reportFolders.aspx

Figure 4: The Challenge of a Hugely Unskilled Agricultural Workforce



In a paper prepared for the China-Africa poverty reduction and development conference held in Ethiopia in 2014, Xiaoyun provides an overview of how high agricultural productivity in China helped to generate an agricultural production surplus; which in turn helped to keep real wages lower and stimulated industrialization through, *inter alia*, agriculture-manufacturing linkages.

While it is not a pre-condition that South Africa first focus on agricultural productivity in order to broad-base industrialization, prioritizing agricultural development will have positive outcomes in varied ways:

- Its labour-intensive nature helps to ease the burden of unemployment;
- Higher levels of agricultural productivity will help the country achieve food security
- It can be used in some regions as a launching pad for sectors such as cosmetics and chemicals
- It can be used as a key driver in broad-basing industrialization
- Productivity in agriculture will stimulate the development of sectors that require more advanced technologies and that require uses of advanced engineering thereby leading to the development of more advanced industries.

One significant area in the application of science, technology, innovation, and engineering relates to the development of a critical mass of alternatives such as plant-based protein and substitution of forest-products such as paper, textiles etc. In economically marginalized settings the development and production of these technologies provides a significant link between advanced livelihoods improvements and local economic development planning. Equally, their promotion provides a huge opportunity for policy makers to *inter alia*, introduce technical change, build relevant competencies in all levels of advanced manufacturing in ways that are appropriate for broad-basing manufacturing and technological upgrading. Ensuring that no-one is left behind through the reallocation of labour which continues to be affected by advancements in agriculture will be a significant policy objective of science technology and innovation policy.

South Africa, through the Industrial Policy Action Plan of the Department of Trade and Industry (DTI), lists nine technologies that are believed to sustain the Industry 4.0, these being (1) Big data and analytics, (2) Autonomous robots, (3) Simulation, (4) Horizontal System Integration, (5) Vertical System Integration, (6) IoT, (7) Cybersecurity, (8) Cloud, and (9) Additive Manufacturing. Indeed unlike other countries in the sub-Saharan Africa, South Africa has a more advanced industries (albeit mainly located in metros), and her manufacturing sector uses modern technologies.

While South Africa's level of readiness to participate in the 4IR especially in her metros, prioritized districts have low levels of readiness. However, 4IR offers opportunities for adoption and diffusion of I4.0 technologies. The role vocational training centres cannot be overlooked.

9. Towards Varied Levels Of Participation

Highlighting and emphasizing its ethos towards inclusiveness the World Economic Forum has established a Centre for the 4IR in San Francisco (USA), with partners in several countries including Japan, India, and South Africa. As its main mission, the C4IR is meant to facilitate the co-design, testing and refinement of governance protocols and policy frameworks to maximize the social benefits and minimize the risks of advanced science and technology (C4IR, 2018). The Centre will facilitate the global development of governance protocols on, inter alia, artificial intelligence, internet of things, blockchain technology, autonomous mobility, drones, precision medicine and digital trade

The inclusion of South Africa in the network of countries with Centers of the 4th Industrial Revolution alongside countries like Japan, State of San Francisco, China and India points to the recognition of South Africa's abilities and her state of readiness compared to other African countries.

As progressive as the notion of inclusiveness in the conceptualization of the global political economy in the context of the 4IR may be, the caveat is that meaningful inclusion is undergirded by each player's level of readiness to influence key decisions. Global leaders in various areas of science and technology have made major strides in placing themselves in positions of strategic influence based on anticipated future benefits. Typical examples are Japan in precision medicine, the USA in biotechnology and Germany in industry4.0 manufacturing technologies.

The location of the C4IR in close proximity to the world's foremost technology companies, start-ups, investors and leading academic institutions in the USA is no coincidence and emphasizes the reliance of the 4IR agenda on scientific and technological innovations for its success. Further, the diversity of institutions and their inter-relatedness spanning technology companies to leading academic institutions emphasize the fundamental importance of developing innovation systems of innovation and emphases on collaboration among institutions responsible for the development and diffusion of new innovations (Lee, et.al. 2019).

For the 4IR innovations to appeal to critical mass and interested parties (e.g. organized labour, leftist political parties and civil society organizations) particularly in the developing world, an emphasis on the relationship between the 4IR technologies and their efficacy to provide much needed solutions to the challenges of socio-economic development should be highlighted. Promising 4IR driven technologies with applications in service delivery such as drone technologies can receive priority in policy development.

Despite the startling evidence suggesting that Sub-Saharan African countries still lag behind in establishing the minimum framework conditions to facilitate the adoption of internet-based services and novel technologies associated with I4.0; with electrification levels remaining suboptimal and internet penetration low relative to most of the other countries used in Santiago's (2018) (see appendix 1); use of drones to deliver medicines have saved lives in the mountainous Rwanda where people in remote villages are cut off from main urban centres due to poor or lack transport infrastructure (Fleming, 2018). Further, despite the cumbersome legal conditions on the use of drones in South Africa, current work by Omnia (a South African science intensive agricultural organisation) shows a number of crop improvement interventions that the use of drones may help achieve; from taking aerial images to collecting analyzable data about soil moisture conditions, crop health (van Vuuren, 2019) and all on-demand data that aid policy decision making.

Since innovation systems involve the relationship among the actors involved in creating, diffusing, and utilizing knowledge and innovations (Cook and Memedovic, 2003), it is important to highlight the limiting regulatory condition in the context of drone technologies and agricultural innovation in South Africa. Van Vuuren (2019) decries the excessively long waiting period and processes followed to apply for a drone operating licence through the South African Civil Aviation Authority. Having observed the limiting factors of regulation on the diffusion of 4IR technologies Coleman (2018) argues that with regards to drones, the regulation does not seem to be keeping pace with the innovative business models that the industry wants to explore.

Regulatory bottlenecks could limit the adoption and diffusion of 4IR technologies and hamper South Africa's participation in 4IR. In the USA, the industry certainty brought by the finalization of drone regulation (although limited in the sense that the operator must be in sight of the drone throughout its operation) led to a dramatic growth in the drone industry.

10. Brief Summary

In sum, the 4IR has great implications. *The internet of things (IoT)* as the virtual interconnection of intelligent assets and devices has potential to improve user experience and/or usability.

Artificial intelligence (AI) or self-learning systems as the collective term for machines that replicate the cognitive abilities of human beings has the potential to transform global production systems. AI can significantly help improve performance without human intervention, and allows for constant analysis of performance data, which enables machines to improve over time; whether this is a robot installed in a factory or a distribution warehouse. Machine-generated insights will pave the way for greater precision and accuracy. While repetitive tasks are performed by machines, people can focus on more complex activities.

Advanced robotics relate to devices that act largely or partially autonomously, interact physically with people or their environment, and are capable of modifying their behaviour based on sensor data. Examples are automated air-ventilation systems in cars and malls, automatic lock-system on various devices due to threat or panic. Advanced robotics permeates various industrial sectors, and its reach extends to a wide range of industries. Robotic innovations have been used for recursive manufacturing processes, and have proven useful for workplace safety. The acceptance of the advanced robotics has been triggered by their potential and their abilities of distributed manufacturing as well as the next generation of human-robot collaboration concepts. Robotics and automation technologies result in shorter cycle times while achieving better floor space utilisation and higher levels of productivity.

According to World Economic Forum (2016)[17], the advancements in latest technological innovations, the power and types of digital devices, computing devices and networks are rapidly developing day by day. This is making education and various information easily accessible and enhancing facilities for virtual development as well as virtual innovation of new skills. With emphasis on the growth of AI and e-learning, application-oriented courses are more preferable than bookish education. Gradual evolution of technologies and scientific innovations are leading to the creation of new educational disciplines, which are developing towards eradication of physical existence of institutional walls.

Controversial innovations, due to biotechnology, like gene drives or implants to increase the efficiency of a human being, as well as designer babies, among others cannot be ignored.

Furthermore, the on-going digital transformation of industries also impacts the traditional model of business as new opportunities for innovative business models emerge. As the costs of deploying technology continue to fall, international differentials in labour costs is no longer becoming a decisive factor in choosing the location of production. This has increasingly resulted to greater spatial changes enabled by technology and bringing locations of production and demand closer together.

South Africa is currently not well placed, ranking between 75th globally on a variety of metrics termed 'Readiness for the 4th Industrial Revolution'. This situation puts enormous pressure on areas where South Africa is currently lagging or weak. These areas are; enabling infrastructure (broadband and communications); system of education and skills - more skilled jobs, less manual work; the traditional separation between primary and tertiary industrial sectors will not be sustainable as the distinctions between different sectors becomes increasingly blurred. Furthermore, selective 'reshoring' of industrial processes to major markets in advanced countries or economies and other structural changes to global value chains; significant technology-driven employment losses in retail and services, mining and parts of manufacturing value chains (e.g. automotive), particularly for lower-skilled workers; growing inequality and exclusion; the danger of "winner-takes-all" outcomes, can lead to greater concentration of production and higher barriers to entry. Jobs and functions are likely to experience some dramatic shifts.

Across the countries covered by The Future of Jobs (2016), it is projected that net employment impact could lead to more than 5.1 million jobs losses due to disruptive labour market changes. Between 2015 and 2020 it is expected that there will be a total loss of 7.1 million jobs—two thirds of which are concentrated in routine white collar office functions, such as Office and Administrative roles—and a total gain of 2 million jobs in Computer and Mathematical and Architecture and Engineering related fields.

Manufacturing and production are expected to experience a downturn but are at the same time expected to have relatively good potential for up-skilling, redeployment and productivity enhancement through technology rather than pure substitution. The forecasted global decline in the employment outlook of Manufacturing and Production comes as a result of labour-substituting technologies such as additive manufacturing and 3D printing. However, the Forum claims that the picture is not entirely gloomy as there is an increase in the manufacturing demand for materials which can be a manifestation of labour-complementing productivity enhancement rather than pure job replacement.

11. Conclusions And Implications for STI Policy Development

The analyses in this report highlights that understanding the key drivers of 4IR is a critical starting point for STI policy development. 4IR brings both opportunities and challenges- from state of readiness, broadening participation, to ensuring that the benefits of 4IR are equitably shared. Likewise, the UN General Secretary's Report to the Commission on Science and Technology for Development (2019) cautions that rapid technological change may further widen the socio-economic divide. Indeed, Schwab (2016) states that it is imperative for individuals to realise their power in being able to influence the extent to which technology is part of their lives.

4IR is particularly relevant to the revitalization of manufacturing as a leading creator of jobs, thereby regaining its position as key contributor to GDP growth (UN Trade and Development Report, 2016; UNIDO, 2018; Lars et.al 2015). It is expected that manufacturing can lead to rising incomes, growth of domestic markets and the diversification of the economy into the services sector.

The 4IR's main driving tenets of mass customization and its supporting technologies can help uplift the living conditions of the people. The key argument is that the technologies that drive the fourth industrial revolution should be harnessed to bring desired solutions in the form of economic benefits to the masses of our people.

At the centre of rekindling the manufacturing sector is the role of universities especially engineering and design and coordination between universities and the relevant departments- Higher Education, Science and Technology, Trade and Industry. Universities that are more closer to marginalized economies can particularly play a more prominent role in developing manufacturing innovations and broad-basing 4IR through manufacturing.

A particular area where 4IR can be broad-based is the green economy especially the manufacture of green technologies. Equally, one of the key concerns in 4IR is defining the role of intermediary cities and small towns.

Real benefits of the 4IR are most likely to accrue from the identification of unique glocalized opportunities and the development of relevant capabilities especially in science, technology, and engineering. Indeed, producers of 4IR technologies will most likely reap the highest benefits in the emerging global value chains. A relevant research theme is that of the role of universities such as University of Venda, University of Zululand, University of Walter Sisulu, etc in the 4IR and in meeting the socio-economic development policy objectives in the 4IR.

Less attention has been paid to the country's diverse cultures especially the interplay between culture and innovation. That is to say, culture-led innovations can provide a significant for a glocalized economy The important policy question is under what conditions can culture become a new source or new driver of sustainable innovations while simultaneously influencing the development of appropriate 4IR technologies which require advanced engineering and design. De-gendering science technology innovation and engineering will be significant focus of this policy objectives.

For the 4IR innovations to appeal to critical mass and interested parties (e.g. organized labour, leftist political parties and civil society organizations) particularly in the developing world, an emphasis on the relationship between the 4IR technologies and their efficacy to provide much needed solutions to the challenges of socio-economic development and service delivery should be highlighted.

Urgent attention should be paid to the regulation especially regulatory bottlenecks that are set to limit the adoption and diffusion of 4IR technologies and South Africa's participation in 4IR.

Adapting agriculture to the emerging realities of the 4IR is an important policy development theme. Indeed, the adoption of 4IR in agriculture is likely to influence the evolution of farming systems as new technologies are introduced.

Applying science, technology, innovation, and engineering to develop a critical mass of alternatives *inter alia*, plant-based protein and substitution of forest-products such as paper bring new opportunities for linking the development of advanced livelihoods with more inclusive forms of manufacturing. The link between agriculture and food science and technologies bring further opportunities for developing and upgrading technological capabilities especially in sectors that still need to climb the technological ladder.

While industrial development policy efforts especially in the metros are required to upgrade South Africa's technologies so they can become more suitable for the 4IR, ensuring that no-one is left behind remains a critical area of policy making. Making 4IR more relevant in economically marginalized settings provides a significant link between advanced livelihoods improvements and local economic development planning.

South Africa needs to pay urgent attention to the development of digital literacy skills in order to fully participate in the 4IR. Indeed South Africa like other countries can capture Industry 4.0 value by:

- Adopting I4.0 systems to capitalize on the gains in efficiency, flexibility, speed/responsiveness, precision and customization they offer;
- Becoming a manufacturer/supplier of key I4.0 technologies;
- Providing knowledge management and analysis tools or services via IoT and other I4.0 technologies;
- Building key I4.0 enabling infrastructures to underpin the expansion if I4.0.

Effective science, technology and innovation policy is central in ensuring that South African firms remain competitive and relevant in the 4IR. However, this requires continuous upgrading and sometimes major transformation. It is critically important that in implementing the Innovation for Local Economic Development Strategy DST identifies strategic economic sectors which are locally relevant (labour-intensive) and globally competitive in their niche areas (production of knowledge-intensive products and services) and prioritize these in STI policy.

Overall, for South Africa to remain competitive in the 4IR needs to pay more attention to *inter alia*, competence building as well as technological upgrading. Developing relevant and responsive STI policies will determine South Africa's success in the 4IR.

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