Investigating the Global Renewable Energy Revolution: a Transitions Perspective

by

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Thesis presented in partial fulfilment of the requirements for the degree of Master of Philosophy in Sustainable Development in the Faculty of Economic and Management Sciences at Stellenbosch University

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December 2020

Declaration

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Abstract

Fossil fuels have helped to shape cultural, technological, environmental and economic spaces, which to date have governed human existence. Fundamental to society's development is the excessive extraction and consumption of the earth's resources, which has pushed the planet beyond its safe operating threshold. The outcome is a critical socio-ecological crisis; a perilous build-up of carbon dioxide levels (CO_2) and other greenhouse gases (GHG). The result is climate change, inequality, loss of biodiversity, food insecurity and environmental degradation. In short, humanity and the planet is faced with a poly-crisis, characterised by an era known as the Anthropocene that implicates human beings as a geological force of nature negatively impacting the planet. The status quo emerged with the first industrial revolution; a development that established fossil fuels as the primary source of energy.

While the research bounds itself to the study of CO_2 emissions, it is categorically stated that climate change is a complex process that is influenced by many factors and as such should not be viewed solely within a monolithic carbo-centric approach. The other GHGs also act as pollutants that contribute to the crises. This theoretical analysis is conducted for the purposes of understanding the elements that drive energy transitions, and their far-reaching implications. The aim of the study is to investigate if the present approach to climate action is sufficient to mitigate CO_2 emissions. This study argues that the renewable energy transition has failed to significantly lower CO_2 emissions because the focus of its policies is limited to the energy sector with a strong techno-economic emphasis instead of a broader mix of policies that also address societal issues. The first two research questions put forward are:

- *What is driving the global RE surge as it seeks to tackle the carbon lock-in?*
- *How is the RE transition reducing fossil fuel dependency and climate risks?*

The first question addresses the quality of the energy transition by analysing secondary datasets. A process of triangulation acknowledges price, policy and technology to be mostly responsible for the fast-tracked dispersions. However, the second research question finds that the set targets as well as the already installed renewables show no evidence of significant decline in CO_2 emissions. The question is addressed by analysing current environmental feedbacks alongside set global climate action targets and other renewable energy policies. It also provides an appraisal of whether or not the measures in place are sufficient to mitigate climatic risks. The third question deals with context. It addresses a relatively unknown theory, referred to as a deep transition,

which provides a theoretical framework to further analyse the energy transition by asking:

- *How is the energy transition associated to the notion of a deep transition?*

The study is predominantly a qualitative meta-analysis survey with some quantitative elements. The data used is secondary and it includes both qualitative sets in the form of policies, as well as quantitative sets such as pricing, statistics on carbon emission and capital investments for infrastructural builds and new technologies. The approach explores transition, economic, ecological, technological, social and metabolic bodies of literature. It is an epistemological survey of critical factors such as the extent (quantity), pace (quality), and context of the transition. The overall research of narrative reviews, which are they are used to analyse data.

Conceptualising and applying the deep transition lens reveals broader societal impacts that transcend energy by influencing all angles from technological to economic, metabolic and social sectors. It also reveals that in spite of demonstrable growth in renewables, the apparent lack of any significant decline in CO_2 emissions indicates that a far deeper and broader understanding of the energy transition is required to effectively ensure decarbonisation.

Four dynamic theories were employed to investigate the concept of a deep transition, namely Techno-Economic; Global Development Cycles, Socio-Technical and Socio-Metabolic. Bringing the deep transition framework into play, produced the following. There was a declining fossil fuel Energy Return On Investment, which was concurrent with a renewable energy installation within the Techno-Economic Paradigm and Multi Level Plan. Simultaneously there was an energy, communications and mobility investment frenzy. Together these four paradigms marked an energy transition immersed within the far-reaching deep transition.

The findings were a shift in the material flows from fossil fuel to renewable energy, which revealed a decline in the carbon footprint but a rise in the materials footprint. Within the Techno-Economic Paradigm there were co-evolutionary interactions between society and the new technology that is accelerating a deep decarbonisation. It was also evident from the Techno-Economic surge that renewables were in the forefront of a greener economy. It was also clear that the transition was part of a broader, smart, digital, integrating system for the information age.

Opsomming

Fossielbrandstowwe het die samelewing help vorm en die kulturele, tegnologiese, omgewings- en ekonomiese ruimtes wat tot dusver die menslike bestaan gerig het, help uitkerf. Die oormatige ontginning en verbruik van die aarde se hulpbronne wat as grondslag vir samelewingsontwikkeling dien, het die planeet verby haar veilige funksioneringsdrempel gedryf. Die uitkoms is ’n kritieke sosio-ekologiese krisis wat tot die gevaarlike opbou van koolstofdioksied- (CO_2-) vlakke en ander kweekhuisgasse (KHG) gelei het. Die resultaat is klimaatsverandering, ongelykheid, verlies aan biodiversiteit, voedselonsekerheid en omgewingsagteruitgang. Kortom, die mensdom en die planeet word gekonfronteer deur ’n poli-krisis, gekenmerk deur ’n era wat as die Antroposeen bekend staan, en wat die mens as geologiese natuurkrag met ’n negatiewe invloed op die planeet impliseer. Die huidige status quo is die resultaat van die eerste industriële revolusie; ’n ontwikkeling wat fossielbrandstowwe as die hoofbron van energie gevestig het.

Hierdie teoretiese ontleding word uitgevoer met die oog op insig in die samestellende elemente wat energie-oorgange en hul verreikende implikasies dryf. Die doel van hierdie studie is om te bepaal of die huidige benadering tot klimaataksie voldoende is om CO_2-uitlatings te verminder. Dié gemengde metode-benadering ondersoek die oorgangs-, ekonomiese, ekologiese, tegnologiese, sosiale en metaboliese korpus van literatuur. Dit is ’n epistemologiese oorsig van kritieke faktore, soos die omvang (kwantiteit), tempo (kwaliteit) en konteks van die oorgang.

Hierdie navorsing voer aan dat die oorgang na hernubare energie (HE) nie daarin kon slaag om die CO_2-uitlatings noemenswaardig te verminder nie. Dit is omdat die fokus van die energie-oorgangsbeleide beperk is tot die energiesektor, met ’n sterk tegno-ekonomiese klem, in plaas van ’n groter mengsel van beleide wat saamweef om wyer samelewingskwessies aan te roer. Die eerste twee navorsingsvrae wat aangebied word, is:

- *Wat dryf die wêreldwye oplewing in HE namate dit poog om die koolstof-inperking aan te spreek?*

- *Dra die HE-oorgang daartoe by om die afhanklikheid van fossielbrandstof en klimaatsrisiko's te verminder?*

Die eerste vraag roer die kwaliteit van die energie-oorgang deur 'n ontleding van die sekondêre datastelle aan. Deur 'n proses van triangulasie word bevestig dat prys, beleid en tegnologie grootliks vir die versnelde verspreidings verantwoordelik is. Die tweede navorsingsvraag bevind egter dat die gestelde teikens, sowel as die reeds gevestigde hernubare energie, geen bewyse van 'n noemenswaardige afname in CO_2-uitlatings toon nie. Die vraag word aangepak deur die huidige omgewingsterugvoere, tesame met die gestelde globale klimaataksie-teikens, sowel as ander beleide oor hernubare energie, te ontleed. Dit bied ook 'n taksering om te bepaal of die maatreëls wat getref is voldoende is om klimaatsrisikos te verminder, of nie. Die derde vraag handel oor konteks. Dit pak 'n relatief onbekende teorie aan wat as 'n 'diep oorgang' bekend staan, en bied 'n teoretiese raamwerk vir die verdere ontleding van die energie-oorgang deur te vra:

- *Kan die energie-oorgang beter verstaan word as deel van 'n diep oorgang?*

Deur die konseptualisering en toepassing van 'n 'diepoorgang' -lens word breër samelewingsinvloede onthul en die grense van energie oorskry deurdat alle sektore, ingesluit die tegnologiese, ekonomiese, metaboliese en sosiale sektore, beïnvloed word. Dit word ook duidelik dat, ten spyte van die bewese groei in hernubare energie, die skynbare gebrek aan enige noemenswaardige afname in CO_2-uitlatings, 'n veel dieper en wyer insig in die energie-oorgang verlang, ten einde effektiewe dekarbonisasie (ontkoling) te verseker.

Acknowledgements

Nothing beats the joy of fulfilment. Nothing!

Two years ago, I did not think this was even possible. Who knew a deep transition was even a ‘thing’, and that the sum total of many small shifts could logically be analysed and understood in profoundly useful ways that shape the world. My forebears would have called it witchcraft. My name is Andy Muranda and I am 44 years old. Having been on this journey for the last two years, I consider myself blessed. The experiences that I have picked up along the way cannot be reduced into mere words. So if I could stare into a blank page and transfer the fullness of my heart, so that all who come into contact with it could feel the intensity, the warmth and vulnerability of this moment, I would. But that would be sortilege.

Each leg of this MPhil journey has re-energised me. Many have sacrificed and propped me up so that I could find ways to demystify the ‘sorcery’. I am sure that it took superhuman feats of strength. I would like to take a moment to acknowledge my heroes listed below alongside their superpowers:

My wife, best friend and biggest supporter, Shingi, a true benefactor giving emotionally, financially and being the lady with the big whip whenever I missed meals or family time. To Ariana, who has paid the ultimate sacrifice of time when I couldn’t make time to play. Salute!

To my father, Richard, it is because of you that I embarked on this journey so many years ago and sadly you never had the opportunity to witness any of my milestones. Each step and with each victory, I live in memory. Thank you! To my mother and grandmother, Mildred and Johanna, who have gone past the stage of shock whenever I announce a new hare-brained scheme. You have both been constant pillars of support in every way.

Then there is faculty. To Professor Mark Swilling, you took a chance and you have my gratitude. A big thank you to Megan, Jess, Michelle, Professor

Musango, Monique and Beatrix for your support. Big heartfelt thanks to Berni and Mark Crewe-Brown. And to my friend Professor Mike Anderson, you unplugged the blockage and got this study flowing again.

I dedicate this study to everybody; may each of you create a just world. And to God, who makes all of the above possible – Thank you! I still have many questions, but as far as this study is concerned I am fulfilled.

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ABinBev	Anheuser-Busch InBev SA/NV
AD	Anno Domini / The year of our Lord
BNEF	Bloomberg New Energy Finance
CE	Common Era
CB	Carbon Budget
CDM	Clean Development Mechanism
CER	Certified Emission Reduction
CO_2	Carbon Dioxide
COP	Conference of the Parties
DE	Domestic Extraction
EROI	Energy Return on Energy Investment
EU	European Union
EV	Electric Vehicles
FCV	Fuel Cell Vehicle
G20	Group of Twenty
GHG	Greenhouse Gas
GMST	Global Mean Surface Temperature
GW	Gigawatt
ICT	Information and Communications Technology
IEA	International Energy Agency
IKEA	Ingvar Kamprad Elmtaryd Agunnaryd*
IMF	International Monetary Fund
INDC	Independent Nationally Determined Contribution
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
KW	Kilowatt
LCOE	Levelised Cost of Electricity
MDB	Multilateral Development Banks
MDG	Millennium Development Goals
MLP	Multi-Level Perspective

MWh	Megawatt-hour
NDC	Nationally Determined Contributions
NGO	Non-Governmental Organisation
PPM	Parts Per Million
PV	Photo Voltaic
R&D	Research and Development
RE100	100% Renewable Energy
REN21	Renewable Energy Policy Network for the 21st Century
RET	Renewable Energy Transitions
SDG	Sustainable Development Goals
TEP	Techno-economic Paradigm
TW	Terawatt
TWh	Terawatt-hour
UN	United Nations
UNCTAD	United Nations Conference on Trade and Development
UNFCCC	United Nations Framework Convention on Climate Change
US	United States (of America)
VRE	Variable Renewable Energy
WMO	World Metrological Organisation

Chapter 1: Introduction

1.1 Introduction

In this chapter I provide an overview of my research interest and locate the topic in the existing body of literature. The literature review and discussion bring energy transitions into focus and outline the background to the evolution of industrial modernity. It is followed by a brief exploration of the fossil fuel lock-in. The chapter also investigates the social influences of fossil fuels and how energy has shaped all aspects of society, both culturally and infrastructurally. It highlights a convoluted pervasiveness of the function and impact of fossil fuels which creates an almost inextricable social mesh. This helps identify fossil fuels beyond their narrow terms of reference. I investigate global warming science and the role that fossil fuels have played in increasing unprecedented levels of carbon emissions. The questions that help steer my research are outlined in the chapter. The parameters of my research are defined, followed by a brief framework of the research design and methodology used to answer the research questions.

1.2 Making Sense of Energy Transitions

The topic of this study is energy transitions. It examines the evolution of energy over time with particular focus on the disruptive nature of renewables vis-a-vis an entrenched fossil fuels regime. Energy transitions have been taking place for many years, often unfolding over decades due to systematic development and appropriation depending on need, price, function and usefulness (Yergin, 2013). Despite their long history, energy transitions only came into explicit focus in the 1970s as concerns around the environment, energy security and price began to mount (Yergin, 2013). Höök, Li, Johansson and Snowden (2012:23) define energy as

> *"the ability within a physical artefact or body, to perform a task or work, the task in question can be either applicable or immaterial to society".*

Energy is a quantitative store of potential, which when activated or unleashed, is transferred to an object in some form or another. Energy types can vary and include light, heat, electrical, chemical, motion, gravitational, nuclear, among other examples (EIA, 2019). The first law of thermodynamics states that energy can neither be created nor destroyed; however, it can be transformed into a variety of forms (Brittanica, 2019).

Energy is either renewable or non-renewable. Renewable examples include solar, geothermal, wind, biomass and hydropower (EIA, 2019). Non-renewable forms of energy are hydrocarbon gas liquids, coal, natural gas, nuclear energy and petroleum products (EIA, 2019). According to Miller and Spoolman (2007) even though fossil fuels can technically be replenished, meaning they are 'renewable', it is the rate of replenishment that presents a challenge. If a resource cannot be restored as quickly or quicker than it is being consumed, it becomes non-renewable (Miller & Spoolman, 2007). Fossil fuels require millions of years to restore from dead matter such as biomass and other organisms. This, in addition to environmental matters, warrants a re-evaluation of their role in society.

A transition, according to Lexico (2019) is *"the process or a period of changing from one state or condition to another"*. On this account, an "energy transition" can be described as the reconfiguration or transformation of an energy system or systems, gradually occurring over an extended period of time. According to Smil (2013) energy transitions ultimately alter the sources used to produce power, motion, heat, and light.

An energy transition is a substantial transformation of an energy system, rather than just a transformation in individual technologies or singular fuel sources. The changes depicted in sections 1.3.2 - 1.3.5 of this study would therefore qualify as individual shifts in fuel sources or technologies. However, when taken as a whole they become a system and collectively represent a systemic shift. Energy systems are complex structures predominantly designed to meet the energy needs of society. According to the Fifth Assessment Report (AR5), an energy system is *"all components related to the production, conversion, delivery, and use of energy"* (IPCC, 2014:1261).

In the history of transitions, energy and technology go hand in hand. The successful adoption of 'new' energies has primarily depended on the advent of new technologies. Smil (2013:10) refers to new technologies as *"dominant prime movers".* The new technologies not only serve as efficient converters of energy, but they are often the first clue to a pending energy shift. The energy transitions of the past, present, as well as those of the future, are the work of inventors working towards meeting a need or solving a problem. The problems solved have not always necessarily been energy related; however, the new technologies require new energy efficiencies. In some cases, energy inspires new technologies. Cheap electricity paved the way for domestic refrigerators, fans, toasters, electric shavers and other appliances. Invariably, successful technologies trigger supplementary inventions that improve efficiencies, for example in 1712 Thomas Newcomen invented the first mechanical steam engine (WEF, 2013) and James Watt improved it in the 1770s (Edquist & Henrekson, 2006; Wisniak, 2018). Although it finally took shape in the eighteenth century, the steam engine had its roots in the vaned wheel and rim device, invented by Heron in the first-century B.C, the first experiments in using steam for power (Keyser, 1992).

Energy transitions take a long time to materialise as they gradually go through the process of changing the sources of heat, light and motion. The protracted proceedings often take several decades to unfold, primarily due to the scale and complexities involved. Smil (2013) contends that only small countries fortunate enough to have the essential resources at hand can transition quickly. Examples include Uruguay, which took ten years to scale up to 95% of renewable energy (Watts, 2015), and the Netherlands which needed twelve years to shift to 50% of natural gas (Loo, 2018). More significant economies such as the United States are faced with challenges due to the complexities involved. It took them 25 years to increase oil from a 5% share to 25%, and for gas, 33 years (Smil, 2013). The global figures do not fare any better, requiring 40 years for oil to reach 25% and 55 years for natural gas (Smil, 2013). This presents a challenge to emerging renewable energy regimes since the element of time is critical for the global climate[1] agenda to be achieved; a prolonged transition spells disaster. While a fossil future is highly undesirable, the transition from a carbonised society to one based on renewables may be prolonged, further entrenching the role of Carbon (CO_2) emissions on a highly fragile planet.

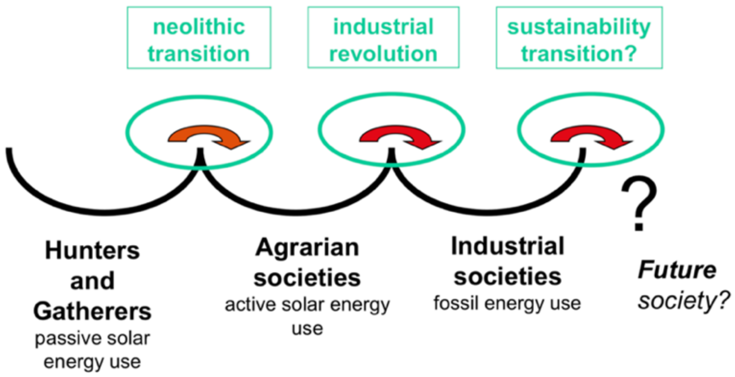
1.3 Identifying Past Transitions and Energy Regimes

To understand the transitions that led to earlier periods of development, which in turn enabled the emergence of industrial modernity, it is essential to establish the different epochs and how they ‘set in' different energy regimes. According to Fischer-Kowalski

[1] The discourse leans towards an undifferentiated cause for climate change – high carbon emissions (Geels *et al.*, 2017a; Gielen *et al.*, 2019). This has led to CO_2 becoming the climate change poster child. However, causes for climate change are varied beyond CO_2, including Nitrous Oxide, Water Vapour and Methane (NASA, 2019a). To an extent the dynamics for climate change are contested.

et al. (2014), humans play a crucial role in defining these periods on account of their development and aspirations to improve their quality of life (Fischer-Kowalski *et al*., 2014). In considering a new geological era, Fischer-Kowalski *et al.* (2015) put forward three possible periods that mark the genesis of change *(Figure 1.1),* namely the Neolithic Transition, the Industrial Revolution and the Great Acceleration. The Neolithic period encompasses a time when humans were solely dependent on solar energy. At first, they merely consumed it in a passive state with its effects being incidental. However, with time as they developed ways of exploiting it as a resource, they became more active in its application. The Neolithic Transition was followed by the Industrial Revolution that propelled society into an age of development sustained by fossil fuels. The succeeding period of change came to be known as the Great Acceleration, a period of continuity from the industrial era that took place in the mid-20th century (Rockström, Steffen, Noone, Persson, Chapin, Lambin, Lenton, Scheffer, Folke, Schellnhuber, Nykvist, de Wit, Hughes, van der Leeuw, Rodhe, Sörlin, Snyder, Costanza, Svedin, Falkenmark, Karlberg, Corell, Fabry, Hansen, Walker, Liverman, Richardson, Crutzen & Foley, 2009). Transitions tend to initiate new and unprecedented heights of human achievement. Each occurs as the result of rapid energy spikes, which are connected to new technologies, spurring growth and a flourishing society. It will be illustrated throughout this study that each stable society generally enjoys the benefits of the dominant energy regime. Agrarian societies had active solar and biomass, and the transition to the industrial era brought with it fossil fuels. The Great Acceleration as a continuity, reinforced the industrial era, further entrenching the domination of fossil fuels. This was achieved through cheaper electricity as already mentioned, which introduced appliances into the home and office (WEF, 2013), and this had the effect of spiking energy demand (Rühl, 2013). This period became synonymous with further development and meteoric growth, achieving unprecedented proportions of consumption which required 'boundless' resources including an 'endless' supply of fossil fuels; the unequivocal hallmark of living in a highly industrialised society. The Great Acceleration *(Figure 1.3)* is briefly explored later in this chapter. It is at the very heart of an insidiously self-destructive path carved out by humans; a path which escalates the rate of GHG emissions.

Figure 1.1: Socio-metabolic regimes



Source: Fischer-Kowalski (2017) adapted from Sieferle *et al.* (2006)

By highlighting these socio-metabolic paradigms, Fischer-Kowalski *et al.* (2015) help to illustrate the enormous impact of human development on the planet. Understanding the big epochal picture helps to put the many technological shifts that governed the major energy transitions in context. Over time, technology and energy are at the heart of a social system that is always in flux (Fischer-Kowalski, 2017).

1.3.1 A history of energies and their technologies

Shifts in energy often coincide with new technologies. The context for energy research is based on present or future constraints which include social, environmental and economic impacts associated with energy sources (Fouquet, 2010). Energy efficiency was a significant driver for the transitions described in this section (Ayres, 2002). According to Fouquet (2010) the United Kingdom (UK) was the first economy to transition to fossil fuels; its history thus offers a clear narrative of this significant transition. The UK can be viewed as a microcosm for the global shifts to new energies. New technologies required energy and novel ways were found to harness it for use in transportation, power, light and heating.

The taxonomic summary in *Table 1.1* helps to sketch some of the significant energy-related transformation periods which are further discussed below. The periods cover technological innovations which mostly take place between the Neolithic era and the industrial epoch. *Table 1.1* also highlights individual energy shifts based on technological advancements, which are not necessarily energy system transitions, but collectively form the constituting elements which in time introduced a new epoch.

Table 1.1: Summary of energy transitions

Substitution (original–new)	Service	Nature of changes	Probable key factors in diffusion	Approx. period (invention to dominance)	Approx. period (diffusion to dominance)
Residential woodfuel–coal	Heating	Supply; Energy; Service	D: Price of energy; C: Invention	1500–1800 (300 years)	1580–1800 (220 years)
Iron woodfuel–coal	Heating	Supply; Energy; Service	D: Price of energy; C: Invention; C: Efficiency	1709–1790 (81 years)	1750–1790 (40 years)
Manufacturing woodfuel–coal	Heating	Supply; Energy; Service	D: Price of energy; C: Inventions	1300–1700 (400 years)	1550–1700 (150 years)
Residential coal–gas	Heating	Supply; Energy; Service	D: Better service; C: Price of energy	1880–1975 (95 years)	1920–1975 (55 years)
Ox–horse	Power	Energy	D: Efficiency	900–1600 (700 years)	1070–1600 (530 years)
Animals–mills	Power	Supply; Energy; Service	D: Different service; C: Econ. of scale	700–1350[a] (650 years)	1000–1350[a] (350 years)
Animals–steam	Power	Supply; Energy; Service	D: Different service; C: Efficiency	1710–1920 (210 years)	1830–1920 (90 years)
Steam–electricity	Power	Supply; Energy; Service	D: Better and different service; C: Econ. of scale	1821–1950 (139 years)	1920–1950 (30 years)
Horses–railways	Land transport	Supply; Energy; Service	D: Better service; C: Price of service	1804–1860 (54 years)	1830–1860 (30 years)
Sail–steam ship	Sea transport	Supply; Energy; Service	D: Better and different service; C: Efficiency	1815–1890 (75 years)	1830–1890 (60 years)
Railways–combustion engine	Land transport	Supply; Energy; Service	D: Better and different service; C: Efficiency	1876–1950 (74 years)	1911–1950 (39 years)
Candles–gas	Lighting	Supply; Energy; Service	D: Better service; C: Price of energy; C: Efficiency	1800–1850 (50 years)	1810–1850 (40 Years)
Candles–kerosene	Lighting	Supply; Energy	D: Price of energy; C: Discovery	1850–1900[a] (50 years)	1860–1900[a] (40 Years)
Gas–electricity	Lighting	Supply; Energy; Service	D: Better service; C: Price of energy; C: Efficiency	1810–1935 (125 years)	1880–1935 (65 years)

D: Main driver for adoption; C: main catalyst for adoption (especially if there was relatively long delay between invention and adoption).

[a] Its peak share, as it did not become the dominant source of energy.

Source: Fouquet (2008)

1.3.2 Energy transitions in heating

During ancient times one of the more significant transitions was borne out of the need for thermal comfort. Heating was a critical human need which enabled humans to move into the colder regions of the world with the means to survive the cold, harsh winters of the global north. In both the Palaeolithic and Neolithic times, heating also played the crucial role of doubling up as a security feature, providing protection from predatory animals. Considered a critical energy source, wood was an essential fuel used for heating. In time, as ancient technologies and know-how improved, there was a shift from wood to coal. This domestic transition to coal took more than 200 years, driven by the slow development of technologies for processing toxic by-products (Fouquet, 2008; Fouquet & Pearson, 2006; King, 2016). The industrial transition was an even slower affair due to the impurities generated by coal that affected manufactured products. In 1709, Abraham Darby introduced a cleaner form of coal known as coke, and by 1790 its industrial use had escalated (King, 2016). Gas was introduced in the 1880s (Fouquet, 2008; King, 2016), and the discovery of natural gas in the 1970s led to a drop in gas price and the domestic use of gas took off (Fouquet, 2008). Other secondary applications derived from heating, such as illumination, were the likely impetus for innovation which led to new lighting technologies.

1.3.3 Energy transitions in light

A process of transition ultimately led to illuminating technologies. Candles were the primary source of light for many centuries, although very little is known about their origins. In the earliest known written account, Thorold Rogers records the cost of candles and the raw materials needed to make them; his notes document prices that go as far back as 1266 (Rogers, 1866). This means candles were already in existence by the late 1200s. However, until the mid-eighteenth century, due to the high cost of candles, the majority of the population was completely dependent on natural light (Fouquet, 2008; Fouquet & Pearson, 2006). Natural light is a product of the sun and therefore represents a passive use of solar for lighting purposes. Gas only took dominance over candles in the early 1800s to about the 1850s; while gas was cheaper, the installation costs of the piping made it inaccessible for most (Dahl & Matson, 1998; Fouquet, 2008, 2010; Spath & Dayton, 2003). Paraffin became popular from the late 1800s because it was cheaper as were the lamps; however, at its peak paraffin never amassed more than 20% of the market share (Fouquet, 2010).

Humphrey Davy introduced the world to the electric arc in 1810, but the gradual replacement of gas by electricity only started in 1880 (Fouquet, 2010). Although incandescent light bulbs made electricity more popular, it was only in the 1950s that electricity became cheaper than gas. From then onwards it gained popularity and market share (Connor, 2010).

The drop in the electricity price corresponds with the advent of the Great Acceleration. Cheap electricity drove demand for energy, as more electrical products entered the market and this in turn spiked energy consumption *(Figure 1.3)*. The transition to electricity from gas took approximately 70 years to unfold (Fouquet, 2010). As humans continued to progress and prosper, it was no longer sufficient to passively enjoy the outputs of uncontrolled energies. The determined drive to 'develop' ushered in the need to harness the power released by energy, to unlock its latent functions and to manipulate them into new possibilities for then and the future.

1.3.4 Energy transitions in power

According to Smil (2004) the epochal energy transitions in power affected everything including agriculture, transportation, weapons, urbanisation, industry, communication, politics, quality of life, economics and the environment. The transitions changed life and elevated society to a ‘higher’ state of being. Before the advent of better and more efficient forms of energy, human beings relied on the conversion of their calorific reserves to grind grain, to collect water and for other domestic uses. This dependence on human calorific energy was found to be inefficient, which led to the ‘honour’ later being conferred from human beings to animals (Smil, 1994, 2004). Animals are stronger and have much more stamina which made them a more reliable energy source. During the 1600s, as animal husbandry improved, they became the primary source of power generation; at first, humans relied on the ox, and soon learnt how to manage the horse (Langdon, 2002). Animals remained a significant source of power until the second part of the nineteenth century when wind technologies finally displaced them.

At first, the wind was used by humans alongside animals, but eventually gained dominance as it offered a more concentrated and prodigious output of power (Langdon, 2002). Wind-powered mills featured where geographical conditions permitted and where there was a market for the technology. The mills also provided cheap power (Fouquet, 2010). However, in the late 1700s, wind technology started making way for the almighty steam engine (Fouquet, 2008).

The next form of power to take dominance in the twentieth century was electricity. According to Fouquet (2010) experimentation with electricity began more than a hundred years before Michael Faraday developed the electric motor in 1821. The price of electricity dropped between the 1880s and 1930s, making it a competitive alternative to the steam engine for industrial use (Fouquet, 2010). By 1950 the steam engine became obsolete, but despite the decline of the steam engine demand for coal continued to soar as a dominant source of power, due to its use in electricity generation. By the 1980s natural gas and nuclear power began to disrupt the dominance of coal (Fouquet, 2010). Nuclear power made it possible to forge, expedite, effectuate, develop, grow an economy, make time, provide services and assemble products. Supply created a market and markets developed an appetite. As demand grew and requests for goods and services came from further and further away, innovation enabled affordable mobility.

1.3.5 Energy transitions in transport

Transitions in power and transport followed a very *“similar path, -oxen, horses, wind and steam”* (Fouquet, 2010:9). The earliest alternative to horses and sailing came about after Richard Trevithick manufactured the first steam locomotive in 1804 (Fouquet, 2010). The railways were only rivalled by water networks and canals, despite their geographical limitations. After dominating the seas for centuries, the sail was replaced by coal-fired engines as the result of an improvement in the efficiency of coal in the latter part of the nineteenth century (Dyos & Aldcroft, 1969). On land Nikolaus Otto patented the four-stroke engine in 1876 (Mohammed & Suleiman, 2017) which revolutionised future road transportation. Thirty-five years later the model-T Ford was produced (Taub, Krajewski, Luo & Owens, 2007), but it took another forty years before cars, trucks and buses managed to displace trains as the leading form of transport for freight and passenger transfer (Tomes, 2008). This shift led to oil becoming the prime source of energy for all modes of transport including air, road and sea travel (Fouquet, 2008; Geels, 2005; Gilbert & Pearl, 2012). Over a period of 200-250 years, the shifts snowballed into a new energy regime. The economy became highly carbonised; a development that came with industrialisation.

Table 1.1 illustrates how gradual the transition from historical forms of energy to fossil fuels really was. This was a convoluted process that involved many adaptations across different sectors at different times. The transition to fossil fuels realistically happened between 1500 and 1920 (Fouquet, 2008). The historical analysis of energy transitions illustrates what appears to be a linear chain of events and technological strides that spanned a considerable period. At face value, these events give the impression of being ‘just technological' marvels of development, which have revolutionised human livelihoods and wellbeing. Over time however, they were disruptive technologies which ultimately ushered in a new energy epoch (Smil, 2013). Though gradual, each step of the transition process for heat (1.3.2), light (1.3.3), power (1.3.4) and transport (1.3.5) was incremental in the entrenchment of a convoluted fossil fuels clutch. Oil and coal introduced broader systemic challenges that were unknown at the time and society became vulnerable to CO_2 emissions.

1.3.6 An industrial transition triggered

The technological shifts of the previous section highlight the history of energy transformations, which resulted in mechanisation. The early transitions that led up to the first industrial revolution reduced labour requirements for food production and improved food security (Fischer-Kowalski, 2017). Prior to the industrial revolution, human labour to food production ratios were high, with 90% of the human population working long hours to yield sufficient food for everyone (Fischer-Kowalski, 2017). The technological changes which helped to improve human lives were inevitable. The vastly refined steam engine prototype in the late 1700s ushered in the industrial revolution (Wisniak, 2018) and a new era in modernity (Kanger & Schot, 2019).

A new age of development supported by a philosophy of 'easy growth at all costs' started soon after the first industrial revolution. It is clear that the industrial revolution was the trigger (Fischer-Kowalski *et al.*, 2014; Perez, 2009; Schot & Kanger, 2018). The technological changes initiated by the industrial revolution created a plethora of societal problems triggered by mass production, global distribution channels and excessive consumption patterns (Institute for Redefinition, 2018; Schot, 2017; Van Der Vleuten, 2018). The history of the concept of the free market is said to have found prevalence during 18^{th} and 19^{th} century Britain (Shiue & Keller, 2007). The term is derived from the French who referred to it as *"Laissez-faire"* which means *"hands off"* – a reference to state interference in the economy (Peck, 2008). The industrial revolution was a major boost to its ideology. It set the stage for the free market economic paradigm to flourish. Alongside the benefits it brought, it also had a profound effect on social issues. Schot (2017) highlights some of the social impacts of the industrial era that have become evident over time. He declares that *"the unfolding of industrial progress has led to high levels of wealth and welfare in the Western world but also to increasing global ecological degradation and widespread social inequality"* (Schot, 2017). Put simply, the world operating within the fossil energy regime is wholly unsustainable. Understanding the circumstances that served as the forerunner to the redefinition of humanity and its geological impact is key to recognising the errors that have been made and is also critical to finding solutions.

1.4 The Fossil Lock-in

1.4.1 The twin fossils – coal and oil

For the last 250 years, the predominant source of fuel has transitioned from *"biomass to coal to oil"* (WEF, 2013:5). According to the WEF report, in each instance, the new fuel was superior, cheaper and faster and more often than not better suited to the purpose. The new technologies also introduced new uses to fuel in ways that transformed the energy system, as per WEF (2013:5):

> *…coal brought industrialisation and facilitated transportation and oil brought a vast increase in mobility... Electrification provided a new and incredibly useful way to deliver and use energy…price was critical in driving shifts and spurring energy demand.*

The industrial era created the conditions that entrenched the lock-in of both coal and oil as the two primary hydrocarbons that dominate the fossil fuel era (WEF, 2013). It is not clear when coal was first discovered although there is evidence of its early use in Bronze Age China, long before the industrial revolution (Dodson, Li, Sun, Atahan, Zhou, Liu, Zhao, Hu & Yang, 2014). Coal came to global prominence because of its role in the industrial revolution. Human survival depended on the use of basic tools. As levels of sophistication advanced, basic tools gave way to essential forms of mechanisation which required energy to power production lines. The realisation of the full potential of coal as a source of energy greased the path to mass mechanisation, minimising any friction that would impede growth, and early developments introduced humans to the seemingly infinite possibilities of a planet powered by fossil fuels.

To fully grasp the far-reaching impacts of coal and oil, it is useful to also understand how fossil fuels shaped humanity. Coal served another rather unconventional role in society; it helped spread social democracy by way of the unskilled workforce (Mitchell, 2011). This critical source of energy amplified the voice of the coal worker. The large number of labourers strategically located at key points in the coal value chain enabled mineworkers to exercise collective bargaining by downing tools, stopping supplies and crippling the economy. In *Carbon Democracy,* Mitchell (2011) claims that the vulnerabilities in the coal sector created conducive conditions for democracy to advance in some countries while others lagged behind.

Unbeknown to its early beneficiaries, the accelerated use of coal marked the beginning of the planet's ecological problems which presently threaten the natural environment. Fossil-fired electricity generation is among the highest emitters of carbon dioxide (CO_2) which exacerbates the planet's climate change problem (IPCC, 2018a).

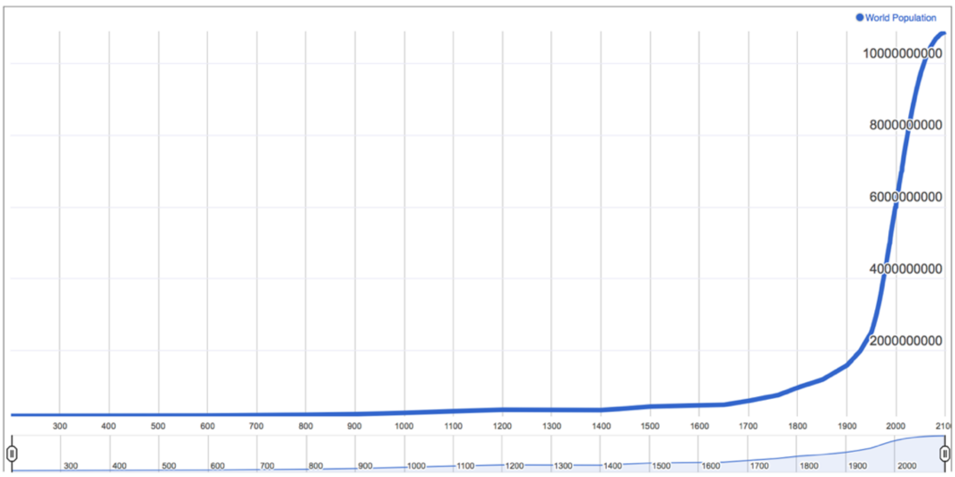
While coal played a crucial role in igniting development, it was only in the early 1900s that society established oil as a significant catalyst for growth (Mitchell, 2011; WEF, 2013). Believed to have been discovered by the Chinese (Li & Du, 2004), the 19th and 20th centuries became awash with oil, shaping them in vastly unprecedented ways. The introduction of the Model-T Ford automobile enabled oil to scale-up. Until that point oil only had a 1.5% share of the global market, compared to wood at 51% and coal at 47% (WEF, 2013). Before the automobile, the main by-product of oil was kerosene which struggled to find a market; however, oil soon became more valuable as it found use in factory boilers, ships and trains (WEF, 2013). Oil had many advantages over coal, such as flexibility, speed, and being less labour intensive in its extraction and transportation (WEF, 2013) again distorting the political economy (Mitchell, 2011). Oil spearheaded the transformation of the 19th century, shifting dynamics in politics, society and global economics (Mitchell, 2011). The petrochemical industry has, in one way or the other, impacted every aspect of life. Oil is at the very heart of the modern world; it is the dominant fuel that has led to highly financialised and globalised socio-economic systems that govern the world (Swilling, 2019a). In the last 250 years of energy transition from *"biomass to coal to oil"* (WEF, 2013:5) humans have developed an appetite for resources, which grew exponentially as more ways were found to colonise and plunder other vital assets of the planet. This behaviour has presented both challenges and benefits.

1.4.2 Energy fuelled population growth

Fossil fuels have not only affected social institutions, culture and political identities, but also impacted on population growth. At the dawn of the agrarian era around 8000 B.C.E (B.C.), the world population consisted of about 5 million inhabitants. From that time to about 1 C.E. (A.D) it grew to approximately 200 million people (Worldometer, 2019). Around the 1800s, an enormous transformation resulted in a sudden spike in the population growth rate. The human population grew from 1 billion to the current level of about 7.7 billion people within a period of two hundred years (Szeman in Garrigou, 2016; Worldometer, 2019). Prior to the industrial revolution, it had taken all of human history for the human population to reach 1 billion *(Figure 1.2)*. Something shifted; there was a transformation, and it catalysed human life. The transformation materialised with the first industrial revolution and was related to energy. In the two hundred years since humans discovered the means to harvest and exploit energy effectively, the world population grew exponentially because energy enabled higher food harvests thus improving the state of food security, and humans were able to stay warmer in the winter, owing to heating and the ability to build better structures. Energy even facilitated better healthcare and improved the general well-being of humans by alleviating the stresses associated with survival. The result of living healthier lives and having an improved state of wellness profoundly reduced human mortality. Energy not only curbed human suffering but also became an enabler of human procreation as life became easier and sustenance was 'guaranteed'. Given the social transformation that emerged after the first industrial revolution, it is undeniable that

> *fossil fuels have made possible the greatest era of social, technological, and economic growth this earth has ever seen (After Oil, 2016:14).*

Figure 1.2: World population: past, present and future



Source: *Worldometer (2019)*

1.4.3 Energy altered and shaped cultures

While fossil fuels are a propellant and a source of heat and power, they should not be misunderstood as neutral combustibles. Their role in the economy is evident. A total of 74% of the global electricity needs are met by fossil fuels, with only 26% being generated from renewable sources (REN21, 2019a). They are visibly harmful;

industrial activity and the production of electricity account for about 65% of all CO_2 emissions that are related to energy (IEA & IRENA, 2017). The remaining 35% of emissions is the result of buildings, heating and transport (IEA & IRENA, 2017). However, fossil fuels have also shaped human cultural value systems, conventions and even what it means to be human (Szeman in Garrigou, 2016). In 'After Oil', a short publication about 'petro-cultures', Imre Szeman (2016:29) states:

> *Oil is not only something you put in your car. It is the foundation of our political identity and institutions, and it profoundly shapes our society and environment.*

The nature of fossil fuels is such that very little escapes their impact. Much of what society has been able to accomplish is due to the availability of fossil fuels and how they have energised the world. This suggests that fossil fuels are not merely a neutral product that serves the needs of society, but that they have reconstituted modern life in unprecedented ways. Szeman in Garrigou (2016:17) succinctly expresses this point:

> *Oil composes space and shapes culture. It modulates our lives, including the clothing we wear, the objects we use, the buildings we occupy, the spaces we move through, the daily routines that structure everyday existence, our habits and perceptions, our commitments and beliefs.*

Fossil fuels have led to 'petro-cultures' and high CO_2 emissions. A parallel case and a microcosm of the 'petro-cultures' crisis, is what could be called the 'wood-cultures' of Easter Island which illustrates the negative consequences likely to befall humanity should 'petro-cultures' persist. The forests of Easter Island were denuded to make scaffolding for the carving of giant stone statues that served as clan status symbols (similar to big cars and other materialistic artefacts today). This resulted in wood for boat-making becoming depleted. Easter Islanders could no longer fish and their society collapsed. This eco-crisis was relatively simple, localised, and visible yet the inhabitants continued to self-destruct.[2] Society's present 'petro-cultures' are a macrocosm of the 'wood-cultures' of Easter Island which represent greater threats to all of humanity and the planet should the ruinous behaviour persist (IPCC, 2018b).

1.5 The Anthropocene

Humans have become the most devastating geological force of nature. From the outset technology and development was intended to improve human wellbeing. It

[2] [See Wright (2004) *A Short History of Progress.*]

however tethered society to fossil fuels. A growing population naturally means that demand for energy goes up. The more energy consumed, the more significant the impact. In South Africa coal-fired generation produces approximately 85% of the country's electricity which contributes to roughly 45% of its total CO_2 emissions (Baker, Burton, Godinho & Trollip, 2015). In 2016 the Russian Federation, America, India, Japan and China, collectively contributed a total of 68% towards global CO_2 emissions (Olivier, Schure & Peters, 2017). Globally, about two-thirds of emissions are due to production and the use of energy; this makes energy central to the human development project (IRENA, 2017a) and the CO_2 discourse.

The age of industrial modernity gave rise to a geological predicament known as the Anthropocene (Fischer-Kowalski *et al.*, 2014) meaning the planet is no longer in the safe, stable period known as the Holocene which lasted 11,000 years (Rockström *et al.,* 2009). The Anthropocene is another unintended consequence. Pronounced a poly-crisis by Swilling (2019a), Kanger and Schot (2019:7) term it a 'double challenge' of 'social inequality' and 'environmental degradation'. Fischer-Kowalski (2017) deems the present status quo, an age that has been forged by a series of transitions propped up by a fossil based energy regime. The transitions set humanity along a progressively unsustainable path to the current era in which we are the primary cause of the planet's destructive trajectory – the outcome of an 'unwitting' human 'experiment' on its own life support systems. Steffen, Crutzen and McNeill (2007) argue that ever since the dawn of industrialisation, the human 'experiment' has altered the geological fabric of the planet. The disruptions to the earth's systems are largely driven by increases in the concentration of carbon dioxide and other gases in the earth's atmosphere caused by massive consumption of fossil fuel energy.

A particular period to note is the 'Great Acceleration', which took place during the 1950s after the Second World War (Steffen *et al.*, 2007). During this time a significant number of countries embarked on developmental trajectories to rebuild after the war (Gumede, 2009). The period also coincided with an increase in the distribution of electricity as it became cheaper than gas (Fouquet, 2008). This led to a growing demand for household gadgets and appliances which further pushed the demand for energy (WEF, 2013). The national requirement for resources to rebuild after the war, coupled with the growing demand for domestic needs, changed the human impact on the planet, increasing atmospheric CO_2 levels *(Figure 1.3)*. The combustion of fossil fuels emits a cocktail of CO_2 and other greenhouse gases (GHG), which have a negative cascading effect on the planet, such as global warming, diminishing agrarian yields, and acidic oceans that affect marine organisms and eutrophication of ecosystems (Steffen *et al.*, 2007). During the past quarter-century, most notably in the last 70 years, some human activities have devolved from being benign to becoming significant creators of impacts on a global scale (Steffen *et al.*, 2007; WEF, 2013). This impact has undermined the nine safe operating boundaries of the planet (Rockström *et al.,* 2009). The boundaries outline the *"safe operating space for humans"* (Rockström *et al.,* 2009:472), by estimating various thresholds that should not be breached if we wish to maintain the earth's stable climate. According to Rockström *et al.* (2009:473) three of the nine boundaries, *"atmospheric carbon dioxide concentration"*; *"biodiversity loss"* and the *"nitrogen cycle"*, have already been breached. Humans are critically within reach of another three boundaries, *"land use"*, *"freshwater" and "ocean acidification"* (Rockström *et al.,* 2009:473) which threaten environmental stability. Carbon dioxide being one of the three breached boundaries is the subject of this study. The remaining three boundaries chemical pollution, ozone depletion and air pollution are either safe or not yet quantified (Rockström *et al.*, 2009).

1.5.1 The Carbon Discourse

The sharp focus on CO_2 as an agent for climate crisis appears largely to be driven by concerns around the reversibility of their concentration levels in the atmosphere and the predicated impacts that are leading to climate change. There are also political reasons for the global emphasis on CO_2 which appear to demonise it. While the demonisation of CO_2 or the heavily carbon-centric approach to climate action, is not the focus of this study some awareness of the political nuances is useful. Ray Evans (2008:5) writing for the Quadrant Journal notes about the wicked portrayal of carbon, where he cites James Hansen, a NASA scientist who stated in the 1980s that he was,

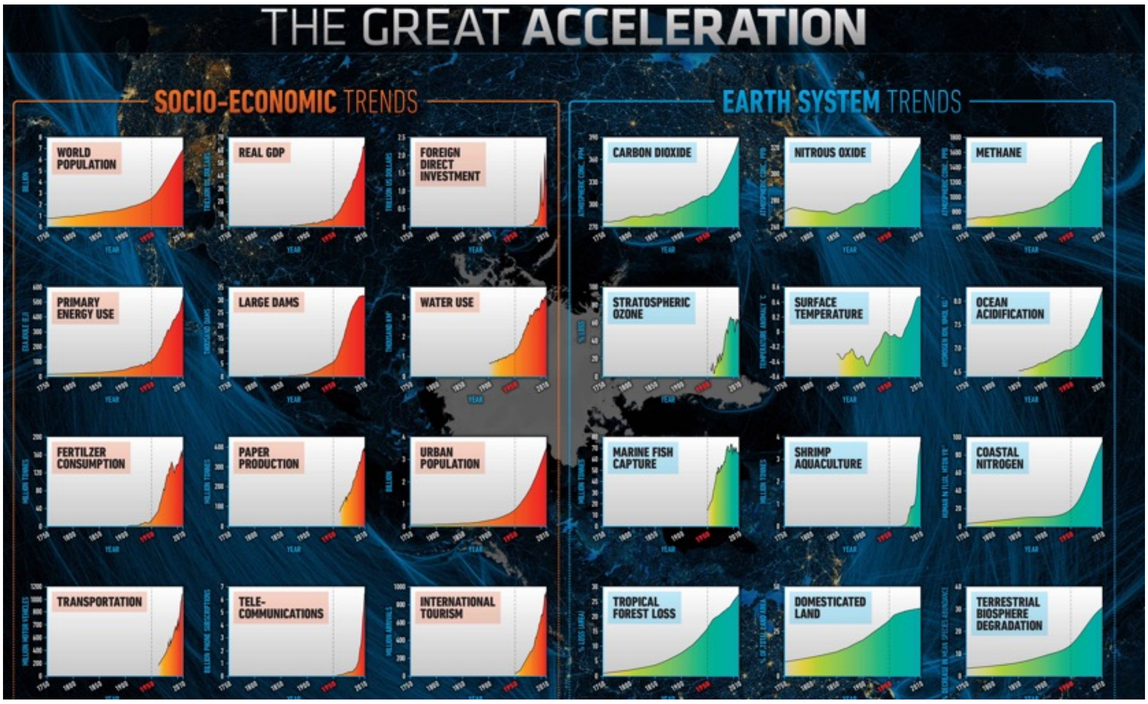
> *99% sure…the [human induced] greenhouse effect has been detected and it is changing our climate now.*

While Hansen, Sato, Kharecha, Russell, Lea and Siddall, (2007) concede that other trace gases are as important, they particularly highlight the impactful role of CO_2. It is on these claims by Hansen and others that Evans (2008) builds his argument. Evans

(2008) also claims that during the same period Margaret Thatcher, the British Prime Minister was eagerly drumming up support against CO_2 as a pollutant, in favour of nuclear power. The result was the anti-CO_2 doctrine which spread throughout the Western world. Although Evans' view seems likely given the energy politics that took place during the mid 1980s (Wade, 1985) his motives appear to support a scepticism towards the notion of global warming. He therefore bolsters his view by drawing on the energy politics, which find fault with fossil fuels on account of their CO_2 emissions in a strategic move that presents nuclear as the cleaner option. He cites the nuclear deal as the ulterior motive that led to the demonisation of CO_2. His view is partially problematic because the Thatcher administration, also advocated for a transition from coal to oil – another heavy GHG emitter. This transition was used to strategically disempower the labour movement and the working masses (Mitchell, 2011; Wade, 1985) – also see section *1.4.1*. Long before the "demonising" politics and the CO_2 science of the mid 1980s, Arrhenius (1896) published an article with the first calculations that illustrated the global warming impact of CO_2 emission. Arrhenius' findings appear to predate the current anthropogenic global warming science, it also solely centres on a CO_2 narrative. In all probability, his carbon-centric approach becomes the precursor that locks in the CO_2 narrative. It is further reinforced by Callendar (1938) who postulates at the time that approximately 150, 000 million tonnes of CO_2 had been released into the atmosphere and 75% of it remained there.

Today the general focus of climate action is largely carbon-centric, this is evident in research documents and reports such as Geels, Sovacool, Schwanen & Sorrell, (2017a,b); IEA, (2019b); IEA & IRENA, (2017); IPCC, (2018d); IRENA, (2017a); REN21, (2019a). The sole focus on carbon emissions is problematic, it is largely premised on the understanding that CO_2 emissions are a major cause of global warming and thus largely responsible for climate change. This may be based on the observed impacts of CO_2 on other planets such as Mars (Forget & Pierrehumbert, 1997; NASA, 2019a; Phillips, Davis, Tanaka, Byrne, Mellon, Putzig, Haberle, Kahre, Campbell, Carter, Smith, Holt, Smrekar, Nunes, Plaut, Egan, Titus & Seu, 2011). Other GHGs also contribute towards climate change as does deforestation, increased livestock farming, nitrogen based farming, etc (Houser & Stuart, 2020; Zissou, 2020). This study acknowledges the monolithic carbon-centric focus as reductionist. Such a focus fails to take into account the complexities of climate change and the other contributing causes, this conflicts with the notion of the great acceleration and the planetary boundaries, which acknowledge other problems that are leading to climate change. While bounding the study to CO_2 addresses the global approach to climate change, the broader complexities are also acknowledged.

Figure 1.3: The Great Acceleration[3] of the mid 20th century



Source: Steffen *et al.* (2007)

1.6 Problem Statement

Fossil fuels are the prime energy source that nourishes the human appetite for progress while simultaneously destroying the environment. Their extraction at an accelerated pace has carbonised the global economy. Emissions of CO_2 into the atmosphere are proving to be unsustainable, creating a set of 'wicked problems' by compromising the planet's safe operating boundaries. Humans have evolved into near-sighted agents of change, lacking in discernment regarding long-term consequences of their actions. This has unleashed cataclysmic havoc, giving rise to the Anthropocene. Failure to remedy this predicament boosts the planet's exposure to danger, the impacts of which on natural and human systems have been intensifying from about 2030 onwards, leading to perilous consequences for countless people.

[3] The great acceleration is a time in the 1950s when population growth, industrialisation, the velocity of energy use and greenhouse gas (GHG) emissions spiked almost uncontrollably. Refer to Steffen *et al.*, 2007

1.7 Research Questions

For a better grasp of the research problem as identified in the problem statement, the following three questions were developed to provide a focal point in the research:

- *What is driving the global RE surge as it seeks to tackle the carbon lock-in?*
- *How is the RE transition reducing fossil fuel dependency and climate risks?*
- *How is the energy transition associated to the notion of a deep transition?*

1.8 Assumptions of the Study

This study makes two major assumptions, at first, considering the climate-change crisis facing society today, it is assumed that the outcomes of this research will empower policy makers to craft better policies that transcend the challenges of climate change. The second assumption is that climatic challenges do not just follow a single story. They are not homogenous in that sense. They differ in cause. The contributing factors and the challenges will be divergent, as will be the solutions and benefits.

1.9 Rationale for the Study

This research will enable policymakers and decision-makers to craft better solutions for a sustainable future. A 'two-headed' goal was adopted in 2015, during the 21st Conference of the Parties (COP21), namely to retain the average global surface temperature well below 2°C and pursue efforts to curb the increment at 1.5°C, relative to pre-industrial times (Pidcock, 2016; Schleussner, Lissner, Fischer, Wohland, Perrette, Golly, Rogelj, Childers, Schewe, Frieler, Mengel, Hare & Schaeffer, 2016). The United Nations Framework Convention on Climate Change (UNFCCC) proposed that member states each determine their contribution towards the global 2°C and less warming limit (COP21, 2015). This ushered in the Independent Nationally Determined Contribution (INDC); a global programme to reduce CO_2 and deal with the 'wicked' problem of climate change (UNFCCC, 2015). In October 2018, the global 2°C and less warming limit was deemed inadequate, and recommendations were made to keep warming to 1.5°C and less (IPCC, 2018b). The reappraised target presents a more realistic goal against global warming and potentially mitigates against the demise of vast populations due to increased risks to *"health, livelihoods, food security, water supply, human security, and economic growth"* (IPCC, 2018b:11). Maintaining the average global temperature increase to below the 1.5°C mark is a very necessary ‘holy grail’. It ensures that planetary and human adjustment to changing conditions will be less demanding (IPCC, 2018b). The planet will endure fewer detrimental impacts of a severe nature and be able to mitigate against harsh climatic events (IPCC, 2018c). The anthropogenic shock to biodiversity, ecosystems, food security, natural resources, cities, tourism and carbon sequestration will be minimal, allowing the planet to recover (IPCC, 2018b). However, achieving this has mostly been theorised to entail a transition to renewables; a transition that is mostly governed by a techno-economic theory. The transition also lacks the social element that addresses issues of equity.

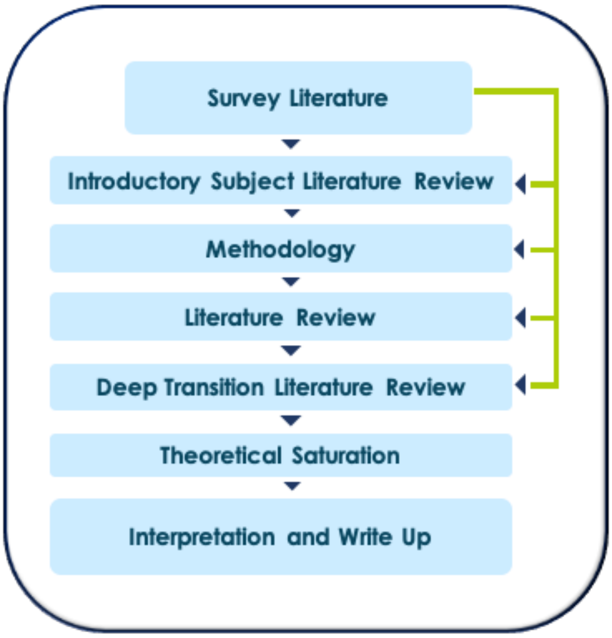
To turn the tide on the global anthropogenic trend, countries such as Denmark, Uruguay and Germany have been at the forefront of the transition from fossil fuels to renewable energy (REN21, 2018a). The gradual adoption of renewables is indicative of a global transformation currently taking place and reinforcing the underlying assumption that RE will lower CO_2 emissions. With a growing sense of awareness regarding climate change, there is an urgent need for clarity from a transition perspective on the current global renewable energy shift and its impact on CO_2. It is therefore essential to gain deep understanding of the transition and gauge the efficacy of the policies that guide it, as well as the underlying assumptions that inform it.

1.10Delimitations of the Study

The development of renewable energy is in its infancy with vast gaps in knowledge. Scholars such as Fouquet (2010) however observe that transitions carry a degree of uncertainty regardless of the research, and Van der Vleuten (2018) points out that the study of transitions is both urgent and timely. This research limits its scope to understanding the present RE phenomenon, and looks at transitions both past and present. Social, economic, technological and metabolic aspects are investigated as they pertain to RE transition, with a specific focus on CO_2 emissions. This study does not necessarily focus on energy justice but will briefly touch on the subject. The research is global in scope, extrapolating data from various sources to build a holistic picture of the RE shift.

This study considers several countries around the world as the shifting global energy system is brought into focus, and the emphasis is on the growing irruption of renewables. As mentioned elsewhere in this document, *"in sustainability transition studies, individual systems remain the dominant unit of analysis"* (Van der Vleuten, 2018:22). The study of individual systems has merit, but also point to profound social implications that go beyond the technological, as put forward by the deep transition theory (Geels, 2012; Schot & Kanger, 2018; Swilling, 2019c). In other words, while this study investigates the new RE regime, it also considers broader impacts that suggest unprecedented complexities governed by energy. Using the global RE revolution as the platform, the study investigates if the transition points to a much more significant transformation and analyses its impact on climate action. While the issues of social equity are not the subject of this study, where relevant they are addressed.

Figure 1.4: The research design



Source: Author (2019)

1.11 Research Methodology and Design

This study is primarily a narrative literature review which consolidates results from the findings of multiple sources of existing literature. The synthesised evidence is used to investigate the global RE revolution. The qualitative study considers both qualitative and quantitative data, however, there are no calculations only analysis of the mixed data. Mixed methods *"involve(s) the collection of both qualitative (open-ended) and quantitative (closed-ended) data in response to research questions"* (Creswell, 2014:267). Using data from mixed methods is a research strength, as it curtails the limitations found in both approaches (Creswell, 2014). This research approach enables the sifting of qualitative, quantitative and mixed methods literature, to build an evidence base for a shifting energy regime. The approach is appropriate for this study, taking into account a wide range of sources and research that have already been applied. Mixed methods also enable issues to be probed from many different perspectives (Roddis, Carver, Dallimer, Norman & Ziv, 2018).

1.12 Chapter Outline

The chapters that follow are organised as follows:

Chapter 2 presents an outline of the research strategy. The chapter also illustrates in detail the methodology used in the research.

Chapter 3 reviews the literature on present-day transitions and analyses current data to answer the first two research questions:–

- *What is driving the global RE surge as it seeks to tackle the carbon lock-in?*
- *How is the RE transition reducing fossil fuel dependency and climate risks?*

The extent, as well as the pace of the renewable energy transition, is probed.

Chapter 4 introduces the concept of a deep transition as a lens through which to understand the current RE transition. The setting and the constituting elements of a deep transition are laid out. The chapter addresses the third research question:

- *How is the energy transition associated to the notion of a deep transition?*

Given the apparent lack of significant declines in CO_2 emissions, and the understanding that fossil fuels enjoy a messy, convoluted pervasiveness that is non-linear, chapter four explores broader systemic contexts for the RE transition. A deeper conception of the energy transition sets the basis for a deep decarbonisation.

Chapter 5 fuses together the lines of argument developed in Chapter 3 and Chapter 4, and deepens insight into the role of the RE transition within the wider deep transition. The chapter illustrates how the RE transition is mostly viewed as technical. The deep transition theory helps to broaden the focus beyond energy, thus addressing wider systemic challenges, making it easier to understand why emissions are not dropping.

Chapter 6 offers concluding remarks, reflections, the implications of some of the findings, and the limitations encountered. Recommendations for future applications and research conclude the study.

Chapter 2: Research Methodology

2.1 Introduction

This chapter gives an overview of the general research framework and methods applied to answer the research questions. I introduce the dominant approach to the research followed by a description of the selected research design type. The next step outlines the methods and procedures applied to gather the necessary data, and the final section in this chapter is a description of the framework that will be applied to the data analysis.

2.2 Research Paradigm

2.2.1 The paradigm wars

A constructivist paradigm is adopted to address this research work. In processing what informs our assumptions about truth and the paradigms that best construct our perspective of the world around us, I initially experienced a paradigm war (Schwandt, 1989). My battle was figuring out how to select an appropriate paradigm, which led to my considering a multi-epistemological approach. In his article *"Solutions to the paradigm conflict"* Schwandt (1989:379), proposes that researchers should determine a paradigm that resonates *"with the values they wish to promote in the conduct of [their]… inquiry."* Schwandt states that paradigms must be selected under *"conditions of uncertainty"* and that *"recognition of values"* ought to steer the process. The values espoused are not moral values but rather that which is good and appropriate (Schwandt, 1989). Through this process, the idea of a multi-epistemological approach was resolved, and I settled on a constructivist view.

2.2.2 The constructivist's gaze

Constructivism is often merged with interpretivism (Creswell, 2014). This approach allows scholars to synthesise qualitative data from secondary sources. One of the traits of constructivism is that it can be abstract and influenced by non-tangible elements that are difficult to measure such as social, ecological and economic factors (Willis, Jost & Nilakanta, 2007). The constructivist paradigm relies on the views of the subjects involved (Creswell, 2014). In my case, the subjects are the scholars who have contributed to the body of knowledge through their own research. To affirm this point, I refer to two different conclusions regarding the current renewable energy revolution. According to Swilling (2019c:228) *"the deep transition [is] underway"* and its main driving force is a revolution in energy systems. On the other hand, Perez (2009) posits that changes in energy are more aligned to shifts in the information and communications technology (ICT) sector. While both parties concede that there are energy shifts taking place, they make different inferences about the bigger picture. In the example above, subjective meanings that are based on their research and experiences may have been applied by each of the mentioned researchers. As a researcher, some sensemaking of the complexity is required (Creswell, 2014).

Constructivism conceptualises learning as a valuable process by which data is translated into knowledge through interpretation. This is done by correlating it to an existing body of knowledge through purposeful elaboration (Resnick, 1989). This conceptual study is an in-depth analysis of both historical and current literature. The constructivist paradigm presents an opportunity to synthesise, summarise and present my interpretation in an aggregated exposition of the already published literature.

2.3 Literature Review Design

2.3.1 The narrative literature reviews

This theoretical review comprises three main sections of literature analysis, which form the overall methodology. The first review is designed to explore the subject of energy transitions in general and to learn what has been said in the existing body of knowledge. A literature review helps to arrange ideas by theme from a variety of sources and is instrumental in developing theories (Meredith, 1993). In this instance, a sense of growth in renewable energies sparked an internal debate within me concerning the sufficiency of the overall transition in addressing climate issues. From this process, theories were developed and corroborated through the narrative review process. Crucially, one of the primary goals was to build a much better understanding of the landscape as it pertains to the topic as well as some historical background which set the context. All three reviews are narrative (semi-systematic) approaches with a strong focus on energy transitions or transitions in general. One of the main advantages of a narrative review is its ability to draw from a wide variety of articles within a topic (Baumeister & Leary, 1997). This broad sweep has the benefit of providing the reader with an update on relevant issues and producing a platform from which to launch other pertinent studies (Cronin, Ryan & Coughlan, 2008). A motley collection of topics and disciplines, which are conceptualised differently to each other, make a comprehensive systematic review onerous and therefore are better suited to a narrative approach (Wong, Greenhalgh, Westhorp, Buckingham & Pawson, 2013). This was made apparent to me in the third review, which handles topics from different backgrounds, namely social, energetic metabolism, materials flow, economic, technology and environmental. The value of this study lies in being able to bring the vast landscape into a more manageable field for analysis (Baumeister & Leary, 1997). By virtue of it being less focused than more systematic reviews, the initial literature review on energy transitions drew from a variety of sources to inform a holistic perspective of the terrain. The approach helped to synthesise multiple studies and documents, ultimately resulting in an overview of the broader subject landscape and its related topics (Petticrew & Roberts, 2008). In contemplating the broader research objectives, the initial review helped me to put in place an appropriate starting point for my investigation (Ridley, 2012).

2.3.2 The thematic narrative literature review

The second and third reviews tackled the three research questions which helped to guide the overall study. Owing to a more focused approach that was specific to the research questions, the sources of data for each of the reviews were much more comprehensive, requiring search criteria that were more explicit and pointed *(Table 2*.1*)*. Fink (2013) states that the review of a legibly constructed question which employs well-ordered and clearly expressed methods is systematic. In general, a literature review is classified as a systematic process of gathering and synthesising past research (Baumeister & Leary, 1997). While both reviews had systematic elements in the collection and arrangement of the literature, they remained by and large narrative. A good review should be reproducible so that it can be reconstructed by someone else using the same methods as a way to test the outcomes and determine its objectivity.

2.4 Searching for the Literature

2.4.1 Search methods

The narrative literature review mainly focused on defining transitions, sketching an overview of historical energy shifts, giving an outline of climatic issues, introducing the fossil-fired industrial era, and painting a broader picture of the related challenges. A good starting point for some general background into RE was the literature from my Renewable Energy Policy class, which gave me an excellent foundation and a 'feel' for the topic. The next step involved selecting appropriate material from the body of literature that I was exposed to during the module. This involved a process of identifying seminal writers. I found the process very helpful as I was able to determine relevant topics and keywords, and to establish a research trajectory. Other materials emerged from prescribed readings suggested by my supervisor. This led to a process that widened the scope to include online library searches. The following keywords bounded the search methods.

Table 2.1: Keywords used for search criteria

LitReview 1	Energy transitions	Energy shifts	Energy policy	Industrial revolution	Fossil fuels	Energy politics	Climate change
LitReview 2	RE investments	RE R&D	Energy EROI	RE Technologies	Energy policies		
LitReview 3	Deep transitions	Socio-metabolic	Socio-economic	Longwave theories	Socio-technical		

Source: Author (2019)

After establishing the initial keywords, an inaugural broad search which included google scholar, google, the Stellenbosch University Library and the Ebsco host link was performed to identify other articles. This was the only time that a comprehensive search was performed, as the hunt for material was iterative throughout the study. The search had no timeline restrictions or publication year range owing to the objectives which were to gain a broad sense of energy shifts from as far back in history as possible. Relevant material enabled a snowballing effect as a referral system, where additional sources that proved to be pertinent were identified from the references of selected literature and scoped for applicability. Johnston (2014) supports this process of finding additional scholars who have worked on similar topics. It is a process that assists in the identification and broadening of scope, but with some degree of focus.

As time progressed, I realised other broader approaches to gathering material. The google search engines proved valuable for popular media articles, open journals as well as scientific articles and reports from development and intergovernmental organisations, such as the United Nations (UN), the International Renewable Energy Agency (IRENA), other research groups like the Bloomberg New Energy Finance (BNEF) and consultants such as McKinsey & Company. The objective for broadening the search was to optimise and maximise the locations for a more global perspective. The search for the second and third literature reviews followed the same criteria, with additional keywords, which were much more pointed for the specific research needs of each of the sections *(Table 2.1)*.

Regarding the third review, I found that research specific to 'deep transitions' is still relatively limited; this rations the literature at hand. While the field is not necessarily in its infancy, a specific search for deep transition literature did not yield high returns. Despite this handicap, other sectors speak directly and indirectly to the topic. The topic is therefore approached in a variety of ways which include accessing literature on transition theory such as the techno-economic, socio-technical, socio-metabolic and global development cycles. An example of this is the literature on the first industrial revolution, which highlights technological changes that were in themselves symptoms of a deep transition in progress. Literature that directly relates to localised transitions, deep transitions and other forms of technological shifts from micro to macro levels, is included in the study.

2.5 Searching the Literature

Once the literature was gathered, a content analysis was performed, and it was collated into thematic categories. This categorisation proved beneficial for the other literature reviews later in the study. I observed that the historical literature tended to be mostly qualitative and that the contemporary articles, as well as the most recent historical material, showed a tendency to be mostly mixed with both qualitative and quantitative data. Initially, I felt the literature had to be academic; this was feasible with the first narrative literature review. For the subsequent reviews, I had to broaden the criteria to include science writers and other 'popular' sources of information (grey media) due to the rapid changes taking place in the renewable energy sector. At times popular media outlets provided the most up-to-date data. In such cases, it was prudent to make sure their sources were valid; in other words research or scientifically based. For the inclusion criteria, the material had to be in English (in certain instances where the literature is seminal, an exception was made). Ultimately it was winnowed down through a process of further categorisation into the themes covered in the narrative review, namely energy transitions, historical shifts in energy, fossil fuels and the Anthropocene. The literature was then analysed, synthesised and summarised into three narrative or semi-systematic literature reviews.

As stated, one research method was chosen to address the research topic and questions, which are reiterated below:

- *What is driving the global RE surge as it seeks to tackle the carbon lock-in?*
- *How is the RE transition reducing fossil fuel dependency and climate risks?*
- *How is the energy transition associated to the notion of a deep transition?*

All three literature reviews embrace both narrative and thematic approaches. In the case of the second and third literature reviews, the three research questions were informed by some underlying theoretical concepts. Both literature reviews are guided by the three research questions which inform the process. The themes were subjected to detailed literature surveys, and the collected data was organised and synthesised into summaries. The analysis of the data was bound by the themes and the theory. In Chapter 3, the three main themes identified helped to address the first research question by a process of triangulation. The themes were price, technology and policy. In the latter portion of the same chapter, the second research question revealed the apparent lack of significant declines in CO_2 emissions. This approach gauged the effect of the global renewable energy roll-out. The third research question was addressed by analysing techno-economic, socio-technical, socio-metabolic and global development cycles which illustrated a broader process of RE transition that is currently not being considered.

2.5.1 Sample Size

Due to the study mostly being qualitative, the determination of the desired sample size was based on the need to understand the phenomena instead of the prototypical sample sizes expected in a more quantitative study (Morse 2000). Material was intentionally sought to address the research questions and bring understanding. The objective was to keep searching for new perspectives until repetition starts to emerge or new content becomes sparse – this would indicate saturation (Morse, 2004).

2.6 Literature Review as a Research Method

In this section, I briefly discuss the distinction between the initial 'scoping' literature review and the subsequent reviews that are included in the study as research methods. The literature review is an ongoing aspect of any research; typically it would not be highlighted as part of the research methods, except when it is explicitly used for this purpose. In this instance, the study is a theoretical analysis of the existing literature. Fundamentally the research analyses literature for data. Snyder (2019:333) in validating the method, states that the integration of perspectives and empirical findings from various sources can tackle research objectives *"with a power that no single study has"*. This idea is further endorsed by Webster and Watson (2002) who claim that a well-constructed review as research method is a solid basis for improving knowledge and facilitating the development of theory. My thesis therefore relates to the literature in two moderately different ways: the first review helps to locate my research in the existing body of knowledge as described in the preceding sections. The subsequent reviews investigate already existing 'points of view' from experts on my topic of interest. In other words, the literature is the data, and my 'fieldwork' is centred within a 'library research'. The different sections are laid out into three different chapters within the thesis to clarify the distinction.

2.7 Data Collection and Analysis

2.7.1 Data extraction

According to Onwuegbuzie and Frels (2016) the word 'data' describes a collection of information. This information can be drawn from multiple sources, which include numbers, words, images, audio, hyperlinks and video. They further add that a literature review process is essentially a formal data collection tool and that this data can be used in a variety of ways, including writing a review. Within the process of reviewing literature, tasks such as discerning, sensemaking, interpretation and the transfer of knowledge should be expected (Onwuegbuzie & Frels, 2016).

Making use of existing data for other research purposes is now standard practice, considering the vast amounts of information available from numerous scholars around the world (Andrews, Higgins, Andrews & Lalor, 2012; Smith, Ayanian, Covinsky, Landon, Mccarthy, Wee & Steinman, 2011; Smith, 2008). Dale, Arber and Procter (1988); Doolan and Froelicher (2009); Doolan, Winters and Nouredini (2017); Dunn, Arslanian-engoren, Dekoekkoek, Jadack and Scott (2015) encourage this approach whenever possible. I chose to use a literature review to collect data for practical reasons, mainly due to the scope of my research area. My research focuses on the global renewable energy revolution; it is therefore not feasible to centre my attention on one location alone as a case study. Similarly, the likelihood of global travel is impractical. Furthermore, the required data on transitions is readily available in academic texts, RE reports and a wide range of other sources.

2.7.2 Analysing the data

Johnston (2014:619) explains that *“secondary data analysis is the analysis”* of existing forms of data. Secondary data allows for re-analysis with new research techniques and also addresses new research questions (Glass, 1976). Glass further suggests that the importance of secondary data may even eclipse that of primary data. To that end primary data must be preserved for meta-analysis. Johnston (2014:619) reinforces the notion of *"secondary data analysis as a systematic method"* that should follow a process and some evaluative measures. She puts forward the following three-step process of secondary analysis.

- Develop the research questions
- Identify the data
- Evaluate the data

In step three of the process Johnston emphasises the importance of evaluating the selected datasets to ensure the integrity of the information but also of understanding the primary acquisition process and methodology.

Johnston (2014) puts forward an evaluation strategy developed by Stewart and Kamins (1993) which I have thumbnailed into a condensed format, see *Table 2.2* below. Their evaluation strategy is supported by Johnston, as it complements the third and last step of her process of secondary analysis. Although I do not handle primary data sets at any point in my study, I felt the approach was at times relevant in evaluating the results from other research, which essentially are my datasets.

Table 2.2: Secondary data evaluation strategy

1	**What was the purpose of this study?**	It is crucial to determine the purpose of the original project that produced the data because this can influence many factors such as the targeted population, the sample selected, the wording of questions on the survey, and the general context of the study (Doolan & Froelicher, 2009; Magee et al., 2006).
2	**Who was responsible for collecting the information?**	Helps to know if primary investigators are well-respected academic researchers, and have a reputation for excellence in research integrity.
3	**What information was collected?**	It is vital for the secondary researcher to have access to adequate documentation from the primary research, including protocols and procedures followed in the collection of the data (Clarke & Cossette, 2000; Dale et al., 1988; Smith, 2008; Smith et al., 2011; Stewart & Kamins, 1993).
4	**When was the information collected?**	In any research, the time when the data is collected must be considered (Boslaugh, 2007; Stewart & Kamins, 1993).
5	**What methods are employed in obtaining the data?**	The quality of secondary data cannot be evaluated without knowledge of the method employed when collecting the data (Stewart & Kamins, 1993, p. 25).
6	**Management of the primary data.**	The secondary researcher should access the raw dataset in order to perform new analyses (Boslaugh, 2007; Stewart & Kamins, 1993).
7	**How consistent is the information with other sources**	It is beneficial to have multiple sources to bolster confidence in findings, whether it is that two or more sources arrive at the same conclusion for comparison or that they do not, providing an option for contrast.

Source: Excerpted from Johnston (2014) quoting Stewart and Kamins (1993)

2.8 Summary

In this chapter I introduced my research paradigm which is located within a constructivist philosophy. My choice of paradigm influenced the research methodology and the methods that were appropriate for the study. The research design incorporated an initial traditional literature review for Chapter 1 which was embedded in a qualitative technique. The review intends to discuss the topic and deepen my understanding of the landscape. The research method is introduced as two additional semi-systematic or narrative literature reviews which address the second and third research questions. The study is based on data collected from across the globe which includes techno-economic paradigms, global economic cycles, socio-technical transitions and socio-metabolic transitions. I have also outlined the method of gathering and analysing the data.

Chapter 3: A Renewable Energy Revolution

3.1 Introduction

The industrial era seems, for the most part, to be in its final stages (Kanger & Schot, 2019). When assessed from the perspective of a fossil fuel lock-in, it becomes apparent that the present regime has entered a period of destabilisation. Although according to the 2018 Renewable Energy Policy Network for the 21st Century (REN21) report, resistance to RE is still extreme, fossil fuel and nuclear investments continue, yet conservatively. The signposts of a destabilisation of the fossil fuel regime are unmistakable as an aggressive and competitive irruption of RE emerges. Despite resistance RE has continued to make incremental progress as costs fall and it seeks to establish itself. To illustrate the disturbance of the fossil fuel era, this chapter highlights scenarios that characterise a transition to a new energy regime. I support the argument that at present there is a renewable energy revolution taking place (Geels *et al.*, 2017b; Schot & Kanger, 2018; Swilling, 2019c). However, the rise is not sufficient enough to tranquilise climatic risks. This is made apparent as CO_2 emissions fail to drop sufficiently (Geels *et al.*, 2017a). In order to establish a diffusing RE regime, this study uses a process of triangulation, focusing on price, policy and new technologies. The chapter also covers several other topics that relate to the triangulation talking points based on the question:

- *What is driving the global RE surge as it seeks to tackle the carbon lock-in?*

The second research objective is embodied in the following question:

- *How is the RE transition reducing fossil fuel dependency and climate risks?*

The latter portion of this chapter addresses the second research question by focusing on climate change literature and the relevant data before concluding on the basis of clear evidence, that CO_2 emissions are not showing any long-term reductions even as renewables are adopted on scale. This finding points to solutions that are beyond the narrow references of mere energy, to a much broader perspective. The rationale behind this chapter is to evaluate the impact of global RE installations against decarbonisation and climatic goals.

3.2 The End of an Era

The age of fossil fuels is coming to an end as society opts for cleaner alternatives. As the global population grows towards the 10 billion mark, the strain on the earth's carrying capacity calls for an urgent transition to a different regime. Fischer-Kowalski (2017) and Fischer-Kowalski *et al.* (2014) refer to a 'sustainability transition' *(Figure 1.1)*. This implies a 'greener' future. The envisioned future transition to a regime that is partially solar based, brings humanity full-circle, especially when considered against humble beginnings in the Palaeolithic and Neolithic eras which were deeply rooted in endless solar energy as portrayed in *Figure 1.1*. The ancient solar epoch is an era long thought to have been suppressed by the oil barons and big coal in the name of profit (Malm, 2013). As humanity finds itself on the brink of a post-industrial (Haberl, Fischer-Kowalski, Krausmann, Martinez-Alier & Winiwarter, 2009), post-fossilised existence (Smil, 2013), fundamental to the survival of the planet and all species is a 'sustainability transition'.

3.2.1 The 'first world' energy state of post-industrialised nations

As machines and technology become more and more dominant, society appears to be shifting towards a service-oriented economy since the tertiary sector now produces a sizeable portion of the gross domestic product. In some economies, this is believed to be as much as two-thirds of the workforce (Haberl *et al.*, 2009).

The weight of human societies on the environment, especially with regards to planetary boundaries, provides the impetus for an energy transition. As previously stated three of the elements have already breached their boundaries which include atmospheric CO_2 concentration levels (see section 1.5), the motivation for this study. Haberl *et al.* (2009) assert that two-thirds of the world is still in transition from the agrarian to an industrial regime. This means that only the one third generally referred to as 'developed' countries has been living in an industrial epoch all along. While the sharp binary distinction which Haberl *et al.* (2009) make between developed and developing nations is problematic, it does provide some insight into the global disparities of resource use and the benefits derived by industrialised nations. However, it becomes problematic because much of the so-called agrarian regime is dependent on the industrial regime – if the latter collapsed, the former would also collapse. While the major benefits are biased in favour of certain nations, the dependency is somewhat mutual which is important to note from the onset. It also deems such a clear-cut binary less justifiable. In their hypothesis of a 'developed one third' Haberl *et al.* (2009:5) referencing Sieferle (1997) also include those who *"live in the industrial archipelagos",* a term used to define what they call *"post-industrial"* pockets, found within developing nations or agrarian societies. In 2013, the average electricity use per capita in Canada was 10000 Watt-hours (Wh) per annum. This was 20 times more than in Haiti and Benin, and 25 times more than in the Democratic Republic of Congo (Garrigou, 2016 quoting Szeman). The global average at the time was 1640Wh per capita per annum (Garrigou, 2016 quoting Szeman). Canada's energy consumption is a microcosmic representation of the consumption patterns of the so-called developed nations. Despite their seemingly non-extractive nature, they spend their profits and income on *"material extensive products"* (Garrigou, 2016 quoting Szeman) which are made from extracted minerals, and services such as long-distance travel, big cars and houses. These and other cultural tendencies affect the energy profile of a society. In addition to income and profits being spent on material extensive products and services, tech-savvy businesses also depend on offshore inputs that are materially demanding to operate. If the whole world developed to the same levels as Canada and other developed nations, consuming energy at the same rate, the global demand for electricity in 2013 would have been about 74 terawatt-hours (TWh) (Garrigou, 2016 quoting Szeman) -a six-fold increase in electricity demand. This figure excludes other fossil fuels and their products, such as those used in vehicles and for heating. At the time, the planet was failing to cope with a global electricity demand of 12.1TWh (Garrigou, 2016). The International Energy Agency (IEA) puts the 2013 electricity consumption figure closer to 19,5TWh (IEA, 2019b). While the figures clash owing to the different measures used, Szeman's point was that the whole world could not afford to live like Canadians. For the sake of the planet and all its life forms, fossil fuel consumption levels need to drop, and ultimately a shift to be made. The total final electricity consumption (TFEC) for 2017 was 21,4TWh, 2.6% more than 2016 (IEA, 2019b). The fossil fuel consumption overall across all energy platforms between 2013 and 2017 is given in *Table 3.1*:

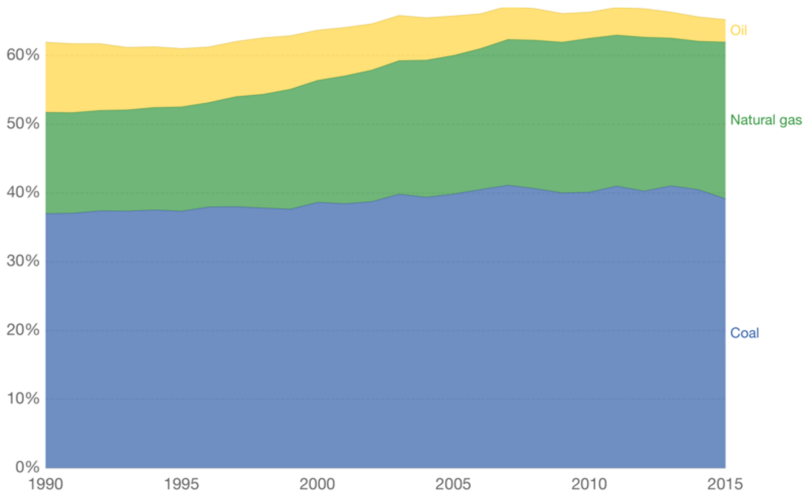
Table 3.1: Global energy consumption by fossil fuel source in TWh

Fuel	2013	2014	2015	2016	2017
Coal	44,95	44,91	43,78	43,10	43,40
Natural Gas	33,71	33,98	34,74	35,74	36,70
Oil	50,69	51,10	52,05	53,00	53,75
Total	**129,36**	**130,01**	**130,78**	**131,84**	**133,85**

Source: Author's adaption of Ritchie and Roser (2019)

On the other end of the Canadian energy conundrum, are the developing nations that are less energy-intense. Challenged by energy insecurity, the levels of consumption are deficient (World Bank, 2018). However, there is a desire for developing states to reach the same levels of growth as their more advanced counterparts. As already stated, such ambitions are dependent on energy and should developing nations scale up the global energy consumptions of *Table 3.1* will also increase exponentially. If they are carbon-based, it would spell climatic disaster (IPCC, 2018b).

Figure 3.1: Electricity generated from fossil fuels



Source: Our world in data (2019)

3.2.2 The 'third world' energy state of developing nations

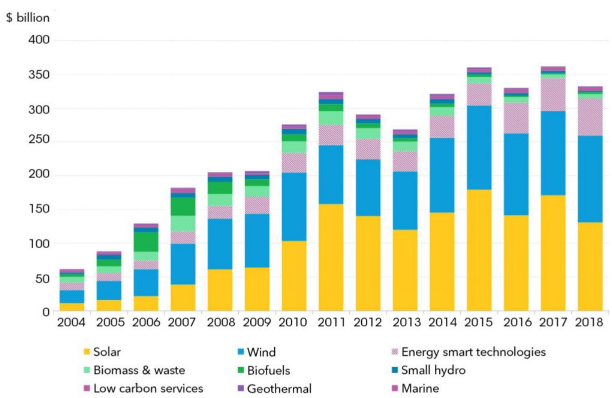
Sustainable Development Goal 7 (SDG) aims to *"ensure access to affordable, reliable, sustainable and modern energy for all"*. Despite this globally espoused goal, many challenges hinder its achievement. The energy need is great. Sub-Saharan Africa has the lowest electrification rate in the world at an average of 42% in 2016 (World Bank, 2018). In 2015, a World Bank study reported that Sub-Saharan Africa's installed capacity for electricity was approximately 96 gigawatts (GW), of which 64% was fossil-fired generation. The remaining 36% was accounted for by renewable energy which included hydropower. Planetary boundaries are critical to the energy framework. In fact, Haberl *et al.* (2009) state that the current energy flows in relation to carbon emissions are beyond the carrying capacity of the earth. Earlier it is stated that only 33% of the world is developed (Haberl *et al.*, 2009). This suggests that the energy flows of the developed world, plus that of developing Africa, as well as the balance of the undeveloped two-thirds of the planet are outstripping planetary boundaries. This is in spite of continents such as Africa only directly consuming less than 6% of the world's energy and producing only 3% of the emissions from a population of about 16% of the global total in 2014 (AFD, 2016). Africa's economic growth averaged 4.5% in the five years preceding 2016. This clearly suggests that the energy demands of the continent and the need for relevant infrastructure gradually continues to rise (AFD, 2016). As mentioned, should Africa and the rest of the developing world decide to increase their reliance on fossil fuels for development and electricity generation to meet their shortfall needs, it would mean none of the targets agreed to in Paris in 2015 can be attained. It can therefore be postulated that Africa and the rest of the developing world's slow fossil fuel uptake has to date moderated an even faster collapse of the planet's systems. In other words, energy insecure Africa and the rest of the developing nations, mitigated an even earlier poly-crisis. The African perspective is critical as it highlights the extent of the overall global energy inefficiencies. It also exposes an energy consumption ratio that is inequitably high in favour of developed nations, yet the outcomes are incongruently calamitous for all. This scenario reiterates the urgent need for energy efficiencies that reduce the global levels of consumption, as well as the need to change an unsustainable fossil fuel regime.

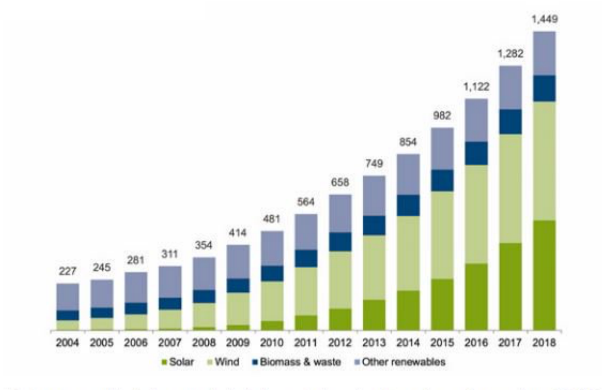
The opening statement in this section *(3.2.2)* quotes the 7th SDG, which is oriented towards *"ensure(ing) access to affordable, reliable, sustainable and modern energy for all"*. As a developing continent Africa has suffered a great deal of injustice from both colonialism and neoliberal investments that favour developed countries, as they pillaged from Africa and exacerbated global inequalities. Centring sustainability in a global context will require social equity, particularly within Africa (Kothari, 2015). African communities are disproportionally disadvantaged in development and climate change, as mentioned above. The continent stands to be prejudiced by an unjust RE transition – just as it has been with fossil energy. Ecological sustainability which leads to climate stability without social equity is unsustainable. The rise of renewables needs to concomitantly be met by policies that merge equity into the equation.

3.3 The Rise of Renewables

Renewable energy (RE) is a sustainable source of energy that is presently on the rise. Some of the most explicit examples are in technological innovations that challenge traditional models of energy. Vastly improved technologies are causing disruptions as they rapidly diffuse (Mathews, 2013a). In real terms, renewables started to grow in share since 2003/4. The period between 2007 and 2017 saw the total global RE capacity more than double (REN21, 2019a). The trend was briefly interrupted in 2012, bouncing back the following year, and in 2018 another 171GW of capacity was added (IRENA, 2019a). However, REN21 (2019a) puts the figure at 181GW for 2018. This total is slightly up from the 2017 sum of 178GW (REN21, 2018a) and much higher compared to 2015 when it stood at 147GW (KPMG, 2016). The overall global RE capacity is approximately 2537GW (IRENA, 2020a), up from 2378GW as of 2018 (REN21, 2019a). Excluding hydro larger than 50MW, approximately 1449GW had been installed by 2018 *(Figure 3.2)*. The total installed capacity has grown consistently since 2004. A comparative analysis of the annual investments in RE and the installed accumulative capacity between 2004 and 2018 shows that even during the 2008 recession, RE grew. The left side of *Figure 3.2* shows RE investments per annum in US$, and the right side is the total in MW for renewables. The sustained growth was due to state subsidies and some stimulus packages. *Figure 3.2,* illustrates how investments tumbled in 2012, 2016 and again in 2018; in spite of the fluctuating investment flow, RE rose steadily, bolstered by subsidies and falling costs.

Figure 3.2: RE investments vs RE capacity 2004 - 2018





Source: Bloomberg (2019) and Frankfurt School-UNEP/BNEF (2019)

In 2017, RE growth was faster than in previous years at approximately 9% year-on-year (Swilling, 2019b). In 2018, it accounted for 84% of additional capacity and a third of the overall global installed capacity (IEA, 2019a). By 2017, a total of 57 countries set their sights on 100% renewable energy generation, 48 countries had targets for RE cooling and heating, and 42 had RE transport targets (REN21, 2017). These are notable numbers suggesting that the commitments are beyond mere sporadic RE fads. Currently, there are 195 countries in the world; this means over a quarter have committed to a full RE transition. Several of the 57 countries committed to 100% RE have gone beyond lip service and are demonstrating that this is not an impossible target *(Table 3.2)*: a number of them achieving 100% and more, RE power generation.

Table 3.2: Countries leading in the RE transition

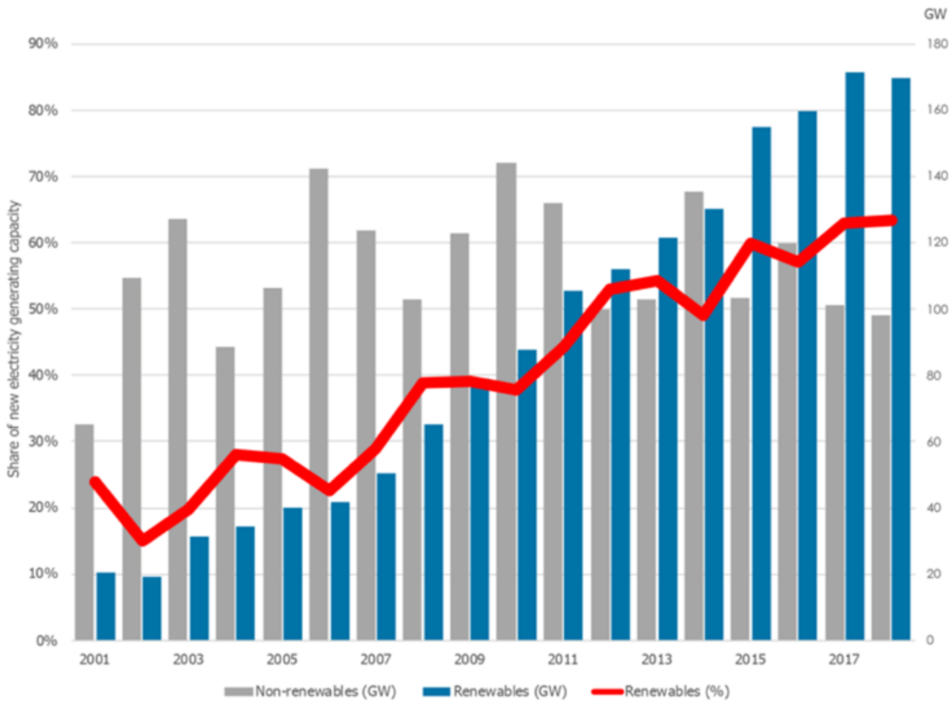
Country	Type of Energy	Trend
Sweden	Solar, wind	Eliminating fossil fuels by 2040
Costa Rica	Hydro, geothermal, solar, wind	Has achieved 95% RE electricity
Nicaragua	Wind, solar, geothermal	Pledged 90% renewable by 2020
Scotland	Wind	98% RE electricity
Lithuania	Biomass, wind, biofuels, hydro	80% pledged by 2050
Germany	Wind, solar	Pledged 65% by 2030
Uruguay	Wind, solar, geothermal	Achieved almost 100% in 10 years
Denmark	Wind, solar	Achieved over 50% renewables (pledged 100%)
China	PV solar	45% of global RE investment
Morocco	Solar, wind, hydro	50% by 2020
USA	Wind, solar, hydro, geothermal	More solar jobs than coal & nuclear
Kenya	Wind, geothermal	50% of capacity from geothermal

Source: Author's adaption from Climate Council (2019); The World Bank (2019)

The global RE revolution is the aggregation of countries that are at the forefront of the transition *(Table 3.2)*, many of which have pledged to play an active part in addressing the global poly-crisis. Based on the empirical data above, the undertaking to mitigate against the socio-ecological crisis seems solely premised on a technological increase of RE. Some nations stand out in their commitment as they achieve what has been deemed impossible elsewhere. Uruguay, Nicaragua, Costa Rica and Scotland have or are on the brink of achieving 100% RE production of electricity (Watts, 2015). Notably, Scotland, in the first half of 2019, produced enough electricity from wind to power two Scotlands (Nield, 2019). The country has 2,46 million homes, the 9.8 million megawatt-hours generated were enough to supply electricity to 4.47 million homes (Nield, 2019). Costa Rica had 300 days of 100% RE power in 2018 (REN21, 2019a).

Another country to note is Uruguay which almost achieved 100% RE in the space of 10 years (Watts, 2015); however, due to its high generation capacity, which often exceeds demand, it has high levels of curtailment. Many hydro generating countries such as Lesotho, Nepal, Bhutan, Paraguay and Albania, produce 100% of their electricity needs from RE (The World Bank, 2019).

Figure 3.3: Share of new electricity generating capacity



Source: IRENA (2019c)

According to IRENA (2019c) in 2018, the capacity of wind energy grew by 49GW; bioenergy added a total of 3,6GW to the energy mix, and solar accounted for 94GW - an increase of 24%. In 2019, solar energy grew by 98GW (+20%), wind increased by 59GW (+10%) and hydropower was up by 12GW (+1%) (IRENA, 2020a). China's lead in the global renewable energy revolution in terms of investments stems from an announcement made in 2017, which saw the scrapping of plans to build 85 coal-fired plants. China committed to investing US$360bn in RE by 2020 (IRENA, 2019a). There were some notable exceptions such as hydropower which slowed down in 2018, the only added capacity being 8.5GW in China (IRENA, 2019a). This is likely due to the environmental impacts of dams and reservoirs required for hydropower. The built infrastructure for hydropower negatively affects homes, natural habitats and land use. Although a robust and stable part of the energy mix, the viability of hydropower hangs in the balance. One of the factors that stand in the way of a much broader proliferation of hydropower is its geographical challenges. Rivers are limited to specific locations. Despite its much earlier appearance in the energy mix, hydropower has seen limited growth over the years. It does, however, remain a significant contributor to global energy needs.

Renewables accounted for almost 70% of the nett increase in global power generation; an escalation of 7% on the figures in 2016 (REN21, 2018; also see *Figure 3.3*). By the end of 2017, 402GW of solar PV was installed worldwide; an increase of about 33% (Schneider, 2018). Wind power saw an increment of 52GW bringing the total installed wind capacity to 539GW.

According to REN21, the countries…

> *…leading in wind and solar PV penetration are Denmark (52.9%), Uruguay (28.1%), Germany (26%) and Ireland (25.2%). Several countries and regions integrated even higher shares of VRE (Variable Renewable Energy[4]) into their power systems over short periods in 2017. South Australia generated more than 100% of its electricity demand (load) from wind power alone on one occasion, and 44% from solar PV alone on another. Other examples include Germany (66% of load; wind and solar combined), the US state of Texas (54% of load; wind alone) and Ireland (60% of load; wind alone)* (REN21, 2018b:10).

Several countries have aligned their policies to allow for shifts to RE that are concomitant with their global commitments and national ideals. These bold moves have seen more significant investments into renewables. In 2017, countries such as China increased their investments by 30.7% from the previous year. However, REN21 also makes the following observation:

> *…when measured per unit of gross domestic product (GDP), the Marshall Islands, Rwanda, the Solomon Islands, Guinea-Bissau, and many other developing countries are investing as much as or more in renewables than developed and emerging economies* (REN21, 2018b:7).

The list above is indicative of a broad uptake. Although sporadic, it highlights a growing renewable energy transition by number and by geography.

The global transition figures show a sector that is both vibrant and incremental; one that is posing a challenge to the present status quo and 'forcing' its way despite all resistance. It is indisputable that there is a growing shift towards RE, backed by some

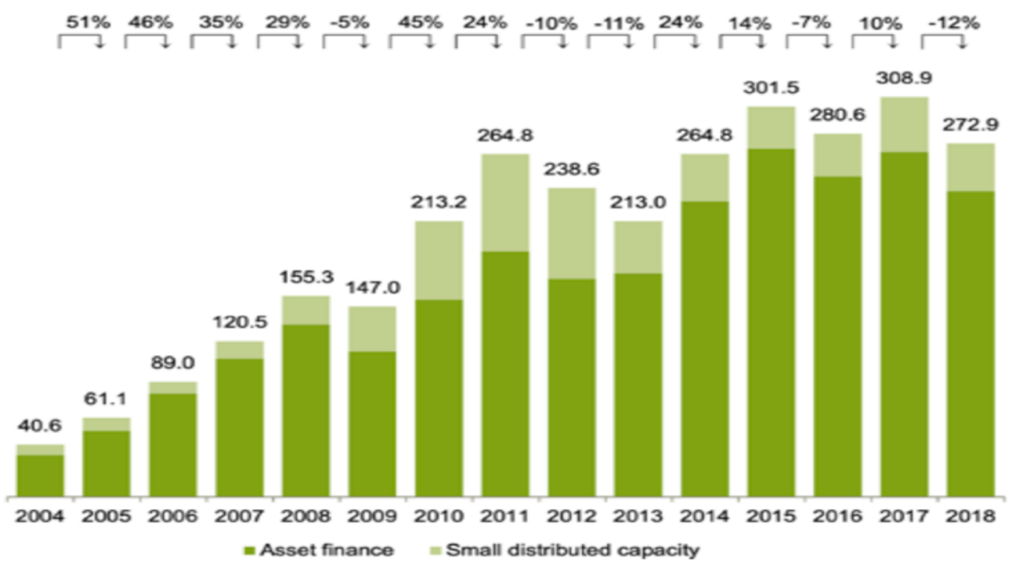
[4] Full form added

very focused commitments from countries that are attempting to mitigate the global environmental challenges. As RE grows it is expected that CO_2 emissions will drop.

3.3.1 Attracting new financing for renewable energy

While figures for actual investments appear in other sections of this study where relevant, this brief section serves to confirm a general growth trend in RE investment and also to highlight new RE finance *(Figure 3.4)*. New RE finance indicates how the sector is becoming attractive to players previously uninterested. Their decisions suggest economic sense and to some extent regulatory policies that channel interests towards RE. Other studies by researchers such as Mazzucato and Semieniuk (2018) have tracked the growth in RE financing and noted a jump from US$45bn in 2004 to US$270bn in 2014, which represented an 18% compounded growth rate. They also noted that net investments in 2014 for RE were twice that of fossil fuels (Mazzucato & Semieniuk, 2018). Between 2010 and 2019, a total of US$2.4 trillion has been invested in new RE products, and solar had more capacity added than any other technologies, whether renewable or fossil fuel (Frankfurt School-UNEP/BNEF, 2019). Given that RE has continued to grow, *Figure 3.4* illustrates how the drop in investment does not equal a drop in installed capacity because of the price drops in RE that make them cheaper.

Figure 3.4: Annual RE investments



Source: Frankfurt School-UNEP/BNEF (2019)

Notably, investments into RE are not just targeting utility installations, but include support technologies and industries. Some new and unprecedented players are joining the RE transition. Corporations such as Royal Dutch Shell acquired the German battery maker Sonnen during the first quarter of 2019, as well as a 44% stake in Silicon Ranch, a solar development company (Motyka, 2019). Shell has been noted to be aggressively investing in RE and is at the forefront of the oil majors breaking trend (Abington & Gilblom, 2019). Other corporations making similar moves include investments in Lightsource by BP as well as Total SA's acquisition of Sunpower' (Motyka, 2019).

This study focuses on the oil majors to highlight the corporate shift and where some of the money is coming from. The RE regime shifts are forcing oil majors to re-imagine their business; failure to change could have a long-lasting negative impacts on their trade. So-called 'oil majors' are not only investing in RE acquisitions but also building utility-scale RE power plants such as ACWA Power (2018). Enel Green was traditionally a fossil fired energy generating business; it currently manages 43GW of RE global capacity out of a total of 89GW (ENEL, 2018). As prices tumble these types of investments are growing in popularity and creating a competitive sector. However, the 'timely' appearance of oil majors looks to be less than fortuitous and more the result of survival and wealth creation. In other words the economics and policies of RE are favouring this. It also implies that financial actors matter in the grand policy discourse (Mazzucato & Semieniuk, 2018). The shift by the majors is pertinent given that in the past the fossil fuel industry borrowed some very sophisticated tactics from Big Tobacco to suppress the true impact of CO_2 and to ensure fossil fuel profits. The parallels are ominous. Despite very clear health risks associated with tobacco known since the 1950s and even earlier, the global mortality from tobacco-related causes is 7 million! [5] Similarly, fossil fuel majors knew about the effects of CO_2 for over 40 years but have concealed the information (Hall, 2015). The entrance of traditional fossil fuel companies into the RE sector is therefore an unambiguous indication of directionality, i.e. a clear shift towards RE especially considering their historical role in suppressing sustainable development. Private funding is also a clear indication of how conducive

[5] See Oreskes and Conway (2010) Merchants Of Doubt. Michaels (2008) Doubt is Their Product: How Industry's Assault on Science Threatens Your Health.

the present RE policies are to the free market economy. Growth in this sector is likely to be led by private investments rather than state sponsored service delivery.

Ongoing innovation and the mass roll-out of solar and wind technologies have enabled price decreases. In 2017 Europe, China and the United States accounted for almost three-quarters of the global investments in renewable fuels and power (REN21, 2018a). In 2018 investment totals (US$288.9bn) were lower than those of 2017, (US$326.3bn according to BloombergNEF), and the decrease can be ascribed to solar power incurring a 22% (24% in Bloomberg, 2019) drop in financial commitments for 2018, resulting in its lowest levels since 2013 (REN21, 2019a). The decline in investment was not due to investor sentiments or shrinking markets, but to a drop in the cost of renewables. A 24% drop in solar commitments counterintuitively translated into record high additions of new photovoltaic capacity, breaching the 100GW threshold for the very first time (Bloomberg, 2019). The argument of falling prices is based on continual growth in the added capacity for RE, with the exception of 2017 and 2018 when it only increased by 3GW (see section 3.3 below). This is relevant because the total investment spent in 2018 was less than that of 2017 (Bloomberg, 2019; REN21, 2018a, 2019a). This means more could be achieved with less. Clearly there is growth in the RE sector and investment flows are on the rise. The following sections explore the main drivers behind RE growth.

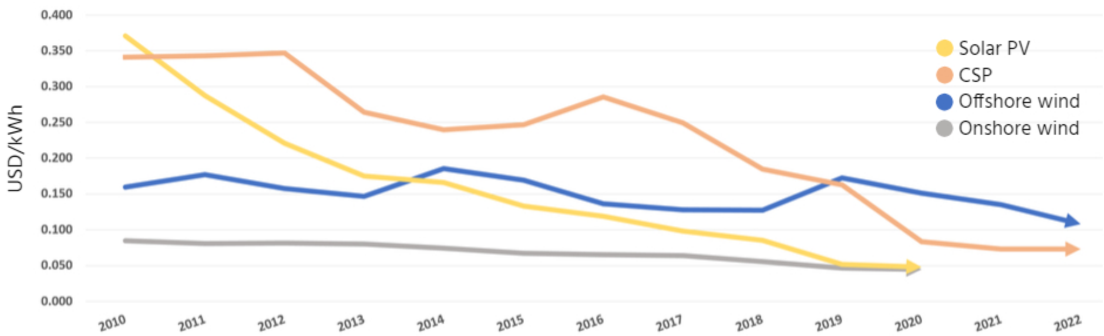
3.4 A Handsome Renewable Energy Price

3.4.1 Plummeting renewable energy costs

In 2018, for the fourth consecutive year, the RE added capacity surpassed all new installations in fossil fuels (REN21, 2019a). At the end of 2018 the fraction of installed global RE capacity was 33% of the total electricity production capacity, accounting for 26% of total generation (REN21, 2019a) due to low RE efficiencies. The costs of RE are in decline all over the world, making RE highly accessible (REN21, 2019a) and attractive. The winning bids for 2017 in Germany were less than US$60 megawatt-hour (MWh) - almost 50% less than the previous two years (IRENA, 2018). The lowest power purchase agreement to be signed in the United States (US) for 2017 was for US$21/MWh (Bloomberg New Energy Finance & The Business Council for Sustainable Energy, 2018). Bids in India, Canada and Mexico came in at approximately US$30/MWh (REN21, 2018a). In that same year, one Mexican tender was below US$20/MWh (Buckley & Shah, 2018) which was the global record low at the time with a 40-50% drop in costs compared to 2016 (REN21, 2018a). Germany also reached its national lowest bid in 2017 of US$45/MWh (REN21, 2018a).

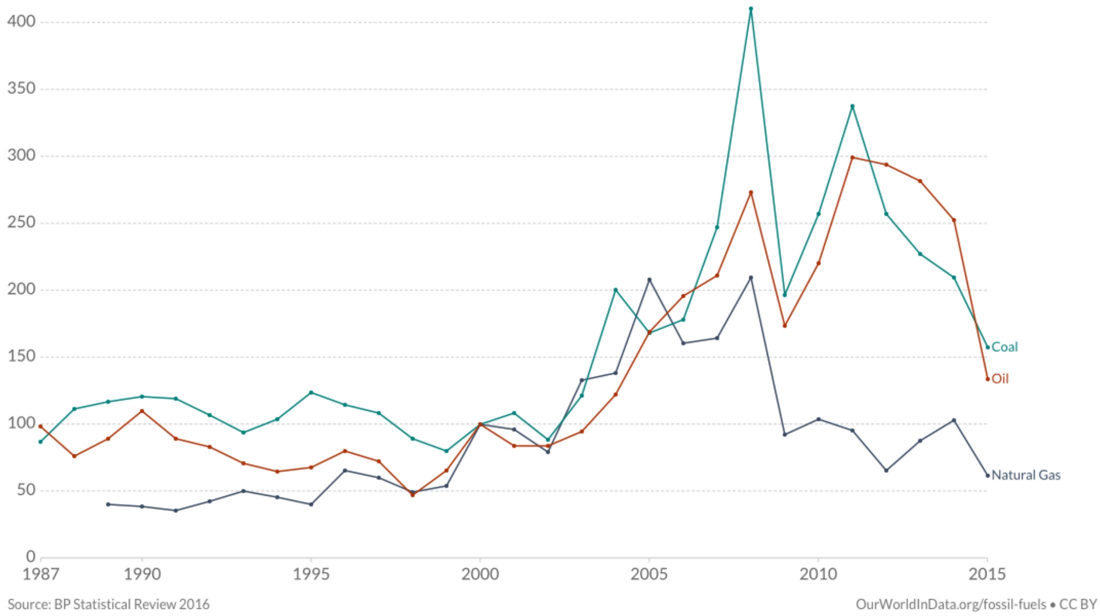
In some parts of the world, the cost of RE is now cheaper than newly installed nuclear energy or fossil fuel generation and in some cases it is even cheaper than established power plants (REN21, 2018a). Since 2010 the cost of producing electricity from offshore wind decreased by 23%, while solar photovoltaic (PV) electricity fell by 73% during the same period, to average at about US$85/MWh (IRENA, 2018, 2019b). Onshore generation from wind now costs about US$60/kWh, with some plants producing for as low as US$40/MWh (IRENA, 2018, 2019b). Fossil fuels are generating electricity on average within the range of US$50 – US$170/MWh (IRENA, 2019b). IRENA projects that solar PV could fall to US$48/MWh and that onshore wind power could cost as little as US$45/MWh in 2020. Much of the cost reductions are attributed to effective policies, changes in the markets, new knowledge and technological advancements. The contrast in the drop of RE costs *(Figure 3.5)* and the steady rise in the cost of fossil fuels *(Figure 3.6)* is clearly depicted. Besides the sudden spikes in 2008 and 2011, the trajectory in *Figure 3.6* shows a steady rise in the cost of fossil fuel, this is in spite of the heavy government subsidies.

Figure 3.5: Renewable energy generation costs



Source:(IRENA, 2020b)

Figure 3.6: Fossil fuel price index 1987 to 2015

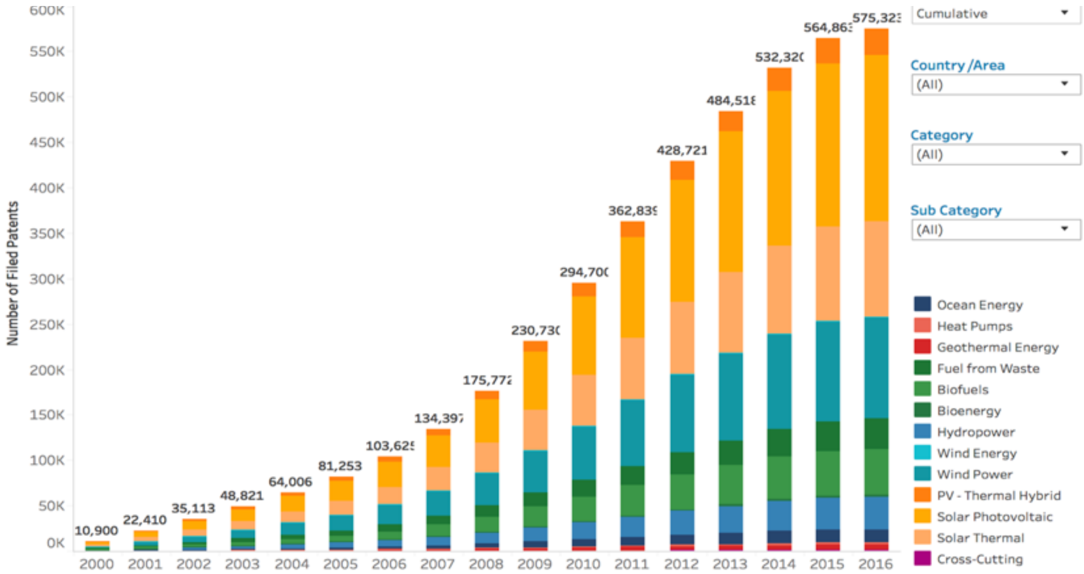


Source: Our world in data, (2016)

The renewable energy price points are making renewables attractive not just from a low carbon transition perspective, but also from an economics point of view. Market forces are proving to be critical in the growth of RE further illustrating how policies (3.6) are supporting the markets and creating conducive environments through various instruments such as subsidies and grants. These market factors that are improving prices highlight an economic focus towards decarbonisation. Pricing is likely to trigger growing popularity for more significant investment in renewables. An increase in investments leads to greater innovation and diffusion. RE is presently flourishing, characterised by the soaring number of developers who seek legal protection for their new inventions *(Figure 3.7)*. This prevalent vibrancy is leading the charge towards a 'new normal'.

3.4.2 Rise in renewable energy patent applications

Figure 3.7: Patents evolution of renewable energy technologies



Source: IRENA (2019b)

Since the year 2000, advancements in RE technologies have increased exponentially. The initial growth was conservative, but from 2006 the number has climbed rapidly (IRENA, 2019c). In *Figure 3.7*, the growth in the number of registered RE patents shows the degree of innovation, and it also highlights new technologies that are likely to come to market. In the space of six years RE patent registrations leapt from just under 11,000 in 2000 to about 575,323 (cumulative) by 2016. While the figures given are comprehensive they are not exhaustive. The registrations are a clear indication of fervent vibrancy in the sector and growth that is a little out of the ordinary. It is a developmental surge.

The escalation in the number of registered patents suggests that much more is happening in the sector in terms of research and development (R&D). This not only supports the idea of substantial development, but also indicates vast flows of investments into the sector. Innovation and R&D are capital intensive in any sector; renewables are no different. The research shows that these investments are made on the basis of some surety that the new technology represents the future's 'new normal'. It is therefore of some significance to understand the investments behind the technological leaps.

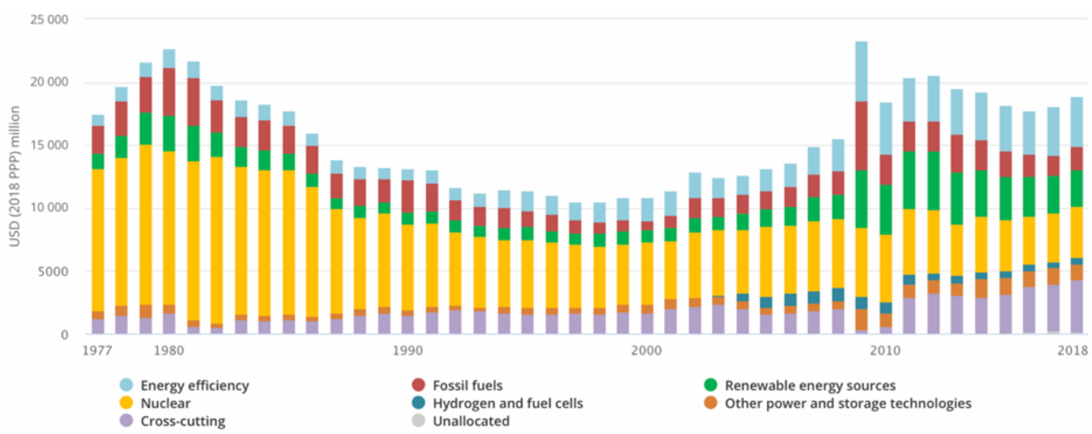
3.4.3 New renewable energy financing for research and development

Preceding the technological R&D advancements described in the previous section, is the capital outlay. This section tracks funding that has been specifically earmarked for R&D purposes. The International Renewable Energy Agency (IRENA) noted that loans, grants and public investments for R&D have consistently been on the increase since 2005. They further state that by 2016 almost 100 countries had adopted such facilities; a number that had risen from a mere 17 countries in 2005 (IRENA & CPI, 2018). During his tenure, former American President Barack Obama proposed an increase in federal allocation towards renewable energy R&D from US$6.4bn to US$12.8bn (Hasan, 2016). This was off the back of the Paris Agreement, where the heads of state decided that each sovereign state should double down on their R&D budgets (Frankfurt School-UNEP Centre, 2018).

R&D is significant to the growth process since it enables the development of new technologies which are better and cheaper. Such technologies are tested and demonstrated in real scenarios. R&D therefore, is the pursuit of knowledge and a vital starting point for future solutions; a platform from which new technologies emerge.

Figure 3.8, shows the R&D investments by member states, tracked by the IEA - a Paris-based autonomous intergovernmental organisation.

Figure 3.8: Total public energy R&D budget for IEA member states

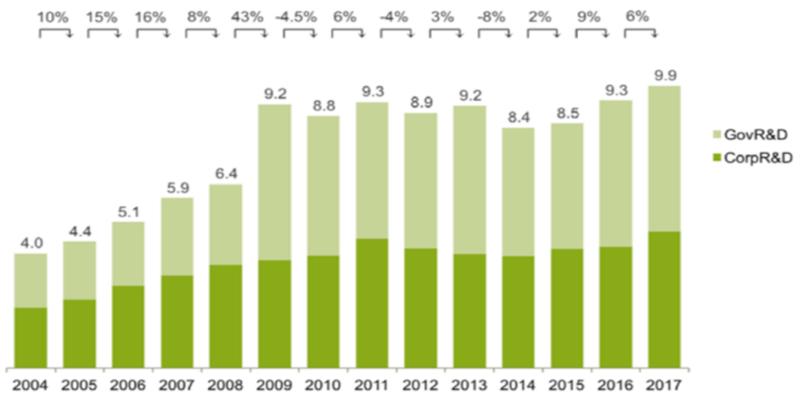


Source: IEA (2019a)

The green colour code represents investments in renewable energy R&D in *Figure 3.8*, showing a steady rise since the early 2000s. According to the Frankfurt School-UNEP centre, which tracks both public and private R&D funding on RE technologies, global budgets grew from US$4bn in 2004 to about US$10bn in 2017 *(Figure 3.9)*. Other sources suggest that this growth peaked in 2013 at US$13bn (UNFCCC, 2017a). Although conservative, the figures confirm a general upward trend in RE R&D funding. Bloomberg reports an overall global investment in R&D by governments at US$15bn for the year 2018; a growth of 4% from the previous year. For private funding, they put the figure at US$20bn (Bloomberg, 2019). The IEA attributes, in particular, the 2018 increase to more significant allocations towards low-carbon technologies (IEA, 2019c). The disparity in the actual figures are pronounced, and this can be attributed to each organisation's area of focus; the IEA for example collects data on government R&D funding from its members. Bloomberg's research arm Bloomberg New Energy Finance (BNEF) has a broader global sweep that analyses both public and private R&D funding. Some significant characteristics to note are the following:

- The portion of R&D spend allocated to cleaner energy has exhibited steady growth. It slumped in 2010-2012 but remains resilient and shows a steady growth pattern. When coupled with other power and storage technologies, which are reported separately, but are developed in support of RE technologies, the renewable energy R&D investment pattern climbs *(Figure 3.8)*. Nuclear has steadily declined in many countries but remains bolstered by Japan’s continued R&D investments that peaked at US$1,1bn in 2018, (IEA, 2019c). Fossil fuels, on the other hand, were on a steady decline since 2013, with a slight reprieve in 2018 (IEA, 2019c).
- Government allocations to R&D for energy technologies that are climate-related such as renewables, energy storage, hydrogen fuel cells, carbon capture, and carbon storage have steadily risen since the early 2000s, fluctuating briefly in the 2010 to 2012 periods. R&D in energy efficiencies have grown *(Figure 3.8)*.
- Government budgets on energy R&D exhibited steady growth from the early 2000s to 2012. The only other time that similar levels of investments in R&D were recorded was during the 1970/80s after the world experienced an oil crisis. At present, the climate crisis has precipitated renewed interest in RE, this time with a more fervent deployment.

Figure 3.9: R&D Investment in renewable energy



Source: Frankfurt School-UNEP Centre (2018)

This section focused exclusively on R&D to highlight the vibrancy of activities at this level. It also gave an account of the herd mentality that is at play as hordes of investors and developers dash for the 'next big thing'. The RE revolution alongside technological innovation is disruptive in the most significant manner. From a techno-economic perspective, the RE revolution is not incidental but purposed, incremental, and a clear indication of a significant shift at play. The data on price, R&D and new patents as presented are highly indicative of incremental decisions that are aggressively leading in a RE regime as the solution to dealing with environmental challenges. It is clear that even as the oil majors and coal barons shift to RE (3.3.1), the pervasiveness of fossil fuels highlighted in Chapter 1 is decidedly being addressed within an economic paradigm. The 'creative disruptive' nature of RE economics is further substantiated by new technologies entering the market.

3.5 Disruptive Renewable Energy Technologies

3.5.1 The leading renewable energy technologies

Solar power, in particular solar PV, is the dominant technology although wind power is narrowing the investment gap (REN21, 2019a). As dominant RE designs, both wind and solar technologies provide direction for further improvement and innovation. The 2018 investment figures support this. Of the US$288.9bn (65% of all new generation capacity - excluding hydropower), US$139.7bn were new investments in solar power (REN21, 2019a). Wind power had investments of about US$134.1bn (REN21, 2019a). The diffusion rate of solar and wind technologies is 'rapid'. In the first quarter of 2019, the leading ‘big investment deal’ was US$4.2bn for a solar thermal plant in the United Arab Emirates (REN21, 2019a). Wind power had US$650 million committed for a 500MW plant in India (REN21, 2019a). These growing investments indicate better technologies as efficiencies lead to better output. Improved innovations make RE appealing. The ameliorated technologies lead to greater adoption of RE, and an increased uptake is hoped to have a direct or indirect effect on overall GHG emissions including CO_2. Some of the most innovative technologies are shown below:

3.5.2 Niche renewable energy innovations

New technologies are being produced all the time. Notably, in 2018 innovators and manufacturers sought to improve efficiencies as well as to bring down the levelised cost of electricity (LCOE). The LCOE is the cost of producing electricity over a period of time. This is often based on the lifespan of the generating system. To improve the RE offering, new records in module and cell efficiencies were realised in 2018. Stability and efficiencies improved on the silicon-based solar cells, rival technologies managed to achieve conversion rates of 20 – 22% (REN21, 2019a). Using perovskite, a calcium titanium mineral, PV technology has advanced to yield a record 28% energy conversion rate (Economic and Social Council, 2018; REN21, 2019a). Bifacial modules that are capable of capturing light from the front and back entered the market, achieving exceptional returns in output (REN21, 2019a). These technological advancements and deployment have numerous social impacts.

Some concepts appear futuristic, but developers are nonetheless advancing with some measure of success, such as a team from the Universities of Cambridge and Ruhr who managed to split water molecules into individual oxygen and hydrogen atoms (Cambridge University, 2018). Goodyear unveiled tyres that charge a vehicle by harnessing the power generated from friction (Goodyear, 2015). Another technological advancement is 3D printed solar trees covered in synthetic leaves made from organic solar cells which can harness solar energy as well as heat and kinetic power when placed outside (VTT Research, 2015). Other advancements include liquid stored sunlight and carbon nanotube electricity that can give off powerful waves of electricity (Earthava, 2019).

Some niche innovations are targeting the subaltern regimes of the RE revolution. The world's first solar-powered laptop was released in Kenya by Samsung in 2011, and although the project appears to have stalled it highlighted many possibilities. In 2016 the Japanese technology company Kyocera, working with Sunpartner a French-based company, introduced a solar charging mobile phone prototype (Bell, 2016; Fincher, 2013; Hartigh, 2011). Since then, solar torches, radios, powerbanks, floodlights, street lights and other novel inventions are gradually becoming ubiquitous (Turman-Bryant, Alstone, Gershenson, Kammen & Jacobson, 2015). In the mobility sector, electric vehicles (EVs) are gaining prominence as the technology improves, soon to challenge oil propelled cars (CompTIA, 2019). This paves the way for the integration of EVs into the new energy systems, as transitions continue in the electricity sector. Blockchain ledgers and cryptocurrency systems are decentralising energy production and enabling the ordinary person to invest and participate in the energy sector (SunEx, 2015). This is a disrupter of the old centralised models that were the reserve of big wealthy corporations. These innovations modernise other sectors of society and boost the RE transitions. They are also indicative of the political and social landscape which is amenable to the idea of ‘greener energy’. While section 3.4 highlighted an economic emphasis towards the RE transition, the present section illuminates an additional focus that is technological. Both perspectives are useful in understanding the current framing of the solutions being put forward. The techno-economic approach is the current paradigm being used to crush the convoluted fossil fuel regime by stimulating RE growth while simultaneously aiming to end dirty fuel supply chains. The corresponding linear assumption is an anticipated end to CO_2 emissions, and as such all policies are geared towards this theory.

3.6 Policies for a Conducive Renewable Energy Environment

3.6.1 Tinkering with policy for a renewables future

A wide variety of policies are formulated at various jurisdictional levels of society which include *inter alia* feed-in tariffs (FIT), renewable portfolio standards, auctions, regulatory mandates, financial support policies, building codes and policies that assist with connecting variable RE technologies onto national grid and energy systems

(IRENA, IEA and REN21, 2018). Many of the policies target the energy sector as well as the technology space and also seek to stimulate financing and investment.

This section gives an overview of various policies and regulatory frameworks that are currently employed and perceived to assist with decarbonisation. It does not zoom in on specific policy topics such as FITs but offers a synthesis of global policies that are enabling and driving change.

Many policy changes that are pro-renewable energy are continually emerging, some of which are ratified at a global level, some at national levels, and corporations drive others. The policies approach the topic from a variety of angles, but mostly with a focus on energy transitions. Examples include regional bodies such as the UNFCCC which lobbies and helps member states with their RE policies. Sovereign states are similarly building policy frameworks geared towards new cleaner forms of energy (Watts, 2015).

Energy is often viewed as the propellant that underpins development and therefore perceived in economic terms, thus narrowing its frame of reference in the transition. The policies below stimulate RE growth by supporting both financial and technological inputs which imply that they are tackling the poly-crisis through techno-economic means. Their inclusion here supports the RE growth hypothesis, but it is prudent to be aware of their techno-economic stance as already highlighted in sections 3.4 and 3.5.

3.6.2 Renewable energy policies at the geopolitical level

> *Achieving sustainable energy development in a region requires rational use of energy resources and technologies and the development of appropriate policies (Mandelli, Barbieri, Mattarolo & Colombo, 2014:656).*

Before the Paris Agreement, there was the Kyoto Protocol credited with the Clean Development Mechanism (CDM) which made provision for the reduction of emissions. Operational since 2006, the CDM is regarded as the first emissions offset instrument whereby environmental investments are credited with saleable certified emission reduction (CER) credits (UNFCCC, 2019). In spite of its potential to mitigate emissions, the programme is widely criticised for loopholes, which may reward entities and projects that have leakages or ones that do not actually reduce CO_2 emissions. Leakages are rises in emissions in other locations despite reductions elsewhere (Dutschke, Butzengeiger & Michaelowa, 2006; Rosendahl & Strand, 2009). Leakages are problematic as the entities in question could be emitting higher or even failing to effect an overall reduction in carbon emissions. Leakages present a challenge because they undermine the CDM scheme and the overall climate action effort. The programme is fraught with registration backlogs and accuracy challenges when it comes to accounting. One of the key goals of the CDM is to promote clean development in poorer countries, as well as benefit such countries (UNFCCC, 2018). The CDM incentives for poorer countries provides a social intervention which attempts to equitably address global poverty. However, Big fossil fuel infrastructural builds taking place in Zimbabwe, Sudan, South Sudan, Angola and Chad (IEA, 2019d; Sguazzin, Marawanyika & Li, 2020; Wright, 2018) suggest that the policy is not as well received. The choice by the abovementioned countries to continue with fossil builds, suggests that they may not recognise the officially stated advantages of the CDM, or that their own benefit analysis identifies even better returns from fossil development. Properly implemented the CDM can lead to sustainable development and make a contribution towards emissions reduction.

The Millennium Development Goals (MDG) were established in 2000 as policy guidelines towards achieving specific social targets. At the time, all 189 UN member states agreed to achieve the target by 2015 (SDGF, n.d.). The 7th MDG's stated aim is *"to ensure environmental sustainability"* (SDGF, n.d.). Although it is not confined to the energy sector, this goal would have been the overarching target that governs renewables; perhaps better considered as the blueprint that sets the pace for appraised energy choices. After the set period for MDGs lapsed in 2015, the Sustainable Development Goals (SDG) were realised during the Sustainable Development summit, and ratified by 194 countries (Nilsson, Griggs & Visbeck, 2016; RIO+20, 2014; United Nations, 2015). The SDGs provide a far greater scope with more detail. They also seek to build on the momentum set by the MDGs. Several SDGs are directly and indirectly applicable to renewables. The more obvious ones are:

- SDG 7 - Access to affordable, reliable, sustainable, and modern energy for all
- SDG 12 - Ensure sustainable consumption and production patterns
- SDG 13 -Take urgent action to combat climate change and its impacts

In all of these cases high-level policies set the tone which stirred world leaders to act within their own jurisdictions. The policies that arise as a result of the global and regional bodies form the blueprint which in turn is agreed to by all the world's countries. A clear example that has been noted elsewhere in this study was the decision taken at the Paris Agreement for all sovereign states to double their R&D budgets for renewables (Frankfurt School-UNEP Centre, 2018) resulting in President Obama’s proposal to increase the American government’s R&D fund (Hasan, 2016). The Paris talks are also synonymous with the INDC commitments by sovereign states to reduce carbon emissions. At a regional geopolitical level, clear efforts to improve energy efficiency and encourage decisiveness are unmistakable. However, the SDGs do not fail to attract their fair share in criticism and for the most part it appears warranted. Some of the censure finds its roots in the original tensions around the use of the term sustainable development, which was made famous by the Brundtland report (World Commission on Environment and Development, 1987). 'Sustainable development' represents a dichotomy created by coupling two words that represent different agendas. There exists an iconic tension between ‘sustainable’ and ‘development’, which has often been referred to as oxymoronic (Spaiser, Ranganathan, Swain & Sumpter, 2017). It is this tension that Kothari (2015) builds upon when it comes to the SDGs by strongly dispelling the myth of growth led development. His simple argument is that all growth is premised on the availability of materials and its extraction. Further, such growth is energy intense and therefore will continue to set the scene for environmental degradation and unsustainability. This becomes a difficulty when Lélé's (1991) view is considered. Lélé sees the problem as one of a literal approach towards 'sustainable development' and this in turn often leads to tensions and confusion. Literally taken, 'sustainable development' simply means development that will last forever (Lélé, 1991). Development as we know it, cannot last forever – the resources we depend on are depleting and when they stop – development stops. However, it is likely that anthropogenically induced disasters may overtake the planet before resource depletion does (IPCC, 2018b). It is this uneasy quandary that underlies the sustained confusion about the definition of 'sustainable development', which impacts the setting of goals and evaluation of their progress.

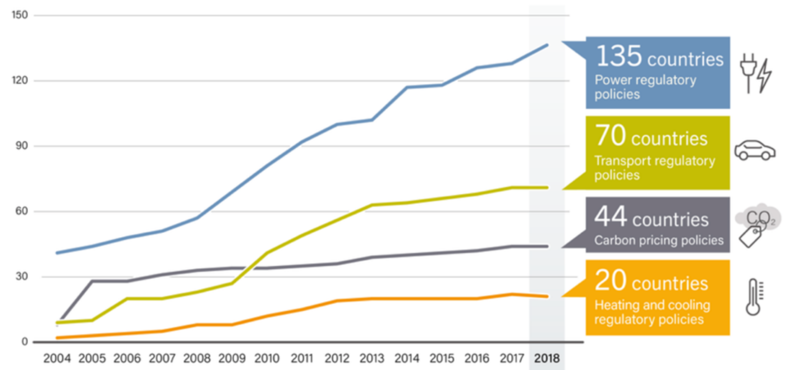
It therefore goes without saying that the concept of sustainable development is a complex one. However, it may be possible to distil some of its most basic and general characteristics, by adopting a systemic approach to the challenges faced. Given this view, the role of geopolitical bodies cannot be understated as they offer a network that synergises the knowledge and efforts of various governments, civic societies, academics, researchers, corporations and other relevant stakeholders. Serving as a repository of policies, they spearhead the RE agenda while offering oversight. This section attempted to capture RE policy in the context of global cooperation and to link them to the broader RE transition. To achieve this, it is essential to further devolve the process to a jurisdictional level of governance, such as sovereign states and progressive cities.

3.6.3 National and sub-national levels taking the renewable energy lead

RE policies appear to be mainly focused on electricity generation, with transport, heating and cooling sectors notably lagging (IRENA, IEA and REN21, 2018) with one exception namely Denmark, the only country in the world that has set a 100% target for total energy derived from renewables (IEA, 2017). This means a complete divestment from all manner of fossil fuels in a comprehensive decoupling exercise. Lithuania committed to 80% of total energy demand being met by renewables by 2050; this was decided after a revision of the nation's energy strategy (Petrova, 2018). While policies from other countries fall short of the targets set by Denmark and Lithuania, according to IRENA, IEA and REN21 (2018), the progress made in terms of renewables over the past decade has been extraordinary, with projections consistently being surpassed and new records being achieved annually. The claim is that a growing number of countries are committing to energy transitions on the back of robust policies, proper planning and ambitious targets (IRENA, IEA & REN21, 2018). The various RE strategies seem to indicate a period of policy maturation at all levels. It is clear that the measures that are being put into place are far more stringent in the promotion and instruction of RE installation, generation and use. However, it is also clear from the disparate uptake of RE that policy consensus is varied. While developed countries drive a stronger decarbonisation agenda, developing countries often have to consider economic growth which largely depends on fossil energies. An overall observation – one which has been alluded to in a number of instances is the economic considerations that drive RE policy formulations, suggesting neoliberal frameworks underpin the process. Radzi and Droege (2014) argue that RE policies are designed to adapt to market fluctuations and socio-economic impacts. Neoliberalism is a largely contentious economic system whose free market principles extend into the public and private domains. In essence it is the state's transition from the provision of public welfare to advocating for competitive markets. The point made by Swilling (2019a) illustrates the dangers of neoliberal practices, as he cautions against the fortification of past social injustices formed by the advent of industrialisation and the free markets. Kothari (2015) makes an impassioned plea, that the more than two billion people living in abject poverty must never be forgotten, as the world "makes peace with the earth". When the markets have more power over human lives and the environment they operate on principles of immolation and profit. The section on RE price *(3.4.1)* clearly demonstrated the profit and cost saving motive that eventually tipped policy and the economy in favour of renewables. On a global scale some of these policies are devoid of local justice in the decisions made about RE. The neoliberal nuances in the current RE policies are many and varied. In many instances they are already demonstrating a challenge in the delivery of low carbon transitions and the eradication of poverty. The global RE transition is repleat with examples of the constrains and enabling environments brought about by neoliberalism. Such examples include the break-up of state owned enterprises, the selling of public assets on account of the political economy of the low carbon transition. This increases the dependency on private actors to deliver public services and goods in a competitive environment. Examples include feed-in-tariffs in Thailand, RE auctions in South Africa and trading incentives in Mexico, which all favour private enterprise (Rennkamp, Haunss, Wongsa, Ortega & Casamadrid, 2017).

It is within the neoliberal policy framework that almost every country in the world has adopted targets for RE, making renewables "*technologically mature, secure, cost-effective and environmentally-sustainable energy supply option to underpin continued socio-economic development, while simultaneously combating climate change and local air pollution"* (IRENA *et al.*, 2018:11). From the time when renewables began taking off in 2004, the number of countries with RE policies rose from about 40 to 135 in 2018 which is a 337.5% spike in 14 years *(Figure 3.10)*. While overall RE policy frameworks vary considerably in scope and broadness, great strides have been made, and much has been achieved. It must however also be recognised that many frameworks fall short of the international climate goals. The shortfalls often suggest the lack of political will, or financial challenges, another reason could also be that these countries felt compelled to endorse such policies without the conviction to fully follow through with them. A total of 145 from the 194 parties to the UNFCCC, who submitted their nationally determined contributions (NDCs) at the Paris Conference, referred to renewable energy, and of those 109 have set quantified RE targets (IRENA, 2017b).

Figure 3.10: Number of countries with RE and carbon pricing policies

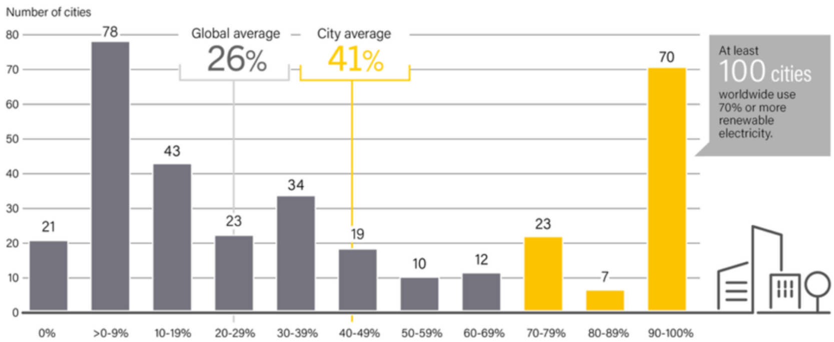


Source: REN21 (2019b)

The quick uptake of renewables is driven by numerous factors which include alleviating climate change, boosting energy security, cutting-back air pollution, and enhancing system resilience (IRENA *et al.*, 2018). Many of the issues highlighted are critical to human wellbeing and survival. Formulating decarbonisation policies is in essence handing humans and the planet a critical lifeline. As more entities realise the value of this, it is likely to lead to further robust policies that are smarter and focused. Decarbonisation policies also highlight an increase in climate literacy and a vested interest in the future of human wellbeing and planetary resilience.

A variety of policies are introduced at national levels to incentivise and promote growth in renewables. As stated, policies differ from one country to another due to specific circumstances and needs. In some parts of the world the uptake continues to be slow, and public funds and incentives are used to stimulate RE activity until such time as private investments can take over (Swilling, 2019a). In other instances, national RE projects have flourished without any government subsidies as in the case of Uruguay (Watts, 2015; WWF, 2014a). Part of the Uruguayan model utilises public and private partnerships which enabled the country to have scaled up to 95% of renewables over ten years, by 2014 (Watts, 2015). Kim and Oh (2017:358) highlight the significance of well-designed public and private partnerships, stating that they have *“enhanced* *energy access in developing countries while accelerating the global transition to renewable-based energy supply to promote sustainable development"*.

Figure 3.11: Renewable power by number of cities and renewable share



Source: REN21 (2019b)

At subnational levels, governments are ratifying policies and setting targets that are more ambitious than their national counterparts, as they play ever more significant climate action roles. In these jurisdictions, cities and provinces are emerging as players at the forefront of the energy transition. They include South Australia, California and the subnational groups of the *"R20[6] – Regions of Climate Action"*, which have set targets that surpass their national governments (IRENA *et al.*, 2018:20). In 2018, 100 American cities set new RE goals committing to 100% renewable energy between 2020 and 2050; the cities include Cincinnati, Cleveland, Denver, Minneapolis and Washington, D.C (Gearino, 2018; IRENA *et al.*, 2018; Minneapolismn.gov, 2018; Sierra Club, 2018, 2019). Owing to earlier policies, several cities had achieved 100% renewable electricity by the end of 2018 (IRENA *et al.*, 2018) - also see *Figure 3.11*.

The cities at the forefront of the renewable energy movement characterise a logical response to the environmental feedback, especially considering that they are on the social frontline. However, the level of social consciousness exhibited by many cities in implementing renewable energy projects, is often encumbered with major issues which require an equitable approach for their just implementation. Unfortunately many such projects are often perceived with much suspicion, which affects how they are received, which undermines their social justice objectives. Much of this mistrust by community member is due to historical injustices. This is better understood through

[6] R20 Regions of Climate Action is a coalition of subnational bodies seeking to implement low-carbon projects and share best practices in renewables and energy efficiency at the subnational level. See https://regions20.org

the analogy of the 'yellow vest protests' in France. Although their protests were against the unfair burdening of tax on the working and middle classes, in addition to the cost of fuel and globalisation (classic hallmarks of neoliberal thinking). The unfair burdening of a segment of society can lead to rejection or revolt (Wong, Shaver, Mackres & Jih, 2020). Similarly policies that appear to unfairly distribute sustainability benefits can intensify social inequalities. Such as in the case of an America project which attempted to increase domestic use of solar by offering tax breaks and other incentives, which only benefited the wealthy property owners with dispensable funds, access to credit and tax equity (Shaver & Shea, 2020). In South Africa, four of the major banks offered an incentivised loan system for home and small businesses to adopt solar (de Villiers, 2019).

Some major cities such as New York, London and Tokyo have GDPs that are greater than some G20 countries (REN21, 2019b) which means that they are responsible for a significant amount of CO_2 emissions. They therefore carry greater responsibility when it comes to addressing climate change. Their vested interest is far more evident when they buck the trend of their national governments by committing to better targets while acting with measures that are substantially more ambitious and achieving significantly greater results. Clearly, in some cases these cities are not just legislating but are also ratifying and enacting additional mechanisms and fiscal incentives as part of their support strategies towards RE. These structures of government create conducive environments for all citizens, including corporations who have become active in matters of climate action and sustainability.

3.6.4 Corporate citizens crafting renewable energy policies

Funding borne out of corporate commitments for RE projects amounts to billions of dollars (IRENA *et al.*, 2018). Typically such investments are backed by advance purchase agreements, and RE policies mitigate the investment risks. On occasion, some companies unilaterally implement their policies where public strategies are lacking (IRENA *et al.*, 2018). Such companies may even qualify for tax incentives or benefits from other RE policies within their territories. Examples of companies that are leading the way, include influential entities such as IKEA, which operates in 28 countries; ABInBev, the world's largest brewery found in 50 countries; Barclays, which operates in 40 countries, Facebook, Google and 186 other corporations who have committed to 100% renewable energies (RE100, 2019). Of the 186 companies, 37 have reached 95% of their goals (Heuvel, 2019).

Multilateral development banks (MDB) like The World Bank and financial institutions such as Nedbank and Old Mutual (South Africa), Amalgamated Bank (USA), Alternative Bank (Switzerland), Bendigo and Adelaide Bank (Australia), have made decisions to stop financing all fossil fuel projects. Alongside financial institutions, numerous other divestment initiatives and policies are nested in a wide variety of groups such as faith-based organisations, various levels of government, educational institutions, philanthropic foundations, non-governmental organisations, for-profit corporations and healthcare institutions (Go Fossil Free, 2019). In July 2018 Ireland fully divested from fossil fuels, becoming the first country to do so, and New York City committed to divesting US$189bn of the city's pension funds within five years (Oregon Senate, 2018). Globally, US$9,20 trillion controlled by some 1081 institutions has been divested, and approximately US$5,2bn controlled by 60000 individuals has also been divested (Go Fossil Free, 2019). Citizens, entities and other political structures are not only making utterances about decarbonisation, but finding the resolve to act. However, resistance to divestments has also been great, such as in the case of the endowments of some leading universities, who have remained steadfast and unwilling to divest from fossil fuels (Mufson, 2020). The endowments in question maintain their fossil fuel investments because they are highly profitable, yielding handsome returns for the universities. Fossil fuel subsidies are covered elsewhere in this study *(section 4.8.2)* and they demonstrate a sector that is financially non-viable and in need of state support. The state subsidies give the impression that the lucrative returns enjoyed by the universities are a misnomer. The subsidies that keep fossil fuels viable are a crutch which artificially sustains the global economies and subsequently benefits the energy companies. Therefore it stands to reason that the ‘propped’ dividends that flow from energy profits also find their way to the universities.

Other policy challenges have been in the area of continued fossil fuel investments. While China is reducing its commitments to fossil fuels at home, in Africa it is counteractively investing in fossil-fired plants. New fossil fuel builds have been funded in Zimbabwe, Sudan, South Sudan, Angola and Chad (IEA, 2019d; Sguazzin *et al.*, 2020; Wright, 2018). While growth in RE is considerable, it is also undermined by policies that counteract these efforts. Such policies are misaligned to the global climate action and highlight the resistance which means that present RE growth policies do not offer sufficient incentives to all stakeholders.

3.6.5 A final word on price, policy and new technologies

From considering the three critical factors of price, technology and policy, it can be deduced that there is at present a rapid RE transition in progress. A triangulation process has allowed the researcher to investigate price, policy environment and new technologies, which together distinctly demonstrated a global RE revolution at hand. Pricing gave a clear indication that there is a favourable price point which is currently driving wholesale investments towards RE technologies and a new regime dispersion. The second aspect of the triangulation process recognises new technologies that are entering the market. The third focused on policy. A good set of governing policies accurately informs law, and good laws are the benchmark for regulation. If policy, laws, or regulations, are deficient or absent individuals and business are likely to do what is most convenient to their interests, often at the expense of other members of society (Schubert, 2016). Investigating price also illustrated that the viability of renewables is largely considered from an economics angle. Prices have to drop before significant growth can be expected. Decisions to support RE have become incremental on the basis of favourable economic conditions. In spite of a clear surge in RE, the question of the impact of renewables on the environment lingers. The section that follows addresses the impacts of growth in RE on the global climate action agenda.

3.7 A Little/small Matter of the Climate Crisis

3.7.1 Current climate action confounds the science

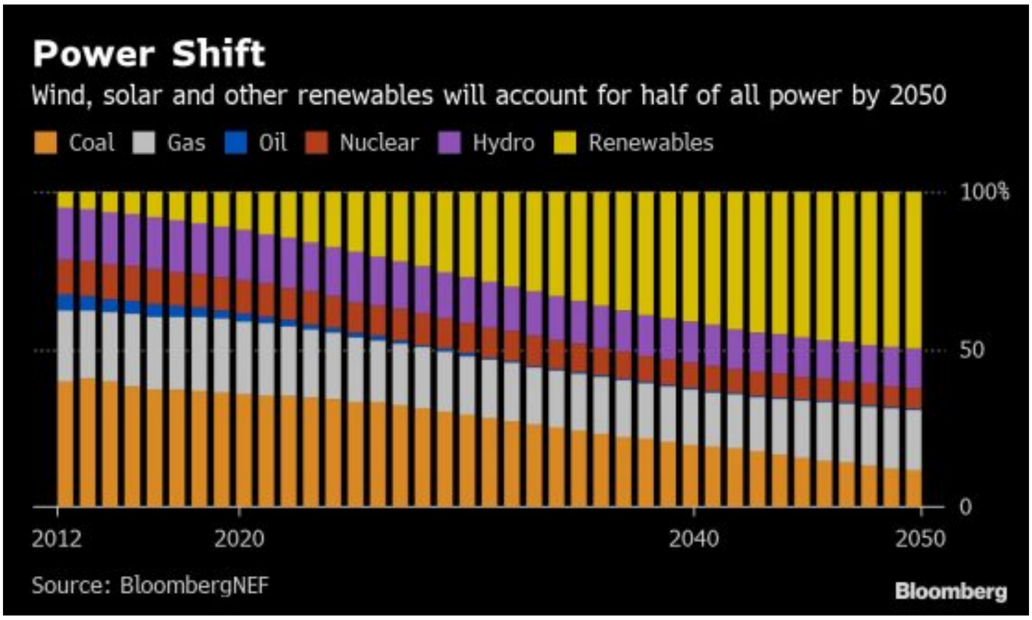
Despite the aggressive expansion in renewable energy installations, fossil fuels have maintained moderate growth, reinforcing the weight of humans on the planet. However, it is also notable that there is a shift, and that fossil fuel growth is gradually tapering off in favour of renewables *(Figure 3.12)*. Swilling (2019a) predicts that it will take some time for the shift to be fully realised. He points out that the global economy and society are still deeply mired in fossil energy; energy underpins the very existence of humanity, every aspect of life is tethered to it, and nothing can exist without it. Energy in its many forms enables the extraction of materials, powers the processes that transform them from raw products to consumable goods, and enables the final disposal of material waste which is no longer useful. Szeman in Garrigou (2016) puts it in this way:

> *We have to understand that we are fossil fuel creatures all the way down. Our expectations, our sensibility, our habits, our ways of being in the world, how we imagine ourselves in relation to nature, as well as in relation to one another — these have all been sculpted by and in relation to the massively expanded energies of the fossil fuel era.*

Szeman is illustrating the difficult task that lies ahead in giving up the 'comforts' of the fossil fuel regime and making the transition to a cleaner, green energy source. Several reasons validate the statements made by Swilling, Fouquet and Szeman, one of them being sunk costs for fossil fuel infrastructures. Investments that have been sunk into previous technologies make it a challenge to transition on a whim (Kemp, Schot & Hoogma, 1998). Investments into utilities such as power plants are furthermore often significant and require the lifespan of the utility in question to pay them off with proceeds from consumers. Any transition which takes place before a power plant's incumbency elapses leaves the state, power company and its citizens encumbered with the remaining costs that are still due.

Other factors that make the task difficult include political will and inadequate policies addressing the transition (IRENA *et al.*, 2018). Former South African Minister of Energy, Jeff Hadebe, stated in a speech that renewable energy is key to cutting GHG emissions in line with the undertaking to the Paris Agreement (Gosling, 2018 quoting Jeff Hadebe). However, based on a 1.5°C scenario, the Paris Agreement's forecast for total decarbonisation is likely to only happen after the year 2050 (COP21, 2015). Other organisations and scholars confirm a similar sequence of events (BMUB, 2016; European Commission, 2018; Govt, 2018; IRENA, 2017c; Roadmap 2050, 2019; State of Green, 2018; UNFCCC, 2017b). While admirable, the decarbonisation narrative does not appear to harmonise with the science. It falls far short as it confounds the data, and if allowed to follow this pathway, the planet is heading for disaster (IPCC, 2018a). An inadequate RE installation process will result in the continued seepage of dangerous levels of CO_2 into the atmosphere and rising planetary risks.

Figure 3.12: Energy transitions - the power shift

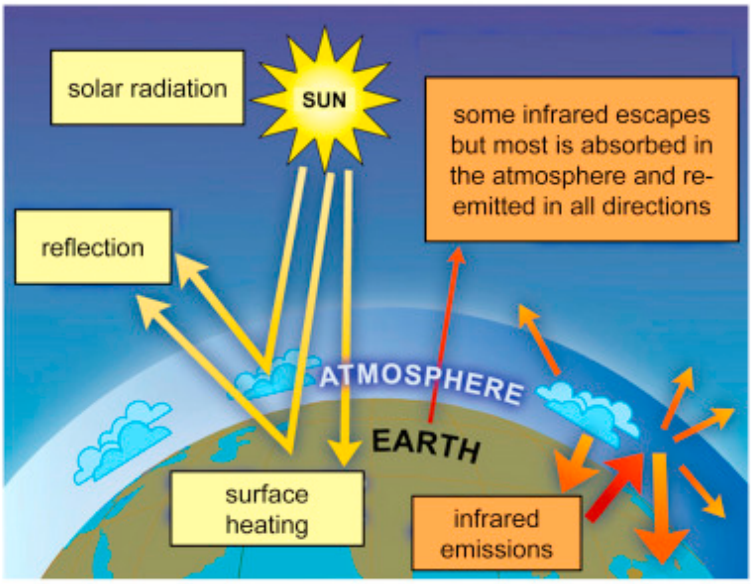


Source: BNEF (2019)

3.7.2 Resilient carbon emissions in the face of renewable energy

An earlier section *(1.5.1)* clarified why this study focuses on carbon emissions and atmospheric carbon concentration levels, given that there are many factors that influence global warming. Carbon appears as the sixth element of the periodic table (Shaik, Cremades & Alvarez, 2019). It is unique from all other elements, largely due to its higher than average ability to bond with a variety of other atoms and form other compounds (Miller, 2019). One of those compounds is carbon dioxide – a gas which is formed when carbon combines with two oxygen atoms. Carbon dioxide is vital to organic and life processes – such as photosynthesis. It is exclusively tracked by a single indicator derived from its concentration in the atmosphere, and it is vital to managing the earth's energy balance. This makes carbon critical to all life. Where that carbon is stored determines the impact that it has – meaning it can be a blessing or a curse. The volume of carbon on the planet remains consistent. It is neither created or destroyed – it is merely displaced and stored either in the earth's atmosphere or some object or living being. One of the ways it is displaced is through the combustion of biomass or fossil fuels, which release the carbon into the atmosphere. The reversal of that process is its sequestration through plants, which take in CO_2, store the carbon and release oxygen. The focus of CO_2 as an agent for climate crisis appears largely to be driven by concerns around reversibility of its concentration levels and climatic impacts. As mentioned in *section 1.5.1* - the demonisation of CO_2 or the heavily carbon-centric approach to climate action, is not the focus of this study. However, it is to be noted that the science behind the greenhouse effect has been instrumental in capturing the attention of scientists, politicians and society. The greenhouse effect has also cemented the relationship between CO_2 and climate change, and the contentions that surround it. Be that as it may, it is broadly accepted that solar radiation freely enters the earth's atmosphere heating the surface. The radiation is reflected off the surface as infrared and much of it is trapped by the CO_2 and water particles in the atmosphere, producing a blanket like effect that keeps the earth warm. Without this natural process temperatures would plunge to below -18°C (Nasa, 2011). In the sense that it is described above and depicted in *Figure 3.13* carbon is a blessing.

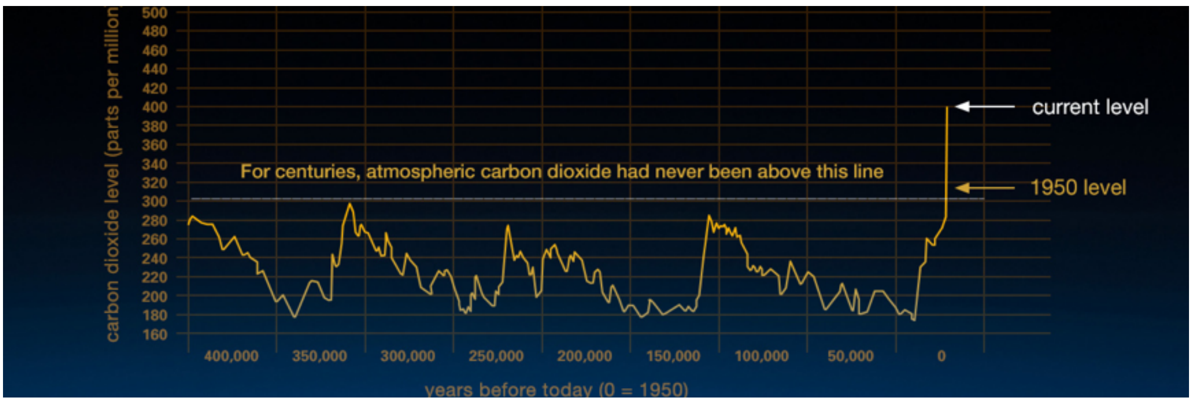
Figure 3.13: The Greenhouse Effect



Source: Anderson, Hawkins and Jones (2016)

A carbon curse is unleashed when elevated levels of CO_2 amplify the earth's natural greenhouse effect. Excess CO_2 emissions trap more heat and increase temperatures. When more heat than necessary is trapped – the warming effect that prevents the planet from plunging into sub-zero temperatures impacts on the present natural balances, leading to melting ice, rising sea-levels and climate challenges. Pre-industrial CO_2 levels were approximately 273 parts-per-million (PPM) (Steffen *et al.*, 2007). These figures subsequently soared to 310 PPM in the 1950s (Steffen *et al.*, 2007). A time which coincides with the great acceleration *(Figure 1.3)* after world war two as western nations developed and energy use spiked. Before the PPM spike that is associated with the great acceleration, carbon concentration levels show a rise that breaches a threshold never surpassed before. The rise appears to coincide with the onset of the industrial revolution. In 2013 CO_2 levels surpassed the 400 PPM mark for the first time in history (NASA, 2019a). As of February 2019, CO_2 concentration levels were 411,75 PPM (CO_2, 2019). Since 2013 the levels have risen by 12 PPM, meaning that it goes up by about 2 PPM per year. The yearly increase in the PPM levels also coincides with the rising temperatures. The rise in carbon emissions closely relates to the burning of fossil fuels, and concomitantly the soaring PPM levels couple with global warming levels. As already mentioned, CO_2 naturally traps heat, and for this reason elevated CO_2 levels in the atmosphere translate to greater heat captured which leads to higher levels of global warming. The temperature of the earth is a vital sign of health and science is saying that it is continually rising. Climate action is an attempt to lower the rise in temperature and stave off climate change. The continual rise means PPM levels remain high in spite of the installed capacity of RE being relatively high. This could be the result of a natural delay in the reversing of the carbon concentration in the atmosphere. It may also accentuate how the focus on CO_2 emissions is too narrow to have any immediate effect on the crisis. The result is the on-going climate change. Climate change is threatening all forms of life. Research by the IPCC (2018b) points to severe impact on the earth's life forms and its ecosystems. Human systems are not spared. The crisis dramatically affects social well-being and the quality of human life.

Figure 3.14: The relentless rise of carbon dioxide levels



Source: NASA (2019)

The IPCC (2018) report states with high confidence that human-triggered global warming has already resulted in notable changes to the climate system, and highlights the negative impacts on ecosystems and organisms, including adverse shocks to human systems and general wellbeing (IPCC, 2018b). The report details a surge in magnitude and frequency of impacts based on an increased global mean surface temperature (GMST), which rose to 0.87°C in the 2006 – 2015 period (IPCC, 2018b) relative to 1850 – 1900, when it was estimated to be about 14°C (Earth Observatory NASA, 2019). If the status quo continues, it is certain that the GMST will also persist in rising and ultimately surpassing the 1.5°C and 2°C targets. This clearly indicates the lack of a causal link between RE growth and decarbonisation. It suggests that other necessary interventions which require attention to achieve any form of low carbon transition, are being overlooked. Perhaps a critical nuance worth considering in the decarbonisation discourse are carbon budgets. The issue of buy in and participation might be better addressed from this angle, especially as they pertain to equity.

3.7.3 Carbon Budgets

A carbon budget is defined as the acceptable upper threshold of total GHG emissions, that can be acceptably emitted over a prescribed period of time. The budget must be within the prescribed scientific boundary that is in line with keeping global warming tolerable and thus climate change bearable. Carbon budgets are important because they help in formulating policy, projection of future climate change and to understand the carbon cycle. Carbon budgets present the baseline for the common governance of the ‘environmental space’ and ‘development space’ that is still available, in other words they provide a very clear way of understanding what is still feasible and what is not in terms of emissions (Baer, 2002). As of January 2020, to ensure a 50% likelihood of maintaining warming below 1.5°C the carbon budget is a mere 500 $GtCO^2$ and for a 66% probability it is 340 $GtCO^2$ (IPCC, 2018a). At the present rate of global carbon emissions (about 40 Gt/yr) it is estimated that the budgets allow for about 8.5 or 12.5 years before the onset of adverse weather conditions. Carbon budgets pave the way for the equity debate. This section does not purport to do this extensive topic justice, but it introduces some of the nuances that ought to be considered in the decarbonisation discourse. This section covers the topic in a very narrow approach, but it is highly crucial.

3.7.4 The argument for equity

Equity has been introduced in previous sections of this study; this section further explores the concept bringing it into sharper focus in greater detail. Höhne *et al.* (2014) argued that policies based on equal cumulative per capita emissions (carbon budgets) would lead to stricter reduction targets. Thus, the targets set would be adequately commensurate with climate goals. In 1990 the Organisation for Economic Co-operation and Development (OECD) advocated for adoption of the *"equity principles of responsibility"* based on need and capacity (Höhne *et al.*, 2014). The idea of carbon targets and equitable responsibility should be inextricably linked in global policy making for a low-carbon transition.

The UNFCCC proposed a Common But Differentiated Responsibility (CBDR) approach, however, world leaders have failed to put together a common plan (Yedla & Garg, 2014). Both the Kyoto Protocol and Paris Agreement have remained largely restricted to voluntary pledges (IRENA, 2017b; United Nations Framework on Climate Change, 2015; Wang & Chen, 2019; Yedla & Garg, 2014). One of the key issues around the equity discourse has been – who should bear responsibility for the state of the environment. Industrialised countries contend that developing countries must adopt legally binding emission targets, while developing countries insist their developmental goals must be recognised, and therefore should be exonerated from legally binding emission targets. Developing countries further contend that industrialised countries are the drivers of climate change and therefore need to take the necessary steps to mitigate. Clearly the equity action plan is a contentious issue in the global decarbonisation debate, however, it is imperative.

3.7.5 A few approaches in equity towards inequity

There are several approaches that policy makers could consider for equitable management of low-carbon transitions. Among these are the adoption of 1850 as the baseline in analysing historical carbon use and responsibility (Baer, 2002; van den Berg, van Soest, Hof, den Elzen, van Vuuren, Chen, Drouet, Emmerling, Fujimori, Höhne, Kõberle, McCollum, Schaeffer, Shekhar, Vishwanathan, Vrontisi & Blok, 2020; Yedla & Garg, 2014). The 1850 baseline brings to light how industrialised countries have for over 160 years overspent their budget allocation (Baer, 2002). The historical carbon overuse has resulted in a large climate debt towards developing countries. One of the strengths of the 1850 approach, is that it not only considers present and future CO_2 reductions, but it also takes into account who has benefited and is therefore responsible for the historical overuse of the environment (Baer, 2002). Aside from the 1850 baseline approach, another cardinal argument pits GDP vs per capita emissions.

3.7.6 Allocating emissions rights in proportion to Gross Domestic Product

It has been argued that emission rights should be allocated to GDP, in other words the higher the GDP of a country, the higher its emission rights. A study done by Yedla and Garg (2014) illustrated how GDP emissions favour industrialised countries. The GDP argument is further shown to be unethical when one pays attention to Yedla and Garg (2014) who assert that CO_2 emissions have traditionally been the product of wealth. It therefore stands to reason that allocating permits to industrialised countries with a higher GDP would be rewarding them for their historical pollution. It may also incentivise them to keep polluting as an unintended consequence. Baer (2002) argues that it incentivises the use of allocations efficiently (in the reduction of emissions per GDP). The policy appears to be an attempt at attracting developed countries to buy into it. The GDP argument complicates the equity discourse on who should play a leading role in mitigating climate change. Baer (2002) also argues that wealthier countries would greatly benefit from the highest allocations, which would exacerbate inequality. Poor nations would suffer injustice due to not being able to utilise as much fossil energy just because they are poor. Baer (2002) argues for per capital rights.

3.7.7 Allocating emissions rights per capita

Baer (2002) cites the environment as a universal 'commons', which is essential for human wellbeing. He further contends that everyone ought to have 'use' rights as well as decision-making rights. Some have argued that this approach is an incentive for some countries to grow their population in order to enjoy a higher allocation. Per capita's consideration of each individual's rights is a far more ethical approach, that does not merely reward wealth, but it acknowledges each human life intrinsically. There are other approaches that are nuanced in their own way and have major implication for society with their own pros and cons and they include:

- differentiated responsibilities and respective capabilities

- The emission gap as per UNEP
- The transfer of finance and technology from developed to developing nations

In 2014 Yedla and Garg, argued that both industrialised and developing nations are breaching the global per capital budgets estimates that were set for the next 40 years. They recommended that industrialised countries reduce their emission to meet their budgets, while developing nations utilised their development allocation to guide their growth pathways. Their proposal is in sharp contrast to Kartha who in 2019 referenced the 1850 historical responsibility approach, and suggested that all emissions need to go to zero. He suggested that the most privileged of our societies – those who benefited the most and attained high levels of prosperity by burning a lot of fossil fuels, must put an end to their emissions. He also argued that they simultaneously subsidise the rest of the planet, by supporting the less privileged who utilise less and emit less to zero their own emissions. Kartha's proposal is audacious yet it fairly exonerates those who are disproportionally affected, while helping them meet achieve environmental sustainability. It also proffers the potential to meet developmental goals in ways that are less destructive and yet equitable in every way. Whether one chooses to adopt Kartha or Yedla and Garg, the two scenarios illustrate the complexities that are involved in the geo-political debate, to establish the most appropriate approaches to dealing with the CO_2 crises, as well as to deal with the equity challenges.

This section did not attempt to address all the nuances of equitable emissions rights, but it merely sought to point out how they are vital to the overall agenda and that any low carbon transition must factor them in. The decarbonisation agenda is highly complex and in thinking about eliminating CO_2 emissions it must conder the fundamentals on equity. These cannot be overlooked. Whatever shape or form they take they must be ethical, represent fairness and look beyond the decarbonisation agenda to social issues. The initial challenge will be to define equity in the climate action discourse. The lack of consensus is helpful in understanding what is hampering progress and in helping to steer policy makers in the right direction. Continued failure increases the likelihood of environmental calamity as noted in the 2018 IPCC report.

3.7.8 A troubling report from the IPCC

The IPCC (2018d) report crystallised what is already known about the plight of planet earth. It states that humanity has until 2030 (10 years) to dramatically reverse human impact on the planet to avoid climate-related risks; during this period humans need to cut GHG by 60% from current levels (IPCC, 2018a). Renewable energy generation would have to scale up by approximately 500% to reach about half of the global electricity requirements by 2030 (IPCC, 2018a). In other words, society has approximately 10 years to sufficiently decouple from fossil fuels. However, in the long term some of the most educated guesses suggest that a complete transition could take well over 100 years (Schot & Kanger, 2018). Failure to reduce the rate of carbon emissions and to apply lower, stricter carbon budgets puts the planet well within the ballpark of the misfortunes outlined by the IPCC report.

Primarily the carbon budget programme which is based on the upper threshold of 2°C warming is effectively challenged by the IPCC (2018a) report. This goes for any climate action that is based on a 2°C scenario *(Figure 3.15)*. The report strongly advocates for some radical shifts in order to stand a 66% chance of mitigating risk based on a 1.5°C scenario. In the very likely gamble that society can achieve 66% mitigation, the remaining 34% scenario will still result in inclement weather and lead to mortality for millions of people (IPCC, 2018b). This confirms that a 1.5°C scenario still falls short of steering clear of climatic disaster (IRENA *et al.*, 2018); more so when it is conceived and the adoption of RE is only acceptable on the basis of cheaper price, which invariably puts economics ahead of socio-ecological factors.

Figure 3.15: Ceres framework based on 2 °C scenario

Source: Ceres (2016)

The likelihood of a majority of global geopolitical bodies, governments, organisations and individuals, who based their climate action on the 2°C scenario is high. Just as the IPCC (2018a) report challenges carbon credits, all climate action still based on an upper 2°C scenario falls short of the target. The other challenge concerns those entities that are presently locked into infrastructures and technologies geared towards a 2°C framework. This threatens the decarbonisation project and makes the projected timeframes very critical due to the planet already bearing the brunt of adverse weather systems. Global warming is already affecting ecosystems, human lives and the planet. If human lives and the planet are to matter, it seems that the economics of energy need to be re-evaluated.

3.7.9 Adverse weather conditions

The first six months of 2018 started off cooler than those of previous years, and as the year progressed it became the fourth warmest year on record due to a continuing warming trend (Hausfather, 2018; NASA, 2019b). A WWF (2014) report warns that Africa is likely to get much hotter than it already is. Using South Africa as example, the report states that if the current levels of CO_2 emissions do not ease-up the country is likely to get between 1-2°C warmer for the coastal areas and 2-3°C hotter in the interior by the year 2050. Beyond 2050, these levels increase to 3-4°C for the coast and 6-7°C for the interior (DEA, 2010). This sequence of events render the issue highly critical and in need of corrective attention. The already surpassed pre-industrial temperatures have resulted in very negative consequences.

An estimated 4.2 million deaths occurred prematurely on the planet in 2016 due to excessive levels of ambient air pollution (WHO, 2018). The pollution was at least two and a half times above acceptable levels which affected more than half of the urban population (WHO, 2018). Fine particulate matter in the atmosphere surpassed the World Health Organisation's (WHO) safety standards, exposing about 91% of the world's urban dwellers (WHO, 2018). In 2017, C40 Cities revealed that 70% of their member cities had been exposed to adverse conditions which were directly connected to climate change (C40Cities, 2017). Given the rising global population and ever-increasing energy demands, such reports are becoming the rule rather than the exception. While it may take some time before climatic conditions reverse, a decarbonisation effort should translate into a plateau based on curtailed greenhouse gas emissions. Instead the opposite has been true; the weather has continually become inclement, even over the last 16 years since renewables have re-emerged on the energy scene. Projections that have been modelled based on current conditions continue to forewarn of pending adverse risks and related climatic shifts (IPCC, 2018b; IRENA *et al.*, 2018; Pidcock, 2016).

Some low-lying island states as well as mainland coastal areas are already experiencing the negative impacts of climate change as water levels rise due to melting ice (Lewis, 2016; NASA, 2019a; Pidcock, 2016; Schleussner *et al.*, 2016). Compared to the year 2000, sea levels could rise by about 40cm by the year 2100 (Schleussner *et al.*, 2016). Extreme heatwaves are projected to last up to 1.1 months, owing to a 1.5ºC scenario (Pidcock, 2016; Schleussner *et al.*, 2016). Heavy rainfall will adversely affect the high northern latitudes, with the Mediterranean expected to experience the complete opposite as water scarcity sets in (Pidcock, 2016; Schleussner *et al.*, 2016). Compared to levels seen between 1986 – 2005, it is projected the Mediterranean will suffer climate-induced rain shortfalls of 9%, and a 2ºC scenario doubles the shortfall to 17% (Schleussner *et al.*, 2016). This is a significant occurrence, given the timeline between the nosediving rainfall patterns and the soaring climatic conditions, especially when compared to the re-installation of renewables and their present rapid diffusion.

It has been illustrated elsewhere in this study, that renewable energy re-installations occurred from around 2004 (REN21, 2019) and that at the same time the number of countries adopting pro-RE policies grew by a magnitude of about 337% (REN21, 2019b), the R&D for new RE technologies took off from the early 2000s (IEA, 2019a), but the rainfall patterns in the Mediterranean started to dwindle from about the same time. These are impacts resulting from preceding emissions and the resultant climate change, and even though RE installations grew over the last few years, they have failed to make an impact on the negative rainfall patterns to date. While it can be expected that it may take time to see any form of climatic reversal from adverse conditions due to a lag between carbon concentration levels and the climate, the prevailing logic appears to be an expectation of a significant drop in CO_2 emissions. This expectation is compounded by a 16-year RE growth that has resulted in 33% of installed capacity. In spite of this, emissions have remained resiliently high with some respite during a few notable intervals. This inability to produce any notable or desired effects is counterintuitive and challenges the present reference points that are influencing and guiding policy for climate action, especially the energy transition. Clearly much more needs to be done to grow RE and to reduce CO_2 emissions.

3.7.10 A stubborn fossil fuel regime

The global consumption of all fossil fuels in 2017 was 134TWh (Ritchie & Roser, 2018). The share of electricity produced from fossil fuels in 2015 was about 65.24% (Our world in data, 2019). Despite the renewed interest in renewables, which began in the early 2000s, the fraction of electricity from fossil fuels hardly changed between 2005 and 2015 *(Figure 3.1)*. The gradual rise of renewables at that time failed to displace the fossil fuel portion of electricity generation. Some likely explanations are that fossil fuels also grew as RE increased, or that RE merely displaced nuclear power which was on the decline. Fossil-fired generation plants also tend to be unaffected due to sunk capital costs which force them to overlook any new technologies and other energy sources.

The energy sector as a whole encompassing both traditional fossil fuels and new renewables appears to have entered a period of uncertainty. What this chapter is uncovering are 'mixed signals' on the state of energy. While renewables are staging a firm 'offensive' against climate change and dangerous emissions, the roll-out in its present form is failing to decarbonise and is therefore insufficient to mitigate risk. The growth of renewables appears certain; however, the data also demonstrates CO_2 resilience. Fossil fuels remain steady. RE is critical to ensuring a sustainable future, but it is also dependant on the decline of fossil fuels. It is clear that decarbonisation needs to be conceived in a far more complex approach. If the fossil fuel grip and its resultant problem is wickedly complex, then it is likely that a limited frame of reference could fall short of a solution. A more complex conception of the solution, which avoids limited reference frames, may be better suited.

3.8 Summary

Chapter 3 set out to investigate the global RE transition. The objective was to consolidate data on the scale of RE growth and to probe its drivers. The research also sought to gauge the level of impact that RE expansion has on CO_2 emissions. This study was premised on the general understanding that a radical energy transition is underway. A colossal increase in renewables was evident from the analysis. The study found a clear indication of favourable price points driving wholesale investments towards RE technologies and stimulating the growth of a new energy regime. Not only was there evidence of growth in global RE installations, but there was also clear substantiation of new technologies entering the market, supported by a variety of policies. However, the growth in RE appeared to fall short of decarbonisation efforts. The study showed that RE growth needs to be complemented by a drop-in fossil fuels for CO_2 emissions to decline. Decarbonisation is hamstrung by insufficient policies. This only became evident when policies that are bounded within a techno-economic framework began to emerge. These factors are misaligned to the fossil fuel complexities pronounced in Chapter 1. The most critical insight from this chapter was that an increase in RE currently does not equate to a reduction in fossil fuels or carbon emissions. Instead the pervasive challenges of the fossil fuel era require a pervasive set of policies that go beyond a techno-economic paradigm. Geels, Sovacool, Schwanen & Sorrell, (2017a:1242) refer to it as the *"multi-dimensionality of the deep decarbonisation challenge"*. The next chapter introduces a valuable conception that helps to deepen the frames of reference for decarbonisation.

Chapter 4: The Deep Transition Conception

4.1 Introduction

This chapter addresses the third primary research question:

- *Can the energy transition be understood as part of a deep transition?*

Up until this point, this study has sought to probe the efficacy of the energy transition, it also reviewed the RE policies currently employed. Chapter 1 gave an introductory background and insight into energy and transitions. It briefly sketched the environmental challenges that are being faced in addition to the broader social impacts caused by fossil fuels. Chapter 3 focused on the present energy transition, paying specific attention to the drivers behind the transformation and how they relate to fossil fuel consumption and climate change mitigation. Chapter 3 also revealed the narrow terms of reference applied to the energy transition, based on an underlying assumption that RE growth will lead to decarbonisation. Chapter 4 addresses the notion of a deep transition (Schot & Kanger, 2018; Swilling, 2019a) as a potentially useful framework for making sense of the energy transition. Swilling (2019a) proposes that a deep transition is under way. His theory is based on the unfolding RE transition, as well as on the intersection of multiple longwave trends. This chapter further explores this proposition and argues that the energy transition currently in progress is embedded within a deeper transition. The argument is structured into two sections: the first lays out the deep transition framework according to four dynamic theories, namely techno-economic (also referred to as techno-industrial), global development cycles, socio-technical and socio-metabolic. The second section analyses the RE transition within the broader framework for a much clearer understanding of the deep transition. The rationale behind this chapter is to investigate if deep transition thinking helps us to better understand the present energy regime shift in broader terms; beyond the techno-economic. This in turn may help to inform effective decarbonisation policies.

4.2 Deep Transitions

4.2.1 Proposing the concept of a deep transition

The notion of a deep transition has two meanings, a narrow and a wider meaning. The narrow meaning was developed by Schot and Kanger (2018), which essentially connects sustainability transition theory with Carlota Perez's theory of techno-industrial transition. The wider meaning is developed by Swilling (2019b) who connects four long-term transition dynamics, namely socio-metabolic transitions, Perez's techno-industrial transitions, sectoral transitions as per sustainability transition theory, and long-term development cycles. These two conceptions are not alternatives; the narrow approach is a sub-set of the wider proposition of deep transition. Both are briefly defined with a view to framing an understanding of the energy transition as the lead sector driving the wider deep transition to a more sustainable world, consistent with the most progressive interpretation of the Sustainable Development Goals.

The notion of a deep transition was coined by Johan Schot as a way to illustrate the key transformations that the global systems have undergone since the late 18th century (Schot & Kanger, 2018). Rather than describing sectoral change, the term characterises a range of transitions across sectors over a long period of time. The transitions in themselves could be imagined as **waves**. Austrian economist Joseph Schumpeter describes **these waves** as a *"perennial **gale** of creative destruction"*, an ambiguous term which he used to infer an evolutionary process that brought about massive economic shifts rooted in smaller novel innovations (Schumpeter, 1975 [orig. pub. 1942]). Of interest is Schumpeter's choice of the term 'gale' to describe the pattern of emergence and innovation; it conjures up circular motions or swirls. Swilling (2019a) uses a similar concept of four long waves to describe change as already mentioned above.

Schot and Kanger (2018) argue that the idea of a deep transition is useful for understanding the nexus between decarbonisation and the complex process of achieving social justice. This makes it a critical topic for investigation. This chapter is primarily interested in the relationship between the RE revolution and a deep transition. Kanger and Schot (2019) put forward a caveat, stating that a second deep transition is one out of many possible outcomes and that it can be achieved through multiple pathways, depending on policy formulation.

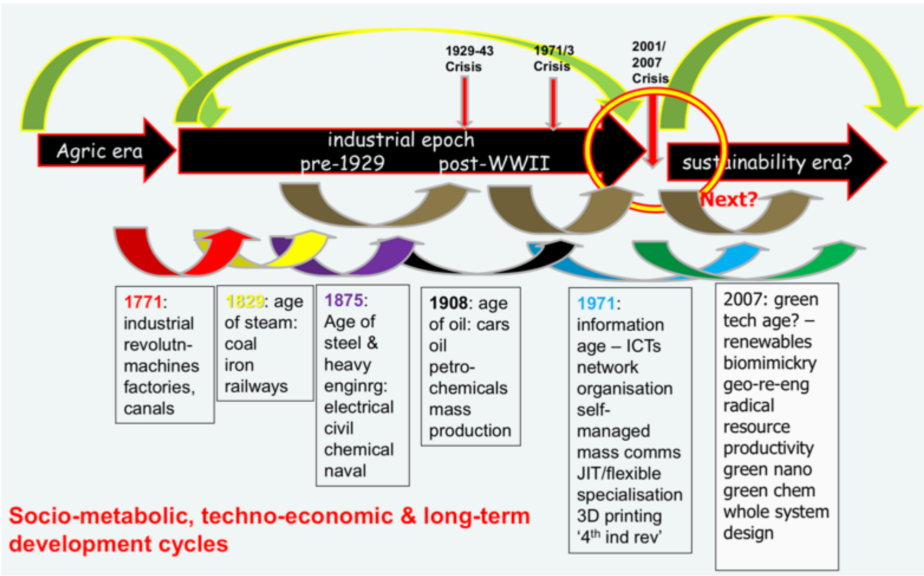
4.2.2 What is a deep transition?

Schot and Kanger (2018:20) define deep transition as,

> *…a series of connected and sustained fundamental transformations of a wide range of socio-technical systems in a similar direction.*

Based on this definition it can be understood that a chain of system transformations involving many sectors can converge to form a deep transition. It is the coming together of many sectoral systems such as energy, mobility, and communications (Swilling, 2019b) to embrace a common denominator such as fossil fuels in the industrial revolution, or a pending RE regime in a post-modern era. On its own the transition of an energy system or any other individual system cannot be considered a deep transition.

Figure 4.1: The second deep transition



Source: Swilling (2019b)

Schot and Kanger's conceptualisation is useful for understanding aspects of the energy transition, namely sectoral dynamics of change as conceptualised by a multi-level perspective (MLP); how niches coalesce into alternative regimes in response to landscape pressures, and how disruptive technologies emerge backed by capital that result in financial crises followed by state-led reorganisations to facilitate deployment periods. However, these two dimensions of deep transition ignore two additional paradigms of the energy transition, namely the socio-metabolic transition from one set of materials to another (Fischer-Kowalski, Krausmann, Wiedenhofer & Haas, 2012), and the industrial dynamics of change as growth and price cycles interact according to Kondratieff patterns (Gore, 2010). Swilling brings these four long-wave dynamics together into an integrated conceptualisation of the 'wider' conception of a deep transition. He does this by broadening the framework proposed by Schot and Kanger (2018) to incorporate the two dimensions that are excluded from their configuration. According to Swilling's harmonising framework, the global economic cycle launches into its 'spring' phase, denoting the beginning of a period of great economic improvement. Its hallmark lies in the rise in price inflation and an acceleration in growth dynamics, marking the end of a period of growth stagnation. Swilling (2019b) notes that investments in energy, communications and transport are key to deducing a global economic cycle upswing. The socio-metabolic regime is congruous with the changes that are taking place in the other cycles, highlighting any fundamental fluctuations in material resource use as well as any energetic transitions. By using the energy return on energy invested (EROI) as a tool for analysis, it becomes possible to pinpoint a socio-metabolic transition.

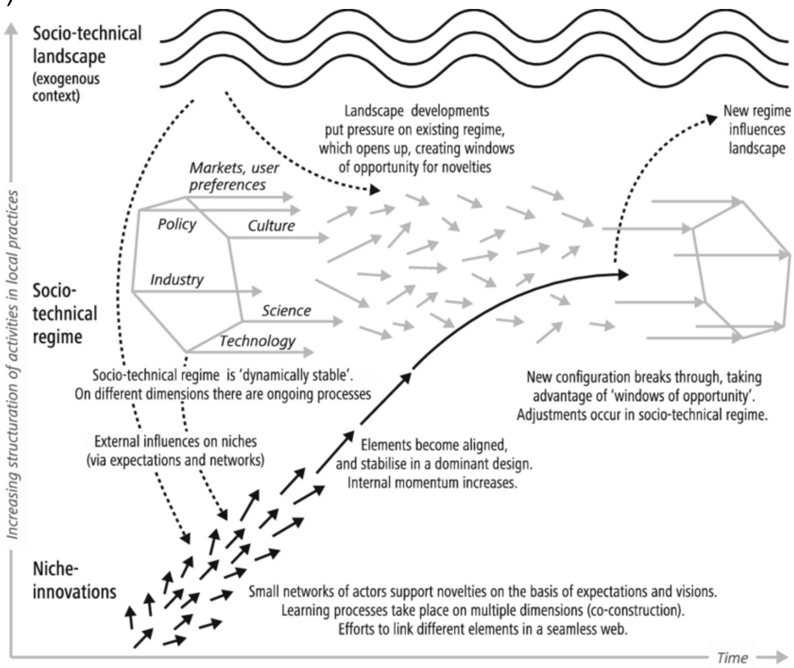
It is important to state that the concept as developed by Schot and Kanger (2018) is not in antithesis to the broader proposition by Swilling (2019b). The two are 'hand in glove' and should therefore not be viewed as antagonistic to one another. With this harmonious understanding of the deep transition concept, it can be appropriately applied in a sensemaking analysis of the energy transition. However, before it is applied a broader conception of a deep transition based on the four dimensions, which incorporate the work of Schot and Kanger (2018) into the architecture proposed by Swilling (2019b), must be individually clarified. The four cycles and their functions are laid out in the following sections.

4.3 Socio-Technical Transitions

Geels (2005) explores transitions which take place at an operational level within society. The fundamental theory behind socio-technical thinking is that the design and function of a system should incorporate both the social and the technical as interdependent elements requisite for development. According to Geels (2005) system innovations are useful in the process of building transition theories, and these can be best described as the transformation from one socio-technical system to an alternative one. As the title of this section suggests, there is a synergy at play between society and technology which precipitates system innovations. Geels (2005) explains the phenomenon through an MLP.

Figure 4.2: The multi-level perspective on system transformation

Source: Geels (2012)



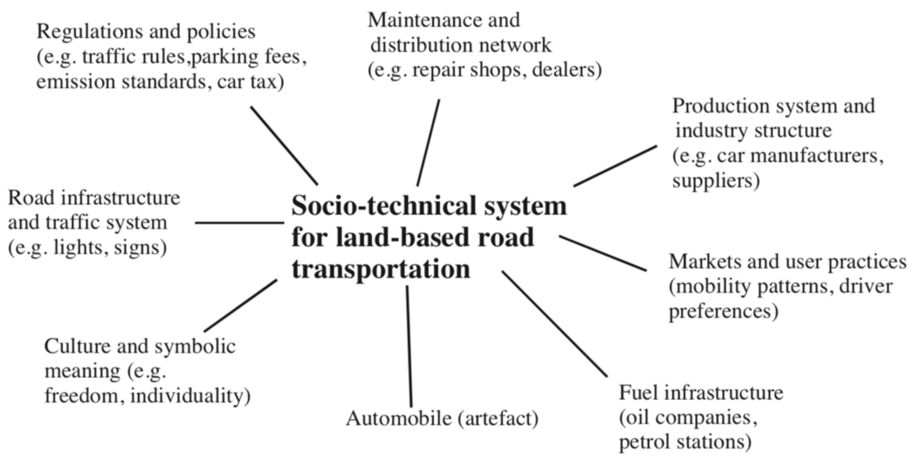
4.3.1 The multi-level perspective

The MLP focuses on technology-in-context with the emphasis on the co-evolution of technology and society. It distinguishes between three levels:

1. The micro-level is made up of technological niches - an environment for radical innovations, experimentation and learning (Kemp, Schot & Hoogma, 1998)
2. The meso-level is made up of socio-technical regime structures where processes, skills, technologies, corporate culture and artefacts are embedded in institutions and infrastructures (Rip & Kemp, 1998:388)
3. The macro-level consists of the socio-technical landscape –globalisation, cultural changes, environmental problems, political culture, worldviews, and social values (Kemp & Rotmans, 2005)

MLP levels display complex interrelations between the three different strata which exemplify natural laws *(Figure 4.2)*. The interdependency of these relationships creates a conducive environment that allows for feedback loops from the macro-level, which filters down through the ranks allowing for responses to take place at both meso- and micro-levels. The feedbacks apply for both good and bad innovation. Thinking along these concepts allows for a re-imagination of pathways to sustainability. The MLP gives rise to the idea of transitions within a socio-technical space that leads to deep structural changes in transport, sanitation, waste, energy and other relevant sectors. These changes are ignited at the micro level to take effect over long periods of time, culminating in vital reconfigurations of the market space, technology, consumption behaviour and knowledge (Geels, 2005).

Figure 4.3: Socio-technical system



Source: Geels (2005)

Figure 4.3 shows an web depicting a land-based transport socio-technical system. Transition allows for modification which ushers in a new socio-technical system altogether, in other words system innovation. System innovations lead to the alteration of existing processes and the modification of associated spheres within the system, involving technological adjustments. Using *Figure 4.3* as an example, the transition of the transport system to a 'commons only' public bus system that runs on RE, would result in changes such as the demise of the private automobile, changes in public policy about single occupancy vehicles, and fewer fuel infrastructures..

Swilling (2019b), finds value in the MLP for the purposes of gaining understanding about the motives behind some sectoral transitions towards sustainability, noting shifts such as green packaging in the retail sector, the circular economy in the waste industry, and RE in the power sector. He articulates how environmental pressures from the socio-technical landscape (macro) level had coerced change in a pre-existing (meso) regime. This had a cascading effect on the niche (micro) level which compelled innovation, ultimately leading to change *(Figure 4.2)*. As a precondition for any change, niche innovations need to be fully fledged or must be assimilated into established regimes so that transition can take place as a form of rebirth to remain resilient and to survive (Swilling, 2019b). Examples of this include corporations such as Shell Oil Company, traditionally an extractive enterprise specialising in fossil fuels, which has begun investing in the RE sector. The move by Shell effectively signals a transition from a sunset sector to a sunrise industry. Other examples include large energy corporations that have made a switch and become herculean players in the RE space (Swilling, 2019b).

4.4 Techno-Economic Paradigm

A techno-economic paradigm (TEP) is characterised by a constellation of innovations that synergise technological and economic shifts (Perez, 1983; Tylecote, 2019). These innovative changes are capable of influencing entire industries and giving rise to economic developments as illustrated by Perez (2002) in *Table 4.1*. The idea of TEPs as expounded by Perez (1983) amplifies the work of Dosi (1982); both scholars acknowledge the idea of technological revolutions as espoused by Schumpeter (1939). The idea is that a revolution spearheads a change of paradigm. A familiar example would be 'Fordism', which revolutionised industrialism, through the assembly line to produce domestic motor vehicles, leading to infrastructures such as roads, fuel stations and power grids (Perez, 2002; Tylecote, 2019). Perez (2009) describes five examples of technological change including 'Fordism' *(Table 4.1),* that shared the same financial and macro-economic dynamics. The critical question is whether the RE revolution can be recognised as a successor to the 'Fordism' model or any of the other techno-industrial revolutions. If it can, then it possibly heralds a new TEP.

The changes referred to earlier described by Perez primarily develop in waves that result in new technological paradigms or highly industrialised regimes. *Table 4.1* gives a condensed taxonomy based on how Perez organises the 'waves' which she describes as the 'five great surges of development'.

Table 4.1: Great surges of development

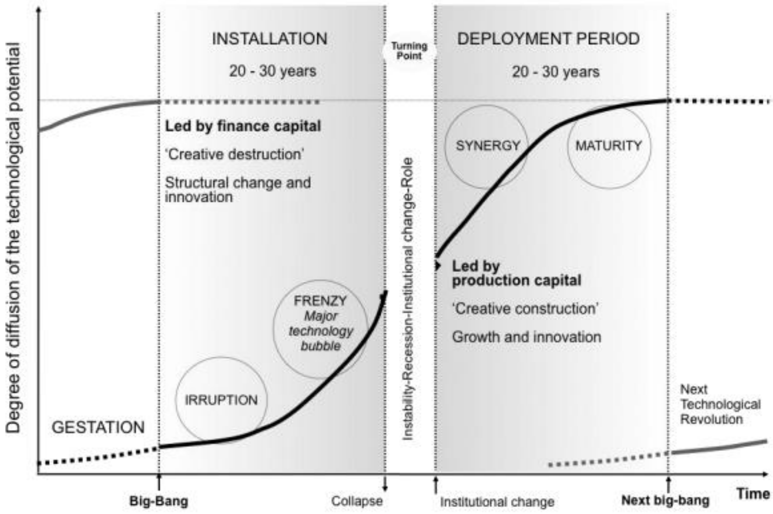
Great surge of development *Core country*	***Techno-economic paradigm*** *'Common-sense' innovation principles*
FIRST: From 1771 *The 'Industrial Revolution'* Britain	Factory production Mechanization Productivity/ time keeping and time saving Fluidity of movement (as ideal for machines with water-power and for transport through canals and other waterways) Local networks
SECOND: From 1829 *Age of Steam and Railways* In Britain and spreading to Continent and USA	Economies of agglomeration/ Industrial cities/ National markets Power centres with national networks Scale as progress Standard parts/ machine-made machines Energy where needed (steam) Interdependent movement (of machines and of means of transport)
THIRD: From 1875 *Age of Steel, Electricity and Heavy Engineering* USA and Germany overtaking Britain	Giant structures (steel) Economies of scale of plant/ vertical integration Distributed power for industry (electricity) Science as a productive force Worldwide networks and empires (including cartels) Universal standardisation Cost accounting for control and efficiency Great scale for world market power/ 'small' is successful, if local
FOURTH: From 1908 *Age of Oil, the Automobile and Mass Production* In USA and spreading to Europe	Mass production/mass markets Economies of scale (product and market volume)/ horizontal integration Standardisation of products Energy intensity (oil based) Synthetic materials Functional specialisation/ hierarchical pyramids Centralisation/ metropolitan centres–suburbanisation National powers, world agreements and confrontations
FIFTH: From 1971 *Age of Information and Telecommunications* In USA, spreading to Europe and Asia	Information-intensity (microelectronics-based ICT) Decentralised integration/ network structures Knowledge as capital / intangible value added Heterogeneity, diversity, adaptability Segmentation of markets/ proliferation of niches Economies of scope and specialisation combined with scale Globalisation/ interaction between the global and the local Inward and outward cooperation/ clusters Instant contact and action / instant global communications

Source: Based on Perez (2002)

4.4.1 The Techno-Economic Paradigm S-curve framework

According to Perez (2009), when a new product is developed it undergoes a process of refinement and enhancement. She considers these to be small innovations in their own right in which the process of improvement plays a critical role in upscaling productivity and stimulating market growth. Freeman (1995), highlights the linkages between individual innovation (product), its industry, and the global shifts and directions that are likely to ensue. This dynamism and direction of technical transformation is noted and confirmed by Perez (2009), who re-emphasises how the behaviour of individual technologies are replicated at a meso level. The same traits manifest in the development of all the innovations within a sector and ripples out to an entire array of interrelated industries. On a continuum, the micro level would be the individual technologies, the meso level encompass the interrelated industries and the macro level a more global outlook on techno-economic shifts. To better understand how techno-economic transitions take place, Perez makes use of an S-curve to provide a workable concept.

Figure 4.4: The phase of the technology cycle (S-curve)



Source: Based on Perez (2002)

Perez's characterisation of the key elements that make up a great surge of innovation or a TEP describes declining costs, endless deployments, unlimited applications that could lead to ubiquity, as well as the TEP becoming a core aspect of the new regime. According to the Perez S-curve, the advent of a new cycle or wave overlaps with the deployment and decline of a previous wave or paradigm. The TEP approach is made up of two key episodes. The first one is an installation phase that may last up to 30 years and is propelled by financial capital seeking capital gains (Perez, 2009; Swilling, 2019b). The second is a deployment episode driven by dividend seeking productive capital which helps to establish the new technology as a dominant regime (Perez, 2009; Swilling, 2019b). Both episodes last a total of between 40 and 60 years. The two episodes are further broken down into 4 phases on account of the lengthy duration of the wave *(Figure 4.4)*. According to Perez, there is a major financial build-up in the second phase, and it is only when this bubble bursts that a deployment is initiated. The burst also marks the shift from gains-seeking capital finance to production finance which is on a quest for dividends (Swilling, 2019b). According to Swilling (2019b) the state plays a pivotal role at various strategic stages throughout the S-curve cycle.

Such a homogenised view of the micro, meso and macro landscapes of the TEP illustrates the evolution of technologies in relation to society and economics. The ‘bird’s eye view’ helps to sketch a picture of the ‘nature of technology’, how it evolves and its symbiotic connections, which ultimately presents it as an object for social science analysis. Perez emphasises that the study of these dynamics provides a way of embedding economic theory in the interactions that take place between technology and social institutions.

4.5 Global Development Cycles

To further understand transitions and their role in macro-economics, the section that follows reviews the long wave phenomenon. Popularly referred to as the Kondratieff waves or K-waves, the cycles illustrate the global economic landscape at various stages that are influenced by price indices, technological innovations, and the shocks that affect global markets. These cycles are elucidated by means of an analogy which describes them as four seasons starting from spring, summer, fall/autumn through to winter.

The Russian economist Kondratieff was the first to be acknowledged for his work on global economic history. His economic theory refers to long waves of economic development that span periods of 47 to 60 years (Kondratieff, 1935). He articulated his hypothesis on long waves in 1926, Kondratieff was confident that it was plausible to speculate and stimulate future economic growth (Narkus, 2012). He also believed that development trends could be influenced by economic, social and cultural affairs (Narkus, 2012). Kondratief's theories of displacement cycles (1926) quoted in Narkus (2012) postulate that infrastructural investment lasts for periods of 50 years or more depending on the cycle.

4.5.1 Defining a long wave cycle

Gore (2010:717) identifies global development cycles as

> *…a long-term global pattern of economic growth in which many countries simultaneously experience growth accelerations or growth decelerations…(the) pattern is not a one-off occurrence but rather these rhythms of economic development recur as long-wave cycles of about 60 years in length.*

The description below is adapted from a condensed translation of Kondratieff's (1935:105,109) article, *"The Long Wave in Economic Life"*, published in the *"Review of Economics and Statistics"*.

> *There is reason to assume the existence of long waves…in the capitalistic economy. The waves are not exactly of the same length, their duration varying between 47 and 60 years…(they) accelerate or retard the rate of growth.*

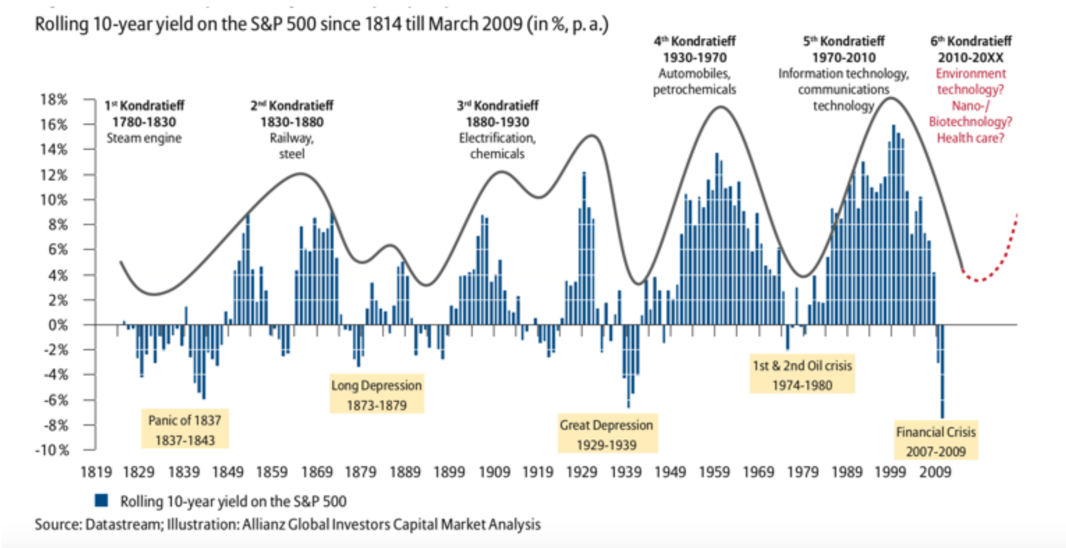
Kondratief's long waves thesis was based on his investment cycles theory (Diebolt, 2014) in which he hypothesised that long wave cycles stem from operations of the economic system (Diebolt, 2014; Kondratieff, 1935). A 'long wave cycle', infers variations of development that are based on innovation and the unfolding dynamics within the economy. The idea that innovation plays a role in the cycles was enriched by Schumpeter (Diebolt, 2014; Schumpeter, 1939).

4.5.2 The nature of long waves - phases

The cycles are believed to have a distinct rhythmic pattern, preceded by technological innovations that often signal the advent of a new Kondratieff cycle; these novel eruptions gradually snowball to become 'the backbone' of a drawn-out economic boost. To fully take effect, the innovations must virtually extend throughout all spheres of the economy and stimulate new surges of productive capacity in every aspect. According to Wilenius and Casti (2015), ever since the industrial revolution of the late 1700s no less than five cycles have been observed. Gore (2010) and Swilling (2019a) contend that a sixth cycle is presently preparing or is on the upswing. Typically the development cycles have ushered in technological breakthroughs which in turn transform whole societies; new industries replace the old, corporate tradition and ways of doing things are challenged and re-invented, and new unprecedented professions begin to arise and come to the fore (Kondratieff, 1935).

Each Kondratieff cycle is characterised by a series of phases or 'seasons' that make up the cycle. The four phases are improvement, prosperity, recession and depression. Kondratieff describes them, as already mentioned, as spring, summer, autumn and winter. The **improvement (spring)**, starts with an upswing, which generally follows a tough economic time. This is a period of recovery depicted by growth in the economy. In **prosperity (summer)**, the cycle shows rapid expansion; it is a period of elevation of the Kondratieff wave depicting bountiful times. Prosperity is followed by **recession (autumn),** the recessionary period which brings with it some economic shocks, and the drop in economic activities introduces a turning point in the cycle. This ultimately culminates in a fully-fledged **depression (winter).** Four dominant attributes characterise the conclusion of old cycles and the advent of new ones: an acute financial meltdown, institutional/social changes, surplus investment capital, and old innovations rendered unexploitable. The financial meltdowns are portrayed *(Figure 4.5)* by cyclic global depressions such as the oil crises of the 1970s and American economic depressions such as the 'Panic of 1837' and the 'Crash of 1929'.

Figure 4.5: Kondratieff cycles – long waves of prosperity



4.6 Socio-Metabolic Paradigm

Attention is now turned to the socio-metabolic paradigm theory which helps give insight into the biophysical profile of a society. All aforementioned cycles are inclined to influence the socio-metabolic profile which is highlighted in the section that follows.

4.6.1 In defining socio-metabolic transitions

When considered from a socio-metabolic perspective, a regime is made up of a society's energy systems which includes generation and conversion technologies as well as other flows of materials (Fischer-Kowalski, 2011). The theory of socio-metabolic regimes was first broached by Sieferle (2001) in his original publication *"Der unterirdische Wald"* which appeared in 1982 (Fischer-Kowalski, 2011). The book explains the process of transformation from one energy system to another, giving vital insight into the theory of socio-metabolic transitions. In searching for a succinct definition of socio-metabolic transitions, the following commentary by Fischer-Kowalski and Haberl (2015:100) proved relevant:

> *The term 'metabolism' evokes an organismic analogy: metabolism is the process by which an organism builds up and maintains its structures through exchanging energy and materials with its environment throughout its life.*

Fischer-Kowalski and Haberl (2015) use the analogy of living organisms as the basis for societal structures. These structures 'share' basic system characteristics that are alike and are therefore an appropriate parallel for a metabolic social state. Socio-metabolic shifts are illustrated by the use of *"material and energy flow data to demonstrate global socio-metabolic regime transitions"* (Fischer-Kowalski *et al.*, 2014:8). In other words,

> *…a social system's metabolism means looking upon its economy in terms of biophysical stocks and flows (Fischer-Kowalski & Haberl, 2015:100)*

4.6.2 Analysing socio-metabolic profiles

Socio-metabolic systems are made up of colonised environments or spaces inhabited by humans (Haberl *et al.*, 2009). Within these spaces are processes which begin with the appropriation of energy and materials from nature for human consumption. This appropriation of resources enables the social complex system to reinvent itself (Fischer-Kowalski, 2011). A substantial amount of fossil fuels, biofuels, non-metallic minerals and metals propel the economy. On this account, socio-metabolic flows refer to all the energy and materials required to sustain human life. This is considered to be the physical economy which is denoted by the metabolic profile of a society. Several measures can be used to analyse socio-metabolic systems which include "*life cycle inventory"* (LCI), *"life cycle analysis"* (LCA), *"input output analysis"* (IOA) and *"life cycle impact assessment"* (LCIA) (Haas, Hertwich, Hubacek, Korytarova, Ornetzeder & Weisz, 2005; Weisz, 2006). Included in the socio-metabolic toolkit are other instruments such as virtual water, energy return on energy invested (EROI) and human appropriation of net primary productivity (HANPP) (Ejolt, 2012). A biophysical view of the economy sketches a structure by which society can understand consumptive patterns, their historicity and also future scenarios. The information obtained can be analysed against the availability or scarcity of resources, stimulating efficiencies. It is this iteration that allows humans to understand the impacts of each person. By tracking the processes and environmental impacts it is possible to comprehend the weight of social systems and to reflect on effective mitigation strategies. For this study an EROI analysis is deployed. EROI is the ratio of the total energy utilised to the total amount of energy derived from a source (Murphy & Hall, 2011). It is significant because the surplus beyond energy production is what drives development, food production and financial systems (Gagnon, Hall & Brinker, 2009; Murphy & Hall, 2011).

4.7 The Four Cycles Summarised

The description of each dimension helps to build an understanding of their individual function, how they could potentially relate to the RE transition, to each other, and to the wider conception of a deep transition. As previously mentioned this enquiry is based on the integration of all four dimensions, embracing the work of Schot and Kanger (2018) into the broader design put forward by Swilling (2019b). In applying transition theory, four statements are derived from the dimensions described in the section above, namely:

1. The RE revolution could be perceived within the socio-technical application of the MLP framework.
2. The RE revolution could be understood as the lead sector of a wider techno-economic surge through the framework of Perez's S-curve.
3. Given that the commencement of long-term development cycles usually coincides with financial flows through mobility, energy and communications, the rise of renewables as a decentralised system managed via decentralised information networks can be understood as possibly signalling the start of the next long-term development cycle.
4. The RE revolution could be seen as part of the next socio-metabolic paradigm by analysing the shift in energy sources using the EROI metrics.

4.8 Towards an Integrated Analysis

The following section deploys the deep transition framework in an ordered and integrating sequence to analyse the RE shift. It follows some theorising logic as seen through the deep transition conception, going from one approach into the next.

4.8.1 A renewables revolution as a sectoral sustainability transition

To better understand the energy transition from an MLP perspective, an interpretive analysis of the unfolding global energy transition follows. The MLP introduces social dimensions to the present RE transition which is presently defined and relegated to a techno-economic paradigm. The MLP illustrates how the RE transition is dispersed to embrace the humanities as the first sign of a new pervasiveness. The energy landscape is presently at the epicentre of stabilising and destabilising forces. The present socio-technical regime is dominated by a fossil fuel lock-in (Geels *et al.*, 2017b). Lock-ins help to entrench the fossil fuel status quo, stabilising the incumbent regime and hindering any RE influence from the niche level. The lock-ins include sunk investments and institutional commitments (Geels *et al.*, 2017a). In the past, this was reinforced by the work of climate change denialists as well as the lack of appropriate policy and legislative frameworks (SkepticalScience.com, 2019). Other lock-in mechanisms included reluctance by energy companies to relinquish their monopolies such as Eskom, South Africa's state energy utility which stalled the signing of RE producer contracts (Baker, 2018). This is further enhanced by cultural preferences such as the convenience of having unlimited access to electricity in significant quantities (Clark, 2013). Conversely, destabilising pressures such as peak oil, air contamination and natural disasters are impacting the incumbent fossil fuel dominance. Regime level shocks in the form of the Japanese Fukushima disaster have further intrenched public sentiment and mounted growing political pressure against nuclear[7] power in favour of RE (Fitzgerald, 2019; Geels *et al.*, 2017b; Moniz, 2011; Murphy & Hall, 2011; WEF, 2013). Citizen concerns about climate crisis are gaining momentum, and as a cultural force they also play a part in destabilising the fossil fuel regime and the landscape (Fitzgerald, 2019).

Similarly, at the regime level, tensions between destabilising and stabilising pressures are also manifesting in the incumbent energy system. Clear benefits are derived from continual investments in fossil fuels which are stabilising the regime (IPCC, 2018c; REN21, 2019a). Discernible indications of sustained support for fossil fuel use include an increase of 11% in global subsidies up from the 2017 figures, as reported by REN21 (2019a). They also note that fossil fuel companies are spending several hundreds of

[7] Though not a fossil fuel, the perceived dangers of nuclear are also helping to drive a pro RE stance.

millions of dollars to block climate change policies and on advertising to shift public opinion. Since 2016, the World Bank Group financed fossil fuel energy in developing countries to the tune of US$6bn (REN21, 2019a). In 2018, US$33bn or 7.9% was committed to nuclear capacity and US$95bn, about 22.8%, financed fossil fuels (REN21, 2019a). End user preferences that help sustain fossil fuel use, as well as vested actors such as oil barons, labour movements, coal companies, policy makers and utility companies enhance the status quo (Ambrose, 2019; Geels *et al.*, 2017b; Michael Bastasch, 2019; Reuters, 2018; Strambo, Burton & Atteridge, 2019). However, in defiance of perceived stability, the adjustments that are taking place at landscape level are breaching the regime; these include climate action policies, eroding commitments to fossil fuel energies, supply constraints at the geopolitical level when one country stops producing and selling fossil fuels, and climate literacy by actors who acknowledge the landscape pressures that are the result of climate change (Hausfather, 2018; IRENA *et al.*, 2018; Newbold, 2016; Wettengel, 2019). It was noted elsewhere in this study *(Figure 3.10)* that the number of countries with RE policies rose from about 40 in 2004 to 135 in 2018, reflecting a 337.5% spike in just 14 years (REN21, 2019b).

Some energy systems around the globe, such as Germany's electricity regime, were destabilised between 2011 and 2016, leading to 29% generation from RE (Geels *et al.*, 2017b). A growing anti-fossil fuel movement (Fitzgerald, 2019) continues to mount strong resistance while stirring a new cultural discourse. The outcome is that both solar PV and wind power have diffused rapidly. As mentioned in 2018, solar PV increased slightly but sufficiently enough to break through the 100GW level for the first time (REN21, 2019a). Added capacity for RE grew by 25% to about 505GW from the year before, and up from 15GW 10 years prior (REN21, 2019a). Wind power installed 51GW in 2018, adding to five years of consecutive additions that surpass the 50GW mark (REN21, 2019a). Total added wind capacity reached 591GW (REN21, 2019a).

Some of the regime upsets have resulted in viability challenges for utility companies such as the withdrawal of funding for fossil fuels and reconfiguration of the sector by disruptive technologies. Divestments have been made by insurance companies (55%), pensions (33%), banks (6%), and other smaller groups (REN21, 2019a). In some cases insurance companies no longer underwrite fossil fuel projects. In 2017, 13% of the insurance industry's global assets were covered by divestment policies, and in 2018 this figure grew to 20%. The scenarios described above characterise what Geels *et al.* (2017) describe as head-on competition between the new RE regime and the old established one. RE technologies are currently observed to be widely breaking through, and this is happening increasingly throughout the world (IEA, 2018; IRENA, 2019d,c; REN21, 2019a). Geels *et al.* (2017) note that this renaissance is driven by the falling RE costs, improved technological performance, the development of complementary technologies such as smart grids, and storage capabilities.

In the current context, socio-technical innovations are breaking through at the niche level, and these fledgling technologies are challenging the norms and presuppositions of the incumbent regime. Such was the case for the initial niche levels of RE innovation, resulting in the solar urban labs of Germany and Denmark that redefined energy politics (Bauwens, Gotchev & Holstenkamp, 2016; Swilling, 2019a). The urban labs allowed for co-experimentation and co-development of both solar and wind technologies (Bauwens *et al.*, 2016). In the opinion of Geels *et al.* (2017) disruptive concepts start to materialise in niches alongside incumbent regimes, to destabilise them. This was observed during the early 2000s, as the energy transition was slowly being nurtured and feed-in tariffs in places like Germany and Denmark made renewables in these regions economically viable (Geels *et al.*, 2017b). Without socio-technical interventions, the RE transition becomes a major techno-economic challenge, highlighting the need for broader social acceptance in order to accelerate low carbon transitions (Geels *et al.*, 2017a).

After 2004, global and regional bodies began to pay greater attention to environmental issues, and programmes such as the clean development mechanism (CDM) were introduced to incentivise RE projects (UNFCCC, 2019). Some governments offered support in the form of grants and incentives for R&D projects (Mazzucato & Semieniuk, 2018) which was followed by tumbling costs in renewable technologies. In the periods 2004 – 2008 and 2009 – 2011 various states increased RE funding support, even during the global financial crisis. Funding from state banks grew in share from 7.5% to 8%, state utilities increased from 6.4% to 14.1%, other state corporations jumped from 2% to 5%, and government agencies from 1.6% to 3.9% (Mazzucato & Semieniuk, 2018). Compared to other actors, energy firms dropped from 12% to 10.6%, industrials fell from 14.1% to 9.8%, and unclassified sources of funding tumbled from 19.5% to 12.7% (Mazzucato & Semieniuk, 2018). The only exception was private utilities that grew in their share of total investment from 18% to 19.6% (Mazzucato & Semieniuk, 2018). There was growing interest at domestic and corporate levels, especially in countries such as Germany, which enjoyed greater political support for RE (Geels *et al.*, 2017b). The endurance of the fossil fuel regime can be attributed to its overall landscape stability, culminating in an initially measured RE deployment. In the last decade the pace of implementation has gradually increased, and more niche innovations are coming to the fore. The mutual processes of the MLP as theorised by the socio-technical paradigm, demonstrate how the transition is more than just an adoption of RE technologies; it is also establishing new markets, user practices and social preferences (Geels *et al.*, 2017a) thus excluding it from narrowly perceived techno-economic references which only focus on the energy sector.

4.8.2 A renewables revolution as part of wider techno-industrial surge

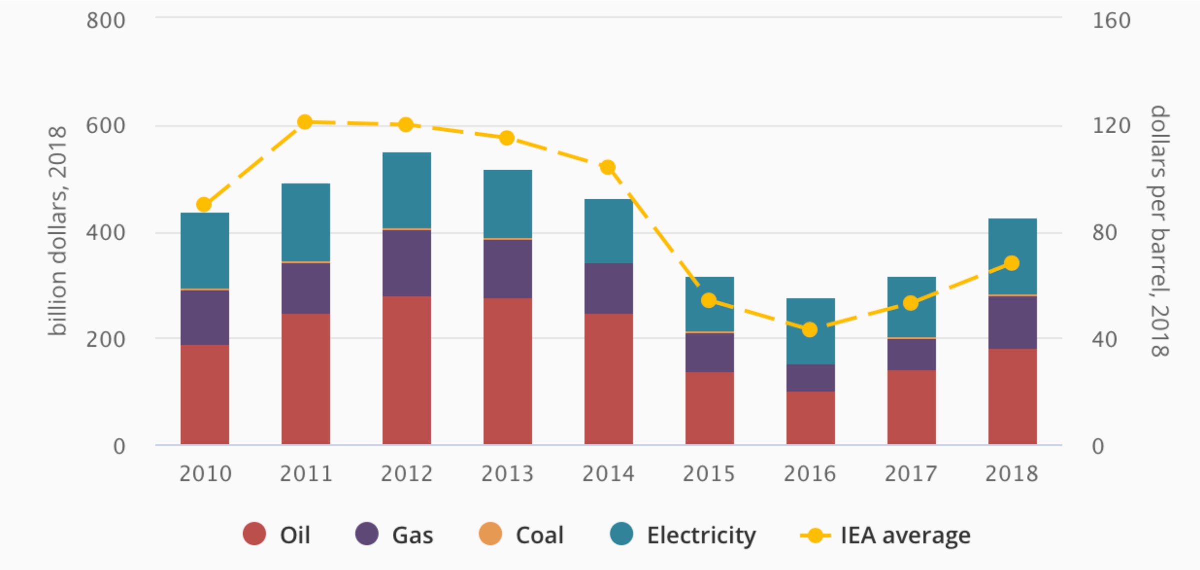
Perez, (2013) singles out the global economic crash of 2008 as the turning point of the 5th cycle, which according to her, was conceived in the early 1970s. Mathews (2013a,b) argues that it was in fact a 6th cycle that emerged during the financial crisis of 2008 and not just the turning point of the 5th. This theory is shared and supported by Gore (2010), Schot and Kanger (2018), and Swilling (2019b). The cycles are asynchronous according to Gore (2010), Mathews (2013a), and Swilling (2019b). The big question is: alongside the technological RE developments, what does the 2008 crisis represent as far as TEPs are concerned? The answer lies in Perez's own views: according to Mathews (2013b) she argued that the IT investments of the 1980s were a TEP and more than just technology-specific developments. To validate this point, she laid out the following criteria:

1. The emergent technology enjoyed falling costs
2. The incumbent technology was losing on price
3. The effects of IT had become pervasive
4. IT was flexible; a departure from the rigidity of the incumbent

Upon closer analysis of the post-2008 RE technologies and their diffusion, the following comparable factors are observed. It has already been highlighted in several instances in this study that RE is enjoying tumbling costs and that in some jurisdictions has become cheaper than the incumbent fossil fuel regime, (IRENA, 2018, 2019b). The tumbling costs of RE were covered in section 3.4.1, as have the ongoing deployments of RE, in Chapter 3. However, a brief summary on falling prices brings into focus the 53% plunge in the cost of solar generation between 2015 and 2018, while onshore wind power came down by 39% (BNEF, 2018). In the 3rd quarter of 2009, the cost of producing solar PV electricity was about US$300 a MWh, and by the 2nd half of 2018 the costs were well below US$50/MWh (Watanabe & Matsuda, 2018). Onshore wind power dropped from about US$100/MWh to below US$50/MWh in the same period, and offshore wind power started off at approximately US$150/MWh coming down to under US$50/MWh after an initial climb (Watanabe & Matsuda, 2018). The cost of solar power has become so cheap that Kuwait has put forward the unorthodox idea of exploiting solar PV for the purposes of ramping up their oil extraction (Hall, 2019).

Parallel to the RE nosedive in prices are the rising costs of fossil fuels which is made evident by the subsidies they receive. At present fossil fuels get double the support that RE gets. In 2017, there were about 115 countries providing fossil fuel subsidies (REN21, 2019a). Since the adoption of the Paris Agreement until 2018, an accumulative US$1.9 trillion has been used to subsidise fossil fuels; in 2018 US$300bn was channeled towards subsidies, reflecting an increase of 11% from the previous total recorded in 2017 of US$270bn (REN21, 2019a). In 2018, oil was the most subsidised energy source, accounting for 40% of subsidies *(Figure 4.6)*. In 2016, electricity had the largest subsidy *(Figure 4.6).* The continued support of fossil fuels distorts their true cost. This is in sharp contrast to RE which in some cases has stabilised to the point of no longer needing subsidies. The continued subsidisation of fossil fuels is suggestive of their high costs which are not reflected in the final end user price. Their continued support further stimulates an ongoing demand for fossil fuels while challenging the RE sector. Subsidies have been used to make fossil fuel extraction profitable. It also shields the end user from the true cost to the environment. The propping up of fossil energies also serves to underwrite neoliberalism rather than merely advocating for it, which ensures its sustained survival – possibly beyond the age of fossilised fuels.However, in spite of the ongoing subsidies, RE continues to rise.

Figure 4.6: Economic value of global fossil fuel subsidies by energy source



Source: Matsumura and Adam (2019)

RE is continually growing in its applications; a previous section briefly touched on laptops and mobile phones that are powered by solar power (see section 3.5.2). Other forms of innovation include solar lamps, radios and streetlights (Chakraborty, 2017; Doignon, 2015). In addition to the production of electricity, RE is providing the transport sector with new energy solutions such as electric vehicles which have the potential of serving as distributed load carriers and emergency power sources (Tanti, 2018) - disrupting traditional power transmission models. Post-modern sustainability enhancing concepts such as smart grids, smart cities, artificial intelligence, smart mechanisms, 5G for grid management, are also becoming part of the energy dialogue (CompTIA, 2019; Geels *et al.*, 2017a; Moradi & Vagnoni, 2018; REN21, 2019a; UNCTAD, 2019). Other areas of investment are telematics and intelligent traffic, AV software and mapping. The emerging trend appears to be a technological mobility ecosystem as the ICT age entrenches itself in transportation; what has come to be known as the ACES ushers in the era of *"autonomous (driving), connected (vehicles), electric-shared"* (vehicles) and smart mobility (Adler, Peer & Sinozic, 2019:1). Challenges in public transit and road congestion have been addressed in Moscow by developing a smart public transportation system which has become one of the busiest in the world (Liksutov, 2018). In 2010, TomTom ranked Moscow the most congested out of 400 cities, and in 2018 after reconfiguring their mobility systems they rapidly jumped to 5th place (Liksutov, 2018; TomTom Traffic-Index, 2019). Smart cities require reconfiguration of all their systems. For projects to be viable ICT necessitates major investments, and the integration of mobility into the greater IoT system. The smart concept is not unique to Moscow; other early adopters include cities such as Barcelona, Amsterdam, Copenhagen, and Dubai. The smart city concept has also been mooted in other locations throughout the world, including South Africa.

RE has a much more flexible and organised structure than fossil fuels which are centralised and rigid (IEA, 2019c; IRENA, 2018, 2019b; REN21, 2019a; Swilling, 2019c). The RE structure allows for off-grid installations, mobile storage, new small decentralised systems and even smaller players in the energy system. Flexibility within RE is very broad since the sector has redefined energy in a number of ways. Feed-in tariffs have resulted in a rapid expansion of small distributed power producers in places such as Italy and Germany which means that businesses big and small, farms and even households can produce electricity and sell their surplus to the grid or have peer-to-peer trading (P2P). Typically these are plants of less than 1MW in size and some are as low as tens of kilowatts; the investments for small distributed systems peaked at US$75.1bn in 2011, falling to US$53.2bn in 2015 and nosediving by 14% in 2018 to US$36.8bn (Frankfurt School-UNEP/BNEF, 2019). While plunging investments may appear alarming, they are actually attributed to the plunging costs of solar power (Frankfurt School-UNEP/BNEF, 2019). The point being that such investments by domestic home owners would not have been possible in the old inflexible energy systems that were centralised. The RE systems are allowing a variety of players to produce and sell energy. A report from IRENA (2019e) pronounces about 12 000MW of installed mini-grids worldwide. Blockchain is giving individuals who are not high net worth access to the energy sector. Investments can be made in any number of solar cells for as little as US$5 each, giving investors access to the power sector where they can participate economically in RE projects (SunEx, 2015). Up until October 2018, US$466 million had been invested in blockchain (IRENA, 2019e). Community ownership is another example of RE flexibility; currently there are approximately 4000-plus community owned projects globally. The majority are in the US, Austria and Australia (REN21, 2016). The project sizes vary from 10kW to 50kW, but some are bigger, such as the 66MW project in Dardesheim, Germany and the 102MW project in Krammer, Netherlands (IRENA, 2019e). Information technology (IT) companies are entering the energy sector and it is expected that by 2025, there will be 75bn up from 15.4bn devices connected and sharing data. These IT companies will supply utility providers, manufacturers and consumers with invaluable information (Statista, 2019).

The RE sector is exhibiting all the ingredients of a RE-led TEP, according to Perez's description of the ICT TEP surge of the 80s. To this effect 2008 could be seen as heralding a new 6th techno-economic paradigm as suggested by Mathews (2013b). This 6th TEP can be seen as one which emerged from the economic crisis of 2008. However, also noted is the turning point of the 5th techno-economic cycle that is asynchronous to the emergence of the 6th (Gore, 2010; Mathews, 2013a; Swilling, 2019b). The distinct characteristics of an emergent RE-led TEP as illustrated above, not only represents an economic framing of RE, but also demonstrate its pervasiveness within the broader economic discourse into other sectors of trade. This means they are not only bounded to the energy sector. This insight challenges the narrow focus of RE policies. The emergent TEP is also the first episode of the Perez S-curve.

According to the S-curve, the TEP approach is made up of two key episodes. The first is the installation phase that may last up to 30 years and is propelled by financial capital seeking 'capital gains' (Perez, 2009; Swilling, 2019b). This was the case in the early 2000s when private funding held the highest share of RE investment at 62.9%, declining only towards the global financial crisis of 2008/9, as the perceived level of risk elevated (Mazzucato & Semieniuk, 2018).

Investments by venture capital and private equity in RE peaked in 2008 at US$10.2bn, and as the recession set in it fell to US$4.8bn bouncing back in 2010 to US$8.2bn (Frankfurt School-UNEP Centre, 2018). Earlier figures by UNEP and BNEF (2010) put private equity at US$4.1bn in 2009, suggesting a 45% shrink. The total amount apportioned to venture capital in 2008 was US$2.7bn which fell by 36% (UNEP & BNEF, 2010). According to UNEP and BNEF (2010) investor caution presented private equities and venture capital players with a capital raising challenge; the appetite for risk was dwindling and many chose flight over risk. Since 2011 private equity and venture capital finance has progressively declined on a sliding scale, reaching US$1.8bn (Frankfurt School-UNEP Centre, 2018). The decline has been a drawn-out retreat from RE investment by both venture capital and private equity since 2017

(Frankfurt School-UNEP Centre, 2018). Public funds on the other hand were the extreme opposite, with investments of US$14.1bn, up slightly from the figures achieved in 2008 (UNEP & BNEF, 2010). Government R&D was up 49% in 2009 at US$9.7bn, compared to corporate R&D at US$14.9bn, which shed 16% from the previous year (UNEP & BNEF, 2010). Although corporate R&D was still higher, the key point of interest is the financial movement; as private funds exited, governments moved in. The government R&D spend was pushed up by the 'green stimulus'. Governments were willing to assume the risk as corporate investors took flight. In response to the recession, 'green stimulus' interventions where being introduced by leading economies such as China, Japan, EU countries and the US. A standard Keynesian reaction to a financial recession is government stimulus and to that end, a total of US$188bn of 'green stimulus' was announced between 2008 and early 2010 (Martinot & Sawin, 2009; UNEP & BNEF, 2010). Another US$55bn was announced during the course of 2010 (UNEP & BNEF, 2010). The stimulus was backed by public banks such as the European Development Bank and Germany's state bank KfW (UNEP & BNEF, 2010). Despite commitments totaling US$188bn, stimulus spending in 2009 was a modest US$20bn and in 2010 jumped to approximately US$75bn (Mundaca & Luth Richter, 2015; UNEP & BNEF, 2011). In spite of the moderate spending, the stimulus helped to ease the financial crunch and keep renewables steady. In America the department of energy supported several projects with a variety of instruments such as cash grants, tax-based incentives, direct loans and partial loan guarantees (Mundaca & Luth Richter, 2015).

The investors were made up of actors such as commercial banks, institutional investors, and energy firms among others (Mazzucato & Semieniuk, 2018). After the financial crisis the installation period continued and RE diffusion scaled up after the initial gestation period. A new phase in the future will be driven by dividend seeking productive capital which will help to establish RE technologies as a prime contender for dominance (Perez, 2009; Swilling, 2019b). This concept aligns with Perez's theory of a significant financial bubble build-up that leads to a bubble-burst, which marks the deployment phase and the shift from gains seeking capital finance to long-term production finance which is on a quest for dividends (Swilling, 2019b). According to Swilling (2019a) the state also plays a pivotal role at various strategic stages throughout the S-curve cycle; at first during the initial phases of the innovation cycle then followed by a transition period which occurs when the bubble bursts. Examples of state involvement are touched on in sections 3.4.3 and 3.6.3, and include grants, subsidies and investments.

The homogenised view of the various phases of the TEP illustrates the evolution of RE in relation to economics. The 'bird's eye view' helps to sketch a picture of the nature of RE, and how it is evolving. Perez (2009) emphasises that the study of these dynamics provides a way of embedding economic theory in the interactions that take place between technology and social institutions. Looking at RE from an S-curve perspective results in sensemaking of the new energy developments.

Mathews (2013a) argues that the present RE transition is almost exclusively framed by neoclassic economics in terms of carbon taxes, yet it is apparent that this approach is too small or too weak to have any decarbonisation effects. To effectively contribute towards breaking the carbon lock-in will require a broader sweep of the entire economy with a pervasive mix of suitable policies. The broader economic outlook also entails working alongside the other paradigm shifts that are put forward by other transition frameworks. To further understand transitions and their role in macro-economics, the section that follows reviews the long wave phenomenon. Popularly referred to as the Kondratieff waves or K-waves, as stated the cycles illustrate the global economic landscape at various stages influenced by price indices, technological innovation and the shocks that affect global markets. These cycles are elucidated through an analogy of the four seasons, namely spring, summer, fall/autumn and winter.

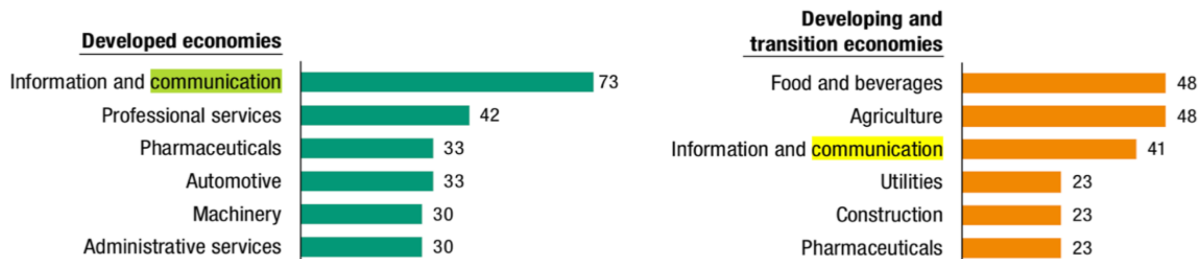
4.8.3 A renewables revolution as part of the next long-term development cycle

The year 2008 marked the beginning of a very critical period in world economics. It ushered in a financial crisis that reverberated throughout the globe. Many transition scholars and experts believe that it was the end of a Kondratieff type 'winter', marking the decline of a global economic cycle (Gore, 2010; Swilling, 2019b). Unlike the Allianz Global Investors (2010) periodisation *(Figure 4.5)*, the Gore (2010) cycle had its inception in 1950, accelerating into the '60s until the 1970s when it entered a growth deceleration period. This was followed by stagflation and a turning point. The 1980s and 1990s ushered in a downswing, decelerating in the 2000s. According to Gore

(2010) the financial crisis of 2008 constituted a deflationary depression. In a deflationary depression demand for goods and services decrease, leading to less production as was the case in 2008. The financial crisis resulted in an industrial production slump, rising unemployment, a drop in international trade and low commodity prices (Claessens & Kose, 2009). A question remains: does the present RE investment frenzy characterise a new global economic cycle? Based on the arguments made by Gore (2010), Mathews (2013a), and Swilling (2019b) the period post-2008 points to the advent of a new developmental epoch. This is illustrated by the investment priorities below.

As previously stated, investments in energy, communications and mobility are strong indicators of an upswing in the global economic cycle (Swilling, 2019b). Between 2013 and 2017 the World Bank noted vibrant activity in the energy, communications and mobility sectors (Saha, Hong, Shao, Modi & Zemlytska, 2018; World Bank, 2017).

Figure 4.7: Promising industries for FDI by region 2017



Source: UNCTAD (2018)

Energy – Growth and investment trends in energy are the subject of this study and are covered throughout the research, specifically in Chapter 3. The focus will now turn to communications and mobility.

Communications – In 2017 the United Nations Conference on Trade and Development (UNCTAD), reported growth decelerations of 14% in global foreign direct investments (FDI), which fell to US$720bn from the previous year. Cross-border mergers and acquisitions also dropped by about 22% to US$694bn. In spite of the decline the World Investment Report shows growth in the communications sector which increased considerably compared to all other sectors that were affected by the slump. Between 2016 and 2017 the value of communication M&A grew 66% from

US$24bn to US$39bn (UNCTAD, 2018). In 2017, *"private participation in infrastructure[8]"* investments in emerging markets and developing economies totalled US$93.3bn for ICT infrastructure across 304 projects. This was an increase of 37% from 2016 (World Bank, 2017). In 2018, it surged 131% to US$90bn (UNCTAD, 2019). Investment promotion agencies (IPA), rated the communication sector as one of the most promising and appealing for FDI in 2017. This was reinforced by a 24% FDI growth from US$39bn between 2017 and 2018 (UNCTAD, 2019). In the 2019 report, the IPAs highlighted how the sector was not only promising, but they confidently stated that it would receive the most investment. This positive sentiment was directed towards both telecommunications and technology corporations in the sector; the IPAs confidence was based on the diffusion of the digital economy into other frontier markets (UNCTAD, 2018).

The world's largest Multinational Enterprises (MNE), are investing vast sums into R&D projects *(Table 4.2)*. In the World Investment Report, 15% of software and IT investments were channelled towards greenfield R&D projects in 2018, coming second only to pharmaceuticals at 17% (UNCTAD, 2019). Overall, the top seven investors in R&D were all digital and technology companies. Representing the top three investors were Amazon, which invested US$29bn, Alphabet US$21bn, and Samsung US$17bn (UNCTAD, 2019). From the world's emerging economies, the top R&D investors were the Republic of Korea's Samsung US$17bn, China's Huawei Technologies US$15bn and China Mobile US$6bn (UNCTAD, 2019).

[8] The private participation in infrastructure database keeps records of investment information for infrastructure projects in low and middle income countries globally. The 59 countries covered in the report are affiliated with the international development association

Table 4.2: Top 20 MNE investors by expenditure 2018

Ranking	Company	Country	Industry	R&D expenditures ($ billion)	R&D intensity
1	Amazon.com, Inc	United States	Tech	28.8	12.4
2	Alphabet Inc	United States	Tech	21.4	15.7
3	Samsung Electronics Co, Ltd	Korea, Rep. of	Tech	16.5	7.5
4	Huawei Technologies	China	Tech	15.3	14.1
5	Microsoft Corp	United States	Tech	14.7	13.3
6	Apple Inc	United States	Tech	14.2	5.4
7	Intel Corp	United States	Tech	13.5	19.1
8	Roche Holding AG	Switzerland	Pharmaceuticals	12.3	20.3
9	Johnson & Johnson	United States	Pharmaceuticals	10.8	13.2
10	Toyota Motor Corp[a]	Japan	Automotive	10.0	3.6
11	Volkswagen AG	Germany	Automotive	9.6	3.4
12	Novartis AG	Switzerland	Pharmaceuticals	9.1	16.5
13	Robert Bosch GmbH	Germany	Automotive	8.7	9.2
14	Ford Motor Co	United States	Automotive	8.2	5.1
15	Pfizer Inc	United States	Pharmaceuticals	8.0	14.9
16	General Motors Co	United States	Automotive	7.8	5.3
17	Daimler AG	Germany	Automotive	7.5	3.9
18	Honda Motor Co Ltd	Japan	Automotive	7.3	5.1
19	Sanofi	France	Pharmaceuticals	6.7	16.0
20	Siemens AG	Germany	Industrial	6.4	6.7

Source: UNCTAD (2018)

In South Asia, the information and communication sector was among the top three industry recipients for investments. Sectorial developments unveil a constructive period of consolidation, which seeks to transform the frenzy into an organised diffusion of the information age (Swilling, 2019b). It is this consolidatory move that is creating an environment for broad synergies across sectors including energy. The materialisation of artificial intelligence (AI) and the exponential Internet of Things (IoT) are reshaping the societies of tomorrow as new possibilities in connectivity take shape. As the IoT seeps into the mainstream, every single conceivable object is potentially a computation device. The digital economy is grounded in three ameliorated ingredients: ‘cloud computing’, 5G networks, and ‘edge computing’, which decentralise the idea of the cloud and brings the power of computation and storage closer. Evolving technologies and the insatiable pursuit for the next big breakthrough are indicative of an upward trend in information and communication investments. The communication and information sector is ameliorating the energy and mobility sectors for smarter global economies. The next piece of the puzzle is mobility; any corresponding increases in investments will serve as conclusive determination of the onset of a Kondratieff type upswing.

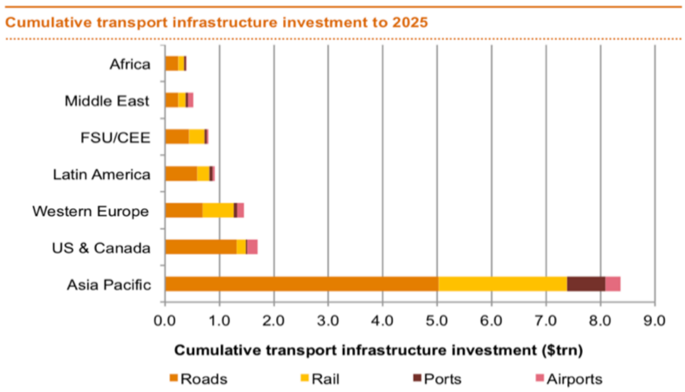
Mobility – According to the World Investment Report, demands for development and commitments to upgrade transport facilities continue to drive FDI in regions such as Asia (UNCTAD, 2019). Greenfield investment doubled for the year 2018 in the ICT, transport and power sectors (UNCTAD, 2019). One of the most discussed geopolitical initiatives is the highly controversial US$900bn Silk City road project or the 'Belt and Road Initiative' (BRI), also dubbed the Chinese Marshall Plan. This project aims to link more than 60 countries in a regional trade route (Bruce-Lockhart, 2017; UNCTAD, 2017). The idea is based on the ancient Silk Road trade route, and it is envisaged that it will open up key passageways, improve regional connectivity, construct port infrastructure, build smooth water-land transportation channels, and improve aviation infrastructure across the more than 60 countries. The idea was first mooted in 2013 by Chinese President Xi Jinping when he visited Southeast Asia and Central Asia. The project will connect Europe, Asia and Africa (China Daily, 2015). A 'Belt and Road' forum for international cooperation held in China led to investment agreements of US$64bn (UNCTAD, 2019). Investments in the BRI to date have totaled US$614bn (Moody's Analytics, 2019). Chinese investments account for 53% of their global investment portfolio between 2013 and 2018 (Moody's Analytics, 2019). Transport infrastructure often leads to commerce and a mammoth project the scale of the 'Silk Road' heralds a new golden era of globalisation. The 62 countries that are either signatories or have in principle expressed interest in the project, represent two thirds of the world's population (Bruce-Lockhart, 2017). The political debate is intense and China's motives are deemed controversial. Nevertheless, the project to date is the most ambitious geopolitical mobility undertaking of the century. It can naturally be assumed that additional public and commercial transportation systems will augment the mammoth infrastructure which will require major investments from China and the participating countries along the silk route. It can be assumed that it will also lead to investments in energy and communication.

Other global mobility investments are not lagging far behind; the rate of investment for transport infrastructure was projected to increase 5% annually between 2014 and 2025 (Oxford Economics & PWC, 2015). Sub-Saharan Africa was estimated to grow at a rate of just over 11%, and Asia -Pacific was expected to get the lions share with annual investments soaring from US$557bn a year to US$900bn in 2025 (Oxford Economics & PWC, 2014).

In 2016 the green bonds market reached US$86bn of which 13% was earmarked for low carbon transportation (UNCTAD, 2017). In 2018 transport was among the top three recipients for green bonds, accounting for US$30bn (UNCTAD, 2019). In the same year the market for green bonds exceeded US$168bn (UNCTAD, 2019).

Mobility start-ups are increasingly the recipients of major investments. According to a McKinsey report, US$220bn has been channelled to more than 1100 companies; the first US$100bn was dispersed by mid-2016 (Holland-Letz, Kloss, Kässer & Müller, 2019). While the investments targeted a wide range of recipients, a significant US$56.2bn went to e-hailing public transportation companies (Holland-Letz *et al.*, 2019). Comparative analysis of the periods 2010-2013 and 2014-2018, revealed a fifty-sevenfold spike of investments for e-hailing companies; that is 5700%; an increase from US$0.2bn to US$11.4bn (Holland-Letz *et al.*, 2019).

Table 4.3: Transport investment projections to 2025



Source: Oxford Economics and PWC (2015)

Investments in rail mobility are growing fast. Some of the more recent global trends are highlighted in *Table 4*.4. In Bangkok investment flows were channelled for the new monorail network to extend the present system. Melbourne and Sydney are each investing in new multi-billion dollar local metrorail systems. In spite of considerable downscaling in capital project investments in the Middle East as a result of tumbling oil prices, there is a drive for investment in passenger rail infrastructures (WSP, 2018). Doha, Riyadh and Dubai, are presently embarked on major metro developments, while Madinah, Kuwait, Jeddah, Makkah and Abu Dhabi are under consideration as financing options are sought (WSP, 2018).

New investments are continually announced for projects that vary in scale from metro level developments to international networks that link various regions of the world. This upswell of investment highlights the global focus on mobility and transport infrastructures. According to the World Bank (2017) and Swilling (2019b) the conditions for a new global economic cycle are aligned to investment growth in energy, mobility and information. At present all three sectors are experiencing a capital boom. Based on the robust financial resource flows into these sectors, it can be concluded that there is a global economic cycle under way or in upswing.

Table 4.4: Mobility trends in 2018

Region	Project	Budget
Kuala Lumpur – Singapore	High speed 350km railway due for completion 2026 (deferred)	US$17bn
Kuala Lumpur	3rd MRT circle line commenced construction in 2017	RM22.5bn
Melbourne – Brisbane	1700km freight link initiated in 2018	US$10.4bn
Canada	Various transit projects	US$20.9bn
London – West Midlands	High Speed 2 (Phase 1)	£27.18bn
West Midlands – Crewe	High Speed 2 (Phase 2a)	£3.48bn
West Midlands – Manchester – Leeds	High Speed 2 (Phase 2b) – awaiting approval	£25.07bn
London City crossing Elizabeth Line	Crossrail 1 open in 2018	£17.6bn

Source: Author's adaption from WSP (2018); Lee & Sipalan (2018); Barrock (2019); House of Lords Economic Affairs Committee (2019); Burridge (2019)

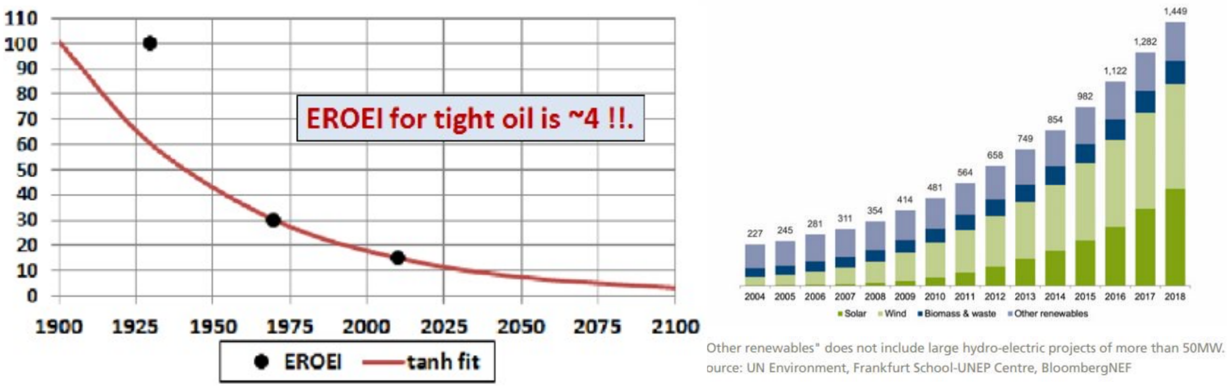
The global economic cycle broadens the RE transition into an intercontinental greening phenomenon whose lead technology is RE. Called *"the green Kondratieff"* (Allianz Global Investors, 2012), it is converging into an integrated system driven by smart applications to improve management and efficiencies. All the aforementioned cycles are inclined to influence socio-metabolic profiles which are highlighted in the section that follows. The socio-metabolic paradigm helps give insight into the biophysical profile of a society. A clear connection is established between RE transitions and a society's metabolic profile.

4.8.4 Renewable energy revolution as part of the next socio-metabolic cycle

Framing the RE transition within the socio-metabolic cycle introduces society's biophysical profile into the transition equation. A changing energy system means a changing metabolic profile. It also means a new EROI, which is likely to affect development and other societal needs that are dependent on a higher EROI. The shift to lower carbon technologies which have an inherently limited EROI according to the laws of thermodynamics, will impact resource use. This shifting socio-metabolic cycle on account of the RE transition proposes yet another angle of RE pervasiveness. One of the enduring arguments for the perpetual use of fossil fuels has been their EROI. In the 1970s, with the effects of externalities excluded, fossil fuels made sense. However, the EROI for gas and oil production is found to have peaked in 1999 (Brandt, Sun, Bharadwaj, Livingston, Tan & Gordon, 2015; Gagnon *et al.*, 2009). This was determined by the use of global industry expenditures which were multiplied by energy intensity of oil companies to approximate the energy consumed (Brandt *et al.*, 2015). In the US, the EROI for gas and oil extraction tumbled from 100:1 in 1930 (that is 100 barrel extracted for every 1 barrel invested) to 12:1 in 2007 for imported oil (Fischer-Kowalski & Haberl, 2015). Coal dropped from 80:1 during the 1930s to 30:1 in the 1970s (Fischer-Kowalski & Haberl, 2015). Global figures typically reflect EROI estimates ranging in the vicinity of 20:1 – 80:1, depending on the fuel (Brockway, Owen, Brand-Correa & Hardt, 2019). Current research has shown how the EROI has continued to drop (Brockway *et al.*, 2019). Should the EROI reach levels of 1:1 (and the trend shows that this is very likely), then there are no returns on energy invested and the surplus falls away. At a ratio of 1:1, the extraction of any fossil fuel ceases to be for the purposes of energy use and perhaps becomes solely useful for its material value. A study from the University of Leeds reveals that the EROI of fossil fuels is now comparable to that of renewables at roughly 6:1, and for electricity it falls as low as 3:1; a nosedive from the previous calculations of 25:1 (Brockway *et al.*, 2019). A game-changer was the realisation that the EROI for oil, gas and coal was calculated at the point of extraction. It did not take into account the energy needed to transform these raw materials into finished products for use in cars or beneficiation for the production of electricity (Brockway *et al.*, 2019). The increasing cost of extraction can be expected to continue pushing down the ratios. Despite these odds the demand for energy remains high, requiring greater levels of investment to achieve quantities that satisfy need.

Murphy (2014) argues that EROI is inversely linked to price. As the energy returns continue to depreciate, more energy is required to meet energetic needs, leading to further investments by oil companies as costs appreciate. An analysis of capital expenditure by major oil companies confirmed annual increases of more than 10%, due to fossil fuels becoming harder to extract (Kopits, 2014). In 2015, the Oil and Gas Journal (OGJ), projected that oil companies were expected to spend US$571bn to find and develop new fossil fuel sources in that year (OGJ, 2015). More investments means additional costs are involved in producing oil, which subsequently leads to higher prices. According to Kopits (2014) at the time of his research, the oil industry required prices in excess of US$100 per barrel to stay profitable. However, Heun and de Wit (2012) contend that higher prices have a negative impact on EROI due to the increase in profitability providing additional capital, which leads to more oil explorations, expending vast amounts of energy in the process.

Figure 4.8: Global crude oil EROI vs global RE capacity



Source: Frankfurt School-UNEP/BNEF (2019) and Roper (2017)

In an effort to keep economies going, subsidies have been applied since the early 1900s to encourage and assist in the exploration of oil (Pfund & Healey, 2011). To date, subsidies are still provided by various state organs. Most fuels benefit from subsidies in one way or another. According to the report, all G20 countries have fossil fuel subsidies. The subsidies have helped to keep fossil fuels in the market for much longer than they should have (Irfan, 2019). The viability of fossil fuels is being propped up by subsidies which are distorting the true cost of fossil sources of energy for the end user. With all things being equal, the real price is likely to indicate a plunging EROI. As energy exploration increases, access to easy fossil fuels diminishes, pointing to the end of an era characterised by cheap fossil fuels.

In considering the drastic reductions in the EROI of fossil fuels and the surge in renewable energy as noted in Chapter 3, Swilling (2019b) suggests they are the signals of a fundamental shift in the patterns of energy use. As *Figure 4*.8 shows (Global crude oil EROI on the left and the Global RE capacity on the right) the socio-metabolic profile is shifting from fossil fuels to RE, based on a comparison of dwindling fossil fuel EROI and the rise of renewables.

4.8.5 Is the renewable energy revolution part of a deep transition

An energy transition coupled with the retirement of fossil fuels is essential to meeting the global objectives of curtailing the average temperatures below the double headed targets of 2^{o}C while aiming for 1.5^{o}C. The Paris Agreement has major ramifications for the energy sector directly, which reverberates to all other spheres and sectors within society. At present the global agenda to limit rising temperatures is linked to GHG emissions and CO_2 in particular. The transition to new energy technologies is generally seen as being about decarbonising the energy systems. Gielen, Boshell, Saygin, Bazilian, Wagner and Gorini (2019) state that RE is central to the overall energy transition, capacitated by technological innovation. They further highlight the record new installations that have led to the 25% (26% as per REN21, 2019a) contribution by RE towards electricity production in 2017 - as a clear sign of the role of RE in the global energy transformation. However, they limit the RE revolution to being just technological shifts. The sustainability challenges currently faced by society are many, and have appropriately been referred to as a poly-crisis (Swilling, 2019b). They are ubiquitous to many sectors and domains of society (Papandreou, 2015). In essence the climate change crisis permeates all areas of society which have been fundamentally moulded by the fossil fuel system (Papandreou, 2015). In dealing with the crisis, a comprehensive response is warranted within a short space of time. The RE transition according to Mathews (2013a) goes beyond the function of merely curtailing CO_2 emissions in a bid to save society's highly industrialised 'civilisation'. Mathews (2013a:10) argues that the present RE transition should not be limited to mere technological shifts, but insights *"derived from Schumpeterian, neo-Schumpeterian and paradigm-shift thinking"* ought to be considered. According to Mathews, the RE energy shift has far-reaching societal consequences.

To consider the contentions of Mathews (2013a) alongside the transition theories of Swilling (2019b) and those of Schot and Kanger (2018), the deep transition conception has presented the lens that frames the present RE revolution beyond just an energy shift.

Swilling (2019b:28) identifies what he calls *"significant transitional dynamics"* from within the four paradigms theory, which he succinctly synthesises in the following manner. The plunging EROI could be the tell-tale sign of a socio-metabolic transition; the rapid RE deployment characterises a socio-technical overhaul; and the techno-economic shift is distinguishable by an escalation in 'green-tech' investments, coupled by financial flows towards the next generation in energy, mobility and communication, pointing to a new global economic cycle. The sectorial transitions across all four paradigms could be framed as a deep transition towards a possible sustainability epoch.

Central to this sustainability thinking is a new cleaner energy regime with impacts that reverberate throughout the social system (Fischer-Kowalski, 2017). In the deep transition analysis presented in sections 4.8.1 - 4.8.4, energy is clearly established as a common denominator interacting with each of the four cycles, suggesting that it has a pervasive role throughout each element within a deep transition. In the MLP, the initial signs that triggered the transition are made explicit. The CO_2 driven environmental landscape feedbacks have led to experimentation that spawned new technologies directed at dealing with the crisis. The desire to innovate is driven by a need to address climate issues which are deeply rooted in the choices of energy made by human beings. Technological shifts are therefore addressing the pervasive issue of energy. However, the shift is not only focused on the energy system, but it is spearheading a sectoral wide coalescence with other paradigms within society. The application of the ICT sector to the power grid (Geels *et al.*, 2017a) is reordering how energy is managed. The simultaneous restructuring of energy production and consumer behaviours is a distinctive feature of the energy system decentralising, which has profound technical, social and economic ramifications. Some impacts include new energy players such as small businesses and even domestic households being able to participate economically in the sector. The RE shift is potentially impacting other forms of social justice and energy democracies, and engendering economic equity (Bauwens *et al.*, 2016; Swilling, 2019a). It is the far-reaching implications of the present energy shift as described above, framed through the sensemaking exercise of a deep transition, that gives it the hallmark of something beyond just a system transformation. However, according to Gore (2010), the present transition may prove to be structurally unnavigable. Swilling (2019a) supports this by suggesting it may linger if the appropriate policies are not implemented to help speed up decarbonisation, restore biodiversity and effect more sustainable resource use. The deep transition conception takes into account socio-technical, socio-metabolic and global economic cycles in addition to the techno-economic paradigm in an endeavour to understand the RE transition. Following the deep transition framing of the RE transition, the pervasive nature of fossil fuels and the resultant wicked problems require an equally pervasive set of policies that help to conclusively tackle the poly-crisis which includes CO_2 emissions.

4.9 Summary

This chapter introduced the concept of a deep transition with the sole motive of investigating the RE shift within the broader context. Deep transition theory integrates four transition concepts, namely techno-economic, global development cycles, socio-technical, and socio-metabolic. This 'integrated four cycles framework' helped to make sense of the energy transition, while tracing its link back to a deep transition. The analysis addressed the following question:

- *Can the energy transition be understood as part of a deep transition?*

By deploying the deep transition framework, the following was observed. There was a declining fossil fuel EROI which coincided with a RE installation within the TEP and MLP, and alongside it was an energy, communications and mobility investment frenzy. Together these four paradigms are acknowledged as a RE transition immersed within a more significant far-reaching deep transition. The research points to a limited frame of reference for the transition that may hinder sufficient decarbonisation as it overlooks the broader nature of the energy shift. The policies formulated are limited, hindering their full effect. Chapter 4 demonstrated how problems from fossil fuel pervasiveness need to be addressed by a more pervasive set of policies.

Chapter 5: Deep Energy Transitions - Findings

5.1 Introduction

Chapter 3 provided an analysis of the RE transition. Chapter 4 described the deep transition framework, referring in particular to the four dimensions that characterise the deep transition. The 4 dimensions are the socio-economic paradigm, global economic cycles, socio-technical paradigm and socio-metabolic paradigm. In this chapter, the lines of argument in Chapters 3 and Chapter 4 are integrated. The aim of this chapter is to use the four dimensions of the deep transition to deepen our understanding of the RE transition. Specifically, when the RE transition is understood as a socio-technical transition (following Geels and others in the Dutch School of sustainability transition studies), how does this help to deepen our understanding of the RE transition? Is it helpful to frame the RE transition as part of a wider socio-metabolic transition (following Fischer-Kowalski et al.)? Following Perez, how is our understanding of the RE transition enhanced by identifying it as part of a wider techno-industrial surge (either as deployment phase of the 5th techno-industrial surge, or the installation phase of the 6th)? And if the next long-term development cycle is conceived as driven by new communications, mobility and energy technologies, is this a useful way of understanding the RE transition? The answers to these four questions constitute the building blocks for understanding the role of the RE transition in the wider deep transition. It is argued that a wide range of instruments woven together is better suited to address a deeply carbonised society.

This chapter is divided as follows:

- The first part summarises the essence of Chapter 3, including the rise of renewables and the persistence of high emissions;
- The second part provides a succinct set of arguments to address the four questions above. This is done by drawing on the overview of the four dimensions of the deep transition in Chapter 4; four statements that answer each of the four questions respectively are provided.

5.2 A Growing Renewables' Future

As renewables grow, they seem set to be the dominant energy of the future. The focal point of Chapter 3 was to analyse the magnitude of the global RE project. As of 2018, the combined RE capacity installed globally was roughly 2537GW (IRENA, 2020a). At the time this figure represented just over a third of the overall global generating capacity which included fossil fuels. Curiously the annual instalments of new RE now exceed that of new fossil fuels. Falling back on the broad agreement that a renewable energy transition is under way, one of the objectives of this study was to establish what was driving the overall RE growth. While many factors can be attributed to the surge, the three key ingredients are price, policy and innovation in RE technologies. Improved technologies are constantly reinforcing the tumbling RE prices and both are bolstered by a new level of consciousness that is driving better RE policies. The notion of rapid growth is clearly supported by a body of evidence that was obtained from a wide variety of sources. The work of various agencies from around the world, such as the International Energy Agency (IEA), International Renewable Energy Agency (IRENA), Renewable Energy Network for the 21st Century (REN21) as well as many other research bodies, have shown that in spite of the stiff resistance, renewables have grown rapidly (IEA, 2019e; IRENA, 2019f; REN21, 2019a). All three agencies as well as other research-based organisations highlight price, policy and new technologies in their data analysis.

5.2.1 Policies for a renewables' future

The last two decades have been typified by a gradual shift in energy policies, which have stimulated RE growth through incentives, legislation and subsidies. Sovereign states adopting RE policies leapt 337.5% in 14 years (REN21, 2019b). The findings in Chapter 3 sketched a vibrant policy environment, which transcends global, regional, national, subnational and corporate contexts. The study focused on providing a bird's eye view of some high-level policies in an effort to gauge if measures are being sufficiently ratified and enacted to stimulate a conducive RE environment. Across all the various levels mentioned, it was clear that there is a sense of climate literacy and an awareness for the need for climate action. However, in spite of the seemingly healthy policy environment, it is notable that some countries appear to merely pay lip service to the climate action agenda. This is evident when countries renege on their commitments which negatively impacts the global targets for a 1.5°C or a 2°C scenario, and is apparent when the global RE installation target required to achieve the objectives set by the Paris Agreement is missed by an average of 40% every year (IEA, 2019e). While policies and climate action have been criticised for not being ambitious enough to effectively deal with climatic risks (Mulvaney, 2019) the research made it clear that there is a growing sense of awareness. The study also presented irrefutable evidence of a policy process that is sufficiently devolved to other political sublevels. Effective policies are proving that rapid transitions to RE are possible. Policies are providing guidance, redirecting resources towards RE implementation, formulating the appropriate fiscal incentives, and nurturing a climate that is suitable for investment. Generally, the application of policy was found to be a contributing factor to RE growth. According to the World Energy Assessment, if employed appropriately, renewable energy is *"highly responsive to overall energy policy guidelines and environmental, social, and economic goals"* (UNDP, 2000:221). However, the policies were found to favour a techno-economic response to fossil fuels. It was also noted that the general RE policy framework, was mostly conceived within a neoliberal approach to facilitate the transition and address the climate crisis. However, this approach did not necessarily attend to the lurking issues of poverty and social inequity. The poor and in particular African communities, as well as other developing economies are at a very high risk of being excluded from the transition benefits (ENERGIA, 2019). They are also in danger of being burdened by the legacy costs of the fossil fuel infrastructure, as wealthier individuals, families and economies adopt and enjoy the new RE dispensation. Both the neoliberal paradigm and the techno-economic framing of the energy transition, appear to be inextricably linked. Additionally, both paradigms have an effect on the broader outcomes of the transition. In one way or the other, they will impact the global agenda to meet climate goals and eradicate poverty. While some policies such as the SDGs and the CDM have made the attempt to address social inequity, they are also severely hampered by numerous challenges, which threaten to minimise their impact.

5.2.2 Technologies for a renewables' future

Solid policies undergird everything that spurred the energy revolution, including technological experimentation and advancements. The current innovations in technology as well as future projections of RE advancements point to a vibrant sector, in a race against time for a risk-free climate. The substance of the technological analysis concentrated on the growth in RE related R&D. A dramatic rise in patent registrations between 2010 and 2016 put the spotlight on RE transitions, which were stimulating hyperactivity in R&D as well as prototyping to meet a growing demand for RE efficiencies. This could be seen in the patent registrations that took place in the same period, which ballooned by 5239%, from a modest 11,000 to an astronomical 575,323 (IRENA, 2019b). By all indications, such a colossal climb denotes a shift in energy interest. It was clear from such numbers that there was and still is something going on in the energy space. The R&D frenzy coupled with a frenetic fascination with RE patenting characterises a race and the sense of urgency which has engulfed our energy futures. In time it has also positively revolutionised RE costs. The RE technological advancements reemphasised a theory which predicates that policymakers are limiting the RE transition to the energy sector only. They also lacked the broad social involvement that considered issues of equity.

5.2.3 Pricing for a renewables' future

In the decade leading up to 2020, renewables entered a new pricing cycle which saw costs begin to tumble. Analysis of the most recent reports from IRENA, IEA and REN21 demonstrated price drops of between 23% for offshore wind power and about 73% - 80% for solar photovoltaic power between 2010 and 2018 (IRENA, 2018, 2019b). The upshot of falling costs is a cheaper levelised cost of electricity (LCOE) for renewables in many parts of the world. So significant are the price drops that in the last decade RE reportedly became cheaper than nuclear power, coal and oil generation (REN21, 2018a). The tumbling costs of RE have a significant effect not only on the magnitude of new installations but also total investments and savings. In 2018, the total amount invested in RE was lower than the previous year, even as the installed RE capacity showed a significant increase. Though seemingly counter-intuitive, the drop was further proof of a more favourable RE pricing environment, demonstrating how more can now be achieved with less money. Put quite simply, savings have been realised since the first price drop in RE, though less capital investment in 2018 made them even more discernible within the analysis. Initially propped up by subsidies, the falling RE costs are also driving an accelerated technological advancement. This clearly outlines how a lower price point makes renewables more attractive. They have become even more appealing to the most unexpected of players in the sector, including fossil fuel majors such as Royal Dutch Shell PLC who historically resisted RE. The favourable pricing is tearing down barriers to RE deployment which was noted in 2017 when more solar PV power was installed than both nuclear and fossil fuel combined (Swilling, 2019a). However, in spite of RE growth the overall effects on CO_2 emissions have been anything but linear and are counterintuitive to expectations. Stimulation of the markets through policy and regulatory instruments for better pricing, further heightened the hypothesis that incremental RE decision-making is based on a narrow policy framework.

5.2.4 Current efforts to decarbonise are insufficient

In exploring the second research question, it was observed that in spite of the prevalence of clean sustainable energy options, CO_2 emissions increased annually on average by 1.3% between 2013 and 2018 (IRENA, 2019f). Having said that, in a 2020 report released by the International Energy Agency (IEA), it was noted that CO_2 emissions stalled in 2019 at around 33 gigatonnes (Gt), to match those of the previous year (IEA, 2020a). The global economy in 2019 grew by 2.9% (IEA, 2020b), meaning that the CO_2 contraction reflected some level of verifiable decarbonisation. Given that emissions are historically tied to growth, it is significant that in 2019 they stalled. This is only the second time in over 40 years it has happened in the absence of a global crisis (Briggs, 2015; IEA, 2020b). The report further highlights that the drop in emissions was due to reforms in the energy sector from the world's most advanced economies. What remains to be seen is whether or not this stabilisation is a temporary pause as was the case between 2014 and 2016. A drop in CO_2 emissions associated with advanced economies is a key finding, which validates the prevailing notion of developed countries being responsible for the high levels of CO_2 emissions globally. Following this logic it can be theorised that the primary drivers of climate change are wealthy societies from the world's most advanced economies. Notably, emissions from less advanced economies grew by 400million tonnes in 2019 (IEA, 2020b) spotlighting a growth trajectory that may need urgent decoupling before it gets out of hand. Addressing this and the broader CO_2 challenge, Dr Birol of the IEA reiterates a point that has been a recurring theme throughout this research; he makes a call for more ambitious policies and investments to meet climate action targets (IEA, 2020b).

Making the transition to cleaner sources of energy is widely viewed as the solution to the climate problem, as it is believed it will stem fossil fuel use. This broadly held conjecture anticipates that an increase in RE should translate into lesser fossil fuels and a corresponding drop in carbon emissions. It is further anticipated that this would lead to a gradual climate change reversal or in the very least to some reprieve from the poly-crisis. The analysis in Chapter 3 highlights an increase in global RE capacity between 2004 and 2019, yet contrary to expectations, there has hardly been a change in carbon dioxide behaviour. In most cases a gradual rise of CO_2 has been encountered with the odd exceptions where it either dropped or plateaued (IEA, 2019f, 2020b; Olivier & Peters, 2010). This calls into question the current climatic efforts being employed to stave off the global poly-crisis. It also leaves a high degree of uncertainty about whether or not the global targets set for climate action can be achieved. This problem is exacerbated by the expected global population growth.

In concluding Chapter 3 it became clear that the conventional approach, which is based on the logic of increasing the RE deployment in order to reduce the carbon emissions, is actually 'behind the CO_2 curve', given the constraints of time, the inadequate rate of transition, and the narrow terms of reference. This way of thinking which appears to be widely accepted by policy makers, researchers, and other global bodies, as the means to reducing carbon emissions, falls far short as a solution. An energy transition with a far wider societal implication beyond mere technological shifts appears to be far removed from the decarbonisation equation.

The following sections look at how the RE transition can be best understood within the context of a deep transition. This is achieved by addressing the four questions given in the introductory section of this chapter. Each question looks at RE from the perspective of one of the four dimensions of transition, starting with the socio-technical.

5.3 The Social Sciences of the Renewable Energy Transition

Following Geels and others in the Dutch School of sustainability transition studies, how does this help to deepen our understanding of the RE transition?

The multi-level perspective (MLP) as expressed by Geels *et al.* (2017a) denotes an upsurge in socio-technical transitions that are related to RE. The acceleration is emphasised by the interaction of three processes that are mutually fortifying:

- An increase in RE niche innovations
- The destabilisation of the current fossil systems
- The reinforcement of external environmental pressures.

The alignment of all three processes that are outlined above produces what Geels *et al.* (2017a:1242) refer to as *"windows of opportunity"*. The emergent outcome is a RE socio-technical transition that is beyond a mere *"adoption of new technologies"*, it *"include[s] investment in new infrastructures, establishment of new markets, development of new social preferences, and adjustment of user practices"* (Geels *et al.*, 2017a:1242).

While the socio-technical transition is a conceptual perspective, it helps to deepen the understanding of a RE transition. It provides the theoretical depth that is advocated by Mathews (2013a) though arguing from a techno-economic perspective; he alludes to a far more significant component of the RE revolution. His argument suggests that there is a transformation of entire energy systems that transcend mere shifts in technology. While the technological ingredient in socio-technical paradigms is easy to grasp, the 'socio' logic, applies to societal 'use'. This includes the selection, adoption and integration of RE by the markets, as well as the setting in of new rules, infrastructures and cultural symbols. The various actors involved include social groups, scientific communities, special interest groups, and businesses.

Within the present RE transition, this connection helps to sketch a more wholistic understanding of the current transformation, which clearly depicts a co-evolutionary process between technology and society. Failure to recognise the broader context would be to overlook the social aspects of the transition. An oversight means societal functions as they relate to the shift and the new RE regime, are bound to happen without clear policy intervention to help guide the process towards best practice to ensure appropriate and just transitions. According to Geels (2005:682) a transition is portrayed *"by the shift from one socio-technical system to another"*. Therefore a RE revolution that is understood from within the context of a more wholistic socio-technical transition enters a whole new dimension, meaning it surpasses the technological. Considering the current impact of RE, here are some societal observations:

- Social acceptance has widened due to lower cost, but much still needs to be done to boost legitimacy and support for stronger policies (Geels *et al.*, 2017a)
- Wider social acceptance is leading to greater RE business support which is noted in the growing anti-fossil movements and divestments (Go Fossil Free, 2019)
- User practice, cultural preferences, purchasing decisions in mobility, buildings and heating still need to change to bolster the transition (Geels *et al.*, 2017a)
- Incentives as well as widespread information on climatic threats are changing some customer behaviours (Geels *et al.*, 2017a; IPCC, 2018a)
- Positive information on cultural, economic and social benefits of RE is shifting perceptions (Geels *et al.*, 2017a,b)

By observing the examples listed above, it becomes possible to not only make sense of the regime level shifts that are occurring, but also to see examples of the social shifts that are slowly emerging. The technological elements coupled with social shifts are producing the multi-sectoral breakthroughs that are destabilising the existing regime. In other words, it is the clustering of all elements as described earlier by Geels (2005) to weaken the fossil regime, which can be understood as having an impact on the transition agenda. Mathews (2013a) describes the need for paradigm-shift reasoning in the dialogue on RE. He argues that an intellectual approach to the RE transition is too weak to have any demonstrable impact. This statement is understood to be in reference to the prevailing narrow focus on technological solutions within an economic paradigm that are likely to miss the multi-sectoral depth and social complexities involved. Suggesting a far-broader dialogue is pivotal to societal, environmental and economic ideals. Such a deep understanding of the RE transition has profound implications, which has an impact on policy formulation. Geels *et al.*, (2017:1242) stress that merely looking at technology to rapidly decarbonise is to *"focus on a single piece of the puzzle"*, while bypassing other critical *"real world"* ingredients required for accelerated transitions.

In his bestselling treatise *"The Third Industrial Revolution",* US author, economist and energy visionary, Jeremy Rifkin, describes how a society's energy system transition affects every aspect of the society from its economy, political power, agriculture, architecture, employment, cities, transportation, to even how humans relate. This point is shared by several scholars including Szeman in Garrigou (2016) who advocates for a deeper understanding of the pervasiveness of energy. On this account society needs to be able to recognise and understand the broader processes that lead to energy pervasiveness. In the words of Geels *et al.* (2017:1242), *"[r]apid and deep decarbonization requires transformation of sociotechnical systems— the interlinked mix of technologies, infrastructures, organizations, markets, regulations, and user practices that together deliver societal functions".* This heightened sense of consciousness empowers humanity to actively shape the new socio-technical paradigm. Failing this, wittingly or unwittingly, society becomes a bystander engulfed in a process of change that affects it with many unintended consequences. This is Swilling's (2019b) point, as well as that of Kanger and Schot (2019) when they warn that a transition could have any number of outcomes pending what policies are devised.

5.3.1 Current efforts towards social equity are insufficient

The reports released by the various energy agencies and institutions such as REN21, IEA and IRENA not only proffer techno-economic approaches to the transition, but they also overlook the social equity issues within the transitions discourse. They come across as only being concerned with environmental sustainability. It has been stated previously that environmental and economic sustainability without any reforms that bring about social equity is unsustainable. Therefore the issue of policies that guide the transition as per Swilling (2019b), as well as Kanger and Schot (2019) is critical, as it addresses far broader implications than just environmental and neoliberal interests. Failure to address social issues within the Deep Transition thinking, perpetuates the wrongs that emerged with the first industrial revolution and the free market distortions, that let to social inequity in the first Deep Transition.

5.3.2 Deep limitations to decarbonisation

From a socio-technical perspective the key issues of ineffectual CO_2 curtailment for climate action becomes easier to understand. Geels *et al.* (2017b) point out how transitions have been swift in the electricity sector but are restricted in other sectors. The reasons for the lack of momentum include consumer resistance, industry opposition and the lack of political will. For instance, there has been less traction in the passenger transport sector. According to IRENA, IEA and REN21 (2018) decarbonisation in petroleum-fueled mobility is gradual compared to the electricity sector. With mobility still entrenched within the petro-carbon regime, this illustrates a transition that is partial in purpose. The policies are therefore deficient and seemingly lacking in other sectors. This means the contribution from other sectors is still quite conservative. Another area cited by Geels *et al.* (2017b) is the food and agricultural sector. Energy transitions in food and agriculture have limited momentum due to industry lock-ins, high costs, industry reluctance, weak policies and cultural attachments to preferred diets which may be energy intensive. An earlier brief discussion on fossil fuel subsidies in section 4.8.4 highlights a concerted effort, globally, to keep CO_2 emitting energy regimes in place. While there are cultural, capitalist and political motives for the reluctance to shift, the fact that there is little momentum, speaks to policy. The issues of policy are not just deficient for the ramp-up of RE diffusion, but they demonstrate an insufficiency to address multiple sectors and various scenarios that are non-linear. They also neglect to address entities who may be negatively affected by the transition or who are unjustly privileged by the status quo, enabling a transition stand-off. Resistance and negative perceptions slow down deployment as investment is curtailed and policy is complacent or argues against RE. The gains of the electricity sector are tempered by the slow advances of the other sectors in what is meant to be a multi-sectoral effort or by pushbacks within its own sector. RE observed through the socio-technical dimension helps us to see and understand this. It also proffers some insight into the shallow decarbonisation that is failing to adequately reduce the amount of gaseous carbon compounds that are released into the atmosphere.

5.4 Understanding Society's Material and Energetic Profiles

Is it helpful to frame the RE transition as part of a wider socio-metabolic transition (following Fischer-Kowalski et al.)?

A new RE based regime threatens present levels of resource use. This is clearly the case when the transition to RE is viewed from the perspective of a socio-metabolic approach. This approach provides a conceptual and methodological lens that offers an alternative frame for reference. According to Fischer-Kowalski (2011) other perspectives mostly focus on the economic angle and technological changes. As put forward in section 4.6.2, the socio-metabolic framing of the RE transition introduces biophysical variables and also acknowledges the role of nature within a society's socio-metabolic profile (Fischer-Kowalski, 2011). Both the biophysical analogy and the incorporation of nature help to highlight a society's material use. For a society to develop it requires significant volumes of resources and materials, which result in the transformation of natural systems, leading to resource exhaustion, pollution and changes in land cover. In addition to transforming natural systems, the escalation in material consumption required for economic growth, poverty reduction and human well-being requires large volumes of energy. Energy drives the extraction, processing, movement, consumption and disposal of materials. In the last four decades global material consumption has tripled. Extraction of materials from nature grew annually from a total of 30 billion tonnes in 1970 to some 85 billion tonnes in 2010 (Materialflows.net, 2019). Concomitantly the global economy grew from US$15.4 trillion in 1970 to US$51.7 trillion in 2010 (Schandl, Fischer-Kowalski, West, Giljum, Dittrich, Eisenmenger, Geschke, Lieber, Wieland, Schaffartzik, Lenzen, Tanikawa & Miatto, 2016). Excessive resource use accompanied by the extravagant consumption of energy, which exceeds planetary boundaries, threatens the entire system with collapse, thereby putting society at risk (Rockström *et al.*, 2009).

It is also vitally important to realise that the transition to RE is not an entirely clean shift; if the world transitions to RE, it will need more steel, more copper, more cement and more rare earth than if it stayed on fossil fuels (Swilling, 2019c). This is problematic as it means that the human impact may happen in other ways that are supposedly green. The socio-metabolic paradigm is instrumental in exposing this.

Through the lens of the socio-metabolic paradigm the greater impacts of the present RE shift on society's resource base becomes comprehensible, as does the potential overall impacts on *"metabolic needs for food, construction and growth"* (Fischer-Kowalski, 2011:154). A RE regime will not only affect the environment and society but will also influence the flow of materials. Beyond techno-economic factors, the RE transition will impact the physical reproduction of human cultures. Culture cannot reproduce itself outside of its link with socio-metabolism. People need energy, shelter and food, which are all made possible by socio-metabolism; however, humans have the power to operate and manage their socio-metabolism.

Based on a RE regime, society needs to consider future limits to growth. This curtailment is attributable to the lower EROI delivered by renewables. Society depends on a higher EROI of energy to drive development at scale. According to Murphy and Hall (2011) a lower EROI results in moderate growth. Curtailed development in turn curtails the demand for materials, which could lead to a downturn in metabolic rates. This is substantiated by Fischer-Kowalski (2011:154) who states that *"when an energy regime changes"*, a society and its metabolism are also changed. These alterations also affect the natural systems that the society interacts with (Fischer-Kowalski, 2011). It is this perspective of the RE transition within the broader socio-metabolic conception that demonstrates the changes in the natural systems linked to technological and socio-economic shifts, for example *"population growth, diets, land use and species extinction"* (Fischer-Kowalski, 2011:154). Societies will ultimately need to consider adjusting to an energy efficient future, which in turn will dictate efficiencies in other resources that are required for economic development and human wellbeing. In light of the decarbonisation agenda, limiting policies to the techno-economic paradigm neglects the complex reproducing dynamics of society and its metabolism and the insidious effects of cultural lock-ins on the fossil fuel hegemony. The transition is ultimately hamstrung by resistance and ineffectual policies. Considering the socio-metabolism paradigm may help provide the rationale for alternative sustainability concepts that are more in line with the agenda.

5.5 Renewable Energy Surging a Greener Economy

Following Perez, this section explores how our understanding of the RE transition is enhanced by identifying it as part of a wider techno-industrial surge (either as the deployment phase of a 5th techno-industrial surge, or the installation phase of the 6th).

The greening of energy systems is part of a wider economic decarbonisation revolution. In framing it as part of the techno-economic surge it becomes plausible to distinguish the RE transition as a revolution – a term that has been used intermittently throughout this study. A revolution is understood to be an insurgency or a seizure of 'power', meaning that RE is not just displacing a power system but something much more dominant, and influential is at hand. To grasp the extent of a revolution requires a brief peek at Perez's insight on TEPs. To date, she has identified five TEPs (or meta-systems) beginning with the first industrial revolution *(Table 4.1)*. A sixth surge that is asynchronous to Perez's fifth has been noted by Gore (2010), Mathews (2013a), and Swilling (2019b). Perez describes each TEP as a macro phenomenon rooted in the micro-foundations of innovation and technological change. Founded on Neo-Schumpeterian theory which synthesises Kondratieff economic theories with Schumpeter's own economic development theories, TEPs are largely interested in technological change within the capitalistic paradigm of growth. The impacts are pervasive throughout the entire economy.

Historic TEPs have displayed an ability to induct other forms of innovation and stimulate new industries (see section 4.4) while influencing the global economy. At face value, the present evolution appears to be bounded within the RE systems. According to Mathews (2013) and Swilling (2019c) and as noted throughout Chapter 4 and 5, the shift is also influencing changes in other systems that exist beyond the RE boundary. A RE transition is enticing other forms of trade into a greener economy.

To ignore the function and impact of technical and institutional shifts in structuring and restructuring the economy diminishes the analytical capacity of economics (Perez, 2009). It also hinders the process of achieving better outcomes. Understanding the dynamic economic impacts brought about by past techno-economic surges enhances the ability of economic science to predict and explain such developments (Perez, 2009). This conceptual insight is helpful in recognising the potential nature of RE technologies as well as making sense of the present-day influences of RE on the economy. As some of these economic and institutional disruptions have already been highlighted in other sections of this study, only a few are briefly reiterated below:

- Decentralised RE systems and smaller power plants are growing in popularity
- Ownership of energy systems and power plants is no longer the exclusive domain of the state or powerful corporations (van Veelen & van der Horst, 2018)
- RE is reconfiguring the models of economic participation in the electricity sector to embrace smaller players (SunEx, 2015)
- The rise of electric vehicles within the transport sector (CompTIA, 2019; Mathews, 2013b) coupled with better storage technologies, is a clear indication of a move towards the consolidation of RE technologies.
- Shifts in other sectors like ITC to consolidate with the new RE system are giving rise to smart grids for improved efficiency and distribution (Mathews, 2013a)
- The greening of energy systems, RE investments and RE growth (Mathews, 2013a) are a further sign of a broader consolidation towards a new regime.

A major element of the TEP is the *"boom and bust"* patterns elaborated by Perez. These are associated with the four dynamic phases described in section 4.4 namely innovation and frenzy (installation), synergy and maturation (deployment). Looking back from the very first industrial revolution of the 1770s, Perez claims the four dynamic phases are identifiable within each of the five historic TEPs. Drawing on her theory which states that it takes between four to six decades for all TEP phases to fully unfold, the RE transition can therefore be perceived to have entered an installation period soon after the 2008/9 global crisis. The ability to discern the prevailing phase of transition proffers some critical insight and helps to illuminate the broader links that would otherwise be obscure. It also becomes plausible to some extent, to anticipate some of the possible pathways that lie ahead for the RE transition and its further development. Following this line of thought and considering Perez's insight, the TEP way of thinking suggests that another future financial crisis could herald the golden age of the present RE revolution. This is widely regarded by Gore (2010), Mathews (2013a), and Swilling (2019b) to be a green economy. Therefore the TEP conceptualisation clearly underscores the substance of the present RE transition, expanding it beyond the realm of the energy sector into an economy wide revolution.

RE viewed via a techno-economic perspective presents the possibility of an emergent green economy. This view is a whole new level of sensemaking, which illustrates the depth and context of the RE transition. On that account, understanding the RE transition from a TEP perspective helps in constituting the criteria for steering social creativity (Perez, 2004) towards better and just economies and societies. This theory is supported by the socio-technical and socio-metabolic conceptions which have argued against a reductionist view of the RE transition; instead they broaden its overall impacts and how it should be perceived.

5.6 Renewable Energy Shaping Modern Economic Infrastructure

If the next long-term development cycle is conceived as driven by new communications, mobility and energy technologies, is this a useful way of understanding the RE transition?

The world is converging in an integrated system driven by peta-data and artificial forms of intelligence. This operating network is administered by highly advanced communications systems. The rise of RE in conjunction with new investments in mobility and communications (Oxford Economics & PWC, 2015; Swilling, 2019b) is an integrating exercise that brings technologies together in a management system that maximises resources. This affirming relationship between the three sectors has long been observed in previous transitions according to Swilling (2019b). This is partially supported by Rifkin's analysis, which highlights a precedent for these symbiotic relationships, although his main focus was communications and energy. According to Rifkin, energy revolutions also entail dramatic changes in communication systems, which need to be sufficiently versatile and agile to be able to manage the new energy regime (Rifkin in Waghorn, 2011). In addition to a new form of communications, the switch in energy systems spawns new forms of mobility (Oxford Economics & PWC, 2015; Swilling, 2019b). Rifkin supports his theory of symbiosis by pointing out how steam in the 19th century made printing technology cheaper, which subsequently improved the speed of production and also made print material widely available. He further highlights the 20th century, where energy and communication were again converged, leading to centralised electricity coupled with the rise of the telephone, which was later followed by radio and television as communication vehicles (Rifkin in

Waghorn, 2011). The periods proffered by Rifkin, also saw the rise of the steam locomotive (in the 1800s) and the automobile (in the 1900s), corroborating the synergistic nature of all three sectors.

The rise of these three sectors indicate a smart post carbon global economy. This is clear from two of the sectors, which are incrementally pulling out from the fossilised economy, in favour of cleaner energies. The transport sector is gradually adopting non-carbonised fuels which is evident from the rise of electric vehicles (EV) and its integration into the broader electricity sector.

The RE transition framed from the perspective of an uptick in energy, mobility and communications, is better understood by pondering Rifkin's *"3rd industrial revolution",* which describes a reformation of socio-institutional dominance linked to the *"conjoining of Internet communication technology and renewable energies"* (Rifkin, 2011:36-37). To that end the emergence of a smart ecosystem is conceivable; one where enhanced communication capabilities create a supportive platform for the emerging RE sector alongside with mobility. The concept of a smart ecosystem is dependent on the materialisation of big data, artificial intelligence (AI) and the exponential Internet of Things (IoT). These and other applications from the information, communication and technology (ICT) sectors will profoundly reshape the societies of tomorrow. As the IoT seeps into the mainstream, every single conceivable object potentially becomes a computation device. Back in 2015 it was projected that 25 billion devices will be connected to the internet by 2020, up from 5 billion (Lincoln, 2015 quoting a 2014 report by Garter). It is into this agglomeration that RE assimilates, leading to a decarbonised technological global ecosystem that allows for stackable technologies. This highlights the future levels of connectivity between sectors, which will allow for different systems to be custom stacked together for automated efficiency and management. These include power management applications for the new energy systems; applications for *"autonomous (driving), connected (vehicles), electric-shared"* (vehicles) and smart mobility (Adler, Peer & Sinozic, 2019:1), as well as a host of other broader smart applications (Rifkin, 2011).

5.7 Rationalising the Carbon Emissions Conundrum

Achieving any form of justice whether social, economic or environmental requires a purposed approach that is well suited to the new realities that are currently emerging. In his most recent book, *“The age of Sustainability”*, Swilling (2019b) describes the unfolding of a current deep transition. He cautions against the possibility of a destabilised transition, which will only serve to reinforce the injustices of the past. The original multi-sectoral transformation process, which began with the first industrial revolution, resulted in a deeply fossilised economy and brought with it many unintended consequences, rendering it destabilised. The science which unveiled the true devastation brought about by the fossilised economy, only happened in retrospect as the realities of development emerged which suggests that such outcomes were unforeseen and not planned for. The sustainability literature unequivocally agrees on the notion of a first industrial revolution being the starting point that ultimately led to the global poly-crisis. In Schot and Kanger's (2018) conception of the first deep transition, they highlight an incremental period of 250 years, which propelled the planet and society into an era of excess. Progressive scholars and policy advocates such as Kanger and Schot (2019) in their work on sustainability, Geels *et al.*, (2017a) in their conceptions on deep decarbonisation, and to a much greater extent Swilling's (2019b) publication on just transitions, - each campaign for society/policy to gravitate towards new paradigms of justice. This ideal includes environmental justice. This is best achieved in a transdisciplinary manner that widens policy prospects.

In thinking further about broader policy frameworks, an ingenious human social experiment by Woolley, Gerbasi, Chabris, Kosslyn and Hackman (2008) best expresses how a multiplicity of ideas, prove to be better for solving wicked problems. The participants below symbolise different policy approaches:

Several teams were given the task of solving a problem that could not be solved by any one particular team member. The solution required a range of expertise. The teams varied both in the level of skill of their members and in whether integration of skills took place. In the case of integration, the members understood and deferred to each other's skills. The results were striking as seen below. You might think that the integrated team with the lower skills would be the least successful. Not so. The team that was least successful was the one with high skill and no integration. Why did this happen? The key is that the problem was too big for any one expert to solve. When expertise was high and integration non-existent one expert would lord it over the others. When expertise was average but integration happened, the combined expertise was greater and sufficient to solve the problem. Using the above experiment Woolley, Gerbasi, Chabris, Kosslyn and Hackman (2008) demonstrate the efficacy of a transdisciplinary approach to a complex problem and the value of considering the broader factors at play. Similarly, if there is ever a problem too big for one kind of expert to solve it is the eco-crisis – the CO_2 emissions!

In the last decade or so, the drive to reduce CO_2 emissions has for the most part been hamstrung even as RE capacity increased. Research and policy on RE are for the most part constrained by what Geels *et al.* (2017b:463) eloquently refer to as a *"focus on rational decision-making"*. This is interpreted to mean technological responses, which pay no heed to the non-linear dynamics as well as the broader social processes happening within the transition. This is a drawback. What this fails to do is acknowledge transitions as highly complex processes, which are often mired in uncertainties, subject to social acceptance and prone to disagreements. The continued global subsidisation of fossil fuels (see section 4.8.4) is but one example of non-acceptance and disagreement. This highlights policy deficiencies and a failure to address some sectors that are negatively affected by the RE transition, warranting counterproductive measures. Simple acceptance issues such as cultural attachments to grid electricity can hamper the roll-out of smaller home solar systems. These can be rejected because they are perceived to be inefficient for running bigger household appliances. The policies are fragmented and at times too weak to change entrenched cultural attachments. All these scenarios go a long way towards limiting the momentum of change. There are numerous examples that illustrate the complexities involved across all the four dimensions of change which demand a multi-dimensional approach. While this study has mostly focused on the RE roll-out and the corresponding effects on CO_2 emissions, the reality is that to be effective requires complex processes and interactions that cut across techno-economic, social, political, business and cultural dimensions (Geels *et al.*, 2017b). By exploring the broader scope of the RE transition through the lens of the four dimensions, this study offers political, technological, social, economic and metabolic insight. It also illustrates the interdependencies that exist between the elements above. The deep transition conception broadens the low-carbon transition to include the social sciences in a more cross-disciplinary approach (Geels *et al.*, 2017b). Additionally it broadens the economic boundaries and takes into account society's resource metabolism in a bid to inclusively understand the dynamics and to comprehensively manage climate crisis. This approach paves the way for aligning climate policy with broader policy objectives.

5.8 Summary

Since the 2015 Paris Agreement, total global carbon emissions grew by 1.7% in 2017, and further by 2.7% in 2018 (Dennis & Mooney, 2018). Although it was anticipated that they would grow even further in 2019 (Carrington, 2019) they defied expectation when they stalled. This may or may not have been the beginnings of a new phase in the decarbonisation effort. It still remains to be seen. On the other hand a significant rise in RE is on record, bolstered by cheaper RE prices, efficient technologies and an enabling policy environment. The IPCC (2018a) suggested that fast climate action may reduce emissions within 12 years, arresting GMST to below the double headed targets of 2^{o}C or 1.5^{o}C by 2030. However, unless the RE transition is rapidly deployed, climatic risk remains an ever present reality. These were the key findings of this study, which confirmed a rapid deployment of RE but one that is insufficient to climate needs; the build-up in the former does not corelate to a reduction in the latter.

The other key finding was that the RE transition is embedded in the conception of a wider deep transition. This finding is at variance with the narrow framing presently employed as a solution to the CO_2 challenge. The second part of Chapter 5 uses the four dimensions of the deep transition to deepen our understanding of the RE transition as summarised in the following four statements:

- Framing the RE transition within a socio-technical transformation illustrates how enhanced co-evolutionary interactions between society and the new technology could accelerate a deep decarbonisation.
- The RE transition viewed as part of a socio-metabolic regime shift is justified by applying the EROI metrics, revealing how the material flow of fossil fuels are shifting in favour of RE with a declining carbon footprint but an increased material footprint.

- Identified as part of a broader techno-economic surge, it can be reasonably argued that the RE transition is spearheading the pathway to a greener economy.
- Driven by increased investments in novel communications, mobility and energy systems, the new global economic cycle enhances our understanding of the RE transition to be part of a broader, smart, digital, integrating system for the information age.

The four dimensions of transition additionally illustrate how the RE shift is impacting every sphere of society, further highlighting the need for progressive policies at every level and dimension to help guide the process. Making all the right considerations from an informed perspective is vital for achieving social justice, improving the economy and indeed achieving climate action objectives, such as decarbonisation. While this chapter sought to fuse lines of argument in Chapters 3 and 4, the following chapter concludes the study by making recommendations and highlighting the limitations encountered.

Chapter 6: Conclusion and Recommendations

6.1 An Overview of the Guiding Strategy Followed in this Study

This study makes the case for a much broader perspective and approach to the RE transition as an appropriate pathway to effectively dealing with the issue of CO_2 emissions. It also notes that there are other polluting causes of climate change. While other GHGs also cause environmental damage, they have not been included in this study, however, the theories explored in this research could also be applied to those pollutants as well. The research interrogates the current renewable energy revolution by tackling three research questions in a comprehensive inquiry. The first research question is premised on the understanding that there is an upsurge in the deployment of renewables. The underlying assumption is that more RE will result in less CO_2 emissions. The enquiry sought to investigate the scale of the RE diffusion in a quantitative probe. Its core proposition was to understand why it is accelerating, while attempting to identify the different claims that either confirm or deny this expansion. It was found that there is rapid growth in renewables driven by falling RE prices, a favourable policy environment and better efficiencies in technology. The second question probed the pace of growth in renewables, and the study determined that RE has being adopted on scale since 2004 and is now 26% of total energy. However, it was also established that the RE expansion was insufficient to meet the set climate action targets. The last question was predicated on the notion that there is more to the renewable energy revolution and sought to establish a link between the energy revolution and a deep transition. Such a link was evident when analysed through the conception of the four transition theories. The deep transition concept highlights a major shortcoming in the decarbonisation agenda, which neglects a broader approach that is crucial to dealing with the CO_2 emissions. Within the broader context of a deep transition, it is likely that emissions have failed to significantly drop because the energy transition is not being understood as part of a wider deep transition. This oversight informs a process of reflective thought, which is given below, followed by some recommendations and the identification of limitations.

6.2 The Renewable Energy Renaissance: A Round-up of the Study

Energy transitions have re-occurred frequently over the past five centuries (Fischer-Kowalski, 2017; Fouquet, 2008, 2010; Fouquet & Pearson, 2006). The literature is clear on how humans are dependent on energy for sustenance and development (Fischer-Kowalski & Haberl, 2015). However, a less obvious fact is the stranglehold that energy has over humanity. This becomes evident from reviewing the work of the following: Mitchell (2011) who highlights issues of social politics that arise from the fossil fuel era; Szeman (2016) who points out the pervasiveness of petro-products and their absolute capture of humanity in ways that are both subtle and controlling; and Swilling (2019a) who illustrates the social inequalities that were created through the exploitation of energy. Though not realised at the time of including these insights in the study, these seemingly obscure impacts of energy later help to highlight the importance of this research, which is premised on the realisation that the influence of energy goes beyond its subliminal function as an omnipresent resource that is often taken for granted. This thinking gives rise to the call for social equity in ALL RE policy.

It is evident that transitions are an inherent characteristic in historical change. They forge new pathways to growth and development. In the period before the rise of fossil fuels, it is likely that many imagined the possibility of a more efficient energy source than whale oil or wood. It is reasonable to assume that Palaeolithic and Neolithic societies would have welcomed a form of energy that is easily accessed and effective for heating, cooking, and smelting. The new fossil fuel energy regime freed human labour to pursue other industrial tasks (Fischer-Kowalski, 2017).

Apart from growth, transitions also present opportunities for humankind to self-correct where necessary. It is at this very point that humanity finds itself. While future transitions may not happen in the same manner as those of the past, much deeper reflection is required of humanity in creating a better planet even as the new energy regime sets in (Fischer-Kowalski, 2011; Geels, 2012; WEF, 2013). It is well-advised to bear this in mind; to look beyond what is immediately obvious. It is not a mere technological shift (Garrigou, 2016; Geels *et al.*, 2017a; Scott, 2018; Swilling, 2019b; Szeman, 2016). The energy transition is profoundly transformative and warrants attention in the form of research and on-going surveillance (WEF, 2013). Otherwise if not heeded to – it is making fundamental changes that affect life, even as it entrenches social inequity. These changes may be happening while society goes on unawares.

By observing the current RE narratives, the underlying rationale behind the rapid expansion of renewables mostly emerges as a linear approach. It is clear that the RE transition is predominantly conceived from an economics perspective in an attempt to decarbonise and mitigate climatic risks. However, beyond techno-economics, this study ponders a much more profound metamorphosis; one which is better understood in its nonlinear way. Considering the argument that a deep transition may be under way (Schot & Kanger, 2018; Swilling, 2019a), it was logical to investigate the link between the energy transition and a deep transition. A deep transition framework helped to stretch the RE conception beyond the bounded techno-economics espoused by energy agencies and society at large. It is this broader reality of the unfolding events that appears to be ill-considered, thus impeding an effective low-carbon transition. Not only does failure to low-carbon transition become possible and imminent, but also the failure to address the underlying issues of poverty and inequity.

If energy transition is understood as part of a deep transition, it helps to bring into focus the appropriate remedies that are in line with addressing the CO_2 crisis. The remedies include but are not limited to finding ways of stimulating ongoing support for the RE transition coupled to interventions to stop subsidies for fossil fuels, preventing financial institutions from investing in fossil fuels as in the case of the European Investment Bank (EIB), and introducing legislation to prevent new fossil fuel plants from being constructed (EIB, 2019). Understanding the energy transition as part of a wider deep transition ultimately leads to the conclusion of this study, which proposes that a deep transition perspective will support research and policies that take into consideration all aspects of society, including those that are seemingly obscure yet critical to a more consolidated decarbonisation effort. Considering the broader and more obscure aspects that initially came about as a result of the pervasiveness of fossil fuels, will go a long way in ensuring that transition efforts unfold in just and equitable ways.

6.3 Implications

One clear implication brought out by this study challenges the misaligned double headed target of limiting average surface temperatures to 2^oC while aiming for a 1.5^oC

scenario, which emanated from the Paris Agreement (Pidcock, 2016). Most global policies are currently aligned to either an upper 2^{o}C or a lower 1.5^{o}C scenario (Pidcock, 2016). However, both targets are *"wide off the mark"* for climate action, since both lead to adverse climatic risks (IPCC, 2018a). Both fail to sufficiently decarbonise within the 10-year timeframe that is deemed critical for averting disaster (IPCC, 2018a). Lower targets that are more ambitious but suited to purpose may actually be attainable if they are set with the idea of a deeper transition in mind. Such a move would diffuse a decarbonisation policy process beyond the techno-economic paradigm and lead to a greater reduction in CO_2 that is in line with climate action. As it stands, the upper 2^{o}C and lower 1.5^{o}C scenarios are misaligned from delivering a speedy and effective reduction in CO_2 emissions.

This study's main proposition is that a broader perspective on the present energy transition is needed. The main impetus for a broader approach is that transitions are convoluted, nonlinear, and disruptive and therefore need to be seen beyond technology and financial viewpoints. The transformation requires a big picture approach which could enable a transition that incorporates instruments that effectively shut down fossil fuels while justly considering all entities including those likely to be affected negatively. This curtails outcomes that are defeatist such as unjust transitions which reinforce past injustices. The broad approach could also minimise conflict and ambivalence and provide ways to reduce barriers to transition while rapidly driving the necessary transformation and reducing CO_2 emissions. A well-conceived RE transition can be a game-changing equaliser when decarbonisation policies are aligned with other sectors like transport, agriculture and food. This can ensure a multisectoral position of agreement in policy as well as a sense of urgency, so that the energy transition is adequately devolved and the gains in the electricity sector are matched by all other sectors. Multisectoral policies can also ensure that other far reaching plans and strategies that are not techno-economic in nature or restricted to the energy space are brought into the fold.

The paragraph above can be summed up as follows. What is required are:

- a multisectoral policy alignment to harmonise sectors and society
- just transitions to stem inequality and the ensuing resistance to RE,
- and a way to address the negative effects of RE.

The broader perspective also needs to take into account other causes of climate change. As clearly stated, other causes to the climate crisis are not the focus of this study, but it is worth noting that failing to broadly consider such causes within policy formulation, ignores systems thinking in dealing with the climate problem. Without a systems approach to GHGs and social issues, the ability to see the whole is lost – as is the ability to effect meaningful change and stave off the climate crises.

Correctly applied carbon budgets would allow each country to set targets that are within the international climate change goals. Budgets would equitably consider the level of action to be undertaken by each country. The approach would be closer to the principles of ‘burden sharing’ or ‘effort sharing’ and therefore more equitable.

6.4 Limitations Encountered in the Study

This study has been an eye-opening exercise, from which I was able to deduce potential value and relevance to a wide range of applications in society. However, the following limitations were encountered:

1. The first is the evident disparity in data. The global figures for energy tend to differ, and this is due to challenges in the accuracy of captured data. The measures used by the IPCC, IEA, REN21 and IRENA can differ. This was confirmed by Professor Imre Szeman of Waterloo University in an email exchange about the figures he used in an article. While it is advisable to use various sources for triangulation purposes, this was not always possible as some essential data was sometimes available from one source and unavailable from another. This made it challenging to verify data all the time. With the variances in measures noted, it is also important to bear in mind that all sources highlight the same “wicked problems” and regardless of datasets used, the planet’s wellbeing is still at stake. That is the heart of the matter.
2. Not all references to energy are “made equal”. Electricity has become the “poster child” for energy references which means it generally assumes a default cross-platform measure. References to 'energy' therefore do not necessarily capture the whole story, and in certain cases the contrast is offered for clarity and accuracy.
3. It is clear that some of the most crucial issues such as social equity at the individual, national and global level are overlooked in the wider climate global arena.

6.5 Policy and Recommendations for a Decarbonised Future

6.5.1 Policies that scale up the global renewable energy transition

In its current form the RE transition is insufficient to meet the set global targets and most critically fails to mitigate major climatic risks. In spite of cheaper RE costs, vastly improved technologies, as well as pro-RE policies, it is clear that the overall RE uptake has not been rapid enough. This finding calls for a smarter re-orientation towards RE growth strategies that are commensurate with the proportions and scale of the climate crisis. It further suggests a need for greater RE funding and investments as well as better policies that stimulate bigger RE growth. For this to happen strong political willpower is a precondition. However, due to raised CO_2 emissions, RE growth strategies on their own are only part of the solution and should be considered in tandem with the following policy recommendations.

6.5.2 Decarbonisation policies that align with the renewable energy transition

While growth in RE is critical, this study finds that an energy transition devoid of decarbonisation policies is not sufficient for the reduction of CO_2 emissions. This is clearly demonstrated by a growing RE regime that currently generates about 26% of the electricity produced globally (REN21, 2019a). The present transition which mostly focuses on RE growth has failed to significantly bring CO_2 emissions down. To this end Geels *et al.* (2017a) advocate for policy mechanisms that are aligned to the research on low-carbon transitions. Effective decarbonisation alongside a RE expansion programme has to be pursued and policies that enable this symbiosis need to be formulated. For RE growth to receive support from low-carbon transitions as part of a dual objective, will require an active decarbonisation process to be conceptualised at the energy policy-making level. This can effectively lead to the shutting down of carbon emissions within the electricity sector while growing renewables. Decarbonisation policies should ensure that the transition from fossil energy attracts the majority of stakeholders while simultaneously managing any resistance that may arise. As noted, resistance includes any subsidisation of fossil fuels and the development of new fossil-fired plants (Irfan, 2019; REN21, 2019a). This is especially relevant while Africa embarks on a massive expansion of fossil fuel electricity (Fuller, 2019). Bold policies that tackle fossil fuels while complimenting RE growth are in line with deep transition thinking, which advocates for a broader process within transition theory and its applications. This way of thinking escalates the process from a mere intellectual and techno-economic exercise to one that begins to embrace a non-linear perspective.

6.5.3 Broader policy mixes to lower Carbon Emissions

The first recommendation put forward by this study is to support the call for more ambitious RE policies as put forward by various energy agencies (IRENA, IEA & REN21, 2018). However, it also recognised that on its own RE growth is insufficient. This study has demonstrated instances of policy oversight in the RE roll-out and has recommended the need for decarbonisation policies that augment growth in RE for the energy sector. When considered from a deep transition perspective, it is clear that the omissions in RE policy are not only limited to decarbonisation or the growth of renewables but also extend to the rest of society in a way that drastically hinders low-carbon transitions (Geels *et al.*, 2017b). This is observed in other sectors such as transport, heating and cooling, where low-carbon transitions are minimal (IRENA, IEA and REN21, 2018). There is very little evidence of policies that take into account the non-linear and broader effects of the present RE transition (Geels *et al.*, 2017b). It is likely that a constructive lowering of CO_2 emissions will not be realised should the RE transition continue in its present form. When analysed according to deep transition thinking, the formation of legislative and policy frameworks that broadly address renewables and overall decarbonisation in a non-linear manner is largely overlooked. This research shows that decarbonisation will require far more than just the ambitious policies referred to by the energy agencies. Many governments are still lagging in spite of their international commitments to facilitate deployment and growth in RE. This lag not only demonstrates policies that lack ambition while displaying a form of resistance, it also highlights an almost exclusive focus on RE. In the likely event that the RE diffusion is scaled up to a more ambitious target, it is probable that climatic risk could be averted. However, this is subject to one proviso, namely that fossil fuels need to be quashed (Geels *et al.*, 2017a,b). The equation between increasing RE output and decreasing fossil fuels requires a broad set of complex policies that stretch beyond renewables into spheres of society that are beyond the energy sector. The policies must also consider and target nonlinear aspects of society that are seemingly unrelated such as cultural preferences for certain types of food. In general, robust policies need to be polycentric in aligning a variety of actors and responsibilities towards the grand objective of lowering CO_2 emissions (Geels *et al.*, 2017a). The policy mixes have to be contextualised to each location and its peculiar needs. Such an approach is cognisant of the deep transition perspective that introduces a broader framework through which to understand and manage the RE revolution.

6.5.4 Need for broader policy research aligned to deep transition thinking

To effectively employ a broader policy-mix as per the recommendation above (6.5.3) will require processes that consider the deep transition concept. Broad-based research can inform the abovementioned policies (6.5.3) by creating cross-disciplinary opportunities for analysis and learning. The transdisciplinary policies that emerge can help to align society with the decarbonisation objective. For policies to support a broader approach to the RE revolution and decarbonisation as per Geels *et al.* (2017a), will require research to pursue knowledge that leads to favourable social outcomes. This research also needs to take into consideration other elements such as business plans, methods of innovation, political tensions and cultural dialogues, to name a few (Geels *et al.*, 2017a). A polycentric approach to research which explores non-linearity as well as other ingredients of transition that are difficult to model, recognises that they are a critical component within the broader RE transition. Incorporating the complexities of a deep transition lays a solid foundation for the formulation of well-suited policies which can save on transition costs while rapidly lowering CO_2 emissions and averting climatic disaster (Geels *et al.*, 2017a).

6.5.5 Deep transition thinking towards social equity

Many of the policies that are formulated do not take into account the fact that the world is not a homogenised society. Sections *3.2.1 and 3.2.2* clearly illustrated how the consumption of energy, development and the resultant emissions were different for different parts of the world owing to the rampant inequality that exists. The same section also highlighted how the poorer countries are disproportionately (inequitably) affected by the outcomes of climate change, in spite of not burning fossil fuels nor enjoying the benefits of growth to the same measure that developed countries do. In other words, they unfairly carry the burden of CO_2 emissions, global warming and climate change. The fact is, the impacts of global warming, inclement weather and climate change are not bounded to the area where the biggest emitters are located. Thus, this investigation provides the impetus for further research into an equitable low-carbon transition and an appropriate approach to achieve such a transition.

6.6 To Conclude

With more questions than answers, as I approached the culmination of this study, I realised that this is only the beginning. I recognise the ubiquitous nature of energy, its influence and the complex web it has spun to be profound. Understanding the emergence of petro-cultures as per Mitchell (2011), Scott (2018), Swilling (2019a), and Szeman (2016) (see sections 1.4.3 and 6.5.2) proved to be instrumental in helping me to grasp the challenge of CO_2 emissions beyond the obvious. If the influence of fossil energy has permeated all aspects of society, then the problems that have arisen are beyond linear, and the solutions need to look beyond what is immediately perceivable. For that reason, it becomes clear that there are difficult issues that are not being addressed, resulting in fossil resistance. This is a major pitfall considering that time is limited (IPCC, 2018b). This study has nurtured my own convictions towards a better future for humanity and the planet. What started off as a technological enquiry has become a profound journey which has challenged my own hypocrisy on many fronts, evolving into an odyssey that is both academic and spiritual. After this thesis, I seek to learn more, but most importantly to play my part in ensuring transformations that lead to true sustainability for everything

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