

**Economic Complexity and the Potential for Green Growth in South Africa**

**by**

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## Abstract

South Africa's reintegration into the global economy post-1994 has not produced the expected levels of industrialisation and growth-enhancing structural transformation that has traditionally been achieved by developed countries in the past. South Africa faces the triple challenge of poverty, inequality and unemployment and needs structural growth that is inclusive and sustainable. However, trying to emulate the traditional structural transformative growth paths that developed countries have followed previously, will prove unsuccessful due to changes in the global economy. This paper, therefore, argues that an alternate growth path is needed, especially given that global warming and the effects of climate change act as a threat multiplier to economic growth and development. Furthermore, the world economy is shifting away from fossil fuels and resource depletion towards greener technologies and products. South Africa needs to adopt a growth path that accounts for the current climate and global context to ensure sustainable and inclusive growth for future competitiveness. This paper, using the Economic Complexity Methodology, identifies green industries that South Africa is best positioned to develop and grow given the existing knowledge and capabilities within the economy. A case study is conducted on the wind-power industry which proves to be a promising option given South Africa's current economic climate and the potential for employment creation. This paper aims to highlight the opportunities for the development of green industries in South Africa and the limitations that hinder this potential.

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### Abbreviations

ADPD	Automotive Production and Development Programme
APEC	Asia-Pacific Economic Cooperation
BRICS	Brazil, Russia, India, China, South Africa
CEPII	Centre d'Etudes Prospectives et d'Informations Internationales
CLEG	Combined List of Environmental Goods
DPRU	Development Policy Research Unit
DTI	Department of Trade and Industry
ECI	Economic Complexity Index
EG	Environmental Goods
EGS	Environmental Goods and Services
FDI	Foreign Direct Investment
FITs	Feed-in-Tariffs
G20	Group of Twenty

## Economic Complexity and the Potential for Green Growth in South Africa

GDP	Gross Domestic Product
GE	General Electric
GERD	Gross Domestic Expenditure on R&D
GHG	Greenhouse Gas
GRI	Gestamp Renewable Industries
GW	Gigawatt
HS	Harmonised System
IEA	International Energy Association
IPAP	Industrial Policy Action Plan
IRP	Integrated Resource Plan
I-WEC	Isivunguvungu Wind Energy Converter
JSE	Johannesburg Stock Exchange
MIDP	Motor Industry Development Programme
MW	Megawatt
NDP	National Development Plan
OECD	Organisation for Economic Co-operation and Development
OEM	Original Equipment Manufacturer
PCI	Product Complexity Index
PPAs	Purchase Power Agreements
PV	Photovoltaics
R&D	Research and Development
RCA	Revealed Comparative Advantage
REI4P	Renewable Energy Independent Power Producer Programme
REP	Renewable Energy Products
SADC	South African Development Community
SAWEA	South African Wind Energy Association
SEZ	Special Economic Zone
SITC	Standard International Trade Classification
SOE	State-owned Enterprise
TBP	Technology Balance of Payments
UN	United Nations
USD	United States Dollar
WTO	World Trade Organisation

## Introduction

When South Africa was reintegrated into the global economy at the turn of the millennium, few would have predicted that 25 years on, it would still face the triple challenge of poverty, inequality and unemployment. It would have been expected that structural transformation of the country's economy would have shifted from low-productivity sectors to high-productivity sectors as per the traditional Lewis dual-economy model. However, premature deindustrialisation, the impact of globalisation (both internationally and domestically) and more recently, global warming and the effects of climate change, pose a serious threat to current economic growth and development.

Carlota Perez (2012) argues that growth in the world economy occurs in surges that last for approximately half a century. These surges are driven by a technological revolution which completely transforms societies, production, technology, systems of organisation, distribution and communication systems. The Industrial Revolution is just one of the examples used in her theory. She argues that the process of adopting the new and unlearning the old takes between 20 to 30 years – a term coined 'creative destruction' by the Austrian economist Joseph Schumpeter. This is the process of destroying the old and innovating, creating something new. Once this process has occurred, countries enter into a new paradigm where new technologies operate at higher levels of productivity and where innovation is gained and shared (Perez, 2012). This is followed by a golden age lasting approximately 30 years. Perez (2012) believes that the next golden age will be driven by "green" innovation in order to be sustainable and feasible. This era will radically transform lifestyles, incorporating millions into this revolution (Perez, 2012). According to Perez (2012), we are on the cusp of a paradigm shift as evidenced by the global trends and the shift to cleaner technologies.

The global environment has changed and while globalisation has contributed to efficiencies in production and allowed for technology transfer, the manner in which countries have integrated into the global economy is important (McMillan and Rodrik, 2011). Given the global shift towards sustainability, South Africa needs to adopt a "greener" industrialisation path encompassing greener goods and production techniques in order to compete globally, create employment in activities which will have longevity and to ensure that structural transformation is sustainable and growth-enhancing. In South Africa, the green sector shows enormous potential for growth and employment and has the potential to improve South Africa's trade balance by increasing exports of green goods and services while simultaneously reducing its dependency on energy imports. It is important however, that diversification in green products is aligned with South Africa's existing capabilities and vision for job creation. Transitioning towards a green economy will involve the transformation of economic activities

and production structures globally. This shift could alter the global competitive landscape, reshaping the comparative advantages in production of countries (Fankhauser et al., 2013).

This thesis, using the Economic Complexity Methodology developed by Ricardo Hausmann and Cesar Hidalgo, will seek to answer the following questions:

1. In South Africa's current productive structure, what are the "green products" that have potential to diversify South Africa's export product mix and provide opportunities for further growth and employment?
2. Once identified, what are the opportunities and barriers for this growth and how might South Africa re-orient its industrial structure to become more competitive in these "green" products and reinvigorate industry in a way that aligns with sustainable development?

To answer these questions, the tools of complexity analysis derived from the Atlas of Economic Complexity (Hausmann, Hidalgo et al., 2014), will be used to look at South Africa's productive capabilities relative to the green economy. The economic complexity methodology provides information about a country's industrial structure and productive capabilities through relative comparisons of country export baskets using international trade data from UN Comtrade (Hidalgo et al., 2007; Hidalgo and Hausmann, 2009; Hausmann, Hidalgo et al., 2014). This data reflects the period 1995-2017 for 128 countries (Hausmann, Hidalgo et al., 2014)<sup>1</sup>. Countries that are too small in terms of their export base, or countries with highly unreliable data are excluded to ensure the integrity of calculations and accurate findings. Hidalgo and Hausmann (2009) found that over time as countries grew and developed, the products countries produced diversified and often became more complex. That is to say that their export baskets diversified. Developed economies tended to export a wide range of products whilst developing countries tended to export a narrow few (Hausmann and Chauvin, 2015). Furthermore, the products exported by developed economies were generally more complex and scarcer (only made by a few other countries) compared to developing countries' products which tended to be relatively simple and ubiquitous (made by several countries). Using this analysis, structural transformation is thereby the process whereby countries accumulate productive capabilities and move into producing increasingly complex products.

For the purpose of this paper, a subset of 248 "green" products are identified from South Africa's export basket to analyse the potential for growth in green industries in South Africa. Using the economic complexity methodology (Hidalgo et al., 2007; Hidalgo and Hausmann, 2009; Hausmann,

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<sup>1</sup> The selection criteria includes all countries with GDP and export information, a population above 1,200,000, a trade value above \$1 billion and reliable data (excluding Chad, Iraq and Macau). The 128 countries that remain after these filters are applied comprise 99% of global trade, 97% of global GDP and 95% of the global population (Hausmann, Hidalgo et al., 2014).

Hidalgo et al., 2014) and applying it to South African products, “frontier” green products will be identified. Once these frontier “green” products have been identified, the opportunities for diversification and growth in these green industries, will be explored in the product space which graphically shows a country’s productive structure and further predicts a country’s potential for growth and diversification. This process will allow for the assessment of South Africa’s current green production capabilities and identify opportunities for diversification into green industries that South Africa is best placed to move into given its current productive capabilities. These findings will be supplemented with current economic information and interviews to inform the feasibility of these options and provide insight into the optimal direction for green industrial policy. In addition to the exploration of South Africa’s potential for green growth and identification of potential industries and products, the consideration of employment opportunities will form a focal point of investigation given South Africa’s high rate of unemployment.

The outline of this paper is structured as follows: Chapter 1 gives an overview of the historical background following South Africa’s reintegration into the global economy, looking specifically at the challenges to structural transformation. Chapter 2 briefly highlights the developing global trends in the green economy. Chapter 3 provides an overview of the economic complexity framework developed by Cesar A. Hidalgo and Ricardo Hausmann and places it within the development literature. Chapter 4 builds on the economic complexity framework and introduces the concept of the Product Space as a way of predicting a country’s diversification path and structural transformational opportunities. South Africa’s product space will be located and analysed according to its structural transformation since 1995. Chapter 5 provides the conceptual basis for green growth and environmental goods and gives an overview of the data that will be used. It will then expand on the methodology for the creation of the product space and provide the foundation for South Africa’s green product space which will be developed and analysed using complexity analytics. South Africa’s green frontier products will be identified using the complexity methodology. From a list of 20 frontier green products, one product/industry will be selected based on the potential for growth in South Africa’s current political and economic context. A case study of this product will be explored in Chapter 6 which will expound on the potential for the growth of this product/industry, the potential for employment as well as the barriers and opportunities that exist. This case study will be substantiated by interviews as well as secondary research. Chapter 7 follows with concluding remarks.

## Chapter 1. Challenges to the Traditional Models of Structural Transformation

South Africa's reintegration into the global economy at the turn of the millennium has led to positive, albeit slow, economic growth. However, despite this positive economic growth, South Africa faces the triple challenge of poverty, inequality and unemployment with industry failing to provide the jobs and growth that is generally expected. South Africa's narrow unemployment rate was 27.6% in the first quarter of 2019 and the broad unemployment rate, which includes discouraged jobseekers, currently stands at 38% (StatsSA, 2019). Rodrik (2014) argues that manufacturing-led growth proves to be the most effective path to raise productivity and spur economic growth within a country. This process enables the structural transformation of a country's economy, shifting it from low-productivity economic activities into higher-productivity activities. Historically, manufacturing has proven to be the most effective driver of growth with the Industrial Revolution enabling Europe and the United States to enter onto a path of sustained economic growth and productivity. Furthermore, industrialisation at the end of the 19<sup>th</sup> century and in the 1960's, allowed non-Western countries such as Japan, Taiwan and South Korea to converge with the West (Rodrik, 2016). Not only is manufacturing able to absorb large quantities of unskilled labour, distinguishing it from other high-productivity sectors such as mining and finance, but it is also a tradeable sector enabling demand beyond domestic borders (Rodrik, 2016). The formal manufacturing sector also exhibits unconditional convergence which means that growth is independent of fundamentals such as strong institutions, thus proving to be a powerful engine of growth (Rodrik, 2016).

However, despite the positive growth and structural transformation attributed to the industrial sector, deindustrialisation has become a global phenomenon. While this is to be expected of developed economies since this emulates the path of maturation as activities eventually move into the modern service sector, this trend is unusual for developing countries. These late industrialisers are de-industrialising at lower levels of income and manufacturing employment, compared to those of developed countries (Rodrik, 2014). For example, in the United Kingdom and the United States, manufacturing reached its peak in 1953 and 1961 respectively, comprising a 25% and 35% share of the workforce with per capita incomes reaching \$18 000 and \$15 000 (Lawrence, 2018). However, in South Africa, manufacturing reached its peak in 1981 comprising a 17% share of the workforce with per capita income of \$11 776 (Lawrence, 2018). Rodrik defines this as 'premature deindustrialisation' where developing countries are not undergoing the degree of structural transformation needed to move economies into higher levels of income and employment.

Rodrik (2014) attributes this phenomenon of premature deindustrialisation to globalisation which has increased openness, global competition, technological changes and shifts in global demand. When

looking at manufacturing as a percentage of GDP value-added, its share has decreased from 17.5% in 1997 to 15.6% in 2017 which seems to confirm this global phenomenon (World Bank Indicators, 2019). However, manufacturing's share of GDP when prices are kept constant at the 2010 level allows a more accurate indication of the changes in quantities of goods produced (UNIDO, 2017). When looking at these indicators, manufacturing's share of real GDP has increased from US\$7.84 trillion in 1997 to US\$12.27 trillion in 2017 (World Bank Indicators, 2019). Therefore, it is not that industrial activities have declined but rather, with globalisation and the rise of global value chains, these activities have been relocated to countries able to produce more efficiently and at a lower cost. For countries such as China, India and other Asian countries, globalisation has resulted in high-productivity employment creation and structural change which has facilitated growth. These countries' manufacturing sectors' have undergone rapid growth with China experiencing manufacturing value-added output of 12.8% annually and Asia accounting for 38% of global output, an increase of 12% since 2000 (Colotla et al., 2018; Romei and Reed, 2019). Therefore, it can be argued that while globalisation has contributed to the general trend of deindustrialisation globally, this is as a result of the dispersion of production systems over borders through international subcontracting and direct investment. While developed countries were traditionally responsible for manufacturing, through globalisation, they have been able to increase efficiency through outsourcing production to countries such as China and India with lower labour costs, focusing their attention on other high-productivity activities such as design and marketing (Dalle et al., 2013). On the other hand, it can be argued that premature deindustrialisation for many developing countries is a direct function of China's dominance in these industrial activities and an inability to compete with established manufacturing bases in China and parts of Asia.

Structural transformation in South Africa and Africa at large has not followed the traditional Lewis dual-economy model of growth as other developed countries have in the past. The Lewis model highlights the heterogeneity in productive structures within the economy. Traditional sectors, such as agriculture, are defined by low-productivity activities while the modern sectors, such as manufacturing and services, are defined by high-productivity activities which drive rapid productivity growth, returns to scale and technological spillovers. Structural transformation occurs as the economy shifts from low-productive to high-productive activities. However, a hallmark of economies in developing countries is not only the dispersion of productivity across the modern and the traditional sectors, but also the dispersion of activities within these sectors. For example, within the modern service sector which is meant to be characterised by high-productive activities, there exists both formal and informal activities, as well as activities which can and cannot be traded (Rodrik, 2014). In South Africa, while labour has moved out of the traditional low-productivity agricultural sector, it has not moved into the higher-productive manufacturing sector but rather, has been absorbed into the service sectors (Rodrik, 2014). This is problematic given that tradeable services high in productivity, such as the

finance and insurance sectors, attract highly-skilled workers which only account for a small portion of South Africa's labour force (Bhorat and Hodge, 1999; Bhorat and Rooney, 2017). As a result, jobs created in the low-productivity, often informal, service sectors are non-tradeable and consequently, do not provide opportunities for exponential growth (Quak, 2015). For this reason, structural transformation in South Africa has not been growth-enhancing as the Lewis model suggests but rather, has been growth-reducing as labour has moved into lower-productivity service activities (McMillan and Rodrik, 2011). The traditional dual-economy model fails to account for the rising level of informality within the modern sector. This trend continues to entrench inequality as pockets of modernisation develop alongside growing informality as surplus labour is absorbed into the low-productivity activities within the service sector, preventing growth-enhancing structural transformation (Quak, 2015).

For South Africa, the rise of globalisation has not only increased competition globally but also domestically as China's export competitiveness has infiltrated local markets. Furthermore, since globalisation promotes specialisation according to a country's comparative advantage, South Africa, a country well-endowed with natural resources has had less incentive to diversify and strengthen its modern manufacturing base (McMillan and Rodrik, 2011; Morris and Fessehaie, 2014). This, coupled with China's growing demand for natural resources as it develops, has led to an over-reliance on natural resource exports for South Africa. Furthermore, the economic slowdown after the financial crisis in 2008 coupled with fierce competition globally makes the traditional trajectory of structural transformation difficult to emulate. It is clear that South Africa cannot follow the same traditional manufacturing growth path of structural transformation that developed countries have followed in the past. However, despite this trend, industrial policy for South Africa continues to target the manufacturing sector, viewing it as the key to unlocking South Africa's growth path and structurally transforming the economy into one that yields high growth and is labour absorbing.

While South Africa and other developing economies try to catch-up to the level of industrialisation achieved by developed economies, the world is changing. Global warming and the effects of climate change pose a serious threat to economic growth and development. A degrading biophysical environment constrains livelihoods and limits economic growth. The increasingly felt consequences of climate change will likely accelerate this change. Globally, there is a general consensus that a shift away from fossil fuels and resource depletion towards greener technologies and products is a necessary step and solutions must be sought to prevent and limit the rise in temperature (UNECA, 2016). In developing countries however, environmental protection is often seen as a luxury that should be dealt with only at later stages of development once more pressing issues such as unemployment and poverty, have been resolved (Altenburg and Assmann, 2017). Unfortunately, economic prosperity is not disconnected from environmental protection. In fact, it is argued that green growth can in some cases drive growth (Bowen and Fankhauser, 2011; World Bank, 2017; Jacobs, 2012). Furthermore,

since many developing countries rely on economic activities in forestry, agriculture and fisheries, environmental degradation undermines the ecological foundations essential for economic growth and human welfare. Pollution and waste are also indicative of inefficiencies in production. Trying to follow in the industrialisation path undertaken by developed countries, while the dominant economic actors are shifting towards greener production techniques and goods, will ultimately drive a wedge between global and local practices (Altenburg and Assmann, 2017). This is already evident as developed countries are increasingly imposing stricter environmental regulations and standards on imports and exports (Kaplinsky and Morris, 2017). This makes it difficult for smaller producers to compete or even participate given that stricter regulations can increase the costs of production. Furthermore, in many developing and low-income countries, the skills and knowledge required to impose certain standards and regulations, do not exist (Kaplinsky and Morris, 2017), and consequently, in order to compete, many of these countries are forced to export to poorer markets that do not require these standards and regulations (Kaplinsky and Morris, 2017). These environmental standards will only increase, making it even harder for developing countries to compete thus limiting the markets available for exports in the future. For this reason, developing countries need to avoid being locked into a growth path which encompasses unsustainable infrastructure and business practices that will make it difficult to transform economic structures in the future (Altenburg and Assmann, 2017).

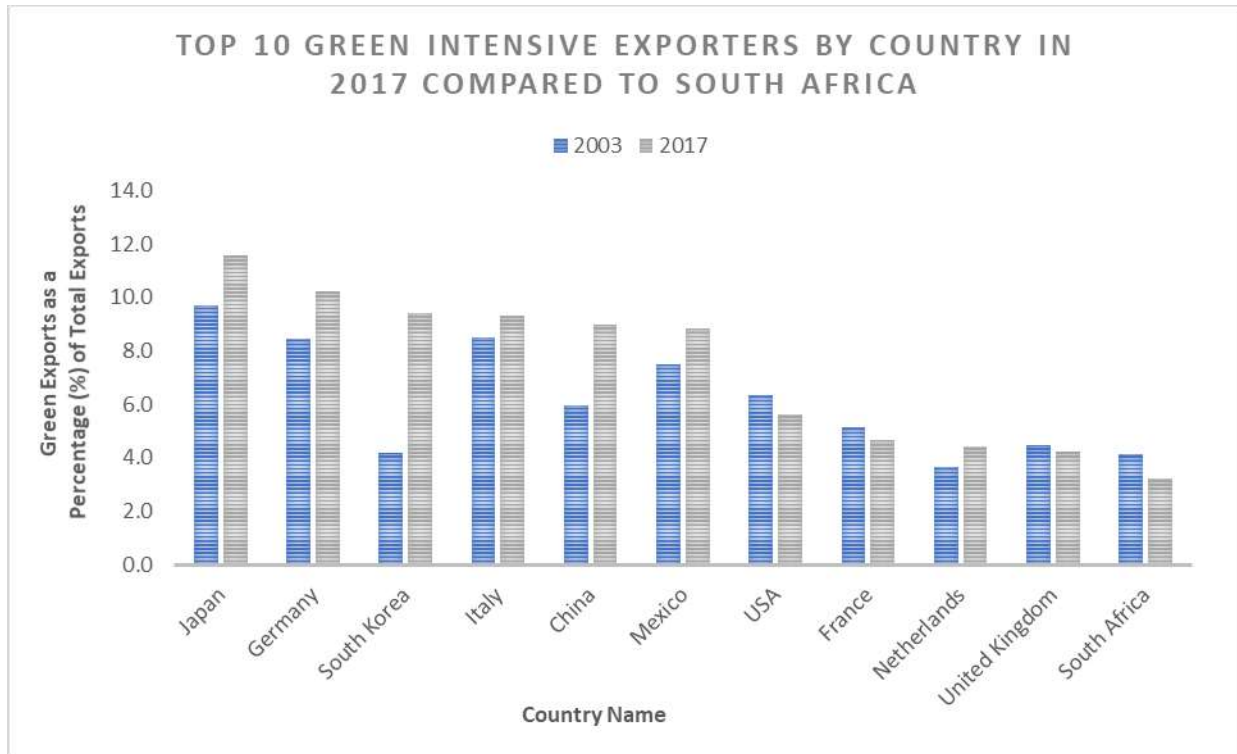
## Chapter 2. Global Trends in the Green Economy

The idea of a green economy and green growth is underpinned by sustainability in development and green industrialisation (UNECA, 2016). The process of greening industrialisation ensures that both growth and structural transformation are geared towards the efficient use of resources, reducing negative environmental impacts and cutting down on harmful emissions and waste overall (UNECA, 2016). The environmental agenda cannot be considered separate from the green economy agenda but rather, the two need to be intertwined with green growth providing jobs in an economy which protects the environment and ensures sustainability. Those that advocate for green growth should not view protection and management of the environment as another economic sector running parallel to conventional economic activity (Fankhauser, 2013). Rather, it should encompass all activities within an economy. Sustainable development, therefore, cannot be mutually exclusive from a green economy since the two are complementary. The economic changes required to combat the effects of climate change are not minor but transformative and system-wide (Perez, 2010). Therefore, a green economy encompasses the production processes and product mix of the whole economy and not only a few sectors (Fankhauser, 2013). Smart industrial policy is about anticipating future markets and adapting to them. Therefore, should South Africa continue to target the revival of the

manufacturing sector as an avenue for growth, this needs to be accomplished through the lens of green growth in order to develop competitiveness in current and future markets and enable sustainable economic growth.

Economic growth and environmental management are becoming increasingly connected in policy discussions globally. In Europe, the creation of new market opportunities is an explicit objective of green growth policies (Fankhauser, 2013). The Chinese have promoted seven strategic industries which include environmental protection, clean energy and cars in the hopes that it can become a leader in green growth (Fankhauser, 2013). Green growth is also a strategic priority for South Korea. This shift towards greener growth globally, and specifically by China, South Korea and Europe, is evidenced by the rising global trade in environmental goods (EGs) as shown in Figure 1. According to the OECD Report on a set Policy Indicators for Trade and the Environment (2019), between 2003 and 2016, global trade in environmentally related goods has more than doubled. In numbers, this is an increase from USD 531.10 billion in 2003 to USD 1 261.24 billion in 2016 (OECD, 2019). This growth has largely been driven by EGs related to renewable energy, wastewater management, and treatment and management of solid, hazardous waste and recycling systems (OECD, 2019). As seen in Figure 1, South Africa's total percentage of green exports has decreased from 2003 to 2017. This is also the case for the United States, the United Kingdom and France. Since demand for EGs is increasing, this could mean that these countries become less competitive in the future. Alternatively, countries shown in Figure 1 (Japan, Germany, South Korea, Italy, China, Mexico and the Netherlands) that have increased the intensity of their green exports could prove to be more competitive in the current and future global trading regime given their increasing intensity towards EGs production and the rising global demand for these products.

**Figure 1.** Top 10 Green Intensive Exporters by Country in 2017 Compared to South Africa (Green Exports as a percentage (%) of Total Exports)



Source: (Own calculations using Comtrade data)

This growth in environmental trade is consistent with global trends in energy generation and consumption as countries are increasingly shifting towards renewable energy, particularly in the generation of electricity (OECD, 2019). With increasing levels of globalisation and interconnectedness as evidenced in the fragmentation of global value chains since the 1970s (Kaplinsky and Morris, 2001), it is clear that countries' export sectors will be, and are currently, affected by global trends. Environmental regulations and requirements are becoming more prominent and are being imposed by more and more leading importers. For example, many countries such as Canada and certain countries in the European Union, have developed national policies that stipulate that environmental impact assessments must be carried out prior to signing any trade agreement (Afesorgbor and Demena, 2018). This means that any country entering into a trade agreement with these countries, has to sign environmental cooperation deals. This presents an opportunity of aligning productive activities to global standards, stimulating the use of cleaner technologies and production processes along supply chains. Alternatively, it also has the potential to harm supply chains and competitiveness should countries not conform to these emerging standards.

While South Africa's development path has historically centred on emission-intensive mining and energy industries which are high emitters of greenhouse gas (GHG), there have been commitments towards addressing climate change through the transition towards an inclusive, climate-resilient and

environmentally sustainable economy (Black et al., 2017). This commitment is embedded in national policy which is promoting the greening of various sectors in the economy to support the creation of jobs and efficient production processes while reducing waste, GHG emissions and pollution (Black et al., 2017). The fruition of these commitments, however, has been slow with concerns over coal sector job losses and employment generation remaining at the forefront of the debate. Africa and South Africa face many domestic challenges in addition to playing 'catch-up' to the developed world in terms of industry. However, South Africa, and Africa at large, are placed in a unique position for sustainable development and green transformation given the relative lack of industrialisation and existing infrastructure compared to that of developed countries. Consequently, South Africa is not locked into a path-dependent growth trajectory and has the opportunity to adopt a green growth strategy, promoting the production of green products and positioning its economy up for future success and competitiveness. The green economy presents an opportunity for South Africa to develop a growth path which is sustainable and inclusive while also enabling it to leapfrog into the fourth industrial revolution.

## Chapter 3. The Economic Complexity Method: An Overview

### 3.1 Economic Growth

The first generation of economic growth models used two different approaches to explain growth. The first focused on the dual characteristics of the economy (Lewis, 1954; Ranis and Fei, 1961). In these models, the economy consists of a traditional (agriculture) and modern (industry) sector. While the traditional sector was viewed to be primitive in its use of technology, the modern sector was viewed to be the productive sector characterised by innovation and capital accumulation (Fortunato et al., 2018). Therefore, economic growth is dependent on the rate at which labour and productive resources move into the modern sector from the low-productivity traditional sector (Fortunato et al., 2018). This is the process of structural transformation. Through this process, static and dynamic gains are generated. Static gains relate to the increase in labour productivity as workers are employed in more productive sectors. Dynamic gains relate to the acquisition of skills and upgrading over time due to access to better technologies on the accumulation of capabilities (Fortunato et al., 2018). The neoclassical growth models of Solow, and later variants, forms the second generation of economic growth models. According to these models, various economic activities are viewed as being structurally similar. Therefore, these different activities can be aggregated into a single representative sector. Growth then, depends on various factors such as savings, capital accumulation (both human

and physical) and innovation. In this sense, economic growth is the process of transformation within a sector (Fortunato et al., 2018).

However, the authors of the complexity methodology, argue that economic growth theory has been limited by the use of simplified aggregate factors to explain economic growth. These theories fail to capture the complexities and knowledge that cannot be accounted for. In this way, economic development has been framed as a problem of accumulation, as opposed to a problem of increased diversity (Simoes and Hidalgo, 2011). Furthermore, the traditional theorising on structural transformation is too simplistic and does not account for countries' unique contexts and capabilities that inform future growth. The economic complexity methodology aims to create a bridge that allows for the marrying of economic theory and existing data, providing an alternative way of thinking about how a country undergoes structural transformation to develop and grow. Instead of focusing on aggregate growth to understand development, the focus is placed on the complexity of an economy and the existing embedded knowledge within, and how to exploit this in order to develop (Hausmann, Hidalgo et al., 2014). There is a shift from focusing purely on growth in terms of increasing productivity, through the accumulation of factors of production (human and capital), towards focusing on the accumulation of productive activities and knowledge within complex networks to determine the potential for economic growth and development (Hausmann and Chauvin, 2015). In this way, growth is not attributed to producing more output but rather, producing increasingly diverse products (and services) which do not currently exist given that these techniques and capabilities have yet to be acquired. The focus for economic growth is placed on analysing the complexity of an economy which is directly related to the amount of valuable knowledge embedded within (Hausmann, Hidalgo et al., 2014). Therefore, the composition of a country's productive output is indicative of the structures existent that hold and combine knowledge. Development and growth are therefore achieved through productive agents, such as entrepreneurs, accessing networks of productive capabilities or "know-how."

Hausmann (2016) argues that economic growth emphasises the importance of technical progress which is based on tools/embedded knowledge, recipes/blueprints/codified knowledge and know-how/tacit knowledge (Hausmann, 2016). Hausmann defines know-how as tacit knowledge, a "wiring of the brain" that allows us to do things that we are not fully conscious of. Hidalgo (2015) uses the term "personbyte" as a unit that measures this tacit knowledge and know-how that an individual possesses. Given that humans are finite, there is a limit to the amount of knowledge an individual can accumulate. In terms of production, many products require more than one personbyte to be produced. Therefore, various, different personbytes need to be combined to produce a certain product. The ability to create these networks of knowledge and know-how, the accumulation of personbytes, is defined as social capital (Hidalgo, 2015). Therefore, while human capital is the knowledge and know-how embodied in individuals, social capital is the ability of society to connect and form networks of

knowledge and know-how (Hidalgo, 2015). However, the ability to form these networks hinges on the availability of communication and transportation technologies, personal values, standards and trust which cannot be traded or transferred easily across borders (Hidalgo, 2015).

Therefore, while tools and codified knowledge, for example, can be shared globally through transport networks and communication channels, collective know-how, the ability to form finance networks, logistic networks and knowledge networks, are difficult to trade and share (Hausmann et al., 2009). It is this difficulty in transferral that can hinder growth. According to Hausmann (2016), know-how grows through specialisation by individuals. Since individuals have limited capacity in the amount of knowledge they can acquire, for know-how to expand, individuals within a society must become more specialised in a piece of knowledge that makes up the whole (Hausmann, 2016). For example, Adam Smith's division of labour theory argued that through the specialisation of tasks, workers would be able to increase their individual efficiency and collectively, their output. Similarly, Hausmann (2016) and Hidalgo (2015) argue that a specialisation of know-how and the increase in the units of different personbytes within a country, coupled with the co-operation of individuals and expansion of networks, allows for the production of increasingly complex products as specialised parts of knowledge (personbytes) contribute to overall output. Development is the accumulation and increasing acquisition of know-how (human capital), which is co-ordinated, combined and recombined (social capital) to produce more complex goods.

As an example, the production process to make a dress requires a design, the sourcing of fabric and a dressmaker to cut and sew the dress. Thereafter, the dress needs to be packaged, branded, marketed and distributed (Hausmann, Hidalgo et al., 2014). It is unlikely that the knowledge and capabilities needed for each stage of the production process is held by one individual, or personbyte, but rather, knowledge of these various processes will be held by different people in a firm or a market. Furthermore, this operation will need to be financed and activities coordinated. This entire operation requires social capital of know-how (knowledge of who holds specified knowledge for each stage of the process) and know-where (knowing the location of these individuals that hold this knowledge) (Hausmann, Hidalgo et al., 2014). It is the interaction of this knowledge through organisations and markets that allow for output of production. This highlights the point that development occurs when know-how across society is accumulated.

### 3.2 Economic Complexity

Economic Complexity therefore relates to the amount of productive knowledge or capabilities existent in a country. The more capabilities (personbytes) a society possesses, the more possibilities exist for combining these capabilities which leads to increasingly diversified and complex outputs (Bhorat et

al., 2019). The amount of embedded knowledge or know-how can be determined by the diversity and ubiquity of the products produced in a particular country. Countries that contain many different personbytes are able to produce a wide variety of products. Furthermore, products that require a large volume of knowledge, combining different personbytes, are only produced in countries where that combination of knowledge exists. Therefore, diversity is expressed through the number of diverse and distinct products a country produces while ubiquity relates to how many other countries are able to produce a particular product. Formally, diversity is defined as:

$$Diversity = k_{c,0} = \sum_p M_{cp}$$

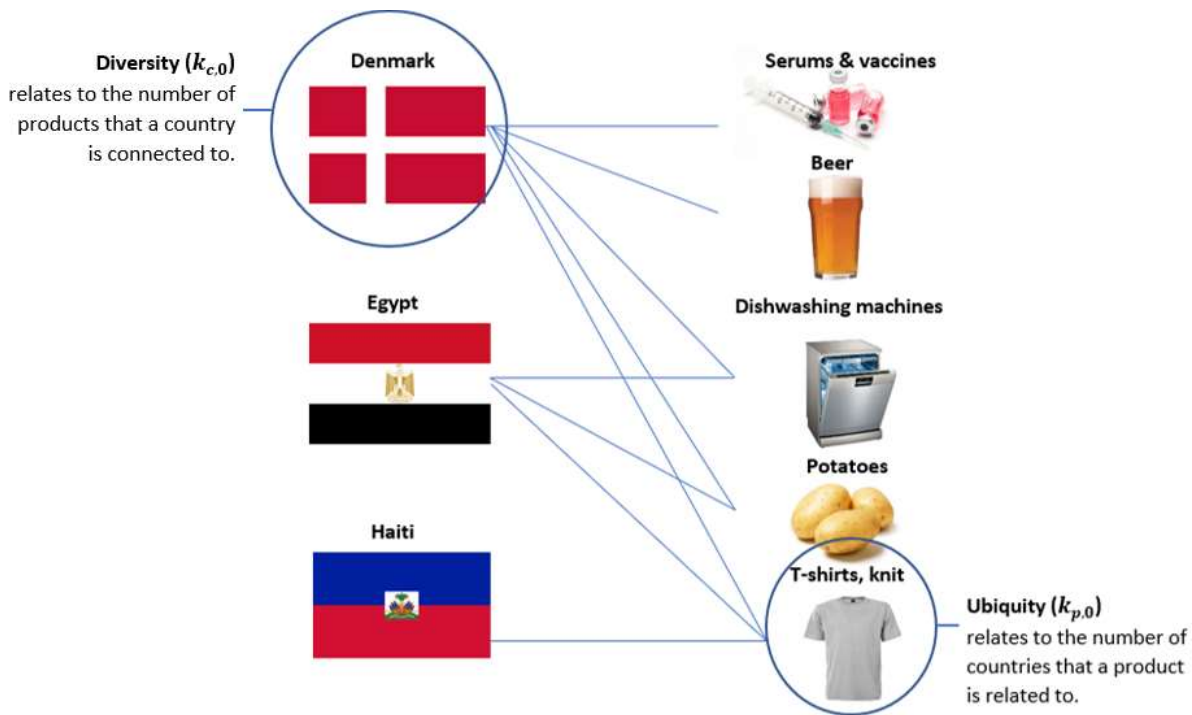
And ubiquity is defined as:

$$Ubiquity = k_{p,0} = \sum_c M_{cp}$$

Source: (Hausmann, Hidalgo et al., 2014)

Where  $M_{cp}$  is defined as a matrix that is 1 if a country  $c$  produces product  $p$ , and 0 if it does not. The diversity and ubiquity of a country is measured by summing the rows and columns of the matrix. Figure 2 highlights this notion of diversity and ubiquity. In this example, diversity accounts for the total number of products a country is connected to. This equals the number of links within a country's network. Therefore, the diversity ( $k_{c,0}$ ) of Denmark is 5 since it is able to produce serums and vaccines, beer, dishwashing machines, potatoes and t-shirts. The diversity of Egypt is 3 since it only produces 3 out of the 5 products and Haiti's diversity is 1 respectively. Ubiquity ( $k_{p,0}$ ) is measured by the number of countries that a product is related to. This then equals the number of links that products have in its network. In this example, the ubiquity of t-shirts is 3 since every country is able to produce this good; potatoes and dishwashing machines are 2 since these products are only produced by Egypt and Denmark; and beer, serums and vaccines have a ubiquity of 1 since Denmark is the only country that produces and exports these goods.

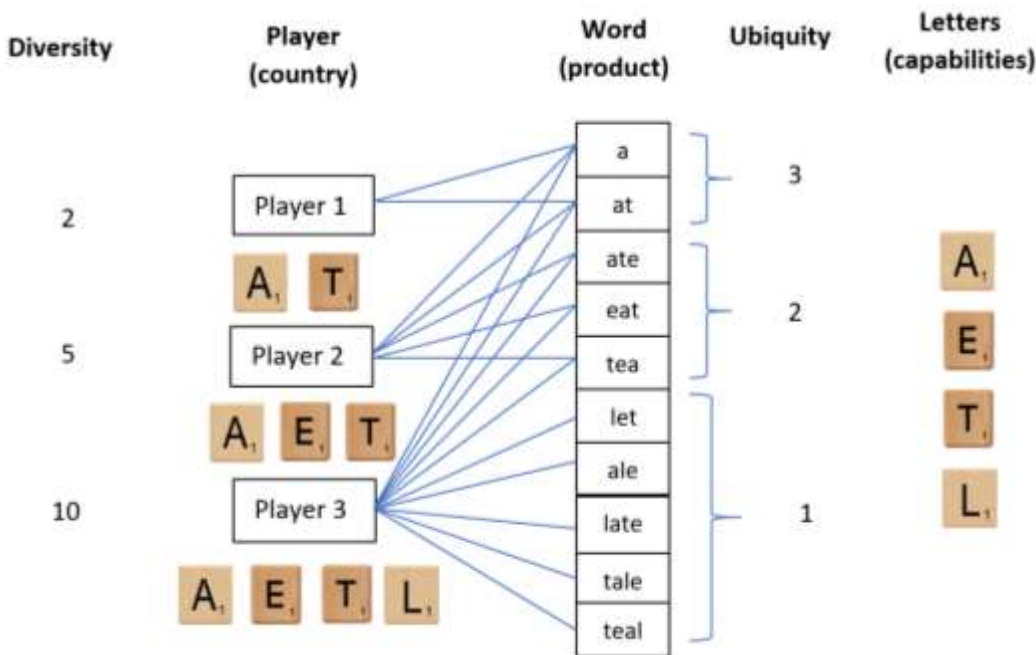
**Figure 2. Diversity and Ubiquity**



Source: (Authors own using Comtrade data)

To further highlight this notion of diversity, ubiquity and ultimately economic complexity which is related to the embedded knowledge within a country, Hausmann, Hidalgo et al. (2014) use the analogy of a game of scrabble (Figure 3). In scrabble, each letter is used to create a word. In this analogy, each letter represents a capability a country possesses, and words represent the products that these capabilities, when combined, are able to produce. Therefore, depending on what fraction of the alphabet a player (country) holds will determine how many words a player can make. Players that hold more letters will be able to produce more words while players with less letters are limited in the number of words they can make. For example, in Figure 3, player 1 possesses 2 capabilities and consequently is only able to produce 2 words. Player 3 on the other hand, possesses 4 letters and is able to produce 10 words. The number of words a player makes is related to the diversity of a country's export basket. Those countries with less capabilities (player 1) are limited in the diversity of goods (number of words) produced while countries with an abundance of capabilities (player 3) are able to produce many products.

Figure 3. Scrabble Analogy



Source: (Authors own)

Furthermore, in the game of scrabble, longer words tend to be harder to make compared to short words which are more common. This relates to the ubiquity of the products a country produces. It is clear in this analogy that longer words (products) also require more letters (capabilities). Ubiquitous products are those that require fewer capabilities and therefore, many countries are able to produce these goods. For example, the words “a” and “at” are produced by all 3 players and would therefore be categorised as ubiquitous words. Non-ubiquitous products, likened to longer words, tend to require a large variety of capabilities which not everyone possesses. The words “let,” “ale,” “late,” “tale” and “teal” are only produced by player 3 and are categorised as being non-ubiquitous words. Therefore, more letters are needed to create longer words just as an increase in capabilities allows for both the diversification of products produced and the potential for non-ubiquity in a country’s product mix.

However, the issue of scarcity presents a problem especially when considering the production of natural resources such as oil and diamonds. Non-ubiquitous goods can include goods such as airplanes, which are high in technological content and difficult to produce, but can also include goods such as diamonds and crude petroleum which are natural resources and consequently, naturally non-ubiquitous (Gala et al., 2018). This is evident when comparing the ubiquity of countries in Table 1. Saudi Arabia, Nigeria, Qatar and Angola are all exporters of oil and are well-endowed with this natural resource. Furthermore, Botswana produces and exports rough diamonds which are naturally non-ubiquitous. These countries’ levels of ubiquity are similar to those of Sweden and Japan, highly developed countries with complex economies, able to produce many non-ubiquitous products such as medicaments (Sweden) and image processing medical devices (Japan). However, despite having

similar levels of ubiquity, these countries' economies are vastly different in terms overall complexity. Therefore, to counter this measurement issue, and control for scarce natural resources, the ubiquity of a certain product in a given country is compared with the diversity of exports in countries that produce and export that same product. In Table 1, these discrepancies are clear. While these selected countries may have similar levels of ubiquity, their levels of diversity diverge significantly, especially when comparing Japan and Sweden to Saudi Arabia, Nigeria, Botswana, Qatar and Angola. Therefore, while all the countries in Table 1 have similar levels of ubiquity, the level of diversity differs significantly which ultimately impacts on a countries level of economic complexity. Japan and Sweden have complex economies given their ability to produce both diverse and non-ubiquitous products.

**Table 1.** *ECI of Selected Countries According to their Diversity and Ubiquity Measures*

Country	Diversity	Ubiquity	ECI
<b>Countries with High Levels of Complexity</b>			
Japan	346	18.59	2.26
Sweden	284	18.66	1.76
<b>Oil and Natural Resource Rich Countries</b>			
Saudi Arabia	70	19.30	0.72
Nigeria	54	19.66	-1.44
Botswana	30	20.07	-0.01
Qatar	26	19.73	0.30
Angola	12	20.67	-1.38

Source: (Own calculations using Comtrade data)

To generate a more accurate measure of the capabilities' existent in a country or the capabilities required to produce a certain product, the *Method of Reflections* is used which uses the diversity and ubiquity measures iteratively to improve the estimate of productive knowledge and complexity within a country. This process continues until convergence where quantitative measures for complexity, both the economic complexity index (ECI) and product complexity index (PCI) are generated.

Formally, this process is defined as:

$$k_{c,N} = \frac{1}{k_{c,0}} \sum_p M_{cp} \cdot k_{p,N-1} \tag{1}$$

$$k_{p,N} = \frac{1}{k_{p,0}} \sum_c M_{cp} \cdot k_{c,N-1} \tag{2}$$

where  $M_{cp} = 1$  if  $RCA_{cp} \geq 1$  and  $N$  corresponds to the number of iterations.

Equation (2) is then inserted into equation (1) to obtain

$$k_{c,N} = \frac{1}{k_{c,0}} \sum_p M_{cp} \frac{1}{k_{p,0}} \sum_{c'} M_{c'p} \cdot k_{c',N-2}$$

$$k_{c,N} = \sum_{c'} k_{c',N-2} \sum \frac{M_{cp} M_{c'p}}{k_{c,0} k_{p,0}}$$

And then is re-written as:

$$k_{c,N} = \sum_{c'} \widetilde{M}_{cc'} k_{c',N-2}$$

where

$$M_{cc'} = \sum_p \frac{M_{cp} M_{c'p}}{k_{c,0} k_{p,0}}$$

When  $k_{c,N} = k_{c,N-2} = 1$ , the equation is satisfied. At this point, this corresponds to the eigenvector of  $M_{cc'}$  associated with the largest eigenvalue. Since this eigenvector is a vector of ones, it does not provide informative information. Therefore, one looks for the eigenvector which is associated with the second largest eigenvalue. This eigenvector captures the second largest amount of variance in the system and is the measure of the ECI which is defined as:

$$ECI = \frac{\vec{K} - \langle \vec{K} \rangle}{stdev(\vec{K})}$$

Where  $\langle \rangle$  is an average,  $stdev$  is the standard deviation and,

$\vec{K} = \text{Eigenvector of } M_{cc'} \text{ associated with the second largest eigenvalue}$

Source: (Hausmann, Hidalgo et al., 2014)

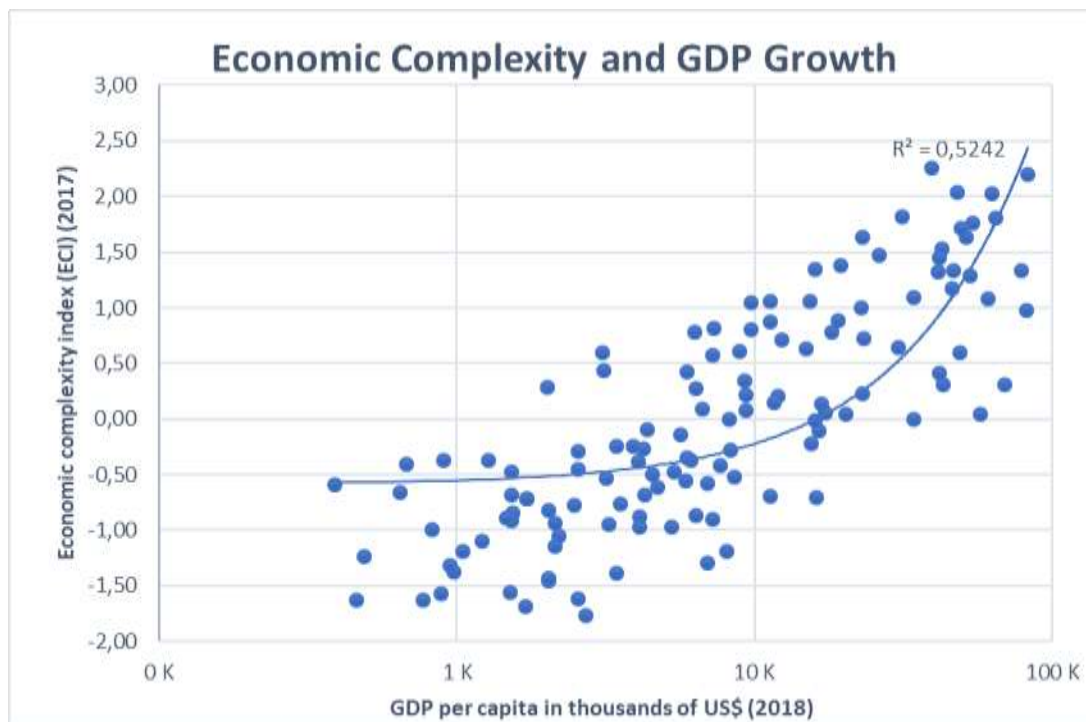
Therefore, the economic complexity of a country and ultimately, the embedded knowledge and capabilities within, can be determined by the complexity of products exported. Ubiquity and diversity are the two building blocks which inform the economic complexity of a country's export basket (Gala et al., 2018). An export basket consisting of diverse, complex, rare and non-ubiquitous goods is indicative of a country with a sophisticated productive structure and vice versa.

### 3.3. The Economic Complexity Index as a Measure for Growth

Using the economic complexity methodology, Hidalgo et al. (2009) created the economic complexity index using international trade data to measure the economic complexity existent in different country

economies. The economic complexity methodology provides information about a countries' industrial structure and productive capabilities through relative comparisons of country export baskets (Hidalgo, et al., 2009). Hidalgo et al. (2009) found that over time as countries grow and develop, the products produced diversify and tend to become more complex. They found that developed economies tend to export a wide range of products whilst developing countries tend to export a limited few (Hausmann and Chauvin, 2015). Furthermore, the products exported by developed economies are generally more complex and less ubiquitous compared to developing countries' products which tend to be relatively simple and ubiquitous. It could be extrapolated therefore, that cross-country levels of economic complexity and therefore productive knowledge, is positively correlated with economic development (Hidalgo and Hausmann, 2009). This is shown in Figure 4 which utilises countries' relative levels of economic complexity (for 2017) and plots these as a function of these countries' level of GDP per capita (for 2018). The positive correlation between economic complexity and GDP is clearly shown.

**Figure 4.** *Economic Complexity and GDP Growth*



Source: (Own calculations using Comtrade data)

It is not increased productivity in the production of one product that drives growth but rather, increased complexity which is gained through increased productive knowledge within a country, measured through the product mix a country produces (Hausmann, Hidalgo et al., 2014). Countries that possess more knowledge, through individuals and organisations, have the potential to produce more diverse products (Hausmann, Hidalgo et al., 2014). Similarly, products that are complex and require large volumes of knowledge to be produced, can only be produced in countries where that knowledge is existent. The accumulation of productive knowledge builds economic complexity as activities shift

from those that are low in complexity (low productivity) towards activities which are more complex (high productivity). Through the process of structural transformation, countries accumulate productive capabilities and diversify into increasingly complex products becoming more complex in the process (Hausmann, Hidalgo et al., 2014; Hausmann and Hidalgo, 2011). Since higher levels of complexity are positively correlated with higher levels of development, for a country to grow in economic complexity and development, the accumulation of productive capabilities is needed.

Therefore, according to Hausmann, Hidalgo et al. (2014), the ECI is closely linked to the level of a country's development and is able to predict its future economic growth. Italian economists Cristelli, Tacchella and Pietronero (2015) however, posit that while the economic complexity methodology has provided a more robust, scientific framework for economic predictions, it is still unable to provide economic predictions for a dynamic and evolutionary system (Cristelli et al., 2015). Their approach builds on the economic complexity methodology, the idea that a country's export basket is able to discount and reflect (mostly) the embedded knowledge encoded within the intangible assets in an economy. However, they argue that regression-based approaches are unable to predict and account for the heterogenous dynamics of country growth. To counter this issue, Cristelli et al. (2015) introduced non-monetary metrics to assess country competitiveness by quantifying the intangible assets to measure the strength and evolution of a country's economic system and consequently, the country's level of fitness. Based on these metrics and comparisons between countries, they were able to generate the fitness-income plane, which highlights the heterogenous evolutionary dynamics between countries. Countries are then plotted on this plane according to their 'fitness.' Cristelli et al. (2015) argue that depending on where countries are placed on the fitness-income plane can determine its potential for economic growth. For example, countries situated in the 'laminar' zone tend to be more resilient to external shocks and consequently more predictable in terms of economic growth. Alternatively, countries generally reliant on raw material exports or plagued by civil war tend to be found in the chaotic regions of the income/fitness plane with low levels of predictability for future growth (Cristelli et al., 2015). The authors argue that one-dimensional, linear indicators are insufficient to predict economic growth given the heterogeneous dynamics of countries. Instead, GDP-measures need to be complemented with non-monetary driven indicators in order to conceptualise the economic dynamics related to country evolution on a multi-dimensional scale, as in the case of the fitness-income plane, to better predict a country's future economic performance (Cristelli et al., 2015).

Whilst these are valid points, especially with respect to the inability to capture the heterogenous and evolutionary dynamics of countries through time, the conclusion that standard regression analysis cannot explain the relationship between two variables is flawed. Regression is the dominant technique used by scholars of economic growth to validate hypotheses on the effect of certain variables (Stojkoski and Kocarev, 2017). Furthermore, while the economic complexity analysis provides a robust measure for assessing a country's current productive structure and potential for future

diversification, these findings should always be analysed within the context of a particular country and complemented with other relevant data (both qualitative and quantitative). The complexity analytics provide visual representations of a country's productive structure through the creation of the product space and hence, whilst the methodology cannot account for the heterogeneous dynamics of countries, it provides a useful tool for analysis of a country's productive structure and capabilities, allowing for further analysis of potential paths for structural transformation and diversification based on existing capabilities.

## Chapter 4. The Product Space

### 4.1. The Product Space and Structural Transformation

Expanding the amount of productive knowledge and capabilities in order to diversify into new and increasingly complex activities gives rise to the 'chicken and egg' conundrum (Hausmann, Hidalgo, Bustos et al., 2011). If capabilities needed for a product or more broadly, an industry, are not present in a country, these products or industries will not exist. However, if these industries do not exist, the accumulation of knowledge needed for these industries is unlikely to materialise as there is no existing industry or product to drive demand, and hence no incentive to accumulate these productive capabilities. This is pronounced when productive capabilities required, differ significantly from those capabilities already present and embedded within a country's existing productive structure. Hidalgo, Klinger, Barbase and Hausmann (2007) and Hausmann, Hidalgo et al. (2014), argue that new capabilities are more easily acquired if they are similar to those that already exist. Countries should therefore move towards producing products that are 'related' or 'proximate' in terms of the productive knowledge required (Hidalgo et al., 2007) thus allowing for the overlapping of existing capabilities and knowledge that would facilitate diversification. This idea posits that countries will move into industries and the production of products that are similar to ones that already exist. For example, it is easier to shift into the production of blouses from shirts, than to shift from producing shirts to jet engines (Bhorat et al., 2019) as the existing capabilities embedded in the economy required to produce shirts are similar to those needed to produce blouses as opposed to jet engines. Within this complexity framework, Hidalgo et al. (2007) and Hausmann and Klinger (2006) developed a product space to explore this hypothesis that learning externalities are involved in the production process.

The product space is a network that allows for the visualisation of all products exported by countries (Figure 5). A limitation of the product space analysis is that it assumes factors of production are limited within national borders and that goods are wholly produced in a given economy (Hickson, 2017). This neglects the advent of global supply chains and the increasing fragmentation of production across

borders that has accompanied the rise in globalisation. Productive capabilities used in the production of intermediate goods therefore may not be directly measured (Hickson, 2017). Notwithstanding these limitations, generating accurate data to account for the intermediate production activities would prove challenging. Consequently, while the product space cannot account for the entire production process, it still provides a superior predictor of economic growth and sound illustrative understanding of the path-dependent trajectory of economic growth.

To map the product space, a measure of proximity is used to calculate the distance between various pairs of products that are likely to be co-exported by a country. Products that are frequently co-exported are strongly connected and will lie closer to each other in the product space. This finding is derived from the assumption that should two products share a large portion of required capabilities, a country exporting the one product will likely export the other (Bhorat et al., 2019). Furthermore, if two products require very different capabilities, they will lie further away from each other in the product space and it is unlikely that they will be co-exported. The collection of these proximities between products creates a network called the product space which can be used to study the productive structures of countries.

The product space is made up of a core and periphery. The periphery of a country's product space tends to be dominated by primary products that are less connected and sparsely populated compared to the core of the product space which typically comprises manufactured products which are more complex. Interestingly, the spread of EGs across the product space is similar to the spread of all traded products. Complex EGs such as "Other engines and motors" are located in the core of the product space while relatively simple EGs such as "Twine and ropes of baste fibres", are located in the periphery of the product space (Mealy and Teytelboym, 2018) Graphically, nodes represent the different products that a country produces, and the size of the nodes illustrate the product share of total exports for a particular country. Their respective colours relate to their product grouping. For example, in Figure 5, the dark blue nodes represent "Ships" as indicated by the product key. These product nodes in the product space are connected by various linkages which illustrate the proximity between two connected products. The shorter and broader the connections, the closer the products are in proximity to one another. Close proximity is indicative of products that share similar capabilities for production (Hausman, Hidalgo et al., 2014). It makes sense for a country to move towards producing a product close to an existing product node given the similarity in capabilities required, as opposed to choosing a product node far away. For example, in Figure 5, the coloured nodes for "Textiles and Fabric" are in close proximity to the coloured nodes for "Garments" while "Textiles and Fabrics" are on the opposite side of the product space to the product nodes representing "Chemicals and Health." This is logical since the capabilities required for producing textiles and fabric are likely be similar to those needed for producing garments, as opposed to those capabilities needed for producing chemicals and health products. Similarly, as illustrated below, groups of products requiring



likely to develop in the future, since countries are more likely to move into producing products nearby, given the pre-existing capabilities that are similar to those required (Hausmann and Chauvin, 2015). Hidalgo et al. (2007) found that when looking at the product space over time for various countries, new export products would emerge close to existing products (Hidalgo et al., 2007). For example, Germany's existing expertise in high-precision machining allowed them to move into the production of wind turbines given the overlap in knowledge required to produce both goods (Fankhauser et al., 2013). This supports the empirical finding that production and the process of growth and diversification is linked to learning, it does not follow a random path but is incremental and to a certain degree, predictive. This implies that future production of a country is influenced by the products a country currently produces (Bhorat et al., 2019).

To explore this hypothesis that the development of production involves learning externalities and that new products generally emerge close to existing products in the product space, two measures, *Distance* and *Opportunity Gain* were developed to analyse opportunities for structural transformation in the product space (Hausmann and Klinger, 2006; Hidalgo et al., 2007). Every two products in the product space have a globally defined proximity between them (Hausmann, Hidalgo et al., 2014). This proximity measure shows the probability of the two products being co-exported. Since products that are co-exported tend to be similar, the proximity between a pair of co-exported products will be short. For a pair of products that are unlikely to be co-exported given that they are very different, the proximity between this unlikely pair will be far. This measure between two pairs of products is called "*Distance*." Distance is defined as the sum of all proximities that connect a new good,  $p$ , to all the other products that a country,  $c$ , is not currently exporting (Hausmann, Hidalgo et al., 2014). Distance is therefore calculated by summing the proximities of all other products that a country,  $c$ , is not yet exporting ( $RCA < 1$ ), to good  $p$  and dividing that by the number of products that country  $c$  is not yet exporting (Hausmann and Chauvin, 2015).

Formally,

$$d_{cp} = \frac{\sum_{p'} (1 - M_{cp}) \phi_{pp'}}{\sum_{p'} \phi_{pp'}}$$

Simply put, *Distance* is the weighted average of products connected to good  $p$  that a country,  $c$ , is not yet exporting.

In addition, to formalise the idea that the development of new and more complex products leads to the development of future opportunities for diversification, a measure of "*Opportunity Value*" and "*Opportunity Gain*" is developed. Given that developed countries in general, tend to have higher levels of income which is positively correlated to increasingly complex products and faster growth, it is

important to determine the complexity of products in the product space. The opportunities for future growth and diversification will differ for countries depending on the products it currently exports. While some countries are only connected to a few relatively simple and poorly connected products, others are connected to multiple, highly complex goods (Hausman, Hidalgo et al., 2014). A country's starting point in the product space, therefore, will influence the value of its future opportunities. The *Opportunity Value* of an unexploited product for a country is calculated by adding the level of complexity of those products that are not currently exported by how close these products are to those products which a country currently exports (Hausman, Hidalgo et al., 2014). Mathematically, this is shown by:

$$Opportunity\ Value_c = \sum_{p'} (1 - d_{cp'}) (1 - M_{cp'}) PCI_{p'}$$

Where  $p'$  refers to the Product Complexity Index (PCI) of the product. The term  $1 - M_{cp'}$ , ensures that only the products that a country is currently not producing are counted (Hausmann, Hidalgo et al., 2014). A higher *Opportunity Value* is indicative of being close to more products and/or more complex products (Hausman, Hidalgo et al., 2014). *Opportunity Value* is used to calculate the potential gain, *Opportunity Gain*, a country,  $c$ , would acquire should it move into producing a new product. *Opportunity Gain* is calculated as the change in *Opportunity Value* when a new product is developed ( $RCA > 1$ ). Therefore, the measure of *Opportunity Gain* quantifies the possible opportunities a new product introduces should it be developed. Formally, *Opportunity Gain* can be written as:

$$Opportunity\ Gain_c = \sum_{p'} \left( \frac{\Phi_{pp'}}{\sum_p \Phi_{pp'}} (1 - M_{cp'}) PCI_{p'} - (1 - d_{cp'}) PCI_p \right)$$

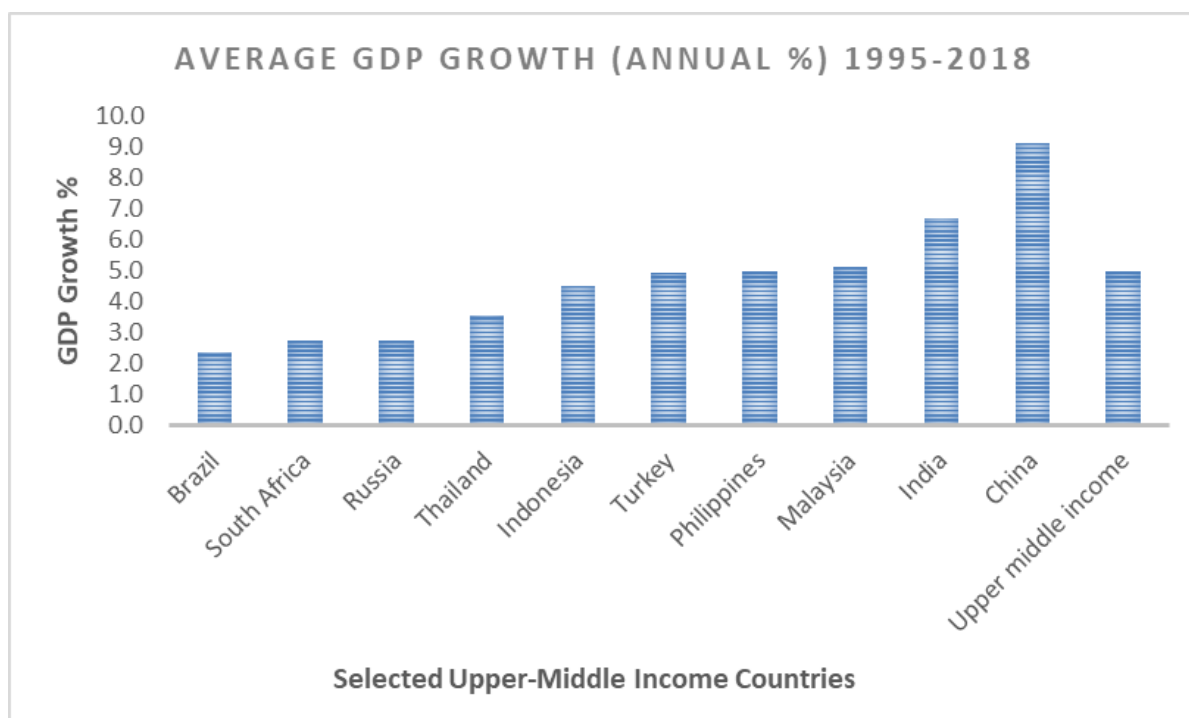
The *Opportunity Value* then summarises the value of a country's position in the product space; how far or near it is from complex products (Hausmann and Chauvin, 2015). If the development of RCA for a new product opens up paths for future diversification, decreasing the distance to other strategic products, it is a strategically valuable product. RCA is based on the definition by Balassa (1965) where a country exports a product with a revealed comparative advantage ( $RCA > 1$ ) if the ratio of exports for that product to the country's total exports is greater than the share of that products global exports in total global trade (Atlas, 2019a). Furthermore, products that are connected to multiple products in the product space prove critical in a country's long-term diversification process. Therefore, the measure of *Opportunity Gain* captures the potential of a new product and how it can improve a country's position in the product space (Hausmann and Chauvin, 2015). The product space is therefore a graphical representation of the connectedness between products, visualising the paths for diversification through mapping out distance and proximities between products.

Structural transformation in the product space occurs when countries move away from producing simple products at the periphery, towards increasingly complex products at the core. However, a country with a productive structure dominated by many connected products in the core of its product space is in a better position to diversify into new products since products in the core are more closely connected to other products and require similar productive capabilities. Economic growth for these countries is also promising since these products tend to be more complex. On the other hand, countries whose productive structures are more sparsely populated and where products exist predominantly in the periphery, will find it more difficult to diversify towards products closer to the core given that their productive capabilities lie further away from these core products. This means that diversification is limited for these countries. Therefore, countries that produce products in close proximity in the product space tend to find diversification easier than those countries that produce products that are isolated and located in the periphery of the product space (Hausmann and Chauvin, 2015).

#### 4.2. South Africa's Structural Transformation and the Product Space

Structural change, the movement of capital and labour into activities and sectors with higher productivity, is key to growing more complex and sophisticated activities and integrating into the global economy (Bell et al., 2018). A productive structure which is more complex enables countries to partake in high-productivity activities leading to faster growth and development (Felipe et al., 2012). However, South Africa has struggled to transform its economy since the onset of democracy and participation in the global economy in 1994. While the economy has grown, this growth has been slow and unbalanced across the various sectors. The persistence of inequality and unemployment prevents sustainable economic growth and has led to a stagnation of the economy with economic growth failing to exceed 2% since 2008 (Jeffrey, 2016). In comparison to other upper-middle income countries, South Africa has performed poorly. While most of these countries' average annual GDP growth has exceeded 4% over the period of 1995 to 2018, as shown in Figure 6, South Africa's average GDP has remained relatively stagnant.

**Figure 6.** Average GDP Growth for selected Upper-Middle Income Countries 1995-2018

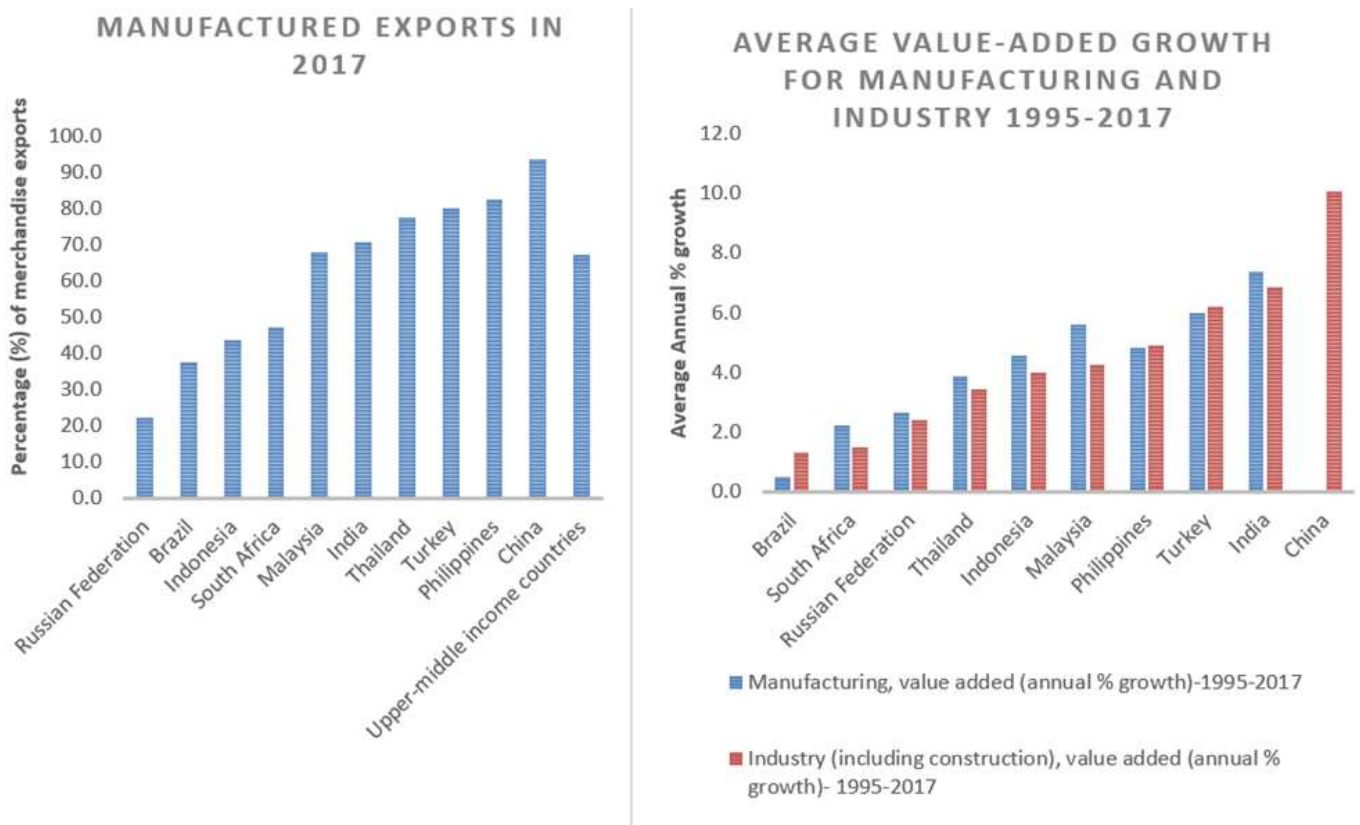


Source: (World Bank, World Development Indicators, 2019)

Furthermore, while South Africa is characterised as an upper-middle income country, it has not managed to reach the level of high-income status that other previously categorised middle-income countries, such as Hong Kong SAR (China), Greece, Japan, Ireland, Israel, Portugal, Spain, Taiwan, Singapore and the Republic of Korea, have. (Bhorat et al., 2014).

Overall, in upper-middle income countries, value-add from industry has spurred GDP growth over the period of 1995-2018. In countries such as Turkey and Malaysia, industry has grown with GDP. This has not been the case for South Africa or Brazil. For both countries, manufacturing, a sub-set of industry, has grown slower than GDP (Bell et al., 2018). As seen in Figure 7, in South Africa (as with Brazil and Indonesia), manufactured exports make up a relatively small share of total merchandise exports at only 47.1% in 2017. However, while Indonesia’s manufactured exports share is also low (43.6%), there has been substantial growth in the country’s manufacturing’s share of value-added growth over the 1995 to 2017 period (4.6%), unlike that of South Africa (2.2%) and Brazil (0.5%). Overall, the percentage share of industry’s value-add to annual growth for South Africa over the period of 1995-2017 has been low compared to other upper-middle income countries

**Figure 7. Economic Indicators of selected Upper-Middle Income Countries**



Source: (World Bank, World Development Indicators, 2019)<sup>2</sup>

South Africa, along with other middle-income countries such as Brazil, Turkey and the Philippines, has been unable to significantly increase its per capita growth rates. The characteristics of South Africa’s stagnant growth are indicative of a long-run growth trap. A growth trap in middle-income countries is characterised by a period of high economic growth followed by a pattern of low growth and productivity (Bhorat et al., 2014). Historically, middle-income countries have fallen into this trap through a general process. Imported technology stimulates a shift in labour from low productivity to high productivity sectors. This increases growth and results in an increase in per capita GDP. These imported technologies tend to be employed in sectors which are labour-intensive, consequently absorbing underemployed or unemployed labour. This continues until productivity growth from technological catch-up eventually plateaus as it is exhausted, wages rise and exports which are labour-intensive become less competitive in international markets as their prices increase. At this point, the movement of labour from low productivity activities to higher productivity activities does not produce further growth as the gains from importing technologies diminishes (Bhorat et al., 2014). In South Africa, there are various factors which have led to this cycle of low growth. These factors include

<sup>2</sup> No manufacturing, value-added (annual % growth) data was available for China

an over-dependence on resource-led export growth, following a capital-intensive industrialisation path, a lack of investment, reliance on state infrastructure to drive domestic growth, and a growth path focused on sectors that lack employment-intensity (Bhorat et al., 2014).

From a policy perspective, legacies of the Apartheid period still undermine growth today. The exploitation of cheap labour by the Apartheid government in the mining and agricultural sectors beyond the point of productive economic gains, and the failure to move the labour force into higher productive sectors, has created a structural blockage for economic growth in present times (Bhorat et al., 2014). Racial politics during the Apartheid era prevented the up-skilling of labour and education of the majority of South Africa's workforce which has caused structural challenges for economic growth in the present day as the necessary skills needed for growth are scarce. A lack of savings due to the low employment rate, coupled with low fixed investment rates prevents further investment into the economy and a take-off of growth (Bhorat et al., 2014). Furthermore, low levels of industrial competition as a result of a concentration in industry as well as high barriers to entry for new firms, prevent further investment to help diversify South Africa's economy. For example, in the manufacturing sector, 70% of the market share was held by five of the largest firms in 22 sub-sectors of the economy in South Africa (Mhlanga, 2018). In the energy, communication technologies, financial services, agro-processing and food sectors, one firm in each of these sectors accounts for up to 45% of the market share (Mhlanga, 2018). This concentration prevents competition within sectors and crowds out investment opportunities. Moreover, volatile labour relations, political uncertainty and a lack of skills in the market raise the cost and risk of doing business in South Africa. Therefore, while the real returns to capital in South Africa provide highly favourable gains, these structural barriers and perceived political risks tend to outweigh the favourable investment returns available (Bhorat et al., 2014).

Technological change, innovation and the development of economies of scale are required for a country to spur economic growth, move up the value chain and compete globally in goods, ideas and money (Bhorat et al., 2014). However, in South Africa, there has been a lack of innovation and technological development. This can be assessed by looking at South Africa's spending on Research and Development (R&D), the number of patents it holds, as well as its Technology Balance of Payments (TBP). In South Africa, Gross Expenditure on R&D (GERD) as a percentage of global R&D expenditure has decreased from 0.42% in 2007/2008 to 0.28% in 2013/2014 (NACI, 2014). Furthermore, according to the Johannesburg Stock Exchange (JSE), this R&D spending has been concentrated in the traditional sectors of South Africa's economy such as mining, minerals and finance (World Bank, 2018). Where South Africa once held only a little less patents than the total number of patents of all the other BRIC countries combined, comprising 49% of the BRICS share, in 2011, South African patents comprised 13% of the BRICS total share (Kaplan, 2014). This lack of innovation is further pronounced when assessing the performance of South Africa's TBP. The TBP comprises both

the payments by nationals to foreigners for the licensing rights to acquire technology, as well as the receipts from foreigners for the licensing of technology (Kaplan, 2014). Licensing receipts prove to be a good indicator of a country's technological strength and innovative activities at the global frontier (Kaplan, 2014). However, in South Africa, payments for technology have risen exponentially while technology receipts have remained stagnant (Kaplan, 2018). While South Africa's annual royalties and licence fee receipts averaged \$58 million between 1991 and 1995, more than any of its BRIC peers, between 2001 and 2010 this trend reversed. Between 2001 and 2010, South Africa's technology receipts averaged \$42 million compared to India at \$102 million, Brazil at \$220 million, Russia at \$293 million and China at \$291 million (Kaplan, 2014). Overall, South Africa has performed poorly in terms of innovation and technological development which is evidenced by South Africa's position in the World Economic Forum's Global Competitiveness Index which stood at 61 out of 137 countries in 2017/18, a significant decrease compared to its position of 47 in 2016/17 (Schwab, 2018).

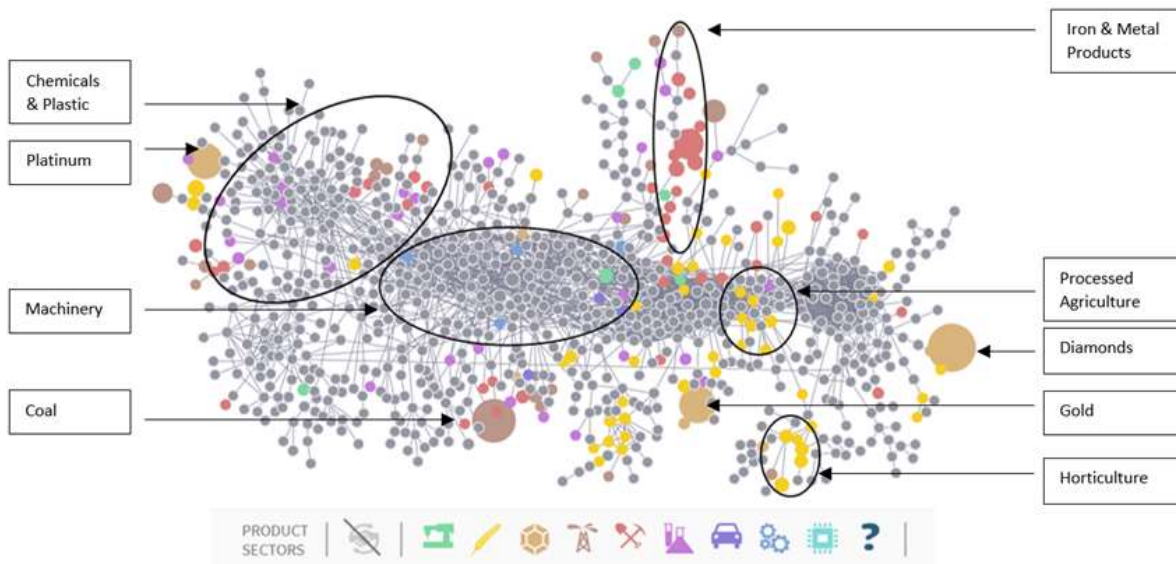
A lack of innovation and stagnant growth is further evidenced when looking at South Africa's exports. Between 2007 and 2012, 90% of South Africa's export growth was attributed to raw materials and lightly beneficiated materials with high technology exports comprising only 4.28% of South Africa's exports compared to India's share of 7.2% and Russia's of 8.85% (Kaplan, 2018; Kaplan, 2014). The broad industry groups that dominate South Africa's manufacturing output are metals, metal products, machinery and equipment; petroleum products, chemicals, rubber and plastics; and food, beverages and tobacco (Bell et al., 2018). These industry groups are led by the resource-based sectors of chemicals and basic metals. This dominance has not changed much since 1995 and clearly shows a strong path dependency effect. Furthermore, there has been a regression since 1995 away from more sophisticated and diversified manufacturing activities towards resource-based sectors led by refined petroleum products, basic iron and steel, and coke (Bell et al., 2018).

While food products, motor vehicles and machinery and equipment have all experienced growth, there has been a lack of growth in terms of expanded knowledge and capabilities. For example, in the motor vehicle sector, while value-added growth has increased, this has largely been a result of the sustained industrial policy through the Automotive Production and Development Programme (APDP) (2013-2020) and Motor Industry Development Programme (MIDP) (1995-2012). While this support has allowed for value-added growth, the industry still runs a trade deficit with local content declining as South Africa fails to develop the capabilities of more sophisticated auto hubs that exist in Mexico and Thailand (Bell et al., 2018). Consequently, the design of these supporting policies allows for import rebates, favouring multinational vehicle exporters, and resulting in downstream import penetration for tier 2 and 3 producers (Bell et al., 2018). The machinery and equipment sector follows a similar narrative. While the machinery and equipment sector grew between 2003 and 2009, spurred by local and regional demand, the sector decreased in competitiveness internationally caused by an appreciated exchange rate, worsening the trade balance through increased import penetration in

higher value, more complex activities (Bell et al., 2018). This exchange rate appreciation was partly due to the commodity boom which ultimately led to the hollowing out of higher value, diversified manufacturing activities (Bell et al., 2018).

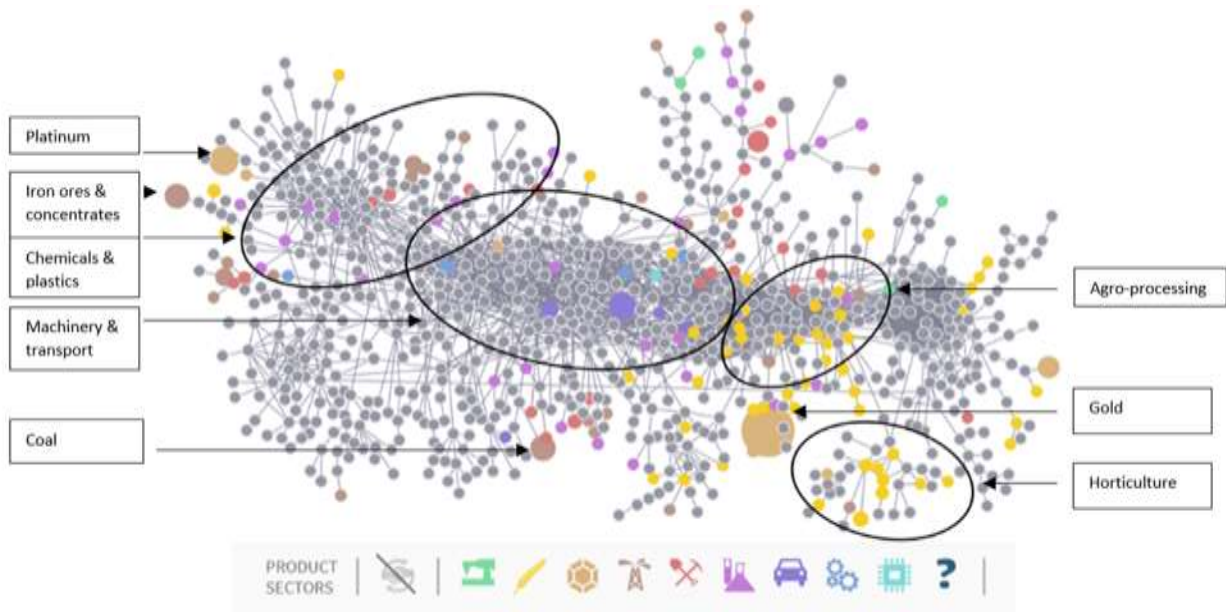
Despite the South African economy's diversification into machinery and chemical products, overall, its productive structure is still dominated by commodities (Bhorat et al., 2019). This is largely attributed to the recent commodity price boom coupled with low global interest rates which led to large investments into the exploration and production of commodities (World Bank, 2015). In sub-Saharan Africa overall, the share of commodities in exports rose from 57% in the period 1990 to 1999 to 76% in the period between 2010 and 2014 (World Bank, 2015). This phenomenon, along with poor levels of growth in manufacturing across the continent, has created dependency and a lack of diversity in productive activities and exports (Kaplinsky and Morris, 2014). This is evident when comparing South Africa's product space from 1995 to 2017 as shown in Figure 8 and 9.

**Figure 8.** South Africa's Product Space 1995



Source: CID (2019)

Key on Product groupings/ clusters by colour: Textiles & Furniture (light green); Vegetables, Foodstuffs & Wood (yellow); Stone & Glass (light brown); Minerals (dark brown); Metals (red); Chemicals & Plastics (light purple); Transport Vehicles (dark purple); Machinery (blue); Electronics (turquoise); Other (dark blue).

**Figure 9.** South Africa's Product Space 2017

Source: CID (2019)

In 1995, South Africa's export basket consisted mainly of products low in complexity, located mostly in the periphery of the product space and relatively isolated from other manufactured products towards the core. Minerals, stone and glass, chemical products, vegetable and foodstuff made up most of South Africa's export basket in 1995. When comparing South Africa's product space in 1995 with its product space in 2017, the composition has not changed much. While 7 new products were added to South Africa's export basket<sup>3</sup>, there has been a lack of exploitation of linkages between sectors as seen by the absence of 'clustering' in the product space (Atlas, 2019b). For example, in South Africa's product space for 2017, 'cars' (indicated by the purple node) are clearly evident, yet auto components are largely missing. Where mining exports are present, as they were in 1995, broad clustering of machinery and equipment are not evident. One would expect to see a clustering of products in South Africa's product space for 2017 located where competitive products were in 1995 as knowledge spillovers and similarity in capabilities are transferred to new, related industries. However, this has not been the case and clearly shows South Africa's failure to exploit potential linkages within the economy, expand potential growth paths, build on existing capabilities and structurally transform the economy. In fact, according to the Atlas of Economic Complexity (Atlas, 2019b), the South African economy has become less complex, worsening its Economic Complexity Index (ECI) ranking from 60<sup>th</sup> place in 2007 to 64<sup>th</sup> place in 2017.

<sup>3</sup> These are products which were absent 15 years ago ( $RCA < 0.5$ ) but are now present today with an  $RCA > 1$  (Atlas, 2019b).

The manufacturing sector in particular, has experienced a decline in capital-intensity and value-add from industry since 2000 (Black et al., 2017). Sectors such as textiles, footwear and metals, which are labour-intensive, have also experienced a decline in their employment and value-add. In addition, while exports have increased at approximately 6% annually since 1990, capital-intensive manufacturing exports have declined (Black et al., 2017). Furthermore, what is not shown in the product space is that since 2001, South Africa's economy has shifted away from the mining, agricultural and manufacturing sectors towards the service sector. This is evidenced not only by the service sectors value added (% GDP) of 61.4% in 2018 compared to that of manufacturing at 11.8% and agriculture at 2.2%, but also in terms of employment (World Bank Indicators, 2019). The service sector employment rate is 71.6% while manufacturing comprises 23.2% and agriculture 5.2% (World Bank Indicators, 2019). What is concerning, however, is that in this service sector in South Africa, many individuals work in the low-productive, informal sectors, thus making it challenging to measure growth as well as facilitate future growth since data is not available. Furthermore, the formal sectors within the service industry such as the finance sector, tend to be capital-intensive and require highly skilled workers which comprise a small percentage of South Africa's population. Given that the majority of workers in South Africa are low-skilled workers, the growth of the service sector and contraction of the agriculture and manufacturing sectors has caused substantial job-losses for numerous workers in South Africa and created barriers to entry in the job-market (Bhorat et al., 2019). Furthermore, a lack of skilled labour and an inadequacy of education and training programs to equip individuals with the necessary skills, precludes these individuals from even participating in South Africa's economy (Bhorat and Rooney, 2017). Service-led growth coupled with premature deindustrialisation does not provide a sustainable growth trajectory for South Africa.

To address these challenges, South Africa's Industrial Policy Action Plan (IPAP) champions the labour-intensive manufacturing sector as a solution to achieve the goals of employment and growth, set out in the country's National Development Plan (NDP), through the creation of jobs and subsequent economic growth (DTI, 2017). In general, fast-growing economies comprise of a broad and diverse manufacturing sector and it is well recognised that value-add from manufacturing leads to numerous multiplier and spillover effects through the upskilling of workers, embedded technological-intensity and an inclusive growth trajectory (DTI, 2017). Historically, manufacturing through industrialisation has been the key driver in creating sustained economic growth. To date, no country has been able to lift significant numbers of their population out of poverty without industrialising, nor transition from a middle to a high-income country in the absence of a vibrant manufacturing sector (DTI, 2017).

However, the global context has changed with the dispersion of production and services across national boundaries intensifying global competition and changing how countries develop and structurally transform. In addition, traditional manufacturing is highly energy- and pollution-intensive

and is unsustainable for the planet – it will therefore be inappropriate to attempt to emulate the traditional growth path of manufacturing-led structural transformation. It is clear that growth-enhancing structural transformation is not an automatic process as is evidenced by South Africa's shift towards growth-reducing informal service activities. South Africa needs to pursue its own agenda and an industrialisation path that feeds off its pre-existing knowledge and strengths. This must be coupled with forward-thinking and anticipation of future global trends, to transform the economy through the modernisation of industry and the development of strategic sectors.

Carlota Perez (2012), an economic historian who has studied economic problems spanning the past 240 years and their specific patterns, argues that history does in fact repeat itself. There have been five technological revolutions which have occurred over the past 240 years with each revolution bringing in a new techno-economic and socio-institutional shift, redirecting innovation and creating potential to leap into future productivity (Perez, 2016). The first technological revolution was the Industrial Revolution in the 1770s, with the rise of factories, machines and canals which were the 'Internet' of that era. The fifth and current revolution began in the 1970s with the age of computers and information technology. Perez (2012) argues that the world is on the cusp of another paradigm shift where smart, green growth will transform lifestyles and has the potential to incorporate millions into a more sustainable and equitable growth trajectory.

In the current global climate, as in the 1930s, there is structural unemployment, growing inequality, social unrest, recessions and feeble growth (Perez, 2016). Perez (2012) argues that in a turning point, where these technological revolutions begin, government action is a critical feature spurring transformation. The global demand for green goods increased by 307% from 2001 to 2015 compared to the demand for total trade of 106% (TIPS, 2018). Furthermore, in OECD countries, average tariffs applied to imported EGs declined from 1.6% in 2003 to 0.8% in 2016 (OECD, 2019). In countries outside the OECD, tariffs on EGs remained significantly higher, yet also declined from 7.4% in 2003 to 4.1% in 2016 (OECD, 2019). This positive growth in trade for green goods and the shift towards sustainable production presents an opportunity for South Africa to transform its industrial sectors and diversify its export base. However, to compete in this market, will require the identification of strategic green products and industries to develop, creating local demand and navigating opportunities for exports. Government will need to take action to redirect South Africa's export-growth trajectory, capitalising on opportunities to transform and green the economy in order to structurally transform South Africa's economy into one that is able to compete in the future and provide equitable growth and employment. Therefore, green products need to be identified and located within South Africa's productive structure to determine what green industries provide the most potential for diversification and development given South Africa's existing productive structure and embedded knowledge.

## Chapter 5. South Africa's Green Product Space

### 5.1. Defining "Green Products"

Globally, there lacks a universal definition for what constitutes "environmental goods" (EGs). Disagreement over what constitutes an EG and the inadequacy of the Harmonised System (HS) to categorise EGs remains an obstacle for the development of a comprehensive list of EGs that countries can agree upon. The lack of consensus over a comprehensive list of EGs is attributed to the practical difficulties that emerge when trying to devise such a list. Steenblik (2005) points to these difficulties which include the lack of specificity of current classifications, such as the HS six-digit level where products can have multiple uses, some of which are environmental and some which are not. Furthermore, there are problems with goods being defined by their relative environmental performance in use given that technology is constantly improving, thus changing the relative performance of certain goods (Sauvage, 2014). The inclusion of both finished and intermediate products in EGs lists complicates matters further since their coverage differs by industry on the HS classification system. Therefore, certain finished products, such as wind-generating sets, have their own unique HS code while other intermediate products used in waste-treatment plants, for example, do not (Sauvage, 2014).

Despite these limitations, there have been numerous attempts to draw up lists of EGs. The dominant method of identifying "green" products has been to categorise sectors according to their level of contribution towards protecting the environment. However, this approach tends to separate sectors into those that are 'environmental' and those which are 'non-environmental', disregarding the broader economic impacts. Moreover, a sector considered relatively benign in its environmental footprint may contribute to the greening of other activities. An example of this is the electricity distribution and control apparatus sectors (Fankhauser et al., 2013). These sectors, while not obviously "green" can contribute to smarter electricity grids and therefore, decreased energy consumption (Fankhauser et al., 2013). A lack of consensus and globally accepted list of "green products" makes it difficult to measure the production capabilities a country has for "green" exports.

In the absence of an internationally agreed upon list of EGs, and since certain lists may exclude goods considered 'environmental' since they have not been included in the context of trade negotiations, for the purpose of this paper, "green goods" will be classified according to the OECD definition of EGs. The OECD defines environmental goods and services as those activities that limit, prevent, minimise, measure or correct environmental damage (OECD, 1999). This paper will combine three existing lists totalling 248 products (see Annex 1). This set of products, which was named the "CLEG" (Combined List of Environmental Goods) by the OECD, uses the 2007 HS classification at the six-digit level, dividing goods according to environmental themes or mediums as shown in Table 2.

**Table 2.** *Environmental themes and media in the CLEG*

Code	Environmental theme or medium
APC	Air pollution control
CRE	Cleaner or more resource efficient technologies and products
EPP	Environmentally preferable products based on end use or disposal characteristics
HEM	Heat and energy management
MON	Environmental monitoring, analysis and assessment equipment
NRP	Natural resources protection
NVA	Noise and vibration abatement
REP	Renewable energy plant
SWM	Management of solid and hazardous waste and recycling systems
SWR	Clean up or remediation of soil and water
WAT	Waste water management and potable water treatment

Source: (Sauvage, 2014)

The data used to calculate various complexity measures used in this paper, however, is classified according to the 1992 HS classification. To circumnavigate this problem, given that certain HS codes in the 2007 classification may not align with those in the 1992 HS classification, a comparison was done between the CLEG list comprising of HS 2007 classifications and their respective HS 1992 classifications. While no difference was found at the HS 4-digit level and therefore, no amendments were needed, at the HS 6-digit level, 17 products were categorised differently. Of these 17 products at the HS 6-digit 2007 classification, 13 products had correlating classifications at the HS 6-digit 1992 classification. Therefore, 4 products at the 2007 HS 6-digit level were dropped to ensure the streamlining of this analysis. This then narrowed the CLEG list of 248 environmental goods down to 244 goods given the overlaps which existed (See Annex 1). Using the 2007 version of the HS classification ensures that any data-availability concerns, given that not all these products were exported in 1992, are removed.

The CLEG list, used by the OECD, combines the 'Friends' list (WTO, 2009) which comprises 154 products; the APEC list (APEC, 2012) comprising 54 products; and a modified version of the PEGS list. The original version of the PEGS list includes numerous HS six-digit codes for cars and other road vehicles. Since these HS lines also include most plug-in hybrid electric vehicles and hybrid electric vehicles, which are classified as EGs, the modified PEGS list excludes those HS lines of vehicles that are not classified as EGs and only considers vehicles which use fuels other than diesel fuel or gasoline (only HS 8702.90 and HS 8703.90) (Sauvage, 2014). The OECD list includes goods

and services that aid in the management of pollution and include products such as pipes, tubes, filters and chemicals which are used in wastewater and sewage treatment; machines for grinding, kneading and mixing used for solid waste recycling services; air compressors and pumps used to control air pollution; and equipment such as optical instruments, for measuring and monitoring the environment (Balineau and Melo, 2011). This list also includes products used in “Resource management” such as renewable energy equipment which includes lattice masts and towers for wind turbines, optical fibres and photosensitive devices used in the generation, concentration and intensification of solar power or equipment used for indoor air pollution control (Balineau and Melo, 2011). These goods have multiple end-uses and don’t always serve environmental purposes. The “greening” of an economy is not only through the introduction of end-products such as solar panels but also in becoming more energy efficient and decreasing waste in industry processes. For this reason, products that can be used to further these objectives should also be considered.

This list of goods is merged with the UN Comtrade export data to allow for the analysis of country trade in green products over the 1995-2017 period. While this list is still unable to account for the environmental benefits of products, dual-use products, production processes of products, and the overall environmental trade flow of a product, it follows the definition of green goods as those activities that limit, prevent, minimise, measure or correct environmental damage (OECD, 1999). This list is not too comprehensive that it compromises the integrity of the definition of “environmental goods”; and it is not too limited that it only considers final, finished products, inhibiting the development of products that have potential for combatting climate change. It provides a good balance and overview of EGs forming the foundation from which this analysis will begin. Using the tools of the Economic Complexity framework, South Africa’s green product space will be developed to illustrate the linkages and potential avenues for growth in various industries and thereafter, frontier green products will be identified.

## 5.2. Creation of the Product Space: Description of the Data and Limitations

The product space is created using international trade data from the United Nations database, Comtrade. Hidalgo et al. (2007), create the product space using product-level trade data at the 4-digit level of the HS (Harmonised System) comprising of 1241 product groups as well as the Standard Industrial Trade Classification (SITC) comprising 1033 product groups. In the creation of the product space, the SITC 4-digit level data published by the United Nations can be used or data at the HS 4-digit classification level compiled by the Centre d’Etudes Prospectives et d’Informations Internationales (CEPII) can be used. While both sets of data provide export information at the product level for over 200 countries, the HS 4 data is more granular and disaggregated into 1240 different

products compared to the SITC data which is only disaggregated into 774 different products (Hausmann and Chauvin, 2015). The advantage of the SITC data is that it encompasses a longer time period with data available from 1964 compared to HS 4 data which is only available from 1995. However, for the purpose of this paper, HS 4 data has been used to allow for greater granularity at the product level, allowing for greater specificity.

There are limitations to this data which must be noted. First, the data encompasses exported goods and does not capture aggregate production. Therefore, productive knowledge used not only in the production of exported goods but also in non-traded goods or services within a country, cannot be captured using this data. However, there is evidence that a high ECI in goods is positively correlated to a high ECI in services (Bhorat, 2017). Therefore, analysing South Africa's exports and product space does not account for all of the existing knowledge within the South African economy since only exported goods, which do not account for the whole economy, can be measured. However, since this paper aims to identify opportunities for South Africa to diversify its export and productive base, it makes sense to look at export data. Second, the data used does not include the export of services. With the rapid spread of globalisation, services are increasingly being traded across borders and comprise a key share of international trade accounting for 13.1% of global trade in 2018 (World Bank, 2018). In South Africa, services already account for 67.5% of GDP with trade in services contributing 8.1% to South Africa's GDP (World Bank, 2018; World Factbook, 2018). Noting that there are no comprehensive service international databases on services available that can match those available for goods (Hausmann and Chauvin, 2015) and accepting that the service data available does not have the level of granularity that allows for disaggregation of services provided, needed to create the product space (Hausmann and Chauvin, 2015), this data is still able to share insight into the potential for the diversification of South Africa's green products.

### 5.3. Identifying South Africa's Green Frontier Products

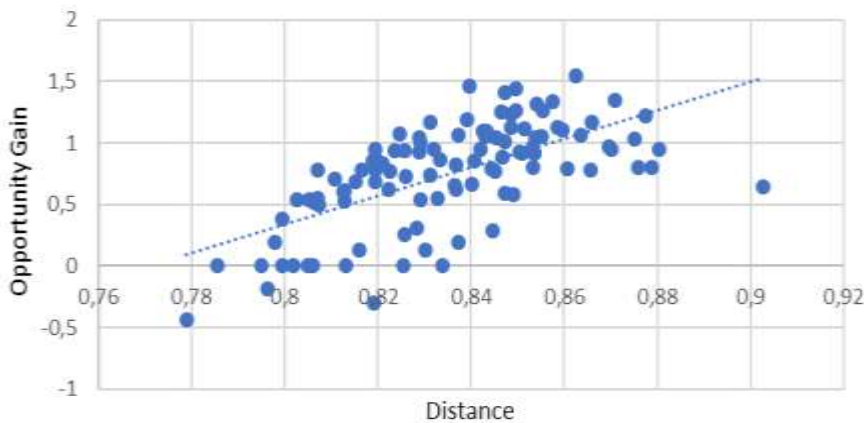
To create South Africa's green product space, the CLEG list of 248 products is used. However, since the product space is created using HS 4-digit level data, the 248 green products at the HS 6-digit level are grouped according to their categorisation under HS 4-digit groupings. Following this step, 106 new groupings for green products emerge (see Annex 2). While HS 4-digit data is not as granular and disaggregated as HS 6-digit data, HS 4 products will allow for the mapping of the product space. However, prior to mapping South Africa's green product space, South Africa's green frontier products need to be identified.

Frontier products are those which have the potential to increase the diversification and attractiveness of a country's export mix while still lying close enough to current capabilities so as to be feasible

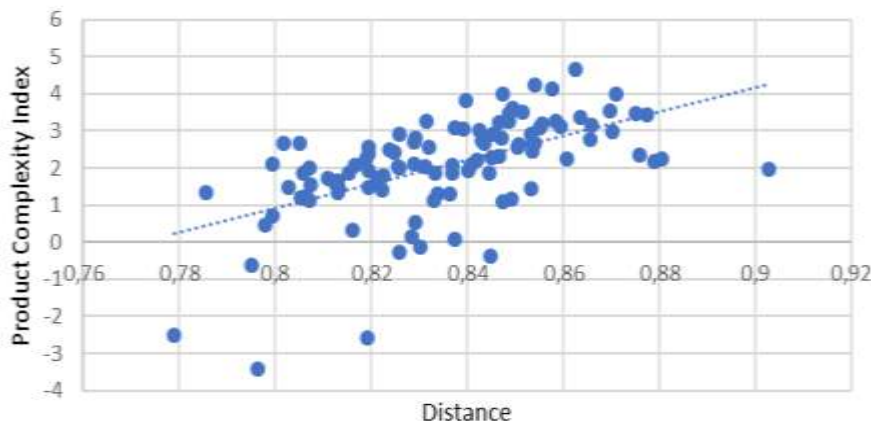
(Hausmann & Chauvin, 2015). Frontier products must satisfy the following criteria: they must be more complex than the average complexity of products South Africa currently exports; they must be feasible given South Africa's current productive knowledge; and they must have the potential to open up paths for further, future diversification and growth. Additionally, in the case of South Africa, these frontier green products should also allow for the potential of further job creation that is inclusive of low-skilled labour given the high rate of unemployment in South Africa and the desperate need for employment generation.

To identify what green products South Africa can diversify toward, complexity analytics are used to identify South Africa's frontier green products. To generate the various complexity variables such as the product complexity (PCI), *Distance* and *Opportunity Gain* (as developed by Hausmann, Hidalgo et al. (2014), the *ecomplexity Stata package*, which was developed by Sebastian Bustos and Muhammed Yildirm (2014), was used. Ideally, the path of diversification would follow those products that have the highest PCI, highest Opportunity Gain and the shortest Distance (Hausmann & Chauvin, 2015). However, in reality, trade-offs exist, and it is unlikely that this mix would exist. Generally, products identified as having the highest PCI tend to be the furthest away in terms of Distance (Hausmann & Chauvin, 2015). Similarly, products identified as having the highest Opportunity Gain tend to be at greater distances away. The trade-off between *Distance* and *Opportunity Gain* as well as *Distance* and PCI can be seen below in Figure 10 and 11.

**Figure 10.** Trade-off between Distance and Opportunity Gain- Green Products



Source: (Own calculations using Comtrade data)

**Figure 11.** Trade-off between Distance and PCI – Green Products

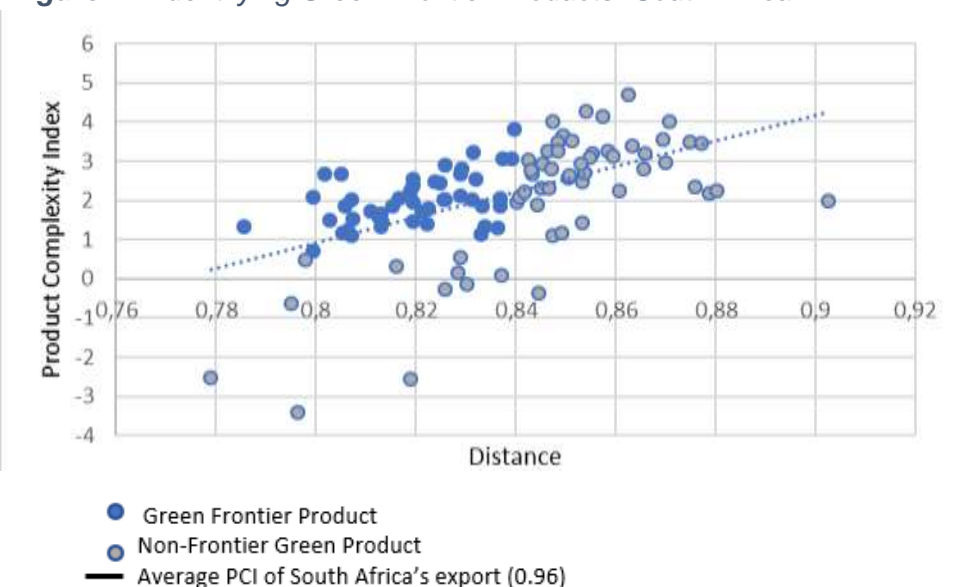
Source: (Own calculations using Comtrade data)

For the purpose of this paper, data at both the HS 4-digit level and the HS 6-digit level is used. This is important since when running the “ecomplexity” command in Stata, distance is not measured since HS 6-digit level products belong to HS 4-digit groupings in the product space. Therefore, HS 4-digit data allows for distance to be measured, and hence the identification of green frontier products in the product space. Once these products have been identified, HS 6-digit data, belonging to these broader product groups at the HS 4-digit level, will provide greater detail into what specific products should be targeted for development and/or show potential for enhancing a country’s Opportunity Gain and future diversification potential. However, it must be noted that country level reporting at the HS 6-digit level is not always as reliable as reporting at the HS 4-digit level. Therefore, while the HS 6-digit level data is important to provide greater detail, it is not the gold standard which will be used (Hausmann, Hidalgo et al., 2014).

Drawing on the methodology used by Hausmann and Chauvin (2015), four consecutive steps are followed to identify South Africa’s “green frontier products.” First, all “non-green” products are removed and only the 106 HS 4-digit level products which include the 248 HS 6-digit level “green” identified products remain. This leaves 106 HS 4-digit level products out of South Africa’s total of 1234 HS 4-digit level products. Second, all green products with a PCI lower than South Africa’s average PCI (which is 0.96) for all its exports in 2017 are dropped to ensure that the products that remain are the ones with the potential to increase the complexity of South Africa’s export mix. From this step, an additional 13 HS 4-digit level products are eliminated leaving 93 HS 4-digit level green products. Third, *Distance* is used to identify products which are more feasible given South Africa’s current product space. However, determining a cut-off as to what distance is or is not feasible is not straightforward since even large distances can be overcome with sufficient investment (Hausmann and Chauvin, 2015). However, for the purpose of this paper, the median distance of green products in which South Africa does not have a comparative advantage, where the  $RCA < 1$ , is used as the cut-off. This further eliminates 48 products which do not have a *Distance* of  $< 0.839$ , leaving 45 products closer to South

Africa’s productive knowledge frontier. Lastly, *Opportunity Gain* is used to eliminate the green products that would not allow for future diversification paths to grow and open. 8 products provide no increase in opportunity gain and therefore, these products are dropped. The 37 remaining products all provide potential for future *Opportunity Gain*. These 37 remaining green products are South Africa’s green frontier products. Figure 12, below, illustrates the green frontier products selected using the strategy by Hausmann and Chauvin (2015) which accounts for the *PCI/Distance* trade-off.

**Figure 12.** Identifying Green Frontier Products- South Africa



Source: (Own calculations using Comtrade data)

#### 5.4. South Africa’s Green Frontier Products

Out of the 37 frontier green products identified, the list was narrowed down to 20 products with the highest PCIs given that *Distance* and *Opportunity Gain* were otherwise similar. This was done to narrow down the selection of products to identify a promising product group for further investigation. The list of these frontier green products is shown below in Table 3.

**Table 3.** South Africa’s Top 20 Frontier Green Products

	HS Product Name	HS 4-digit	PCI	Distance	Opportunity Gain	RCA	CLEG Category
1	Other lifting machinery	8428	3.25	0.83	1.17	0.32	SWM
2	Equipment for temperature change of materials	8419	3.08	0.84	1.07	0.22	REP
3	Industrial furnaces	8417	3.07	0.84	1.19	0.76	SWM
4	Other parts for machines and appliances	9033	2.91	0.83	0.94	0.29	MON

## Economic Complexity and the Potential for Green Growth in South Africa

5	Other engines and motors	8412	2.80	0.83	1.00	0.48	REP
6	Parts of railway locomotives	8607	2.69	0.83	1.05	0.53	CRE
7	Parts for use with electric generators	8503	2.55	0.83	0.94	0.08	REP
8	Mineral wools and insulating materials	6806	2.55	0.82	0.87	0.40	HEM
9	Multiple-walled insulating glass	7008	2.48	0.82	0.93	0.12	HEM
10	Self-propelled bulldozers, excavators and road rollers	8429	2.44	0.82	1.07	0.66	SWM
11	Trailers and semi-trailers	8716	2.38	0.82	0.94	0.90	CRE
12	Electric signal and traffic controls	8530	2.26	0.82	0.85	0.67	CRE
13	Nonwoven textiles	5603	2.11	0.83	0.93	0.36	WAT
14	Railway track fixtures	8608	2.06	0.82	0.78	0.84	CRE
15	Gas turbines	8411	2.06	0.84	0.82	0.07	REP
16	Electric heaters	8516	2.02	0.83	0.74	0.27	SWR
17	Refrigerators, freezers	8418	2.01	0.83	0.73	0.60	REP
18	Other plastic plates, sheets etc.	3921	2.01	0.81	0.78	0.25	HEM
19	Articles of cement, of concrete or of artificial stone	6810	1.95	0.82	0.78	0.31	HEM
20	Glass fibres	7019	1.85	0.82	0.69	0.12	HEM
	<b>AVERAGE</b>		<b>2.43</b>	<b>0.83</b>	<b>0.91</b>	<b>0.41</b>	

Note: WAT = Waste water management and portable water treatment; SWR = Clean up or remediation of soil and water; SWM = Management of solid and hazardous waste and recycling systems; REP = Renewable energy plant; MON = Environmental monitoring, analysis and assessment equipment; HEM = Heat and energy management; CRE = Cleaner or more resource efficient technologies and products

*Source:* (Own calculations using Comtrade data)

The top 5 HS 4 products in the table above are “other lifting machinery,” “equipment for temperature change of materials,” “industrial furnaces,” “other parts for machines and appliances” and “other engines and motors.” With reference back to the CLEG list, “other lifting machinery” and “industrial furnaces” are categorised under “management of solid and hazardous waste and recycling system”; “equipment for temperature change of materials” and “other engines and motors” are categorised under “renewable energy plants”; and “other parts for machines and appliances” are categorised under “environmental monitoring, analysis, and assessment equipment” (OECD, 2019).

The average PCI for these top 20 green frontier products is 2.43 with an average distance of 0.83. Interestingly, in a paper by Bhorat et al. (2019) which investigated frontier products for South Africa across the entire product space (not only across green goods), the average distance of these top 20 frontier products was 0.84. While this distance is similar to the average distance of frontier green goods in this paper, the average distance for green goods is still closer. This suggests that following a path of expansion and growth towards green industries is on the whole, more feasible and attainable given the slightly shorter distance.

Since EGs are not classified at the HS 4-digit level but rather at the HS 6-digit level, and to inform and add more granularity to the HS 4-digit level green frontier products identified above, it is important to analyse which HS 6-digit level environmental products exhibit potential for future growth opportunities.

The same process for identifying green frontier products was repeated with the 248 green products for the HS 6-digit level data. The process of elimination was completed through eliminating products with a PCI below 0.96 and with no potential for future *Opportunity Gain*. The measure of *Distance* was not accounted for since HS 6-digit level data is not used to create the product space. As an additional filter, HS 6-digit level products that did not belong to one of the HS 4-digit level groupings that were identified to be a “top 20” green frontier product, were removed. Based on these criteria, 36 green frontier products at the HS 6-digit level remained. To narrow this selection down to 20 products, their respective PCIs were ranked from largest to smallest. The 20 HS 6-digit green frontier products are shown in Table 4 below.

**Table 4.** Top 20 Frontier products HS 6-digit Level

	HS 6 Product Name	HS 6-digit	PCI	Opportunity Gain	RCA	CLEG Category
1	Mineral heat/sound insulating materials	680690	3.45	1.43	0.69	HEM
2	Railway rolling stock parts	860799	3.38	1.13	0.22	CRE
3	Gas turbine engine, not turbo-jet, parts	841199	3.20	1.22	0.02	REP
4	Non-domestic, non-electric dryer	841939	3.18	1.14	0.24	REP
5	Machinery for temperature change	841989	3.05	1.03	0.30	REP
6	Heat exchange units, non-domestic	841950	2.96	0.97	0.13	REP
7	Bogies & bissel-bogies for railway, non-driving	860712	2.84	0.97	0.46	CRE
8	Driving bogies & bissel-bogies for railway	860711	2.83	0.98	0.00	CRE
9	Industrial heating/cooling, parts	841990	2.80	1.06	0.25	REP
10	Compression refrigeration equipment	841861	2.68	0.92	0.20	REP
11	Freezing equipment	841869	2.68	0.93	0.52	REP
12	Coupling devices for railway	860730	2.64	1.06	0.03	CRE
13	Engines; parts, for engines and motors	841290	2.64	0.99	0.24	REP
14	Industrial furnaces	841780	2.62	1.05	0.36	SWM
15	Air brakes for railway	860721	2.56	0.93	0.26	CRE
16	Parts/accessories for optical/electric instrument	903300	2.55	0.84	0.29	MON
17	Slag wool, rock wool	680610	2.52	0.80	0.15	HEM
18	Distilling plant	841940	2.49	0.96	0.40	REP
19	Mats of glass fibres	701931	2.46	1.07	0.13	HEM
20	Parts of electric signal & traffic controller	853090	2.40	0.89	0.63	CRE

Note: SWM = Management of solid and hazardous waste and recycling systems; REP = Renewable energy plant; MON = Environmental monitoring, analysis and assessment equipment; HEM = Heat and energy management; CRE = Cleaner or more resource efficient technologies and products

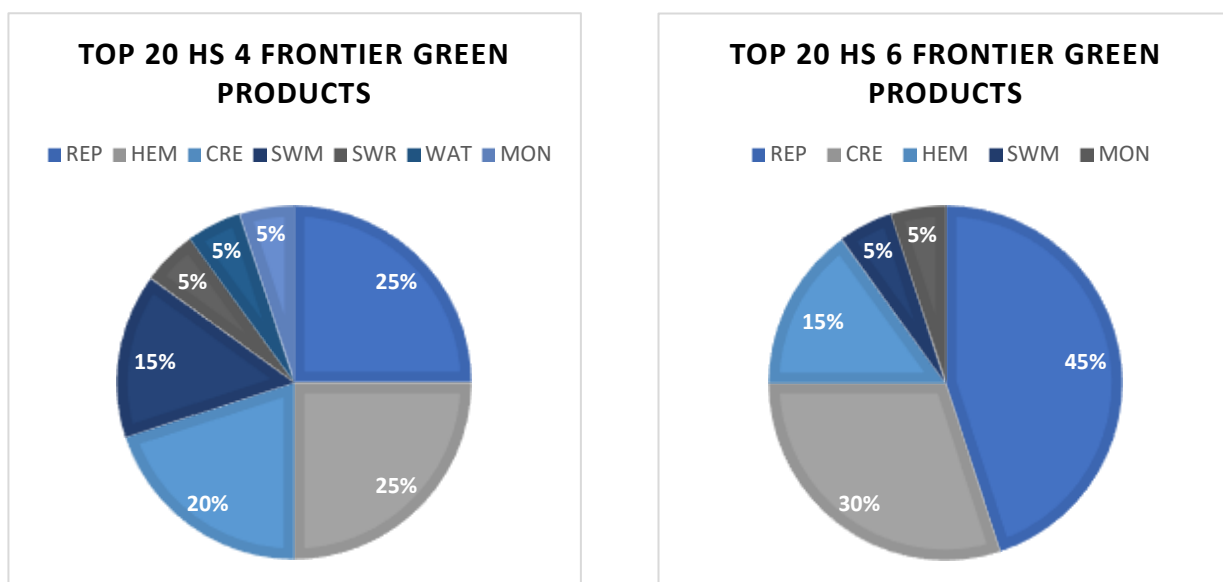
Source: (Own calculations using Comtrade data)

When looking at South Africa’s green frontier list, the industries and products identified appear to be more capital intensive than labour-intensive. For example, green sectors which are labour-intensive

would include textiles, wood carpentry for construction and industries relating to agro-processing. However, some of these industries and products lack the complexity to enhance South Africa’s overall ECI and therefore, are not frontier green products. In the South African context, it is critical that new industries that are targeted for development have the potential to create employment, especially for low to medium-skilled workers. However, it is difficult to derive the total employment benefits that could be created from developing various frontier green industries. This is because many of these products and industries, by the nature that they are categorised as being EGs, have multiple intermediate and end uses (as mentioned in chapter 5.1) and can be used in activities that are both sustainable and unsustainable. This makes it difficult to measure future employment potential in the green sector and lends itself to the problem of double-counting in possible job creation. Furthermore, without the definite known trajectory of the use of these products or industries, it is difficult to ascertain the value-chain effects and the indirect potential for job creation along the supply and demand chain. Therefore, it is important to identify and target industries that have a clear trajectory toward greening the economy and creating sustainable employment opportunities.

In both tables, products categorised under “renewable energy plant” comprise a significant share of these top 20 frontier products. A breakdown of product shares according to their category is shown in Figure 13 below. At the HS 4-digit level, REP products comprise 25% of top 20 frontier products and at the HS 6-digit level, REP products comprise 45%.

**Figure 13. HS 4 & 6 Top 20 Frontier Green Products**



Source: (IEA, 2018)

This is a significant finding given South Africa’s dependence on coal and the ongoing struggles in the power sector, especially with regards to Eskom, South Africa’s state-owned electricity utility. Since the first industrial revolution, the use of energy has played an integral role in economic development

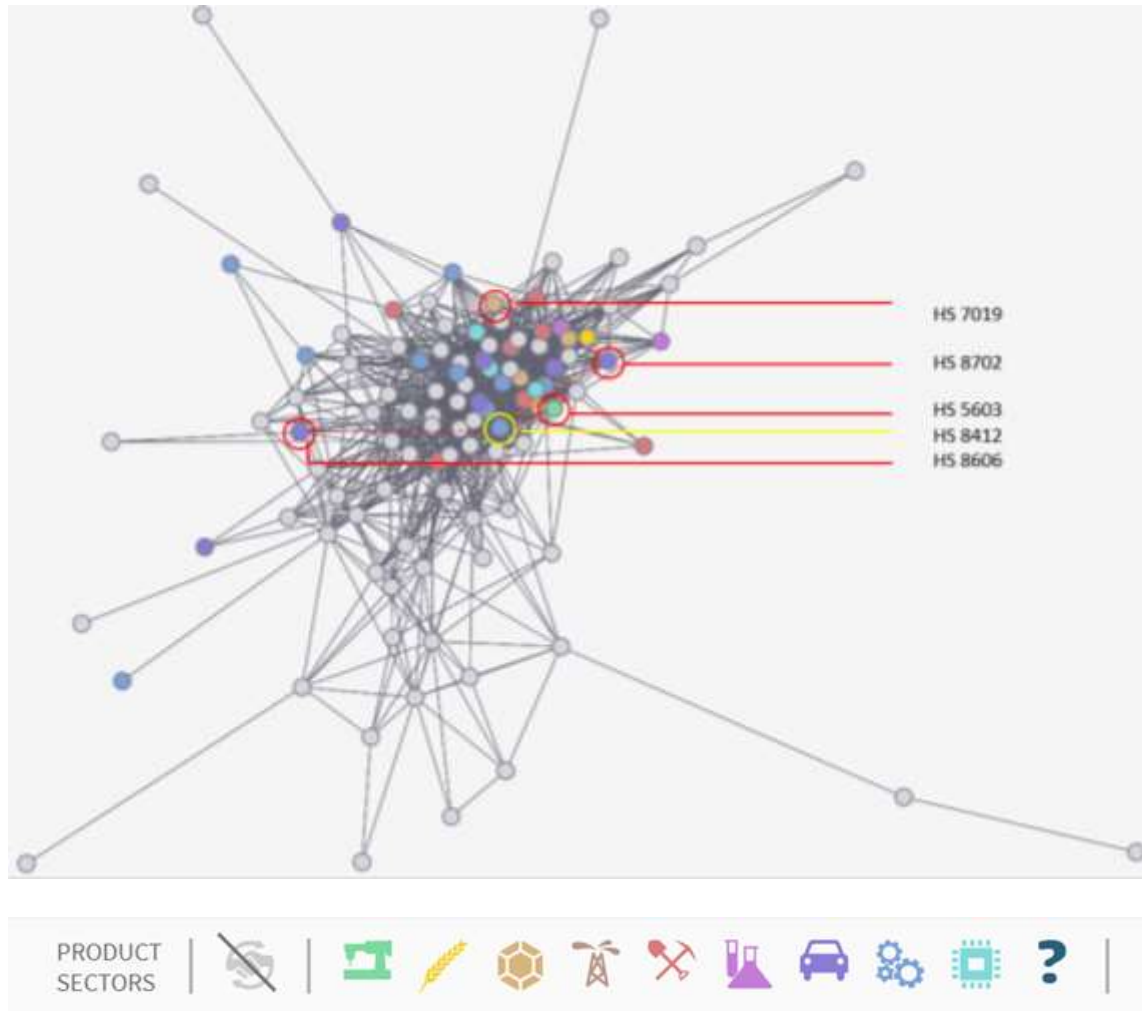
globally (Mathu, 2018). In South Africa, 88% of electricity generation is produced from coal (Mathu, 2018) with Eskom supplying 95% of South Africa's energy needs (Eskom, 2019). An unreliable energy supply has negatively affected industry in South Africa and has strengthened the need to diversify South Africa's energy mix. The National Development Plan- 2030 (NDP) aims to increase the share of renewable energy sources into South Africa's energy mix, reducing its reliance on coal. Furthermore, the Integrated Resource Plan (IRP) issued by the Department of Mineral Resources and Energy (DMRE) aims to address the deficiencies in the country's electricity supply chain through the development of the independent power producers (IPP) under the governments tendering programme for renewable energy, the renewable energy independent power producers' program (REI4P). Within this context, it is important to explore the opportunities for energy production from renewable sources in South Africa. Of the products categorised as "REP" in both lists, product HS 8412, "Other engines" and more specifically at the HS 6-digit level, HS 841290, "Engines; parts, for engines and motors" refer to parts for wind turbines and in particular, wind turbine blades, according to the OECD CLEG list of environmental products (OECD, 2019). However, it is important to visualise where this product lies in South Africa's product space since the location of a product in the product space is predicative of products that a country will likely diversify into (Simoes and Hidalgo, 2011). Since products that require similar capabilities tend to be clustered together in the product space, identifying the products that are closely linked to HS 8412, "Other engines" can illuminate further areas for potential growth since development is path-dependent (Simoes and Hidalgo, 2011).

## 5.5. Mapping South Africa's Green Product Space

Complexity network analytics were used as a tool to create South Africa's green product space. To create this product map visualisation, various inputs were needed. The proximity measure was used to calculate the proximity between products and allow for the mapping of the product space. To do this, the proximity command "genproximity" in the ecomplextity Stata package, developed by Sebastian Bustos and Muhammed Yildirm (2014), was used in Stata to calculate the proximity between all HS 4 products for South Africa in 2017. After this, only the green HS 4 products were kept and used as inputs into the code to create South Africa's green product space. This was done in order to maintain the true structure of South Africa's product space and highlight proximity of green products in relation to this. Furthermore, a list of all HS 4 product codes was used with a dummy variable, 1, assigned to the 106 green HS 4 products and a 0, assigned to the product variables that were not categorised as being green. In addition, another list of all HS 4 product codes was used again with a dummy variable, 1, assigned to the 37 frontier green products and a 0, assigned to all the other products. This was needed in order to colour the green frontier nodes in the product space diagram

in their respective colours whilst leaving the non-frontier green product nodes uncoloured. These inputs were inputted into a code developed in Python by Caitlin Allen, a researcher at the Development Policy Research (DPRU) Unit at the University of Cape Town, to generate the product space (Figure 14).

**Figure 14.** South Africa's Green Product Space



*Source:* (Product space generated by Caitlin Allen, author's own inputs)

Key on Product groupings/ clusters by colour: Textiles & Furniture (light green); Vegetables, Foodstuffs & Wood (yellow); Stone & Glass (light brown); Minerals (dark brown); Metals (red); Chemicals & Plastics (light purple); Transport Vehicles (dark purple); Machinery (blue); Electronics (turquoise); Other (dark blue).

It is important to note that the coloured nodes represent South Africa's green frontier products whilst the non-coloured nodes are the non-frontier green products. Generally, in the product space, coloured nodes represent the products that a country exports with an  $RCA > 1$ . However, in this case, South Africa only exports 7 out of the 106 green products with an  $RCA > 1$  at the HS 4-digit level and therefore, the aim is to establish what green products, that South Africa does not yet have a  $RCA > 1$  in, have the potential for future development. The identification of these frontier green products in the

product space is important in order to establish a possible green growth trajectory for South Africa which will increase future competitiveness of its export base given the changing global climate towards greener production and goods (UNECA, 2016). As mentioned, South Africa exports very few green products and those which it does export, are related to iron and steel or lack product complexity. Mealy and Teytelboym (2018) find that green products, on average, tend to be more complex suggesting that a challenge in addressing climate change and sustainable development is the fact that cleaner energy technologies are relatively sophisticated and require considerable investment and expertise.

When looking at South Africa's green product space, it is clear that most of the frontier green products are clustered closely together indicating the relatedness of these industries in terms of know-how and networks needed for further development. Products clustered together in the product space do not only require similar capabilities but also, tend to have similar levels of complexity (Hausman, Hidalgo et al., 2014). These frontier green products identified have a higher ECI compared to South Africa's export basket overall. Furthermore, the fact that South Africa only exports 7 green products with a revealed comparative advantage aligns with Mealy and Teytelboym's (2018) argument, that green products tend to be more complex and therefore challenging to develop.

Therefore, while green diversification may provide an opportunity for South Africa to gain competitiveness in this new era of green growth, various constraints and challenges could be hindering this process of development. However, the development of one of these industries and the added knowledge gained in this process has the potential to spill-over into other, related frontier green industries, increasing knowledge and improving the skills-base across the sector. A green frontier product that will be explored in this paper is HS product code 8412, "Other engines and motors" positioned in the centre of South Africa's green product space (circled in yellow and highlighted in Figure 14). Other frontier green products closely connected to this product (in terms of capabilities and know-how needed) include HS code 8702 (motor vehicles for transport >10 persons), HS code 8606 (railway cars, not self-propelled) and HS code 5603 (non-woven textiles) (circled in red in Figure 14). Interestingly, non-woven textiles are predominantly used as filters in motor vehicles contributing to improved oil and fuel consumption, increased engine performance and enhanced air quality (Wilson, 2016). Given that all these products are related to engines, it is likely that the knowledge required to develop these products would be overlap and require similar networks to develop.

As discussed in the section above, "Identifying South Africa's Frontier Green Products" the HS 6-digit product level provides increased granularity. At the HS 6-digit level, the product grouped into the HS 8412, "Other engines and motors" is HS 861290, "Engines; parts, for engines and motors" which in the environmental context, refers specifically to wind turbine blades. While wind turbine blades are not related to vehicles, they fit into the engine product grouping since blades turn around a rotor which

spins a generator and creates electricity (Ragheb and Ragheb, 2016). Preliminary research shows that there is significant potential for wind energy generation in South Africa (SAWEA, 2019a). Moreover, while the operation of wind farms does not necessarily create many jobs, the manufacturing of wind turbine parts such as blades, has the potential to absorb sizeable quantities of semi- to skilled labour. Furthermore, it is interesting to note that HS 7019 (glass fibres circled in red in Figure 14), and more specifically, “mats of glass fibres” HS 701931, are key inputs into the development of wind turbine blades. These products are also identified as being a green frontier product for South Africa. Therefore, the growth of one industry has the potential to stimulate the growth of another green industry in South Africa, highlighting the connectedness between products in the product space. Based on these findings, the potential for the manufacturing of wind turbine blades in South Africa will be explored as a possible avenue for growth, diversification and employment generation for the South African economy.

While the total employment effects are difficult to derive for green industries overall, given the dual-use nature of these products and the difficulty in capturing the indirect employment effects that would accompany this growth, it is easier to predict and hypothesise the potential for employment for industries and products destined for the renewable energy sector. This is because of the existing renewable energy industries and the various studies that have been conducted in South Africa which have assessed the impacts of transitioning from coal to renewable energy jobs (IASS and CSIR, 2019). To explore the potential for growth, diversification and employment creation in the wind turbine blade manufacturing sector, a case study was conducted. Interviews were conducted with Dr Fernal Abrahams, the Deputy Director of Energy for the Western Cape Government; and Jarrod Lyons, the Green Economy Investment and Finance Liaison for GreenCape and Wesgro and the Investment Promotions Manager for the Atlantis Special Economic Zone (SEZ). These interviews were supplemented with desktop research to verify the interviews and to strengthen the case study.

## Chapter 6. The Potential for Wind Turbine Blade Manufacturing in South Africa- A Case Study

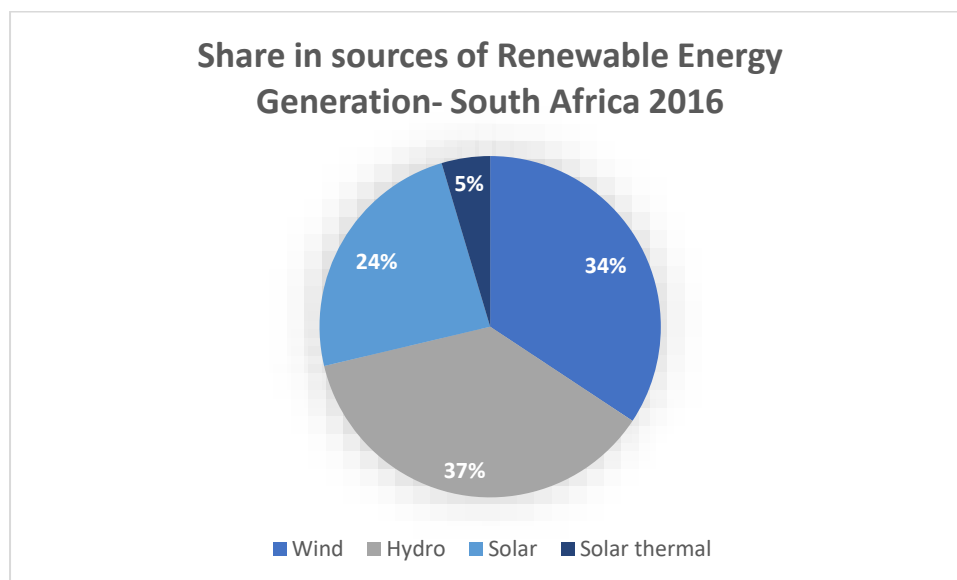
### 6.1. Locating the Wind Industry

According to the Ren21 Report (2019), wind energy is one of the most economical ways of increasing generating capacity. However, while lower prices have helped wind power to expand into new markets, driving up sales, competition for manufacturers of wind turbines has increased (Ren21, 2019). Furthermore, the global shift from feed-in-tariffs (FITs) towards competitive mechanisms such

as tenders and auctions for wind projects, has intensified this competition, resulting in fewer manufacturers as intense price competition has excluded many companies along the value chain (Ren21, 2019). In 2018, 37 wind turbine manufacturers serviced the global market with the top 10 companies capturing 85% of the global share, an increase from 80% in 2017 and 75% in 2016 (Ren21, 2019). The top five manufactures, Vestas (Denmark), GoldWind (China), Siemens Gamesa (Spain), GE Renewable Energy (United States) and Envision (China) accounted for nearly two-thirds of the total number of turbines delivered in 2018 (Ren21, 2019). However, while most wind turbine manufacturing is located in China, the manufacturing of wind turbine components, such as wind turbine blades, are increasingly being manufactured close to growing wind energy markets (Ren21, 2019). This is a strategic move by companies to decrease transport costs and expand into new markets.

At the end of 2018, 4 countries in the Middle-East and 12 countries in Africa had a cumulative capacity of 5.7 GW of wind power capacity (onshore) with Morocco (1 GW), Egypt (1.2 GW) and South Africa (2.1 GW) accounting for most of this total (Ren21, 2019). According to Ren21 (2019), in the Middle East and Africa, South Africa has been identified as being an up-and-coming region for both wind and solar power. This is evident when looking at South Africa's shares in renewable energy generation as see in Figure 15.

**Figure 15.** South Africa's share of Renewable Energy Sources



Source: (IEA, 2018)

In 2015, the renewable energy industry in South Africa accounted for 85% of Foreign direct investment (FDI) into the country in the form of foreign equity and financing (equity and debt) (DoE, 2015; SAWEA, 2018a). In 2018, South Africa received USD 3.9 billion in investment for renewables, an increase of 33-fold from 2017, and the most in the Middle East and African region (Ren21, 2019).

This was largely due to the re-invigoration of the country's renewable energy auction programme, the Renewable Energy Independent Power Producer Programme (REI4P), after two years of delays (Ren21, 2019). Furthermore, according to the International Energy Association (IEA), global investments in renewable energy are expected to increase by over a third by 2022 with wind power expected to comprise approximately 40% of investments (SAWEA, 2018a). Significantly, the IEA predicted that within South Africa, wind is expected to be the largest form of renewable energy by 2022 (SAWEA, 2018a). In absolute terms and growth, South Africa is the leader in the region for non-hydro renewable generation. Given these strong market indicators for the wind sector in South Africa, it seems likely that there exist various opportunities for wind turbine manufacturing to grow this industry.

## 6.2. Manufacturing Potential

Renewable energy procurement in South Africa occurs through a competitive bidding process known as the Renewable Energy Independent Power Producer Programme (REI4P). The REI4P was launched in 2011 with the aim of achieving energy security, economic development and environmental sustainability in line with South Africa's National Development Plan (NDP) (SAWEA, 2019a). This programme aimed to achieve the procurement of low-cost electricity, increased local manufacturing, increased local job creation and increased South African ownership, as well as South African Black ownership (SAWEA, 2019a). To date, South Africa has 22 commercially operating wind power plants with a total installed capacity of 2078 MW (SAWEA, 2019b). These wind power plants are distributed across 3 provinces and account for 52% of South Africa's renewable energy power generation (SAWEA, 2019b). However, despite these positive trends, South Africa's wind energy industry is still in its infancy and is comprised mainly of wind turbine Original Equipment Manufacturers (OEMs) (DTI, 2015). In South Africa, wind turbine towers are locally manufactured by two companies, DCD Wind Towers and Gestamp Renewable Industries (GRI). Towers tend to be the first components of a wind turbine to be locally produced since they are expensive, large and difficult to transport over far distances (Abrahams, 2019). In addition to the production of wind turbine towers, internals for wind towers which include lifts, ladders, doors as well as other electrical and mechanical parts are manufactured locally by RESOLUX AFRICA.

While no blade manufacturing for wind turbines exist currently in South Africa, the country possesses the skills and expertise given its ability to manufacture blades for other purposes, such as helicopters (DTI, 2015). Furthermore, Isivunguvungu Wind Energy Converter (I-WEC) was a local company that produced South Africa's first wind turbine blade in 2011, boasting a local content of approximately 80% with fibreglass, the main input material, being sourced locally (DTI, 2015). However, I-WEC was

forced to close down in 2013. Fernal Abrahams (2019), Deputy Director of Energy for the Western Cape Government, argues that in the wind turbine manufacturing sector, financial support is paramount. If a company is manufacturing wind turbine blades for a project, they need to guarantee that these blades will be operational for 20 years and will be able to produce the level of energy agreed upon in a contract (Abrahams, 2019). To ensure this, international testing of at least one year and international certification is needed. I-WEC, South Africa's first wind turbine blade manufacturing plant, was unable to secure this due to a lack of financial support which prevented them from manufacturing and installing enough blades to get certified while maintaining their financial health (Abrahams, 2019). Furthermore, Abrahams (2019) says that developers prefer to do business with firms that they know. Given that I-WEC did not have an established reputation and trade history, this inhibited their potential for growth (Abrahams, 2019).

While the global dynamics for many OEMs suggest strong vertical integration of supply chains, it is not unusual for OEMs to outsource production of wind turbine components and focus on their core competencies where they have a comparative advantage (DTI, 2015). Therefore, it is common for OEMs to localise the production of their wind turbine blades provided there is sufficient demand in the local market (DTI, 2015). Since South Africa already has wind tower manufacturers and RESOLUX, a manufacturer of internals for towers, Abrahams (2019) believes that there is potential to attract a manufacturer of wind blades which will then attract manufacturers of other parts (Abrahams, 2019). Once manufacturing companies of different elements of a wind turbine are clustered together, the potential for future business and opportunities increases as the industry becomes established (Abrahams, 2019). However, to attract suppliers and develop a supply chain, the market needs to be big enough to guarantee that the investment is worthwhile (Lyons, 2019). According to the DTI report (2015) a minimum capacity of 400MW annually is needed to attract OEMs to establish local blade manufacturing facilities. Therefore, the market would need to exceed the 400MW threshold for another blade manufacturer to enter the market.

The promulgated Integrated Resource Plan (IRP) 2019, South Africa's policy blueprint for the power sector, was recently promulgated in October 2019. Up until 2021, 1362MW of generating capacity has already been committed to the generation of wind energy. From 2022 until 2030, an annual allocated capacity of 1600MW for wind energy was set. It is envisioned in the plan that by 2030, wind will account for 17.8% of South Africa's annual energy generation which places wind energy as the second largest producer of energy after coal at a projected 58.8%. This is a significant increase from the projected 13.8% of wind energy by 2030 which was projected in the last promulgated IRP released in 2011. The increased allowance of wind energy in the IRP sends a strong positive signal for the wind manufacturing industry and support for further localisation. Based on this projection, there is significant opportunity for the establishment of more than one wind turbine blade manufacturer firm in

South Africa given that the allocated annual capacity (from 2022) of 1600MW exceeds the 400MW annual threshold needed in order to attract an OEM into the market.

Prior to the promulgated 2019 IRP, Jarred Lyons, the Investment Promotion Officer of the Atlantis Special Economic Zone (SEZ), said that this positive signal for further wind generation already started increasing investor interest when the IRP 2018 draft was released. LM Wind Power, which was recently bought by General Electric (GE), is currently interested in establishing a wind turbine blade manufacturing factory in South Africa (Lyons, 2019). Now that the IRP has been promulgated, this should help to transform interest into commitment. However, LM Wind Power had hoped to establish a blade manufacturing factory five years ago (Abrahams, 2019). At the time, there was uncertainty in the South African market and consequently, LM Wind Power opted to establish a factory in Brazil instead. However, now that talks have re-emerged, LM Wind Power would prove to be a strategic investor since they produce blades for a range of OEMs. This is the success of their business model in that production is not limited to a certain OEM, allowing for a wider market to supply to (Abrahams, 2019). Therefore, should they establish a factory in South Africa, the expertise and knowledge for the production of a range of wind turbine blades would be transferred to South African workers.

### 6.3. Potential for Job Creation

In terms of the potential for job creation, both Lyons (2019) and Abrahams (2019) believe that wind turbine blade manufacturing would have a significantly positive affect on the South African labour market. At the peak of GRIs manufacturing performance, 320 people were employed at a technically skilled level. These workers received specialist training with many afforded the opportunity to receive training overseas too (Abrahams, 2019). Abrahams (2019) believes that this process and outcome would be similar for the wind turbine blade sector. However, while blade manufacturing is extremely labour-intensive requiring high levels of precision, it also requires a semi- to skilled labour force. Given South Africa's lack of skilled labour and need for low-skill labour-absorbing industries, this is problematic. However, Abrahams (2019) argues that these workers would not necessarily require a degree. While engineers are needed at these factories, most of the work requires technical skills which are learnt on the job (Abrahams, 2019). Furthermore, Lyons (2019) says that in his engagements with LM Wind Power and other multi-national renewable energy investors, it is apparent that while they are not particularly interested in employing unskilled labour, this is also not a deterrent. By the very design of these companies, 'on the job' training is more important than previously acquired degrees or skills. Therefore, these companies, such as LM Wind Power, place a greater emphasis on having access to a pool of labour in South Africa as opposed to skilled workers since there will be on-the-line training (Lyons, 2019). This makes sense since these industries are bespoke and while the

theory of an engineer, for example, is important, the knowledge to produce a wind turbine blade is learned. Lyons (2019) believes that should LM Wind Power establish a manufacturing factory, 200-250 jobs would be created accompanied by a R400 million investment. This would allow for approximately 40-50 % of the South African market to be serviced which means that there would still be a need for at least another blade manufacturer, if not more (Lyons, 2019).

In terms of potential for job creation, 200-250 new jobs is a small number in comparison to employment in coal power stations. The Medupi coal power station, for example, employs approximately 600 to 800 people fulltime (Gosling, 2019). This is considerably more than a wind turbine blade manufacturing plant or a wind farm. However, this is not an accurate comparison as the Medupi coal power station generates 100 times more energy than South Africa's largest wind farm (Gosling, 2019). According to former Eskom engineer, Tobias Bischof-Niemz, the correct comparison would be to compare the number of permanent jobs created per unit of energy generated. This measurement shows that renewable energy is actually more labour-intensive than coal and therefore, net employment is higher in the renewable energy sector compared to the coal sector. However, comparing employment data across the coal and renewable energy sector is challenging and complex. In South Africa, studies on employment across sectors do not use a standardised metric and methodology which makes it difficult to compare these results (SAWEA, 2018b). For example, employment can be measured by the total number of jobs created without specifying how long these jobs last for or, they can be measured according to a job-year. In the energy sector, jobs created per MW of installed capacity is a more suitable metric however, this measurement does not account for the investment required to generate these jobs. Without a standardised measure of employment, studies that estimate the job creation potential of these different energy sectors are highly metric, and context specific and therefore, results should be interpreted with caution.

#### 6.4. Export Potential

While there is potential and a market for the establishment of wind blade manufacturing in South Africa, South Africa's location poses a significant barrier for further market expansion and export potential. Potential markets for South Africa could include South America, Australia and Africa given the establishment of wind farms and wind potential in these regions. However, South America already has established wind turbine blade manufacturers and since Australia is located near to China, the cost of doing business with China is cheaper (Abrahams, 2019). This cost is directly related to proximity since currently, in terms of cost of labour between South Africa and China, there is relatively little difference (Abrahams, 2019). Therefore, it is ultimately distance that impacts on South Africa's ability to export competitively. On the African continent, markets for wind turbine blades exist in

Morocco, Egypt and Kenya, however, India's close proximity to these countries drastically reduces transport costs of delivery (Lyons, 2019). LM Wind Power has reiterated this and said that they would first focus on the South African market and thereafter, seek out market opportunities in Botswana and Namibia (Lyons, 2019). As it stands, the entirety of the Southern African Development Community (SADC) region market size is equal to the market size of South Africa (Lyons, 2019). This market is not currently big enough to sell to investors as an export opportunity. However, Abrahams (2019) posits that the sub-Saharan market needs to be explored further regarding export opportunities since to the best of his knowledge, there has not been any in-depth market research conducted for wind turbine manufacturing and in particular, export potential.

## 6.5. Barriers to Development

Within South Africa, the policy space has arguably been (and still is) the biggest barrier for the development of local manufacturing at a utility scale. The inconsistency with South Africa's REI4P has been detrimental for the development of the wind turbine manufacturing industry and the development of the renewable industry at large. In 2015, after the announcement of the preferred bidders for round 4 of the REI4P were announced, the energy minister at the time announced that round 4 would be followed by an expedited round announcement (SAWEA, 2019a). However, this did not come to fruition and instead, a three-year stalemate followed the signing of the Power Purchase Agreements (PPAs) for round 4 bidders and the subsequent cancellation of the 'expedited round' was enacted. This has had detrimental effects on local manufacturing with many companies having to close down or reduce operations as a result (SAWEA, 2019a). For example, despite RESOLUX's available capacity and knowledge to manufacture and produce internals for wind turbine towers, the company currently operates as a distribution centre, importing components and supplying to the local market (Lyons, 2019). In order for RESOLUX to begin manufacturing these products again, a significant amount of offtake is required before manufacturing becomes financially feasible. Uncertainty in the market caused by the REI4P hiatus has hindered local demand. Furthermore, GRI in Atlantis had to put their workers on 30% time due to the slump in the market and were only able to remain in business because they were able to diversify their supply base, supplying wind towers not only to the local market but also to Brazil (Abrahams, 2019; Lyons, 2019). Only with the recent revival of the REI4P and signing of contracts for round 4 did demand increase, allowing these companies to increase capacity once more.

Moreover, Lyons (2019) argues that a lack of manufacturing in the wind turbine sector is also partly due to the local content requirements. While the DTI had the intention of promoting local manufacturing through the introduction of local content requirements in the REI4P bidding rounds,

industry interpreted these requirements to include the entire production process from importing parts to the eventual installation of these parts (Lyons, 2019). Therefore, instead of promoting local manufacturing development, parts (such as solar panels or wind turbine blades) were imported from China. To make up for the local content requirements, South African firms were made responsible for the logistical aspects and installation of these parts (Lyons, 2019). Therefore, a lack of local development and manufacturing has taken place, contrary to the initial intention of the DTI.

Abraham (2019) adds that over the past few months, there has been further debate about South Africa's energy sector. Arguments for pursuing nuclear have been revived and coal lobbyists are perpetuating the narrative that job losses in the sector will further damage the economy (Overy, 2019). Overall, renewable energy is incorrectly portrayed as the most expensive form of energy generation despite the fact that coal now costs R1.30 a kilowatt-hour compared to renewables at 60 cents (Abrahams, 2019; Bloom, 2019a). The significant backlash and lobbying against renewable energy projects significantly impact on the likelihood of success for wind blade manufacturing in South Africa according to Abrahams (2019). This narrative needs to be changed and rectified in order to alleviate political pressure and create a positive business environment for investment. Because the policy space has been unstable, there has been a lack of local demand driving this sector. Local demand would come from companies awarded contracts under the REI4P (Lyons, 2019). The stalemate of round 4 of the REI4P meant that local demand contracted significantly. The poor policy space and subsequent lack of demand has prevented South Africa from being a first mover and establishing a reputation for wind blade manufacturing.

## 6.6. Opportunities for Development

While policy uncertainty and seemingly limited potential for export markets has hampered the potential for wind blade manufacturing in South Africa, it is important to note that data trends do not always predict future opportunities. There are various factors to consider when investigating the potential into an industry. Lyons (2019) is optimistic about the potential for wind blade manufacturing development in South Africa. He argues that leadership plays a critical role in enabling or disabling this potential. President Cyril Ramaphosa appears to be in favour of promoting renewable energy industries and recently sent a statement to the UN Climate Summit in New York, with reference to an \$11-billion renewables funding facility. While this deal has since been excised from governments statement, members from the Presidents Eskom Sustainability Task Team have confirmed that this was a recommendation made to the President (Bloom, 2019a). Therefore, South Africa needs to strategically align industrial opportunities with the country's vision, especially if it is coming from the top tiers of leadership in the country (Lyons, 2019). In addition, the DTI is also committed to rectifying

the local content requirement policies and ensuring that these policies promote local content in manufacturing activities. The DTI recently engaged proactively with local manufacturers and potential manufacturers on issues faced with the local content policies imposed by the REI4P (Lyons, 2019). While policy has not yet changed, this proactive step is likely to result in increased interest in solar PV and wind turbine manufacturing since it is highly probable that there will be a change in policy towards more stringent local content requirements for these various projects (Lyons, 2019). Furthermore, Abrahams (2019) argues that the unbundling of Eskom into operation, transmission and distribution, may open up the market for renewable energy projects such as the manufacturing of wind turbine blades. However, it ultimately depends on whether or not the Minister of Mineral Resources and Energy, Gwede Mantashe, is committed to a sustainable agenda. In April 2019, the Minister urged the coal sector to pushback against the perception that the industry was dirty (Bloom, 2019a). However, he has since changed his position and has argued that South Africa needs to shift towards cleaner technologies and consider the impacts of climate change (Bloom, 2019a). This signals a positive commitment towards the renewable energy sector however, given that the Minister is responsible for both energy and mineral affairs, mining might have significant access to him and prevent this sustainable agenda from being prioritised (Abrahams, 2019).

The SAWEA (2019) report strongly argues that investment in local manufacturing in the wind sector is dependent on a sufficiently large market and specified megawatt procurement allocations from year to year. The IRP, which the government has committed an allocated capacity of 1600MW annually from 2022 until 2030 for wind energy proves to be a positive step in promoting investor confidence and certainty in the sector (DMRE, 2019). In addition, round 4 of the REI4P was signed on 4 April 2018 which allowed GRI to revive its manufacturing of towers for these designated projects and sent a positive signal to investors, re-igniting talks with LM Wind Power. The potential opportunities for wind turbine blade manufacturing are directly contingent on South Africa's REI4P programme. In order to maintain this momentum and secure investor confidence, it is paramount that the REI4P continue with continuity, certainty and transparency with subsequent rounds occurring within 12-18 months of the prior round (Lyons, 2019; SAWEA, 2019a). The success of this industry is dependent on the size of the market, support for local industry and a long-term strategy.

## 6.7. Discussion

Analysis from trade and environmental indicators show that there exists a strong correlation between positive policy and regulation on EGs and the growth in net exports of equipment for renewable energy plants (OECD, 2019). Conversely, countries that continued to spend a large proportion of their GDP on subsidising and supporting fossil fuel activities, seemed to hurt the competitiveness of their

renewable energy industry domestically (OECD, 2019). In South Africa, it is estimated that \$4.2 billion (R56.6 billion) is spent annually on coal subsidies, making it the fourth largest subsidiser of coal out of the G20 countries (Bloom, 2019b). According to the South African country study by the ODI, approximately \$3.4 billion was given over the 2016/17 year for SOE subsidies comprising predominantly of Eskom's coal-fired Medupi and Kusile power plants (Bloom, 2019b).

This support for the coal-power sector through subsidies has implications for development of the renewable sector, especially with regards to the development of wind manufacturing industries as well as other clean technologies. These subsidies allow for the improper pricing of coal-power, allowing this source of energy to remain competitive. However, within the South African context, the economy is reliant on coal and commodities which dominate the export sector. In addition, coal mining employs 82 000 people with Eskom employing a further 50 000 people (Kings, 2019). Given South Africa's high unemployment rate and stagnant economic growth, it is understandable that maintenance of these norms and strong support for the coal sector continues. However, since the inception of the REI4P in 2011 to 2018, 31 072 job-years were needed in construction and another 5456 job-years were needed in operations in the renewable energy sector (Bischof-Niemz, 2019). Moreover, the Department of Energy's (DOE) Integrated Energy Plan (2016) includes a study of the employment needs for different power generating technologies including coal-fired power plants and wind and solar PV plants. This study assessed the yearly energy output of these different power generating technologies, accounting for the respective production rates, maintenance and lifespan of both the coal and renewable energy operations. Their findings showed that at least 30% more jobs would be needed in the renewable fleet (wind and solar photovoltaic farms) compared to the energy-equivalent coal fleet (Bischof-Niemz, 2019). While these findings are not certain given the lack of standardisation across employment metrics and difficulty in predicting the future of the energy sector, it is important to look at global supply and demand trends in this sector. In a recent report entitled, "Understanding the impact of a low carbon transition on South Africa," it was found that should the world achieve a growth path consistent with the Paris Agreement targets, while South Africa continues to rely on coal and other commodities for exports, South Africa will face a 'transition risk' of approximately R1.8 trillion in present value terms (Huxham et al., 2019). Most of this risk would fall on the public balance sheet, straining public finances and jeopardising the country's sovereign credit rating (Huxham et al., 2019). Therefore, while climate change is transforming the global economy, South Africa has a very narrow and constrained time-frame in which to act and transition into a more sustainable and low-carbon development path.

However, even if South Africa pursues a green growth agenda covering all sectors of the economy, these findings cannot be isolated from various other factors at play, namely, the need for workers equipped with the skills to operate in this new and transitioning space and the fact that many of the green frontier sectors identified are capital intensive. South Africa, therefore, needs to be strategic in

the sectors and industries it targets to transform the economy in line with a green, sustainable agenda. Whilst this transformative process will take time, strong leadership is needed along with enabling government policy to create a favourable environment for investment into these renewable energy manufacturing industries. According to the OECD findings (2019), creating a policy environment which is favourable to the deployment of renewable energy, increases the demand for environmental goods domestically. This can lead to an increase in imports of these goods if local firms are unable to supply these goods (OECD, 2019). Alternatively, the same policy environment has the potential to increase incentives, stimulating innovation in local firms and creating long-term competitiveness of related industries, thus possibly decreasing demand for imports and in turn, increasing exports (OECD, 2019). Therefore, countries that provide strong support for the renewable energy industry could help to strengthen their trade balance in relation to these industries. This enabling environment and government leadership will not only be needed to create an enabling, investor-friendly environment but also be needed across the economy. The education sector in particular will need to be targeted and transformed in order to meet the needs of these future industries and equip South Africans with the skills to partake in the green economy.

## Chapter 7. Conclusion

The economic complexity method provides a scientifically rigorous method based on complexity to give key product-level insight into South Africa's development path in line with a green economy, identifying potential products and possible industries for diversification. It provides empirical evidence to support the structuralist view that argues production sophistication is the prime avenue in which to overcome underdevelopment (Gala et al., 2018). This methodology incorporates large volumes of trade data, allowing for more accurate and disaggregated information which can positively inform development theory and policymakers to allow for better-informed decision making for industrial policy and overall country strategy (Simoes and Hidalgo, 2011).

However, while the economic complexity methodology is important because it further helps explain levels of income and aids in the prediction of future growth, it cannot account for the institutional and social factors which can impede or propel growth. In the case of South Africa, while a sustainable development agenda is supported on paper, reliance on coal power poses a serious threat to this agenda, not only because it comprises a large proportion of South Africa's exports but also because it absorbs a large portion of labour. Therefore, while this paper has identified opportunities for diversification potential based on the country's existing knowledge and skills, the process of diversification is complex, involving various actors and forces. Growth and diversification are not based solely on a country's capabilities in determining future growth but also on the strength of

institutions, political will and social context among other factors. While the complexity methodology is unable to account for these forces, if anything, it provides a robust entry point in identifying prospects for future growth and helping to inform policy going forward.

In the context of green growth, it is paramount that policymakers place economic growth at the centre of environmental management discussions. In South Africa, the triple threat of poverty, inequality and unemployment means that in addition to the growth factor, policymakers must also consider the impacts of environmental policies in terms of job creation and social upliftment. South Africa's reliance on mineral products and energy-intensive sectors is a significant stumbling block, that unless addressed, will impede any meaningful effort South Africa may attempt to follow the diversification path towards green industries and products as is clearly seen in the green product space. This will maintain the current status quo - the underdevelopment of these green products and industries. However, the global shift towards greener development and technologies make it critical for South Africa to redirect its growth path towards more sustainable industries. This will not only allow for future competitiveness but also ensure that the jobs created today still exist in the future and are not under threat.

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## Annex 1

OECD Combined List of Environmental Goods				
HS 2007	Category	Product Name	HS 1992	Product Name
380210	WAT	Carbon, activated	380210	Carbon, activated
390940	HEM	Phenolic resins	390940	Phenolic resins
392010	SWM	Plastic sheet, ethylene	392010	Plastic sheet, ethylene
392030	HEM	Plastic sheet, styrene	392030	Plastic sheet, styrene
392111	HEM	Plastic sheet, cellular of styrene	392111	Plastic sheet, cellular of styrene
392113	HEM	Plastic sheet, cellular of polyurethane	392113	Plastic sheet, cellular of polyurethane
392510	REP	Plastic tanks, <300 L	392510	Plastic tanks, <300 L
400259	SWM	Rubber, NBR, not latex	400259	Rubber, NBR, not latex
441872	EPP	Assembled flooring panels, multilayer	441830	Parquet panels
450410	NVA	Agglomerated cork blocks	450410	Agglomerated cork blocks
450490	HEM	Agglomerated cork articles	450490	Agglomerated cork articles
530310	EPP	Jute, raw	530310	Jute, raw
530500	EPP	Other	530599	Other
540500	HEM	Artificial monofilament, > 67dtex	540500	Artificial monofilament, > 67dtex
560314	WAT	Nonwovens; whether or not impregnated, coated, covered or laminated, of manmade filaments, (weighing more than 150g/m2)	560300	Nonwovens; whether or not impregnated, coated, covered or laminated, of manmade filaments, (weighing more than 150g/m2)
560721	EPP	Binder twine, sisal	560721	Binder twine, sisal
560790	EPP	Twine ropes, other materials	560790	Twine ropes, other materials
560811	NRP	Made up fishing nets, manmade material	560811	Made up fishing nets, manmade material
560890	NRP	Knotted netting, natural material	560890	Knotted netting, natural material
630510	EPP	Sacks & bags, packing, of jute/bast fibres	630510	Sacks & bags, packing, of jute/bast fibres
680610	HEM	Slag wool, rock wool	680610	Slag wool, rock wool
680690	HEM	Mineral heat/sound insulating materials	680690	Mineral heat/sound insulating materials
680800	HEM	Boards, of veg fibre with mineral/cement	680800	Boards, of veg fibre with mineral/cement
681011	HEM	Building blocks, bricks of cement/artificial stone	681011	Building blocks, bricks of cement/artificial stone
681019	HEM	Tiles of cement, concrete	681019	Tiles of cement, concrete
681091	HEM	Prefab structural items of cement/concrete	681091	Prefab structural items of cement/concrete
691010	WAT	Porcelain bathroom, kitchen fixtures	691010	Porcelain bathroom, kitchen fixtures
700800	HEM	Multiple-walled insulating glass	700800	Multiple-walled insulating glass
700991	REP	Glass mirrors, unframed	700991	Glass mirrors, unframed
700992	REP	Glass mirrors, framed	700992	Glass mirrors, framed
701931	HEM	Mats of glass fibres	701931	Mats of glass fibres
701939	HEM	Webs, nonwoven fibreglass products	701939	Webs, nonwoven fibreglass products
730210	CRE	Rails, iron	730210	Rails, iron
730230	CRE	Rail crossing material, iron	730230	Rail crossing material, iron
730240	CRE	Rail sole plates, iron	730240	Rail sole plates, iron

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730290	CRE	Rail construction material, iron	730290	Rail construction material, iron
730300	WAT	Tubes, cast iron	730300	Tubes, cast iron
730431	WAT	Pipe, iron, cold rolled, nes	730431	Pipe, iron, cold rolled, nes
730490	WAT	Pipe, iron or steel, nes	730490	Pipe, iron or steel, nes
730630	WAT	Pipes, iron/steel, welded, nes <406mm	730630	Pipes, iron/steel, welded, nes <406mm
730690	WAT	Tubes, iron/steel, riveted <406mm	730690	Tubes, iron/steel, riveted <406mm
730820	REP	Towers, iron/steel	730820	Towers, iron/steel
730890	REP	Structures, iron/steel, nes	730890	Structures, iron/steel, nes
730900	WAT	Tanks, iron/steel, >300L	730900	Tanks, iron/steel, >300L
731010	WAT	Tank, iron/steel, 50-300L	731010	Tank, iron/steel, 50-300L
731029	WAT	Cans, iron/steel, <50L, nes	731029	Cans, iron/steel, <50L, nes
732111	CRE	Cooking appliances for gas, iron	732111	Cooking appliances for gas, iron
732119	REP	Other cooking appliances & plate warmers incl. appliances for solid fuel, other than for gas fuel/for both gas & other fuels/liquid fuel.	732113	Cooking appliances and plate warmers :-- For solid fuel
732189	REP	Non-electric domestic appliances, & parts thereof, of iron/steel (incl. appliances for solid fuel), other than for gas fuel/for both gas & other fuels/liquid fuel.	732183	Other appliances :-- For solid fuel
732190	CRE	Parts, non-electric thermic appliances, iron	732190	Parts, non-electric thermic appliances, iron
732490	WAT	Sanitary ware, iron	732490	Sanitary ware, iron
732510	WAT	Cast articles, non-malleable cast iron	732510	Cast articles, non-malleable cast iron
732690	WAT	Articles of iron/steel, nes	732690	Articles of iron/steel, nes
761090	REP	Aluminum structures for construction	761090	Aluminum structures for construction
761100	REP	Aluminum tanks, >300L	761100	Aluminum tanks, >300L
761290	SWM	Aluminum casks, <300L	761290	Aluminum casks, <300L
830630	REP	Frames, metal	830630	Frames, metal
840219	SWM	Boilers, nes	840219	Boilers, nes
840290	SWM	Boiler parts, nes	840290	Boiler parts, nes
840410	APC	Auxiliary plant for boilers	840410	Auxiliary plant for boilers
840420	APC	Condensers for steam power units	840420	Condensers for steam power units
840490	APC	Auxiliary plant for boilers, parts	840490	Auxiliary plant for boilers, parts
840510	APC	Water gas generator producer	840510	Water gas generator producer
840681	REP	Turbines; steam and other vapour turbines, (for other than marine propulsion), of an output exceeding 40MW	840619	Activate carbon
840682	REP	Turbines; steam and other vapour turbines, (for other than marine propulsion), of an output not exceeding 40MW	840619	Activate carbon
840690	REP	Steam turbines, parts	840690	Steam turbines, parts
840991	NVA	Spark-ignition engine, parts nes	840991	Spark-ignition engine, parts nes
840999	NVA	Diesel engine, parts	840999	Diesel engine, parts
841011	REP	Water wheels, <1000kW	841011	Water wheels, <1000kW
841012	REP	Water wheels, 1000-10000 kW	841012	Water wheels, 1000-10000 kW
841013	REP	Water wheels, > 10000kW	841013	Water wheels, > 10000kW
841090	REP	Water wheels, parts	841090	Water wheels, parts
841181	REP	Gas turbine engine, nes <5000 kW	841181	Gas turbine engine, nes <5000 kW

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841182	REP	Gas turbine engine, nes >5000 kW	841182	Gas turbine engine, nes >5000 kW
841199	REP	Gas turbine engine, not turbo-jet, parts	841199	Gas turbine engine, not turbo-jet, parts
841280	REP	Engines; pneumatic power engines and motors, n.e.c	841280	Hydraulic/pneumatic power engine, parts
841290	REP	Engines; parts, for engines and motor	841290	Engines and motors, nes
841320	WAT	Hand pumps, not measuring	841320	Hand pumps, not measuring
841350	WAT	Reciprocating pumps, nes	841350	Reciprocating pumps, nes
841360	WAT	Rotary pumps, nes	841360	Rotary pumps, nes
841370	WAT	Centrifugal pumps, nes	841370	Centrifugal pumps, nes
841381	WAT	Pumps, nes	841381	Pumps, nes
841410	APC	Vacuum pumps	841410	Vacuum pumps
841430	APC	Compressors for refrigeration	841430	Compressors for refrigeration
841440	APC	Air compressors, for towing	841440	Air compressors, for towing
841459	APC	Fans, motor > 125 W	841459	Fans, motor > 125 W
841480	APC	Air compressor, hoods	841480	Air compressor, hoods
841490	APC	Pumps, compressors, etc. parts	841490	Pumps, compressors, etc. parts
841581	REP	Air conditioners, reverse cycle	841581	Air conditioners, reverse cycle
841780	SWM	Industrial furnaces, nes	841780	Industrial furnaces, nes
841790	SWM	Industrial furnace, parts	841790	Industrial furnace, parts
841861	REP	Compression refrigeration equipment	841861	Compression refrigeration equipment
841869	REP	Freezing equipment, nes	841869	Freezing equipment, nes
841919	REP	Water heaters, no electric, nes	841919	Water heaters, no electric, nes
841939	WAT	Non-domestic, non-electric dryer	841939	Non-domestic, non-electric dryer
841940	SWM	Distilling plant	841940	Distilling plant
841950	HEM	Heat exchange units, non-domestic	841950	Heat exchange units, non-domestic
841960	APC	Machinery for liquefying gases	841960	Machinery for liquefying gases
841989	WAT	Machinery for temperature change	841989	Machinery for temperature change
841990	REP	Industrial heating/cooling, parts	841990	Industrial heating/cooling, parts
842119	SWR	Centrifuges, nes	842119	Centrifuges, nes
842121	WAT	Water filtering machines	842121	Water filtering machines
842129	WAT	Filter machine, liquids, nes	842129	Filter machine, liquids, nes
842139	APC	Filtering machinery, gases, nes	842139	Filtering machinery, gases, nes
842191	SWR	Centrifuge parts, nes	842191	Centrifuge parts, nes
842199	WAT	Filter machine, parts	842199	Filter machine, parts
842220	SWM	Machinery for cleaning/drying bottles/containers	842220	Machinery for cleaning/drying bottles/containers
842290	SWM	Parts of washing, filling, closing machinery	842290	Parts of washing, filling, closing machinery
842833	SWM	Continuous goods conveyor or elevator belt	842833	Continuous goods conveyor or elevator belt
842940	SWM	Tamping machines & road rollers, self-propelled	842940	Tamping machines & road rollers, self-propelled
846291	SWM	Hydraulic presses for working metal	846291	Hydraulic presses for working metal
846596	SWM	Splitting or slicing machines for wood	846596	Splitting or slicing machines for wood
846599	SWM	Machine tools for wood, cork or hard plastic	846599	Machine tools for wood, cork or hard plastic
846694	SWM	Parts of metal shaping machine tools	846694	Parts of metal shaping machine tools
847420	SWM	Machines to crush stone, ores, minerals	847420	Machines to crush stone, ores, minerals
847982	SWM	Machines to mix, knead, grind, nes	847982	Machines to mix, knead, grind, nes

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847989	SWM	Machines & mechanical appliances nes	847989	Machines & mechanical appliances nes
847990	SWM	Parts of machines & mechanical appliances nes	847990	Parts of machines & mechanical appliances nes
848110	WAT	Valves, pressure reducing	848110	Valves, pressure reducing
848130	WAT	Valves, check	848130	Valves, check
848140	WAT	Valves, safety or relief	848140	Valves, safety or relief
848180	WAT	Taps, cocks, valves, appliances, nes	848180	Taps, cocks, valves, appliances, nes
848190	WAT	Parts of taps, cocks, valves	848190	Parts of taps, cocks, valves
848340	REP	Gearing, ball screws	848340	Gearing, ball screws
848360	REP	Clutches, shaft couplings, universal joints	848360	Clutches, shaft couplings, universal joints
850161	REP	AC generators, of an output <75 kVA	850161	AC generators, of an output <75 kVA
850162	REP	AC generators, 75-375 kVA	850162	AC generators, 75-375 kVA
850163	REP	AC generators, 375-750 kVA	850163	AC generators, 375-750 kVA
850164	REP	AC generators, >750kVA	850164	AC generators, >750kVA
850220	HEM	Generating sets, spark ignition engines	850220	Generating sets, spark ignition engines
850231	REP	Electric generating sets; wind-powered, (excluding those with spark-ignition or compression-ignition internal combustion piston engines)	850230	Steam turbines, parts
850239	REP	Electric generating sets; (excluding those with spark-ignition or compression-ignition internal combustion piston engines), other than wind powered	850230	Steam turbines, parts
850300	REP	Parts for electric motors & generators	850300	Parts for electric motors & generators
850421	REP	Liquid dielectric transformers <650KVA	850421	Liquid dielectric transformers <650KVA
850422	REP	Liquid dielectric transformers 650-10,000KVA	850422	Liquid dielectric transformers 650-10,000KVA
850423	REP	Liquid dielectric transformers >10,000KVA	850423	Liquid dielectric transformers >10,000KVA
850431	REP	Electric transformers, <1KVA	850431	Electric transformers, <1KVA
850432	REP	Electric transformers, 1-16 KVA	850432	Electric transformers, 1-16 KVA
850433	REP	Electric transformers, 16-500KVA	850433	Electric transformers, 16-500KVA
850434	REP	Electric transformers, >500KVA	850434	Electric transformers, >500KVA
850440	REP	Static converters, nes	850440	Static converters, nes
850490	SWM	Parts of electrical transformers & inductors	850490	Parts of electrical transformers & inductors
850590	REP	Electro-magnets, nes	850590	Electro-magnets, nes
850680	CRE	Primary cells, primary batteries nes, volume < 300 cc	850619	Primary cells, primary batteries nes, volume < 300 cc
850720	REP	Lead-acid electric accumulators, non-vehicle	850720	Lead-acid electric accumulators, non-vehicle
850980	CRE	Home appliances, electric motor	850980	Home appliances, electric motor
851410	SWM	Industrial electric resistance furnaces & ovens	851410	Industrial electric resistance furnaces & ovens
851420	SWM	Industrial induction/dielectric furnaces & ovens	851420	Industrial induction/dielectric furnaces & ovens
851430	SWM	Industrial/lab electric furnaces & ovens	851430	Industrial/lab electric furnaces & ovens
851490	SWM	Parts of industrial electric furnaces, ovens	851490	Parts of industrial electric furnaces, ovens
851629	SWR	Space heaters, electric	851629	Space heaters, electric
853010	CRE	Railway electric signal & traffic controls	853010	Railway electric signal & traffic controls
853080	CRE	Electric signal & traffic controls	853080	Electric signal & traffic controls

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853090	CRE	Parts of electric signal & traffic controller	853090	Parts of electric signal & traffic controller
853710	REP	Electrical control & distribution boards, <1kV	853710	Electrical control & distribution boards, <1kV
853720	REP	Electrical control & distribution boards, >1kV	853720	Electrical control & distribution boards, >1kV
853921	HEM	Filament lamps, tungsten halogen	853921	Filament lamps, tungsten halogen
853931	HEM	Fluorescent lamps, hot cathode	853931	Fluorescent lamps, hot cathode
853932	HEM	Lamps; discharge, (excluding ultra-violet), mercury or sodium vapour lamps, metal halide lamps	853939	Lamps; discharge, (excluding ultra-violet), mercury or sodium vapour lamps, metal halide lamps
854140	REP		854140	Photosensitive/PV/LED semiconductor device
854370	WAT	Electrical machines and apparatus; having individual functions, not specified or included elsewhere in this chapter, n.e.c	854380	Electrical machines and apparatus, nes
854390	WAT	Parts of electrical machines, nes	854390	Parts of electrical machines, nes
860110	CRE	Rail locomotives, externally electrically powered	860110	Rail locomotives, externally electrically powered
860120	CRE	Rail locomotives, electric accumulator powered	860120	Rail locomotives, electric accumulator powered
860210	CRE	Rail locomotives, diesel-electric	860210	Rail locomotives, diesel-electric
860290	CRE	Rail locomotives, non-electric	860290	Rail locomotives, non-electric
860310	CRE	Self-propelled railway cars, external power	860310	Self-propelled railway cars, external power
860390	CRE	Self-propelled railway cars, nes	860390	Self-propelled railway cars, nes
860400	CRE	Railway maintenance vehicles	860400	Railway maintenance vehicles
860500	CRE	Railway passenger/special purpose coaches	860500	Railway passenger/special purpose coaches
860610	CRE	Railway tank cars	860610	Railway tank cars
860630	CRE	Railway cars, self-discharging	860630	Railway cars, self-discharging
860691	CRE	Railway cars, closed & covered	860691	Railway cars, closed & covered
860692	CRE	Railway or tramway goods vans and wagons; open, with non-removable sides of a height exceeding 60cm, not self-propelled	860692	Railway or tramway goods vans and wagons; open, with non-removable sides of a height exceeding 60cm, not self-propelled
860699	CRE	Railway cars nes	860699	Railway cars nes
860711	CRE	Driving bogies & bissel-bogies for railway	860711	Driving bogies & bissel-bogies for railway
860712	CRE	Bogies & bissel-bogies for railway, non-driving	860712	Bogies & bissel-bogies for railway, non-driving
860719	CRE	Railway axles, wheels	860719	Railway axles, wheels
860721	CRE	Air brakes for railway	860721	Air brakes for railway
860729	CRE	Brakes, non-air, for railway	860729	Brakes, non-air, for railway
860730	CRE	Coupling devices for railway	860730	Coupling devices for railway
860791	CRE	Railway locomotive parts, nes	860791	Railway locomotive parts, nes
860799	CRE	Railway rolling stock parts, nes	860799	Railway rolling stock parts, nes
860800	CRE	Signals for rail, waterway, port, airfield	860800	Signals for rail, waterway, port, airfield
870290	CRE	Buses, non-diesel	870290	Buses, non-diesel
870390	CRE	Automobiles nes, gas turbine powered	870390	Automobiles nes, gas turbine powered
871200	CRE	Bicycles	871200	Bicycles
871411	CRE	Of motorcycles (including mopeds) :- Saddles	871411	Of motorcycles (including mopeds) :- Saddles
871419	CRE	Motorcycle parts	871419	Motorcycle parts
871420	CRE	Wheelchair parts	871420	Wheelchair parts
871491	CRE	Bicycle frames & forks	871491	Bicycle frames & forks

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871492	CRE	Bicycle wheel rims & spokes	871492	Bicycle wheel rims & spokes
871493	CRE	Bicycle hubs, free-wheel sprocket wheels	871493	Bicycle hubs, free-wheel sprocket wheels
871494	CRE	Bicycle brakes	871494	Bicycle brakes
871495	CRE	Bicycle saddles	871495	Bicycle saddles
871496	CRE	Bicycle pedals/cranks	871496	Bicycle pedals/cranks
871499	CRE	Bicycle parts, nes	871499	Bicycle parts, nes
871639	CRE	Trailers nes for goods transport	871639	Trailers nes for goods transport
890790	SWR	Buoys, beacons, pontoons	890790	Buoys, beacons, pontoons
900190	REP	Prisms, mirrors & optical elements, unmounted	900190	Prisms, mirrors & optical elements, unmounted
900290	REP	Mounted lenses, prisms, optical elements	900290	Mounted lenses, prisms, optical elements
900580	MON	Telescopes	900580	Telescopes
901380	REP	Optical devices, appliances and instruments, nes	901380	Optical devices, appliances and instruments, nes
901390	REP	Parts and accessories of optical appliances nes	901390	Parts and accessories of optical appliances nes
901530	MON	Surveying levels	901530	Surveying levels
901540	MON	Photogrammetrical surveying instruments	901540	Photogrammetrical surveying instruments
901580	MON	Surveying instruments nes	901580	Surveying instruments nes
901590	MON	Parts/accessories for surveying instruments	901590	Parts/accessories for surveying instruments
902511	MON	Thermometers, liquid-filled	902511	Thermometers, liquid-filled
902519	MON	Thermometers, not liquid filled	902519	Thermometers, not liquid filled
902610	MON	Liquid flow/level measure/check equipment	902610	Liquid flow/level measure/check equipment
902620	MON	Pressure measure/check equipment	902620	Pressure measure/check equipment
902680	MON	Equipment to measure/check gas/liquid properties	902680	Equipment to measure/check gas/liquid properties
902690	MON	Parts of fluid measure/check equipment	902690	Parts of fluid measure/check equipment
902710	MON	Gas/smoke analysis apparatus	902710	Gas/smoke analysis apparatus
902720	MON	Chromatographs, electrophoresis instruments	902720	Chromatographs, electrophoresis instruments
902730	MON	Spectrometers, spectrophotometers	902730	Spectrometers, spectrophotometers
902750	MON	Instruments using optical radiations	902750	Instruments using optical radiations
902780	MON	Physical/chemical analysis equipment	902780	Physical/chemical analysis equipment
902790	MON	Microtomes, scientific analysis equip parts	902790	Microtomes, scientific analysis equip parts
902810	MON	Gas supply/calibration meters	902810	Gas supply/calibration meters
902820	MON	Liquid supply/calibration meters	902820	Liquid supply/calibration meters
902830	HEM	Electricity supply, calibration meters	902830	Electricity supply, calibration meters
902890	HEM	Parts/accessories for gas, liquid, electricity meter	902890	Parts/accessories for gas, liquid, electricity meter
903010	MON	Ionising radiation measure/detect instruments	903010	Ionising radiation measure/detect instruments
903020	MON	Cathode-ray oscilloscopes/graphs	903020	Cathode-ray oscilloscopes/graphs
903031	MON	Electrical multimeters	903031	Electrical multimeters
903032	MON	Multimeters; for measuring or checking voltage, current, resistance or power, with a recording device	903081	Parts for electric motors & generators
903039	MON	Instruments and apparatus; for measuring or checking voltage, current, resistance or power, with a recording device (excluding multimeters)	903081	Parts for electric motors & generators

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903084	MON	Instruments and apparatus; n.e.c	903039	Voltmeters, non-recording
903033	MON	Instruments and apparatus; for measuring or checking voltage, current, resistance or power, without a recording device (excluding multimeters)	903039	Voltmeters, non-recording
903089	MON	Electrical measurement instruments	903089	Electrical measurement instruments
903090	MON	Parts/access, electr measuring instruments	903090	Parts/access, electr measuring instruments
903110	NVA	Machines for balancing mechanical parts	903110	Machines for balancing mechanical parts
903120	MON	Test benches for measuring equipment	903120	Test benches for measuring equipment
903149	MON	Optical instruments and appliances; for measuring or checking, n.e.c	903140	Other optical instruments and appliances
903180	MON	Measuring equipment, nes	903180	Measuring equipment, nes
903190	MON	Parts/access for measuring equipment	903190	Parts/access for measuring equipment
903210	MON	Thermostats	903210	Thermostats
903220	MON	Manostats	903220	Manostats
903281	MON	Hydraulic/pneumatic automatic controls	903281	Hydraulic/pneumatic automatic controls
903289	REP	Automatic controlling equipment nes	903289	Automatic controlling equipment nes
903290	MON	Parts/accessories for automatic controls	903290	Parts/accessories for automatic controls
903300	MON	Parts/accessories for optical/electric instrument	903300	Parts/accessories for optical/electric instrument
940510	HEM	Chandeliers, ceiling/wall lights	940510	Chandeliers, ceiling/wall lights
940520	HEM	Electric table, bedside & floor lamps	940520	Electric table, bedside & floor lamps
940540	HEM	Electric lamps, fittings, nes	940540	Electric lamps, fittings, nes
950720	NRP	Fish-hooks	950720	Fish-hooks
Total no. of products			Total no. of products	
248			244	

Annex 2

Combined List of Environmental Goods (CLEG) grouped according to their respective HS4 Code		
	HS4 Product Code Name	HS4 Product Code
1.	Activated carbon	3802
2.	Amino-resins	3909
3.	Other plates of plastics, noncellular and not reinforced	3920
4.	Other plastic plates, sheets etc.	3921
5.	Plastic builders' ware	3925
6.	Synthetic rubber	4002
7.	Wood carpentry for construction	4418
8.	Agglomerated cork	4504
9.	Textile bast fibers	5303
10.	Vegetable textile fibers	5305
11.	Artificial monofilament >67dtex t<1mm, strip, straws t<5mm	5405
12.	Nonwoven textiles	5603

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13.	Twine and ropes of baste fibers	5607
14.	Nets	5608
15.	Bags for packing goods	6305
16.	Mineral wools and insulating materials	6806
17.	Panels of vegetable fibers	6808
18.	Articles of cement, of concrete or of artificial stone	6810
19.	Ceramic sinks, washbasins, and similar sanitary fixtures	6910
20.	Multiple-walled insulating glass	7008
21.	Glass mirrors	7009
22.	Glass fibers	7019
23.	Railway construction material of iron or steel	7302
24.	Tubes of cast iron	7303
25.	Tubes, seamless, of iron or steel	7304
26.	Other tubes, pipes and hollow profiles of iron or steel	7306
27.	Structures and their parts, of iron or steel	7308
28.	Tanks etc. > 300 liters, iron or steel	7309
29.	Tanks etc. < 300 liters, iron or steel	7310
30.	Stoves and similar non-electric appliances of iron or steel	7321
31.	Sanitary ware and parts of iron or steel	7324
32.	Other cast articles of iron or steel	7325
33.	Other articles of iron or steel	7326
34.	Aluminum structures (bridges, towers etc)	7610
35.	Aluminum containers, >300 liters	7611
36.	Aluminum containers, <300 liters	7612
37.	Ornaments, statuettes, etc. of metal	8306
38.	Steam boilers	8402
39.	Auxiliary parts for use with boilers	8404
40.	Water gas generators	8405
41.	Steam turbines	8406
42.	Parts suitable for use with spark-ignition engines	8409
43.	Hydraulic turbines, water wheels and regulators	8410
44.	Gas turbines	8411
45.	Other engines and motors	8412
46.	Pumps for liquids	8413
47.	Pumps, compressors, fans, etc.	8414
48.	Air conditioners	8415
49.	Industrial furnaces	8417
50.	Refrigerators, freezers	8418
51.	Equipment for temperature change of materials	8419
52.	Centrifuges	8421
53.	Dish washing machines	8422
54.	Other lifting machinery	8428
55.	Self-propelled bulldozers, excavators and road rollers	8429
56.	Machine tools for molding and forging metals	8462
57.	Machine tools for working wood	8465
58.	Parts and accessories for metal working machines	8466

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59.	Machinery for working minerals	8474
60.	Machines n.e.c.	8479
61.	Appliances for thermostatically controlled valves	8481
62.	Transmission shafts	8483
63.	Electric motors and generators	8501
64.	Electric generating sets and rotary converters	8502
65.	Parts for use with electric generators	8503
66.	Electrical transformers	8504
67.	Electromagnets	8505
68.	Primary cells and primary batteries	8506
69.	Batteries	8507
70.	Electromechanical domestic appliances	8509
71.	Industrial electric furnaces	8514
72.	Electric heaters	8516
73.	Electric signal and traffic controls	8530
74.	Electrical boards	8537
75.	Electrical filament	8539
76.	Semiconductor devices	8541
77.	Electrical machines with individual functions n.e.c.	8543
78.	Electric trains	8601
79.	Other rail locomotives	8602
80.	Self-propelled railway coaches	8603
81.	Railway service vehicles	8604
82.	Railway coaches, not self-propelled	8605
83.	Railway cars, not self-propelled	8606
84.	Parts of railway locomotives	8607
85.	Railway track fixtures	8608
86.	Buses	8702
87.	Cars	8703
88.	Bicycles	8712
89.	Parts of motorcycles or wheelchairs	8714
90.	Trailers and semi-trailers	8716
91.	Other floating structures	8907
92.	Optical fibers	9001
93.	Lenses and other optical elements	9002
94.	Binoculars and telescopes	9005
95.	Liquid crystal devices	9013
96.	Surveying instruments	9015
97.	Thermometers, hydrometers etc.	9025
98.	Instruments for measuring properties of liquids or gases	9026
99.	Instruments for physical or chemical analysis	9027
100.	Gas, liquid or electricity meters	9028
101.	Instruments for measuring electricity	9030
102.	Measuring instruments	9031
103.	Automatic regulating instruments	9032
104.	Other parts for machines and appliances	9033

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105	Lamps	9405
106	Fishing and hunting equipment	9507