UNIVERSITY OF LJUBLJANA
FACULTY OF ECONOMICS

MASTER'S THESIS

THE END OF FOSSIL FUELS AND THE TRANSITION TO RENEWABLE ENERGY SOURCES IN LIGHT OF CLIMATE CHANGE

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LIST OF ABBREVIATIONS

AEVs – autonomous electric vehicles
AVs – autonomous vehicles
b/d – barrels per day
BNEF – Bloomberg New Energy Finance
BOS – balance of system
BP – British Petroleum
CATL – Contemporary Amperax Technology
CCS – carbon capture and storage
CO_2 – carbon dioxide
CO_2e – carbon dioxide equivalent
COP – Conference of the Party
COPs – Conferences of the Parties
CSP – concentrating solar power
EIA – Energy Information Administration
EJ – exajoules
EPA – Environmental Protection Agency
EPA – Environmental Protection Agency
ESG – environmental, social and governance
ETS – Emissions Trading Scheme
EU – European Union
EVs – electric vehicles
GDP – gross domestic product
GHG – greenhouse gas
GJ – gigajoules
GM – General Motors
GW – gigawatt
GWEC – Global Wind Energy Council
HDVs – heavy-duty vehicles
IEA – International Energy Agency
IEEFA – Institute for Energy Economics and Financial Analysis
IMF – International Monetary Fund
IPCC – Intergovernmental Panel on Climate Change
IREA – International Renewable Energy Association
kW – kilowatt
kWh – kilowatt hour
L&G – Legal & General Investment Management
LCOE – Levelized Cost Of Energy
LNG – liquefied natural gas
MAC – marginal abatement cost

MPC – marginal private cost
MSB – marginal social benefit
MSC – marginal social cost
MW – megawatt
MWh – megawatt hour
NO_2 – nitrogen dioxide
NO_x – nitrogen oxides
OECD – Organisation for Economic Co-operation and Development
OGCL – Oil Gas Climate Initiative
OPEC – Organisation of the Petroleum Exporting Countries
PIF – Public Investment Fund
ppm – parts per million
PV – photovoltaics
RE – renewable energy
RES – renewable energy sources
ROCs – Renewables Obligation Certificates
Shell – Royal Dutch Shell
SO_2 – sulfur dioxide
TW – terawatt
TWh – terawatt hour
UN – United Nations
UNFCCC – United Nations Framework Convention on Climate Change
US – United States of America
VW – Volkswagen

INTRODUCTION

Climate change is global, uniquely uncertain and has long-term effects. It is no longer just a scientific concern: it is also of concern regarding economics, geopolitics, national and local politics, law, and health. It is one of the defining challenges of the 21st century (Maslin, 2013). Climate change affects people and important economic sectors. Economic growth is generating unintended but dangerous changes in climate systems (Wagner & Weitzman, 2015). Burning fossil fuels has the unintended effect of changing the global climate (Maslin, 2014).

While skepticism remains, the fundamental activities that result in climate change are scientifically proven; during the last several decades human activities have been singled out with very high certainty as the principal factor of most observed climate-generated changes (Schneider & Mastrandrea, 2010). The most sensible approach to putting a stop to the undesireable effects of future climate change would be to cut greenhouse gas (hereinafter: GHG) emissions. The most basic cause of global climate change is fossil fuel consumption (Pollin, 2015).

Since the Machine Age, human activities have been contributing further GHGs to the atmosphere. The burning of fossil fuels is the leading contributor to these increased emissions of carbon dioxide (hereinafter: CO_2). A result of this has been that the concentration of CO_2 in the atmosphere has risen from 280 parts per million (hereinafter: ppm) to 405 ppm in 2017 and is currently rising at around 3 ppm per year (Peake & Everett, 2018a). Following the United Nations Conference of the Parties (hereinafter: COP) in Paris in 2015, a total of 195 countries committed to limiting their GHG emissions "consistent with holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels" (UNFCCC, 2015).

The Intergovernmental Panel on Climate Change (hereinafter: IPCC) predicts that the global average temperature by the end of the 21st centuary could go up between 1.8°C and 4.0°C, the scale is because of the uncertainty of how much GHG we will release by the end of the 21st century (Maslin, 2013). Climate scientists warn that average global warming above 2°C could highly set off destructive events (Wagner & Weitzman, 2015).

The challenge facing the world is to provide the energy societies need to raise their standard of living but at the same time to drastically reduce our dependence on fossil fuels. We will need to increase our supply from renewables very significantly, and particular the supply of electricity; and the cost of renewable energy sources (hereinafter: RES) must become lower than energy from fossil fuels. Renewable energy (hereinafter: RE) is seen as a measure for avoiding the perilous and destructive environmental effects from fossil fuel burning (Maslin, 2014).

Between 2010 and 2016, various RE technologies have seen high growth rates: world wind power output increased almost three-fold and solar photovoltaics (hereinafter: PV) output increased almost ten-fold (BP, 2018a). Expansion in the manufacture of renewable technologies has also produced dramatic cost reductions. These RE growth rates are likely to carry on, driven by environmental concerns, and the local air pollution consequences of coal-fired electricity generation in China and India (Everett, Boyle, Scurlock & Elliott, 2018).

The climate change agenda (decarbonisation) and the coming of new technologies across the energy sector, particularly in electricity generation – new storage, transmission, and distribution technologies – and the fast-changing technological landscape in electric vehicles (hereinafter: EVs) will eventually force out the fossil fuels (Helm, 2017). In order to increase the share of renewables, different designs of feed-in tariffs and other renewable support policies have been implemented in different countries. There is a broad political and scientific consensus that RE has to play an important role in the pathway to a low carbon energy sources (Schenker & Löschel, 2017).

The primary economic policy instruments for mitigating emissions are widely known: carbon taxes, carbon trading, regulations such as limits on vehicle emissions or subsidies for renewables. Any form of these measures will cut the demand for fossil fuels. Any form of carbon pricing will raise the price of fuel for the final consumer, so investment in alternatives, such as RE, will be encouraged. Revenues from carbon taxation can also be used to subsidise clean technology (FitzRoy & Papyrakis, 2016).

The rising global temperature and concerns about climate change have resulted in politicians throughout the world to review about their countries' GHG emissions. To achieve a meaningful climate action, global cooperation on global public good provision such as GHS emission reductions is needed (Koke & Lange, 2017). Policymakers worldwide have agreed that there should be a considerable amount of reductions in GHG emissions (UNFCCC, 2010, 2015). The political determination has resulted in the arrival of the environmental movements and international agreements such as the adoption of national and sub-national climate policies (Burtraw, 2013). An accepted characteristic of these policies is that they lay down targets to curb GHG emissions (Garnache, Merel, Lee & Six, 2017).

At present, electricity generation is undergoing a major transition: moving away from fossil fuels towards RES. We will see an extensive energy transformation throughout the world in the next few decades. Largely driven by the need to stop catastrophic climate change, we will shift from fossil fuel dependence to rely on RES.

By studying climate change policies of Germany and Norway, the thesis will try to understand how the **problem** – our dependence on fossil fuels, GHG emissions, resulting in global warming – can be remedied through more promising policy interventions by governments.

The **research question** is:

What are the impacts of more promising climate change policies for the transition to renewables and new breakthroughs in technologies on the future of fossil fuels over the medium-to-longer run?

The **main objective** of this thesis is to explore the end of fossil fuels by analysing the following three issues:

1. Promising climate change policy instruments to correct the greenhouse gas externality: In economists' terminology, the emission of GHS is known as an externality and externalities cause inefficiency (Stern, 2016).
2. The shale revolution in the USA (hereinafter: US): The development of fracking technologies in the US has transformed the world's oil and gas markets and changed geopolitics (Helm, 2017).
3. Renewable energy and new breakthroughs in technology: Renewables offer the possibility of inexhaustible, carbon-free fuel and the costs of these alternatives have been dropping at a rapid pace (Schwarz, 2018).

By closely analysing the above three issues and more, the thesis will try to disclose the end of fossil fuels over the medium-to-longer run. In other words, the **aim** of the thesis is to show that these issues will eventually push fossil fuels away in the next few decades and pave the way for the transition to renewables in the longer run. The thesis will try to explore the issues in relation to recent developments such as the Paris Climate agreement, commitments made by national governments in tackling climate change, and investments made by automakers and oil companies towards environmental commitments.

This master's thesis is a qualitative design, using an abductive approach. The nature of this research design will be a combination of exploratory, descriptive and explanatory. This thesis is mainly based on multiple-source secondary data, to be precise, compiled from diverse sources. In order to link the research question and the main objectives of the thesis, a case study strategy is chosen. Two cases are selected on the basis that similar results are predicted to be produced from each one. Germany and Norway are two leading European countries heavily investing in renewables and taking climate policies seriously. Germany, a country not known for its sunny climate, is a leader in solar energy (Schwarz, 2018). In Norway, 98 percent of electricity production comes from RES (Government.no, 2016). Norway is by far the undisputed world leader with the highest market share for EVs by capita globally (Portvik & Christiansen, 2018).

The purpose of the master's thesis is neither to test an existing theory nor to generate a hypothesis. The thesis follows an argumentative design: by presenting a statement, that is, fossil fuels will eventually be squeezed out of the energy mix in light of stricter climate change policies, pressure from institutional investors and falling cost of renewables and then bringing in contributions of different authors to argue the statement. Climate change requires an entirely new way of thinking and climate change policies must go beyond than just correcting the GHG externality if they are to incentivise action on the scale required. Governments must retain climate change as their prime concern: subsidies are imperative if new technologies are to succeed and an effective economic scheme must be initiated for working towards a low-carbon economy.

The thesis is structured in six parts. The first chapter is a brief overview of the environmental problem that humankind is currently facing. The second chapter argues that the governments of the world can respond to externalities in one of two ways: command-and-control policies and market-based policies. The third chapter of the thesis ends with the analysis of the future of fossil fuels in light of electrification across transport and power sectors through the rise of renewables and investor pressure due to co-ordinated efforts to tackle climate change by governments. The fourth chapter focuses mainly on two RES: solar PV and wind energy. The fifth chapter looks into two of our responses to climate change: adaptation and mitigation. The final, sixth chapter examines two countries: Germany and Norway. In the case of Germany, the thesis will look into Germany's energy transition initiative to move away from fossil fuels and nuclear power to a clean alternative. In the case of Norway, it will look into Norway's lead on EVs sector and the government's generous incentives to meet its climate change goals.

1 AN INTRODUCTION TO CLIMATE CHANGE AND ITS IMPACTS

Many people get weather and climate confused: the terms are repeatedly used as though they mean the same thing (Maslin, 2014). Weather describes the prevailing state of the atmosphere over a few days or weeks. Climate describes the average of daily weather systems over a long period of time (IPCC, 1996; Hussen, 2013). Climate is harder to establish: it demands the collection of decades of data (Dessler, 2016). Climate is molded by components and changes of a system which includes the land, water, glaciers, atmosphere, and organisms. The climate system transforms gradually subject to its inner forces or ‘forcings’ and alterations in outer forces. Forcings are of two kinds: natural phenomena such as volcanic explosions; and anthropogenic (human-generated) alterations in atmospheric make-up (Perman, Ma, Common, Maddison & McGilvray, 2011).

Although CO_2 is the most studied of the GHGs, many other gases have similar heat properties. They include methane, water vapor, the chlorofluorocarbons, and nitrous oxide to name a few (Tietenberg & Lewis, 2015). Forecasting future climate is important because the rise of one class of global pollutants, known as GHGs, increases warming globally (Maslin, 2014). A serious issue associated with the modeling of future climate is that the difficulty of establishing future carbon emissions. The biggest unknown in the models is the estimation of future global GHG emissions over the next decades. It consists of many variables such as the global economy, population growth, technological progress, usage of fossil fuels, the rate of fuel switching, the pace of deforestation, the success of political agreements to reduce carbon emissions and personal lifestyle changes (Maslin, 2014).

1.1 Understanding climate change

The climate is affected by a number of factors: the greenhouse effect plays a key role among these factors. We need the greenhouse effect: it keeps the Earth at a temperature favorable to life (Broome, 2012). But the greenhouse effect is now increasing and leading our atmosphere to warm further (Broome, 2012). The "enhanced greenhouse effect" is when humans move into the picture and emit more GHGs (Nordhaus, 2013). The current worry over the effect of GHGs is that they have very long residence times in the atmosphere. Emissions entering the atmosphere now will influence the climate for a very long time (Tietenberg & Lewis, 2015).

Past changes in climate were driven by natural sources. But current climate change is driven increasingly by human activities. The major cause of global warming is the emissions of CO_2 from the burning of fossil fuels. Everything we do almost requires the combustion of fossil fuels, which produces emissions of CO_2 into the atmosphere (Nordhaus, 2013). There is growing scientific evidence that shows global warming is mostly generated by human activities, especially, the increased use of fossil fuels since the beginning of the industrial revolution (Hussen, 2013). Climate change is considered to be the most significant natural world crisis that human society has confronted with. The climate science is clear-cut – human actions are having an effect on the climate system, playing a part in global average temperatures, melting of glaciers, and rising average global sea levels (IPCC, 2007).

Human activities release around 42 billion tonnes of CO_2 into the atmosphere each year. The biggest share derives from burning fossil fuels and industrial processes and the rest is owing to deforestation and other land-use changes. CO_2 is continually circulated between the atmosphere, plants, and animals through growth, death and decay, and also directly between the atmosphere and ocean. Almost half of the CO_2 pollution is absorbed either by land and forests (known as, land sink) or by the oceans (known as, ocean sink). The rest piles up in the atmosphere; there is no hole in the sky for it to escape through (Juniper & Shuckburgh, 2017).

GHG concentrations have risen from 285 ppm carbon dioxide equivalent (hereinafter: CO_2e) in the mid-1800s to about 445 ppm CO_2e today. CO_2 has increased from 280 ppm in the mid-1800s to about 405 ppm in 2017. Between 1930 and 1950, we were adding at a rate of 0.5 ppm CO_2e per year, increasing to 1 ppm CO_2e per year throughout 1950 - 1970 and to 2 ppm CO_2e per year from 1970 till 1990. The rate is now almost 3 ppm CO_2e every year. The rise in GHGs in the atmosphere up to now correlates with average warming across the earth's surface of around 1°C (Stern, 2016).

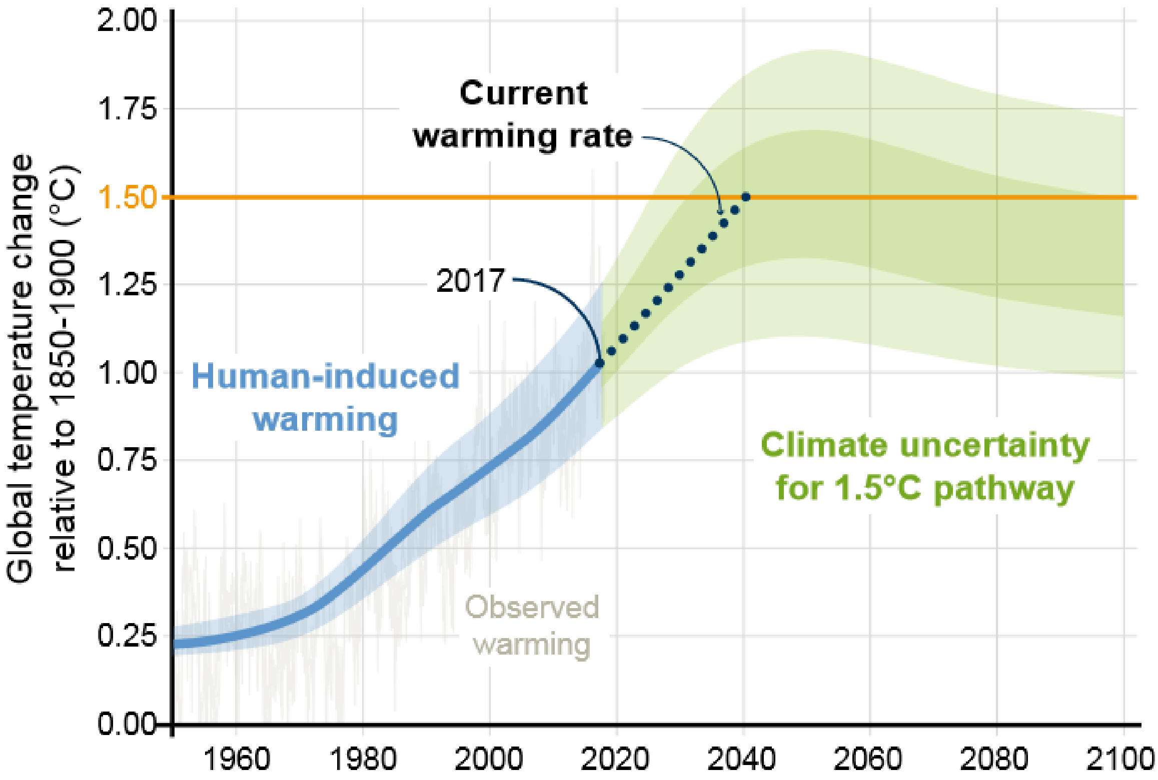
The world has passed CO_2 concentrations of 400 ppm, and rising at 3 ppm per year. Counting other GHGs, the International Energy Agency (hereinafter: IEA) forecasts that the world will reach somewhere around 700 ppm by 2100 unless major emitters adopt strong additional steps (Wagner & Weitzman, 2015). If the world keeps on discharging GHGs along a "business as usual" path, concentrations of GHGs could increase to the region of 750 ppm CO_2e by 2100. At these levels of GHG concentrations, some climate models show a median temperature rise over the next one or two centuries of about 4°C or more, with significant probabilities of well above 4°C (Stern, 2016).

According to the latest report by the World Meteorological Organisation, the 20 hottest years officially measured have been in the past 22 years, with the 2015 – 2018 considered to be the top four. The report says that if the tendency remains, temperatures may increase between 3°C and 5°C by 2100 (World Meteorological Organization, 2018). The physical and human geography of the planet would likely be transformed with temperature increases of 4°C or more: deserts, coastlines, rivers, rainfall patterns would be redrawn (Stern, 2016). We are already seeing the impact of temperature rise, but that is a small temperature increasing in proportion to what we are putting in danger (Sorrell, 2013).

According to the latest report by Christian Aid, ten of the most expensive climate change driven destructive weather events of 2018, each leading to damages over $1 billion. Four of them gave rise to more than $7bn each: the most costly weather events were Hurricanes Florence and Michael in the US, with costs around $17bn for the former and $15bn for the latter. These figures only show insured losses and do not show uninsured losses and the costs of lost productivity. Scientists have shown that these destructive weather events such as heatwaves, wildfires, droughts, floods, and hurricanes throughout the world in 2018 were directly influenced by human-induced warming (Christian Aid, 2018).

Scientists defended for decades the global temperature rise must be maintained below 2°C above pre-historical times to prevent the worst impacts of climate change. This is a widely accepted target in the international discussion as a temperature beyond which climate change is dangerous and it is embodied in international agreement of the Paris climate deal (Stern, 2016). But scientists have now reasoned out that limiting below 1.5°C is the prudent and responsible course of action for the world. According to climate scientists, we will hit the 1.5°C mark by 2030 if we carry on as we are. The scientists of the new IPCC ″Special Report on Global Warming of 1.5°C″ alert that in order to hold the global average temperature at 1.5°C, global net human-induced CO_2 emissions must go down by about 45 per cent by 2030 from 2010 levels and arrive at net zero by 2050. The new report also concludes that $2.5 trillion must be annually invested in clean energy (Intergovernmental Panel on Climate Change, 2018).

Figure 1: Human-induced warming reached about 1°C above pre-industrial levels



Source: Intergovernmental Panel on Climate Change (2018).

According to the IPCC report, the world has already warmed by around 1°C and the 1.5°C temperature could be overshot in 2030 as shown above in Figure 1. The report states there must be immediate and important changes by individuals and in following global systems: energy, transport, land usage, buildings, cities, and industries (Intergovernmental Panel on Climate Change, 2018). The report also says to curb warming to 1.5°C, we will need to spend 2.5 per cent of global gross domestic product (hereinafter: GDP) for two decades (McGrath, 2018a).

The IPCC Summary for Policymakers points to some substantial arguments concerning the impacts on the earth of 1.5°C and 2°C (McGrath, 2018c). The report says that if we fail to limit temperature rises below 1.5°C, coral reefs would be 100 per cent wiped out at 2°C of warming; global mean sea levels rise will be around 10cm more for warming of 2°C compared with 1.5°C – that is to say, keeping to 1.5°C denotes that 10 million fewer people would be left unprotected to the risks of flooding; in a world that is warmed up to 1.5°C, about 14 per cent of the population are exposed to a heat wave every five years, that increases to 37 per cent of the population at 2°C. The additional half a degree Celsius would expose an additional 420m people to heatwaves, and cause 10 million more people to face risks from rising sea levels. In addition, there will be impacts on ocean temperatures and acidity; impacts on the ability to grow crops such as rice, maize and wheat (McGrath, 2018a). The report found that a 2°C rise was far more dangerous than an increase that was half a degree Celsius lower. The recent report also showed that half a degree of additional warming can be expected to result in additional damages globally between $8tn and $11tn before 2050 (Hook, 2018e).

Climate change will bring about a set of certain impacts (e.g., increasing temperatures including extreme heat events, increases in sea level, increasing acidity of the ocean) as well as a large number of potential impacts (e.g., increasing flood and drought intensity and frequency, increase in hurricane intensity and frequency). These physical impacts on the climate system are only the first step in determining climate impacts (Dessler, 2016).

The concern is that the climate will not heat up steadily as more and more GHGs are added through the burning of fossil fuels. On the contrary, our activities will contribute enough GHGs that the climate system will be subjected to a massive and fast change to a completely new climate state. This massive climate alteration might occur on a timescale of a few decades. This prospect unsettles scientists because sudden and unexpected changes have previously occurred. Therefore, sudden and unexpected shifts do occur and we must act on their likelihood critically. Climate models do not forecast the frequency of a sudden and unexpected change, and most experts regard the likelihood to be low, but not zero. If a sudden and unexpected change did happen, its consequences could be fatal to the natural world (Dessler, 2016).

1.2 Impacts of climate change

A key principle in understanding the impacts of climate change is the difference between managed and unmanaged systems. A managed system describes societies that take follow-up measures to make sure the well-planned use of resources to fight against environmental issues (Nordhaus, 2013). Because human management dominates these systems, the ability to adapt management practices to changing conditions offers the possibility of mitigating at least some of the harmful impacts (Dessler, 2016). Agriculture and health care are examples of a managed system. An unmanaged system functions mostly through no human efforts. It is unmanageable because the system is very great for humans to manage or because humans choose to leave it alone (Nordhaus, 2013). Examples would be hurricanes (intensification), ocean acidification, damage to wildlife and natural ecosystems, and rising sea levels.

Clearly, this thesis cannot deal with every one of them in details but it briefly focuses on a few key concerns that are important to human societies.

1.2.1 Impacts of climate change on sea level rise and ocean acidification

One of the main worries over the coming decades is the impact of sea level rise on coastal areas and human communities near the coastline (Nordhaus, 2013). The IPCC report forecasts that by 2100 sea level will rise by between 45cm and 75cm above today's levels (Dessler, 2016). This is an enormous challenge for the human community because a sizable amount of the world's population lives within a few feet of sea level (Dessler, 2016).

According to Metz (2010), sea level has been firmly fixed throughout the first 1900 years AD, but since 1900 sea level has been increasing. Until 1990 this increase was about 1.7mm per year, but between 1993 and 2010 it has gone up to 3.2mm yearly.

Dessler (2016) points out two reasons as to why the sea rises in response to warming temperatures. First, as grounded ice (e.g., glaciers of the world and ice sheets on Greenland and on Antarctica) melts, the meltwater reaches the ocean, adding to the total volume of water and thus, sea level. Second, water increases in volume when it heats up (the heat trapped by GHGs goes into heating the oceans), which also tends to raise sea level. According to Dessler (2016), there two big ice sheets on the Earth: one in Greenland, and the other in Antarctica. If both of them melted totally, the sea level would go up about 65m.

The Population who are at risk are those live by river deltas, including Bangladesh, Egypt, Nigeria, and Thailand (Maslin, 2014). Also, increased sea-level will intensify the frequency of flooding events (Dessler, 2016). For the Marshall Islands in the Pacific and Maldives, a sea level rise of one meter would submerge 75 per cent of the dry land, forcing the islands unliveable (Maslin, 2014).

Maslin (2014) claims that the predicted upsurge of 50cm by 2100 can be solved if there is economic prudence or an organised plan of action or adaptation measures in order to protect coastal regions. However, all of the adaptation remedies are difficult and costly. Our choice is between building big-budgeted sea walls or simply vacating those areas (Dessler, 2016). If sea level rises by over one meter in the next 100 years, then humankind would have serious problems adapting to it (Maslin, 2014).

Ocean acidification is one of the most alarming features of CO_2 build-up. It is an example of an unmanageable system. Increasing CO_2 concentrations in the atmosphere are rapidly mixed into the upper layer of the oceans (Nordhaus, 2013). One of CO_2's characteristics is that it dissolves in water. Once it has dissolved in water, CO_2 is transformed to carbonic acid. This action is known as ocean acidification. The net result is that, as oceans suck up further CO_2, the oceans will be transformed into further acidic (Dessler, 2016). Nordhaus (2013) estimates humans are expected to contribute at the minimum of 3 to 4 trillion tons of CO_2 to the oceans by 2100. According to Maslin (2014), the oceans have already absorbed about a third of the CO_2 resulting from human activities. Wagner & Weitzman

(2015) point out that oceans are already over 10 per cent more acidic than they were around 1990 and they are expected to be over 25 per cent more acidic than at the beginning of the industrial revolution.

Many sea organisms make shells out of calcium carbonate, and their capability to do this is impacted by the acidity of the ocean. Dessler (2016) says because calcium carbonate dissolves more readily in acid, eventually, the acidity will increase to the point where it is fatal for species. According to Nordhaus (2013), some studies have discovered that the mortality rate of fish rises greatly as CO_2 concentrations increase above three times the present levels. This will also have an effect on humans as fishing is a major source of food. Dessler (2016) points out that about a billion people rely on the ocean as their primary source of protein. If the amount of protein available for human consumption from the ocean decreases, there is no simple adaptation to solve that problem. Corals are seriously damaged by both warming seas (known as bleaching, which occurs when corals are exposed to higher ocean temperatures) and ocean acidification. Scientists have warned climate change poses the greatest threat to the world's largest reef system: Australia's Great Barrier Reef (Juniper & Shuckburgh, 2017).

Studies show climate change has intensified the risk of certain extreme weather conditions. Destructive weather events such as wildfires, hurricanes, heatwaves, droughts, and floods can create extensive devastation and disturbance, with large financial costs and occasionally loss of life. According to Juniper & Shuckburgh (2017) when climate change threatens basic needs and welfare this can exacerbate existing tensions and may increase the risks of regional conflict and migration.

1.2.2 Impacts of climate change on agriculture

Agriculture is most expected to feel the impacts of climate change, both globally and regionally (Nordhaus, 2013). The question is if the planet can sustain itself with an extra two billion people by 2050 and a fast-changing climate. Agricultural yields depend on a variety of factors including temperature, rainfall and sunshine (Juniper & Shuckburgh, 2017). It is apparent that with a few degrees of warming, there will clearly be both winners and losers. Crop yields (particularly in the higher latitudes) will be better, it will be the poorest countries in the Tropics that will experience the worst (Maslin, 2014).

According to Nordhaus (2013), the adverse effect of climate change on farming depends on two major factors. Climate change is expected to provoke hotter climates with dwindling soil moisture in many countries. A study suggests that present climates in many parts of Latin America, Africa, and Asia are already hotter and are just ideal for food production, but additional warming would lower productivity in those areas. A second factor is that climate change may start unfavorable impacts on the water cycle, that is, systems that provide water for farming. Examples of that include the reduction in mountain snowpack and major changes in seasonal river runoff.

Studies suggest that the impacts of climate change on agriculture will be manageable and are likely to be small for the next few decades. However, in the long run, with unchecked concentrations of CO_2, global temperature will go above 3°C, resulting in a decrease in food production. A drop in food production would create a massive challenge considering the predicted increase in population during the 21st century. In the extreme, floods and droughts can drive the prices up to a point where the poorest go hungry (Juniper & Shuckburgh, 2017).

2 ECONOMIC INSTRUMENTS IN FIGHT AGAINST CLIMATE CHANGE

Market theory is founded on an assumption that markets function efficiently and resources are distributed efficiently. In reality, markets do not always function efficiently (Mankiw, Taylor, & Ashwin, 2013). Markets can break down and when this occurs resources are not distributed efficiently. Market failure occurs when markets do not function efficiently. There are a number of sources of market failure: externalities, public goods and information gaps (Mankiw & Taylor, 2014).

Firms make decisions depend on the private costs and benefits they incur but do not include the social costs and benefits of their decisions. Consequently, the price mechanism does not show the true cost and benefit of a decision and it can open on to a market outcome where the quantity might be privately efficient but socially inefficient and as a consequence, the market allocation of resources might be too high or too low. Price does not function as a true indication to consumers and producers to permit them to make wise decisions (Mankiw & Taylor, 2014). The economist’s usual assumption that a market economy opens on to socially desirable outcomes is invalidated by the presence of externalities (Smith, 2011).

2.1 Externalities

Mankiw & Taylor (2014) state “externality arises when a person or business engages in an activity that influences the well-being of a bystander (a third party) who neither pays nor receives any compensation for that effect. If the impact on the bystander is adverse, it is called a negative externality; if it is beneficial, it is called a positive externality.”

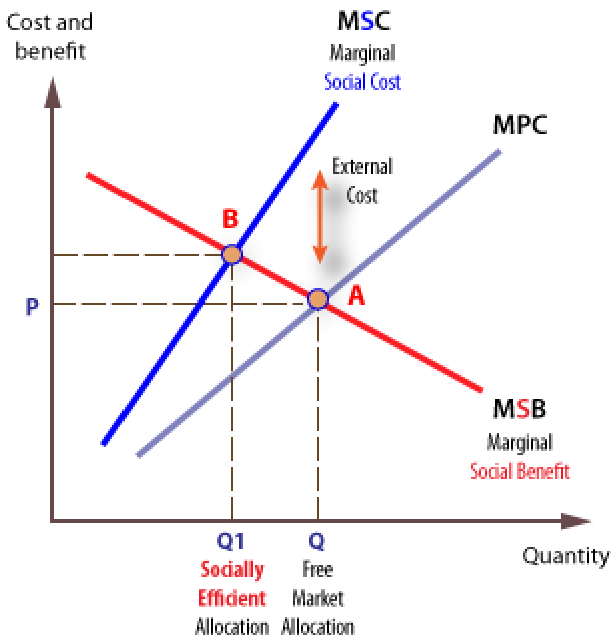
Schwarz (2018) says “externalities, also known as third-party or spillover effects, occur when two parties make a decision that affects others, but the two parties do not internalise those third-party effects into their decision.”

This thesis focuses on negative externality. To understand what economists mean by negative externality, we first need to understand three types of costs: external costs, social costs and private costs.

A private cost is internal to a firm and it is the cost of doing something to the firm. Also, private costs may stand for the market price a consumer spends to buy the good or service. External costs may happen in the production and the consumption of a good or service and are the cause of externalities. A chemical factory polluting a lake with its rubbish is an example of an external cost in production. This leads to an external cost to the fishing industry. Adding the private cost to the external cost gives the social cost. The social cost is the full cost experienced by the society of a good or service.

Externalities are an important source of market failure. Market failure results because in a free market the price mechanism (i.e. the forces of supply and demand) will only include the private costs but not the external costs. Almost all environmental problems appear from negative externalities, where producers or consumers do not take the full social costs of their own decisions (Himmelweit & Simonetti, 2000).

Figure 2: Free market and optimal levels of production



Source: Gavin (2015).

Figure 2 shows the interrelation between private cost, external cost and social cost. In a free market, the supply curve is the marginal private cost (hereinafter: MPC). The supply curve is also the firm's marginal cost curve and contains a plant's expenditures for inputs. The external costs, that society takes on due to the plant's pollution, are ignored. External costs are negative externalities (Gillespie, 2016). When negative externalities are existent, the market outcome is not efficient. To reach the efficient production level, we need to acknowledge both the firm's marginal cost and the marginal external costs of production. Together, they amount to the marginal social cost (hereinafter: MSC) of production (Acemoglu, Laibson, & List, 2016). The social optimum equilibrium level of output results where MSC equals marginal social benefit (hereinafter: MSB). The presence of externalities in environmental problems alters the basic supply and demand diagram (Gillespie, 2016).

The problems induced by external costs can be witnessed in the current environmental concerns over global warming. Left to themselves producers would not be worried about the consequences for humanity at large of the operations they carry out no matter whether it causes greater environmental damage (Gillespie, 2016).

According to the Stern Review, climate change is the largest market failure encountering the whole world (Gillespie, 2016). Climate change affects the welfare of people all around the world. The emitters do not compensate the harmed people (Tol, 2014). Every year, tens of billions of tons of CO_2 is released into the atmosphere by seven billion of us. The costs are huge but those emitting the pollution are not paying for it (Wagner & Weitzman, 2015). GHG emissions have been legally classified as pollutants (Nersesian, 2016). CO_2 is obviously an externality. We burn fossil fuel to produce electricity and drive cars. We do not burn fossil fuel to discharge CO_2. Hence emissions are unintended. The issue is that those who release the emissions do not pay, and those who are suffering are not compensated.

2.2 Economic theory: government intervention

Free markets do not always bring about the socially efficient quantities of goods at socially efficient prices and that is one of the main reasons for government intervention in the marketplace (Baye & Prince, 2013). The governments of the world have deployed a strategy for remedying the impacts of climate change, based on economics (Broome, 2012). Regulations, carbon taxes, and carbon trading (cap-and-trade schemes) are three policy instruments currently used to price and limit GHGs. Each has benefits and problems, and choosing among them hinges on situations. Combination of policy instruments will be advantageous (Stern, 2016).

Economics shows one big lesson about externalities: markets do not necessarily fix the problems they create. Regarding damaging externalities like CO_2, unregulated markets generate too much because markets do not impose a price on the external harm from CO_2 emissions. Economics presents a definitive remedy for removing the inefficiency: the externality can be fixed within the system of the market by setting a price on it (Broome, 2012). The remedy is to internalise the externality (Acemoglu, Laibson, & List, 2016).

The last couple of decades have seen a fast advancement in the opportunity for deploying incentive-based (market-based) environmental policies – so-called market mechanisms – which includes taxes on carbon-based energy sources, air travel, and on a variety of hazardous air pollutants from industry; tax breaks for cleaner motor vehicles, cleaner fuels and energy-saving materials, emissions trading schemes for sulfur dioxide (hereinafter: SO_2), and CO_2 (Smith, 2011).

The moment an externality prompts a market to reach an inefficient allocation of resources, governments respond to externalities in one of two ways: command-and-control policies and market-based policies (Mankiw & Taylor, 2014). Command-and-control policies: where the government directly command and control the allocation of resources and behavior. Market-based policies: where the government provides incentives for companies to internalise the externality (Acemoglu, Laibson, & List, 2016).

2.2.1 Command-and-control regulation

Governments can fix an externality by controlling certain behaviors either mandatory or banned (Mankiw, Taylor, & Ashwin, 2013). A government may lay down the law to ban certain types of behavior (Gillespie, 2016).

Environmental rules can have numerous shapes and forms. The government may control an upper limit of pollution that a plant may release. At times, the government imposes plants to take on a specific technology to cut emissions (Mankiw & Taylor, 2014). In all circumstances, to form appropriate rules, the government policymakers must have knowledge about particular industries and about the various substitute technologies that those industries could choose. These details are a lot difficult for policymakers to achieve (Mankiw, Taylor, & Ashwin, 2013).

In most cases of pollution, the situation is not this simple: it would be impractical to ban all polluting activity. For example, practically all forms of transport produce some unwanted polluting by-products. But it would not be realistic for the government to ban all transport. Thus, instead of trying to remove pollution altogether, society has to reflect on the costs and benefits to decide the kinds and quantities of pollution it will permit (Mankiw & Taylor, 2014).

To date, the climate change policies of most countries have banked excessively on conventional command-and-control instruments which directly regulate emissions or technology choices. Through the remaining regulatory schemes, many countries have commanded the industry to adopt certain specific low-carbon equipment and processes. Similarly, governments have required households to make use of products that will reduce energy use or carbon emissions – for example by ending the sale of conventional incandescent lightbulbs, to ensure that households switch to low-energy alternatives (LED lightbulbs). These forms of direct regulation have the disadvantage that they are prone to be rigid, one-size-fits-all solutions which do not take account of differing circumstances (Smith, 2011).

The command-and-control regulatory scheme usually yields not many rewards for manufacturers to search for cost-effective practices to control pollution itself. It occurs because policymakers have concentrated on the incorrect target. For example, policymakers decide the technology that the manufacturer must follow. It forces the manufacturer to set up effective ways to operate the selected technology. Instead of emphasizing manufacturer efforts on creating economical methods to exercise the selected technology, the policymaker should motivate manufacturers to come up with the most cost-effective technologies (Acemoglu, Laibson, & List, 2016).

Some regulations are set to encourage the use of RE. The UK government has introduced Renewables Obligation Certificates (hereinafter: ROCs) to encourage the use of power generated from RES. Electricity suppliers are given a set minimum percentage of power that must come from renewable sources. Companies who generate the RE are issued with ROCs which link to the amount of RE they have generated. They then sell these certificates on to suppliers. Suppliers that fall short of the target percentage of power from renewable sources have to pay a financial penalty. The money raised from these penalties is distributed between the suppliers who did reach the target (Anderton, 2008).

2.2.2 Carbon taxes and subsidies

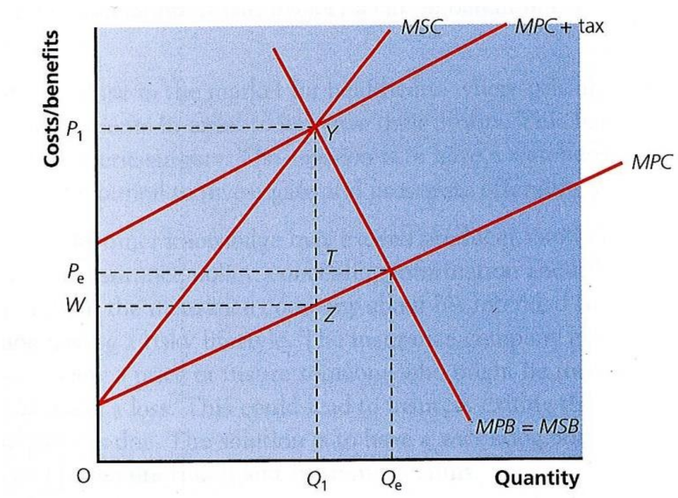
The distinctive feature of the market-based approach is that polluting is costly to the polluter and this cost creates an incentive for changes in polluting behavior. With the incentive-based policy, the way for cutting pollution is fundamentally passed on to the emitter (Smith, 2011). A market-based approach internalises the externality that the good produce, i.e., let the manufacturer of the good pay for the cost of its externalities. The most familiar incentive-based policies to take on externalities are Pigouvian taxes and subsidies.

Economists view pricing GHG emissions as an effective way to curb them. Governments can levy a tax on each tonne of CO_2 released: in the 1990s, this approach was pioneered by Finland. Higher charges would mitigate but then politics has to be reasonable. Politicians are reluctant to upset voters, who do not like taxes. According to two prominent economists, Joseph Stiglitz and Nicholas Stern, to stay on track with Paris goals, a levy of the $40 – 80 range is considered to be necessary by 2020.

Two types of carbon taxes are in existence: Carbon taxes whose revenue is spent on environmental goals and carbon taxes whose aim is to induce behavior in way of doing things well-suited with climate change goals. Tax revenues spent on renewable technologies fall in the first group. The taxes that are intended for influencing people to buy more fuel-efficient cars, or cut the number of miles they travel every year, fall in the second group (Giddens, 2015).

Giddens (2015) states that carbon taxes are likely to succeed where they incorporate a number of the features – i.e., if taxes are clearly intended as such, aimed at altering behavior, whether of organisations in society, such as companies, or people in general; anytime possible are incentives instead of taxes, because incentives induce positive reasons; form part of an overall fiscal strategy; and where their environmental outcomes are explicitly expressed and noticeable.

Figure 3: Pigovian tax and carbon emissions



Source: Gavin (2015).

In a free market, the equilibrium price is OP_e and the equilibrium quantity OQ_e as is shown in Figure 3. However, the socially optimum price is OP_1 and the social optimum quantity OQ_1, where MSC equals MSB. The vertical distance ZY represents the external cost. By imposing a tax equivalent to the external cost of ZY, the government internalises the externality. A Pigouvian tax is a tax aimed to persuade producers who generate negative externalities to cut quantity toward the socially optimal level (Gillespie, 2016). In reality, the Pigouvian tax internalises the pollution externality. It causes the efficient market outcome (Acemoglu, Laibson, & List, 2016). A government can accomplish any level of pollution it desires by fixing the tax at a suitable level. The greater the tax is, the bigger the cut in pollution. In truth, if the tax is too steep, the plants will shut down altogether, cutting pollution to zero (Mankiw & Taylor, 2014).

The leaders of carbon taxes have been the Nordic countries. Carbon taxes are a type of Pigovian taxes: they are mainly designed to change behavior rather than to raise revenue. In Sweden, the tax on CO_2 emissions started at €27 in 1991 and it has been €117 per ton emitted since 2009. The Swedish government also taxes other GHGs such as NO_x and SO_2. According to the Environmental Quality Objectives adopted by the Swedish government, by 2020, GHG emissions should be down 40 per cent from their 1990 level. GHG emissions were down 16 percent by 2011. During the period (1991 – 2011), GDP was up 58 per cent. It shows that pricing carbon does not seem to threaten the country's competitiveness (Henry & Tubiana, 2018).

2.2.3 Carbon trading: tradable pollution or emissions permits

In this approach, the government establishes a fixed number of permits (credits) to emit the pollution. It then either auctions them off or grants them to specific firms. Firms may then buy and sell the right to pollute on a market set up to trade the permits. In this approach, the government set the total allowable level of emissions. However, the ability to trade permits creates beneficial incentive effects. Companies with greater emissions per unit of production will need more permits to make the same amount of output than will businesses with smaller emissions per unit of production. It puts businesses with cleaner production methods at a competitive advantage. In addition, firms have an incentive to make investments in cleaner production methods, as long as the marginal cost of doing so is lower than the cost of buying more pollution permits (Besanko & Braeutigam, 2015).

The most successful example of emissions trading is the U.S. SO_2 program – the use of permits to limit the emissions of SO_2 since 1990 (Giddens, 2015). This scheme was so triumphant that it was used as the foundation for the European Union’s (hereinafter: EU) Emissions Trading Scheme (hereinafter: ETS) (Nordhaus, 2013).

The EU's ETS started operation early in 2005. The ETS covers 31 countries, which include the entire 28 EU member states as well as Iceland, Norway, and Liechtenstein. The ETS caps CO_2 emissions from large installations (Giddens, 2015).

Figure 4: The European carbon credit price, 2008 — 2018

Source: Sheppard (2018b).

As the economic crisis took its toll on the European economies, the European carbon credit price ended up so low as to have no impact on curbing pollution as is shown in Figure 4.

The financial crisis led to a huge surplus of carbon credits due to reduced emissions. After a long slump, the EU announced the changes to its carbon trading system by introducing 'Market Stability Reserve' (hereinafter: MSR), aimed to eliminate surplus supplies of carbon credits that had amassed. The result was that a 230 per cent rally in the price of carbon credits between the start of the year 2018 and September, which took the allowances to a 10-year high above $25 per tonne of CO_2 – a move that is likely to encourage switching to cleaner fuels (Sheppard, 2018b).

The jump in the price of carbon credits, which big manufacturers must buy to offset their emissions, is also likely to have a big impact on those businesses as they face higher bills. MSR has now driven polluters to run after a smaller amount of carbon credits to stay in accordance with the scheme, which carries huge monetary fines for those who fail to accumulate enough credits relative to the amount of carbon emissions they generate. Carbon Tracker predicts the price of carbon credits to reach €35 to €40 a tonne on average from 2019 to 2023. The higher carbon price should reduce emissions and encourage fuel switching (Sheppard, 2018c).

These ideas are not just some wild theoretical scheme. They have been used in a variety of contexts over the last half century (Nordhaus, 2013). Many politicians have advocated either a regional or a global carbon trading scheme. The most successful system of carbon trading scheme is ″cap and trade″ (Besanko & Braeutigam, 2015; Maslin, 2014). While cap and trade generally apply to firms, the principle can also be applied to individual citizens in the form of a carbon card. Each citizen is given a quota of carbon emissions for a year and each time he or she purchases a good or service with carbon embedded in it, some of the quota is used up. As with firm-level cap and trade, those who underuse their quota can sell the surplus to those who are over emitting carbon (Dobson, 2016).

Though curbing carbon emissions using carbon credits may look very different from using taxes, actually, the two policies have a lot in common. In either case, companies pay for their emissions. With Pigovian taxes, polluting companies need to pay a tax to the government. With carbon credits, polluting companies have to pay to purchase the credits. Both Pigovian taxes and emission credits internalise the externality of pollution by making it expensive for companies to contaminate (Mankiw & Taylor, 2014).

According to Nordhaus (2013), "Putting a price on the use of carbon serves the primary purpose of providing strong incentives to reduce carbon emissions. It does this through three mechanisms: by affecting consumers, producers, and innovators." First, carbon pricing will inform buyers about what products have large carbon content and thus should be consumed infrequently. Second, it will give signals to manufacturers about which resources use carbon to a greater extent and which use to a lesser extent. It thereby influences companies to move to low-carbon technologies in order to lower their costs and boost their profits. Finally, carbon prices will provide market incentives for inventors to produce low-carbon products and come up with new techniques to oust current and old technologies (Nordhaus, 2013). An essential point is that the carbon price should be at a level correspondent with the scale of goal, i.e., achieving emissions reductions in line with a 2°C (Stern, 2007).

Economics teaches the two most important policy lessons in tackling climate change. Firstly, consumers and producers must encounter economic incentives to alter their behavior toward low-carbon activities. Actions that result in emissions of GHGs have to become more costly, which requires increasing the prices of fossil fuels. Secondly, markets on their own will not fix this problem. There is not any "free-market solution" to climate change. We need national and international governments to work together and take charge of climate change policy decisions. Environmental policies must be legislated and enforced by governments (Nordhaus, 2013).

To avoid potentially catastrophic climate change, the world must arrive at net zero CO_2 emissions by 2050. According to a report from the Energy Transitions Commission, achieving net zero carbon emissions from heavy industry (cement, steel, plastics) and heavy-duty sectors (shipping, aviation, heavy road transport) is technically and economically possible by mid-century. The report shows that full decarbonisation is technically feasible with technologies that already under development and that the total cost to the global economy would be less than 0.5 per cent of the GDP. The report outlines a detailed action plan for policymakers and investors. The report indentifies four complementary sets of policies: carbon pricing, specific regulatory mandates, active public policy coordination for infrastructure development and optimal public policy role in driving technological progress (Energy Transitions Commission, 2018).

3 THE EFFECTS OF BURNING FOSSIL FUELS ON THE CLIMATE

Fossil fuels are bad because they speed up global warming (Denny, 2017). Debates on climate change always start with the emissions and accumulation of GHGs in the atmosphere. However, the real starting point is with people and their everyday lives. Greater atmospheric concentrations of GHGs result in warming of Earth's surface and water (Nordhaus, 2013). Global carbon emissions were stable during 2014 – 2016 but started increasing in 2017 as the Chinese economy regained and as emissions climbed in the rest of Asia and the EU (Hornby & Hook, 2018). According to British Petroleum's (hereinafter: BP) annual statistical review of world energy, in 2017 carbon emissions climbed up by 1.6 per cent globally (Vaughan, 2018d). According to research, carried out by the Global Carbon Project, global carbon emissions are projected to be 2.7 per cent in 2018. According to the data, global CO_2 emissions will reach over 37.1 billion tonnes in 2018 (Earth System Science Data, 2018).

Fossil fuels make up large contributions to global primary energy consumption: in 2014 it amounted to about 81 per cent (Peake & Everett, 2018b). In 2014, world primary energy demand was 575 exajoules (hereinafter: EJ). The world population in 2014 was about 7.2 billion, thus the average energy consumption per person was about 80 gigajoules (hereinafter: GJ), equal to the energy content of around 6 liters of oil per day for each person (Peake & Everett, 2018a).

The annual primary energy demand is expected to stay about uniform in Organisation for Economic Co-operation and Development (hereinafter: OECD) countries over the period up to 2035 at 230 EJ while increasing greatly in non-OECD countries from 315 EJ to 500 EJ. The global population is forecast to increase to 9.2 billion by 2050, compared with 2.5 billion in 1950 and 7.2 billion in 2014, and demand for energy is expected to go up by 34 per cent during 2014 – 2035, based on current trends. By 2035, the world GDP is projected to more than double, with China and India together providing almost half and the OECD countries about a quarter of the growth (Andrews & Jelley, 2017).

The Stern report says that if we do not do anything, the impacts of climate change could amount to between 5 per cent and 20 per cent of world GDP every year and if we do everything, this will cost us only 2 per cent of world GDP and we can also reduce global GHG emissions (Maslin, 2014).

More than one-fourth of the world's fossil fuel consumption is used for electricity generation. In the last 20 years, the world's electricity consumption has been increasing at 3 per cent per year and this growth seems likely to continue (Peake & Everett, 2018a).

3.1 Coal

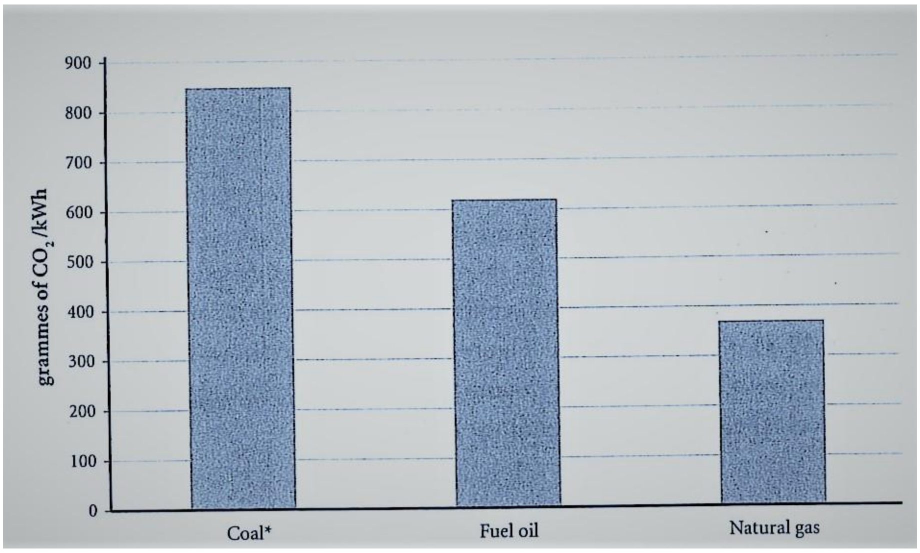
From a pollution perspective, fossil fuels are bad but they are not equally bad: coal is the dirtiest in carbon emissions (Helm, 2017). Between 2000 and 2010, the global demand for coal grew by over 70 per cent. China and India accounted for more than 90 per cent of this growth (Helm, 2015). Coal's share in the world energy has gone up from around 25 per cent to almost 30 per cent since 1990, and it has caused most of the emissions growth (Helm, 2017).

Three of the world's greatest coal users are China, India, and the US (Denny, 2017). Australia is also a big coal consumer (Liu, Chen, & Liu, 2017).

According to Helm (2017), coal is linked to water and air pollution, and serious health impacts: lung disease is the most obvious consequence. Coal-burn produces smog and particulates, contributing to urban pollution and more than three million premature deaths each year. Coal produces other GHGs and has very low thermal efficiency once the full cycle is taken into account – from the opening of mines, through the transport of the bulky coal, to the combustion processes and the waste, and finally the losses in the electricity networks (Helm, 2017).

Schwarz (2018) notes that when coal is burned, trapped radioactive particles are released into the atmosphere; in the US, people who live next to a coal-fired power plant experience a greater dose of radiation than those living next to a nuclear power plant, if both are operating normally. Coal mining also results in the deforestation and degradation of the landscape. Studies of areas near coal-mining operations document higher rates of cancer, birth defects, and higher rates of death from chronic heart, respiratory, and kidney disease.

Figure 5: CO_2 intensity of fossil fuels



Source: Helm (2015).

Figure 5 indicates a crucial distinction in carbon emissions in respect to burning fossil fuels: natural gas for electricity generation turns out to be about half as polluting as coal (Helm, 2015). For example, burning a pound (1lbs = 0.454kg) of coal generates over three pounds (1.362kg) of CO_2. The CO_2 released by coal burning is 35 per cent higher than that released by burning oil and 72 per cent higher than that by burning natural gas (Liu, Chen, & Liu, 2017). Each day around 6.4 pounds (= 3kg) of coal is burned for each person on Earth (Denny, 2017).

All activities are not equally CO_2 intensive. Electricity generation is the largest cause of carbon emissions, making up about one-third of human-caused emissions, and the combustion of coal to provide heat in the electricity generation process emits the most CO_2 on a per unit of electricity basis (Schwarz, 2018).

Other CO_2-intensive activities include cement, iron, and steel production. The emissions per dollar of output are smallest in services (for example, accounting, insurance, finance and legal services) (Nordhaus, 2013).

In the US, coal-fired electricity plants generated about 30 per cent of the nation's electricity in 2016. According to official projections, coal-fired electricity generation is likely to fall by 2030. However, coal production in the US is expected to stay fairly constant for the next two decades. Despite the predictions of coal production, the numbers in the official projections show a continued steady decline from today's levels, because of rising awareness of environmental concerns. Domestic use will decline due to cheap natural gas, but the lull will be taken up by exports (Denny, 2017; Crooks, 2018d).

Usage of coal is increasing for a larger per cent of electricity generation in developed countries such as Germany and Japan, which both began to phase out their nuclear plants in the wake of the nuclear accident in 2010 (Schwarz, 2018). A trend of returning to coal power has swept Europe in the last 10 years because of the sharp rise in the prices of oil and natural gas. European thermal power stations are being rebuilt to generate a total power of 200,000 megawatts (hereinafter: MW) before 2020. So far, most of these thermal power stations have adopted natural gas as fuel (Liu, Chen, & Liu, 2017).

Coal is still a dominant fuel in many developing countries. India is highly dependent on coal and is accelerating construction of thermal power stations (Liu, Chen, & Liu, 2017). China's energy use has had a dramatic effect on global CO_2 emissions, particularly since 2000. China's recent industrial expansion has been mainly fuelled by coal. In 2016, China's coal consumption made up half the world's total and it emitted 28 per cent of the world's CO_2 emissions (Peake & Everett, 2018a). China increased its coal use at a rapid rate to support economic growth until it had to consider other alternatives due to high levels of pollution as well as commitments to reduce its emissions of GHGs. Today, China is prominent among developing countries trying to combat dense smog due to coal-fired electricity plants, which currently account for 75 per cent of electricity generation (Schwarz, 2018).

3.2 The future of coal-fired power plants

In developed countries that include the external costs of coal production, coal is criticized as dirty fuel (Schwarz, 2018). America's aging coal plants are under assault from two sides: government regulators, who have tightened the state and federal limits on air pollution from power plants, demanding coal plant operators to install scrubbers and more pollution-reducing technologies; and the market for electricity, because of large supplies of low-cost gas made available by America's shale revolution and increasingly from RES. In short, coal plants are more uneconomical to run. Many of these plants have already outlasted their estimated life spans and would need expensive upgrades in order to win acceptance from the Environmental Protection Agency (hereinafter: EPA) to remain open. Every major coal-burning utility in the US is faced with a complex series of decisions over the next ten years: shut the plants down or keep them running for another a few more years

(Martin, 2015). Typically, coal plants have a 40-year lifetime, making new coal plants a high-risk investment (Schwarz, 2018).

According to Schwarz (2018), some states in the US have initiatives to reduce their carbon emissions. The Regional Greenhouse Gas Initiative (RGGI) contains a number of north-eastern states, while a California initiative now contains other states and even Canadian provinces. The US electric utilities have been closing down a huge number of coal plants before their planned retirement or switching them to natural gas. The US utilities have no plans to build new coal plants in the near future.

In 2014, China's premier announced war on air pollution. Four years later, a new study by the Energy Policy Institute at the University of Chicago has shown that air pollution has decreased and China is winning its war against pollution at a record pace (Huang, 2018). The study found that cities on average have curbed levels of fine particulates (PM 2.5) by 32 per cent in just four years. According to the study, if China sustains these reductions, Chinese citizens would see their life expectancies extended on average by 2.4 years (University of Chicago, 2018).

Michael Greenstone, who carried out the research said: "We do not have a historical example a country achieving such rapid reductions in air pollution" and "What these last four years have demonstrated quite loudly is that things can change and they can change rapidly – it requires political will" (Greenstone & Schwarz, 2018). China's war on pollution strategy has caused a number of unexpected results, including gas shortages. China has demonstrated itself ready to go through self-inflicted economic discomfort if the long-term results are proved to be rewarding (Shan, 2018).

Despite China's ambitious strategy, according to the National Bureau of Statistics, the country's coal use rose by 0.4 per cent in 2017: it is the first rise in coal energy usage since 2013 (Feng, 2018). According to a Greenpeace analysis, China's carbon emissions rose 4 per cent in the first quarter of 2018 (Hornby & Hook, 2018).

China remains to be the major country in coal production and usage. It injected 34 GW of capacity from coal plants in 2017. However, in a promising sign, that was around half its capacity increase in 2015 (CoalSwarm, Greenpeace, the Sierra Club, 2018). In 2017, the Chinese government announced it was stopping or delaying work on 151 coal plants that were either under or earmarked for, construction (Morton, 2017) and it has been instructing northern cities to consume natural gas instead of coal for heating homes. China's approach of transitioning away from coal and to gas is also having a greater impact on liquefied natural gas (hereinafter: LNG) markets. Gas imports to China have been soaring as Beijing attempts to shift energy system away from coal, to fight air pollution and the country is expected become the world's top LNG importer by 2030 (Terazono & Crooks, 2018). China raised its imports of LNG by 50 per cent last year to around 38 million tonnes after

Beijing strengthened measures designed to control pollution from coal use, overtaking South Korea as the second biggest importer globally, after Japan (Sheppard, 2018d).

According to CoalSwarm, Greenpeace, and the Sierra Club report (titled Boom and Bust 2018), several new coal-fired power plants being built throughout the world started to fall between 2015 and 2017. As of January 2018, the report found a remarkable 29 per cent fall in new coal plant construction throughout the world and 73 per cent fall in the last couple of years. For now, several newly finished coal plants dropped 28 per cent in 2017 and a 41 per cent drop in the last couple of years. The report also notes "with declining deployment and high levels of retirement, coal power capacity is now caught in a squeeze: if current trends continue, by 2022 yearly retirements will exceed new capacity and the global coal fleet will begin to shrink." (CoalSwarm, Greenpeace, the Sierra Club, 2018).

In recent years, China has been especially forceful in tackling its coal overcapacity and accompanying air pollution issues (CoalSwarm, Greenpeace, the Sierra Club, 2018). Three factors play into that: the boom in China's renewable industry; a slow-down in power-demand as the country rebalancing the economy away from energy-intensive industries; and the government's concentration on improving the dire air quality (Werber, 2016).

As of 2017, coal supplied just over 60 per cent of China's energy mix, although that has declined from 80 per cent in 2010. However, under its Paris Agreement commitment, China is committed to raising the share of RE to 20 per cent of its energy mix by 2030 and has set national targets to cut coal to 58 per cent of its energy mix by 2020 (Feng, 2018). When the problems of global climate change are added, it is clear that the country has many reasons to switch from coal to RE, particularly for electricity generation. China has considerable hydroelectricity resources, which in 2016 supplied nearly a fifth of its electricity. It is currently the world's largest investor in RE (Peake & Everett, 2018a). In recent months, it has been making a determined attempt to cut coal use to improve its air quality. Coal imports are now running well below last year's levels, as the authorities drive a shift to burning gas. China's rapid industrialisation has driven coal demand over the past 15 years, but that growth has started to slow as its economy becomes more energy efficient and uses more RE (Sanderson, 2018).

Even Germany has recognised that coal will have to go if it is to meet its green aspirations. Britain has publically committed to phasing coal out by 2025. France has pledged to shut all coal-fired power stations by 2021. The big oil and gas companies in Europe have publically turned their guns on coal. These companies have an opportunity to be seen to be taking a responsible approach to climate change and to get on the front foot, and have not only pushed the case for gas against coal but have also supported the case for carbon pricing. The most notable convert to this position is Royal Dutch Shell (hereinafter: Shell), but Statoil, Total and Engie have now joined in (Helm, 2017).

Coal's fate most depends upon the future treatment of carbon emissions. CO_2 makes up around 80 per cent of GHG emissions (Schwarz, 2018). Transitioning to gas reduces emissions fast. Gas has roughly half the carbon emissions of coal, and this is before taking into account all the other pollution that comes from mining and burning coal. Among the dirty fossil fuels, natural gas is the least hazardous one. The future, therefore, is relatively brighter for gas in a gradually decarbonising world. The US shale revolution has shown how this can be done (Helm, 2017).

3.3 Oil

Oil now makes up about a third of the world's energy use and about the same fraction of atmospheric CO_2 generated by humans. It drives industry and is an important geopolitical factor (Denny, 2017). Decreasing conventional reserves and geopolitics have forced developed nations to look for ways to extract oil in deep water and other fields. High oil prices and technological advances of recent years have made it economically feasible to get unconventional oil – the shale oil and tar sands oil that have become rapidly increasing stocks of our supply during the last decade (Denny, 2017).

According to the recent EIA statistics, as of 2015, oil is the largest source of energy consumption, accounting for 36 per cent of all energy used in the US. Oil dominates other energy sources as a transportation fuel (70 per cent is for transportation). Beginning in 2009, oil production in the US started to soar with new fracking technology. In 2015, production surged to 300 million barrels per month (10 million barrels per day) (Schwarz, 2018). The US imported 60 per cent of its oil as recently as 2005. With the fracking revolution, the US is now permitting its producers to sell oil abroad for the first time since the 1970s. Shale oil is making the US self-sufficient in oil (Andrews & Jelley, 2017).

Hydraulic fracking is crucial to drawing out unconventional oil and gas from shale rocks. Without fracking, shale oil and gas could not be drawn out economically; fracking is technically strenuous and costly. The technical difficulty is in part due to the need to drill vertically down to a shale deposit and then twist the drill bit so it drills horizontally within the shale. The fracking part consists of pumping water (with some sand and chemicals mixed in) into the borehole under high pressure. This action fractures the shale and releases the oil or gas, which is forced up through the wellhead (Denny, 2017). Hydraulic fracking is a relatively quick process to start and stop. Lower prices mean lower profitability, or losses, for high-cost suppliers. Frackers can halt existing drilling, and postpone new drilling (Schwarz, 2018). The bad news is that it is harder to extract and refine than conventional crude. The good news about unconventional oil is that there is a lot of it. (Denny, 2017).

However, fracking has come under attack by environmentalists because it causes damage: it may contaminate local groundwater, and it causes minor tremors. Environmental concerns have led to scrutiny of fracking practices, and to various degrees of regulation and restrictions in different countries. The EU countries are in the process of setting up regulations but, the US is not. Without federal restrictions, states are coming up with their own rules governing fracking; Vermont and New York have banned the practice (Denny, 2017).

The Organisation of the Petroleum Exporting Countries (hereinafter: OPEC) producers have been very cautious of weaker global economic growth forecasts from International Monetary Fund (hereinafter: IMF), which referred to the US-China trade war and volatile developing and emerging markets. IMF has now cut its global economic growth forecasts to 3.7 per cent in 2018 and 2019, down from 3.9 per cent. OPEC has lowered its oil demand growth estimates for 2019, amid weaker forecasts for the global economy. The world's biggest oil producers are mainly concerned about oil production from the US shale oil companies, swamping the market, as the US shale industry helped tip itself into a downturn when booming shale oil production created a glut on world markets in 2014. The US EIA has raised its forecast for domestic production to record 12.1m barrels per day (hereinafter: b/d) for 2019. If global demand for oil decreases, oil price will certainly decrease. When oil prices are low for an extended period, the quantity supplied will eventually decline (Schwarz, 2018).

Oil spike in 2018 was driven not by excess demand, but too little supply. Apart from the missing Iranian oil exports, fellow OPEC Venezuela saw its output plummet, owing to its internal crisis, and supply has been falling for more over a decade in Mexico. The remedy for the supply-side issues must come from US shale. But shale has its difficulties. Logistical challenges, rising labor and equipment costs and lack of adequate pipeline capacity are currently slowing down the US shale oil production.

3.4 Natural gas

Among all the dirty fossil fuels, natural gas is the least hazardous one. Although it also emits GHGs, it emits less CO_2 and less pollution than oil or coal and may play a role as a bridge in the transition to RE (Robertson, 2017). Moving a greater portion of electricity to natural gas is an urgent way of curbing CO_2 emissions (Nordhaus, 2013). If we need to burn fossil fuels, then gas is the least bad form to deploy (Denny, 2017).

About a fifth of the world's energy consumption comes from natural gas and a fifth of atmospheric CO_2 generated by humans. It is easier to transport than oil. There are greater reserves of natural gas than oil: the two countries with the greatest confirmed reserves are Russia and Iran. But shale gas is abundant in the US, Canada, and Europe. Shale gas is an unconventional natural gas that is extracted from oil shale deposits; it requires fracking the shale but thereafter it is easier to extract and process. Shale gas production has increased fast over the last 12 years and now makes up half of US natural gas (Denny, 2017).

According to expert studies, modern natural gas combined-cycle power stations produce electricity cheaper than new coal plants. The short-run costs of coal are greatly reduced than those of gas (Nordhaus, 2013). However, the polluting effect and high carbon intensity of coal is leading coal to be replaced by gas and renewables. Shale gas is expected to grow, as in nuclear and hydro generation mainly in Asia. But the largest growth is expected in renewables throughout the world (Andrews & Jelley, 2017). Gas is the cleanest of dirty fuels and switching from coal to gas creates less air pollution and gas-fired power plants typically generate about half the CO_2 emissions of coal-fired power plants and therefore, over the next two decades, the future is relatively better for gas in a gradually decarbonising world (Crooks, 2018k).

A combination of three technologies, namely horizontal drilling, new seismic-information technologies, and the ability to frack open rock structures have turned the US from a declining oil and gas producer into a renewed fossil fuel superpower. The shale revolution has transformed the fossil fuel industry, changed geopolitics, and brought new companies into the market (Helm, 2017). The US shale boom has helped total US oil output more than double since 2010 to nearly 11m b/d (Raval, 2018).

In the early 2000s, the US shale revolution was carried out by smaller independent companies. In recent years, the large oil companies have shown great interest in the shale projects this is because unlike the large traditional conventional projects, shale projects can generate production quickly and provide more flexibility. The oil majors such as ExxonMobil, Chevron, BP, and Shell have learned how to adapt to the unique demands of shale production (Raval & Crooks, 2018). It was found out that the costs of the fracked gas could be lower than for conventional production. Shale processes are very unique from conventional large oil and gas projects. They can be switched on and off quickly and ramped up fast (Helm, 2017).

Since the shale industry's birth in the early 2000s, exploration and production companies have needed a steady flow of cash to pay for drilling and completing new wells: the industry has been characterised by a debt-fuelled pursuit of growth. But thanks to the rise in oil prices and improvement in production techniques, which actually have brought costs down, the sector's top companies are now generating significant profits, and can now for the first time cover the cost of new wells themselves. According to Wood Mackenzie, the US shale oil companies need a crude oil price of about $53 a barrel to generate profit. According to Pioneer Natural Resources, one of the most successful producers in the Permian Basin of Texas and New Mexico, the company's wells need oil only in the low $20s to break even. According to the IMF economic outlook in 2018, Saudi Arabia needed Brent crude prices to average almost $88 (breakeven oil price) a barrel to balance its budget. Brent crude is currently trading around $55 a barrel (Crooks, 2018j; Crooks, 2018i; Bullock & Crooks 2018; Bloomberg, 2018d).

The shale renaissance in the US has rapidly decreased the US's reliance on imported unrefined petroleum. The energy-trade deficit has come down from $416 billion to $53 billion in the first ten months of 2017. According to the IEA, by 2025 the shale boom in the US will have freed-up more oil and gas than in any other country. The US is a net gas exporter since 2017 (The Economist, 2018g).

The transition is being steered by exports of LNG throughout the world. America's shale boom has been great for international buyers: China is particularly looking to diversify its energy mix. In 2018, China National Petroleum Corporation signed a contract to purchase LNG from Cheniere Energy – an American supplier. According to the IEA, the US is come to be the world's second-largest LNG exporters by 2022, competing with the likes of Australia and Qatar. More LNG assists the switch towards low-carbon energy, ultimately slowing down the speed of climate change (The Economist, 2018g).

Natural gas is often described as 'the fuel of the future'. However, sales of turbines for gas-fired electricity generation have fallen sharply and are expected to remain weak, under pressure from the rise of low-cost RE and slowing demand in developed countries. There are three significant manufacturers for gas turbines: General Electric (hereinafter: GE), Siemens and Mitsubishi Hitachi Power Systems. GE was expected to sell only about 50 heavy-duty gas turbines for generating electricity in 2018, down from 107 in 2017. The gas turbine market has been tough for other manufacturers as well. Bloomberg reported that Siemens was looking at a potential sale of its gas turbine business. The Mitsubishi Heavy Industries also plans to cut 30 per cent of its power division workforce after 2021. The plunging costs of wind and solar power have made it harder for gas-fired plants to compete, and the need for fossil fuel back-up is not as clear-cut as it had seemed. Other solutions for the variability of wind and solar such as battery storage, virtual power plants – made up of small-scale distributed energy sources, are becoming competitive (Crooks, 2018h; 2018a).

3.5 The future of fossil fuels

In order to cut carbon emissions, the usage of fossil fuels will have to come down drastically in the coming years. The best hope for cutting carbon emissions comes from the application of science to the energy market: the right combination of innovative engineering, private investment and public support turned out to be transformational for solar and wind power. The costs of renewable electricity and energy storage will continue to come down, improving power markets globally. The energy industry needs a radical new approach to engaging every part of society in their decision-making. There are many options for reducing GHGs. Some are available today, such as fuel switching and others are more expensive, such as carbon capture and storage. Alternatives to fossil fuels have become more efficient and widespread. A stream of investment in RES over the past years, together with shrinking costs in new energy technologies has created a radical change in the global energy industry.

3.5.1 Outlook for coal

The case against coal is undeniable both on health and natural factors – globally air pollution from coal kills 800, 000 people annually (Carrington, 2017b). A growing number of European and US banks, pension funds, insurers and other institutional investors have announced bans or restrictions on coal investment in support of global efforts to tackle climate change and air pollution. Climate policies and the falling cost of renewables have sent coal into decline in most of the developed world. But coal still accounts for about 30 per cent of global energy consumption and more than that in most emerging markets. The World Bank stopped its financial support for coal-fired power stations in 2010 and will stop lending for oil and natural gas exploration ventures after 2019 in connection with the growing perils caused by climate change. Banks including ING, Deutsche Bank and Royal Bank of Scotland have stopped lending for new coal mines and projects, while others including HSBC and JPMorgan Chase have halted funding for coal plants and mines in the developed world. Insurers including Axa and Zurich have cut some coverage for coal-related companies (Ralph, 2018a). According to analysts at Citi, spending on new coal projects has fallen 80 per cent from $10bn in 2012 to $2.2bn in 2018 (Sanderson, 2018).

According to the IEA's latest coal market report, global coal demand is forecast to remain stable for the next five years. In terms of the total global energy mix, coal's contribution will decline from 27 per cent to 25 per cent by 2023, mainly due to the growth of renewables and natural gas (IEA: Market Report Series - Coal 2018, 2018). According to the analysis from Carbon Tracker, over 50 percent of the EU’s 619 coal-powered plants are running at a loss. The report says the rise of RE, stricter air pollution and climate change policies and rising carbon prices are pushing coal-fired electricity stations into an unprofitable business. It is estimated closing them will avoid losses of €22bn for the plant’s owners. Falling cost of renewables is on course to construct new solar and wind farms more economical than keep going with current coal stations by the mid-2020s. Coal-fired electricity capacity could be replaced by cheaper renewables, with building new onshore wind and solar PV projects projected to be less expensive than operating existing coal plants by 2024 and 2027 respectively (Carbon Tracker, 2017). All coal power must be phased out if the EU is to meet the Paris targets (Carrington, 2017a). Furthermore, at COP 23 in 2017, a new pact of 20 countries pledged to gradually stop using coal has been launched. The pact aims to have 50 members by 2018 (United Nations Climate Change, 2017).

There are many options for reducing GHGs. Some are available today, such as fuel switching. Others are not economical, such as carbon capture and storage (hereinafter: CCS) (Nordhaus, 2013). Coal’s future depends on clean-coal technologies that will facilitate power plants to burn coal with lower emissions. Clean-coal technologies include plants that operate at much higher temperatures and so use less coal to produce electricity, CCS, and coal gasification that converts coal into a synthetic gas (syngas) (Schwarz, 2018).

Carbon can be captured (at considerable cost) and piped into underground stores. These stores can be sealed. But there are huge limitations: besides the costs, there is the shortage of enough holes: CO_2 needs much more space than coal, oil and gas it is produced from (Helm, 2017). In addition, when CCS technology is added, the cost of electricity rises. While capturing the CO_2 is uneconomical, but transportation and storage are likely to be the more controversial parts. One problem is just the size of the materials that would be put into storage. Another issue is the risk of leakage. This would not only reduce the value of the project but could pose problems for health and safety (Schwarz, 2018). At present, CCS faces many hurdles. It is expensive, untested, and would need to be scaled up to handle tens of billions of tons of CO_2 each year. Firms will not invest in CCS on a large scale because it is financially risky (Nordhaus, 2013).

3.5.2 Outlook for oil

Forecasts for when oil demand will peak differ considerably. The term peak oil here means the prospect of oil demand peaking in the next decades and oil reserves being left in the ground (Raval & Sheppard, 2018). BP's latest annual energy forecast expects global oil demand to peak by the late 2030s (BP, 2018b). However, Wood Mackenzie, a global energy research consultancy group that global oil demand will peak in 2036. Wood Mackenzie's thinking was driven by the impact of EVs and driverless or autonomous electric vehicles (hereinafter: AEVs) or robo-taxis. Wood Mackenzie expects AEVs to become commercial by 2030 and widely accepted by 2035 (Sheppard, 2018e; Wood Mackenzie, 2018). The oil industry is confronted by a serious challenge: whether to invest in oil at a time when climate change concerns could see oil demand peak sooner than expected as RE expands and the adoption of EVs grows more rapidly. Institutional investors worry that actions to combat global warming could leave energy companies facing up big losses. Mainstream asset managers, pension funds and insurers are increasingly concerned about the potential financial impact of global warming and of policies to limit it (Raval & Sheppard, 2018).

In May 2018, sixty big investors, that manage almost $10.5tn in assets, demanded oil and gas companies step up their efforts on climate change and appealed them to be more transparent and accept responsibility for all of its emissions (Financial Times, 2018). Legal & General (hereinafter: L&G) Investment Management, one of the biggest owners of BP and Shell shares, claims EVs, the rise of renewables and a backlash against plastics has threatened to curb oil demand. L&G has led the way in telling the world's biggest oil majors to concentrate less on the risks of short-term price moves and to get ready instead to govern an industry in decline (Raval & Sheppard, 2018).

A report by researchers at the Institute for Energy Economics and Financial Analysis (hereinafter: IEEFA) labeled the fossil fuel industry "weaker than it has been in decades" and put forward the industry's basic weaknesses: one of them is the climate movement. The global fossil fuel divestment and clean energy movement is the rapidly growing divestment movement and according to the new divestment report investors with $6.2 trillion in assets under management have committed to divest from fossil fuel, up from $5.2 trillion in the previous report in 2016. The fossil fuel divestment movement began by students on US university campuses as a moral call to climate action in 2011 and today with almost 1000 institutional investors have made the pledge to sell off their investments in fossil fuel companies (Carrington, 2018). The major energy companies have recognised that divestment is a serious threat to their future. The decision by the three US energy majors, ExxonMobil, Chevron and Occidental Petroleum to join in the Oil Gas Climate Initiative (hereinafter: OGCL) is the latest indication of how pressure from investors and public is pressing the industry to focus on the risk of global warming. The OGCL, a group of companies supporting to limits on GHGs, was launched in 2015, agrees to support the 2015 Paris Agreement on climate change. Some of the OGCL members include BP, Shell, Total, Saudi Aramco, China National Petroleum Corporation (Crooks, 2018e).

Driven by investor demand, the oil industry has mostly discontinued new investment in the type of mega-projects. The oil groups are being forced into delaying difficult long-term investments. It's more and more challenging now to persuade boards to execute on projects that have 20- to 25-year life, which used to be the industry standard. The big oil groups invest extra capital into short-term projects, which meet with success at a fast speed, in addition to RE (Raval & Sheppard, 2018). As energy companies have been under pressure to control costs and increase returns to investors, so-called short-term operations such as shale projects have become more attractive amid the expected global shift towards RE. Shale projects require modest cash: depending on market moves, operations in the shale business can be ramped up and down. Chevron is going to keep capital spending flat even with costs of drilling in deep water coming down, the rise in oil prices and global demand for oil reaches 100m b/d (Crooks, 2018b). The company put a substantial amount of oil and gas fields in the North Sea for sale, joining oil companies such as BP and Shell, in a switch from high-cost regions to assets that will generate the best returns such as US shale assets (Sheppard, 2018a). There has been an increasingly cautious approach to new projects: a shift towards smaller, lower-risk projects (Ward & Mooney, 2018).

According to Rystad Energy, a Norwegian consultancy, during the second half of this decade overall capital spending by energy supermajors is assessed to drop around 50 per cent to $443.5bn. During 2010 – 2015, the capital expenditure was about $875.1bn. (Raval & Sheppard, 2018). According to Wood Mackenzie, the average budget for upstream projects confirmed last year was $2.7bn, the lowest for a decade and a half the $5.5bn average over that period. After big cost overruns on big projects over the past decade, the industry is keeping a tight control on spending. Spending restraints are here to stay as oil and gas companies confront fast-growing opposition from abundant US shale industry, in addition to the long-term transition to cleaner technologies such as renewable power and EVs (Ward & Mooney, 2018).

ExxonMobil, the largest US oil group, aims to control its involvement in the threat of climate change: the company has set objectives to stop leaks of methane, which is a potent GHG, by 15 per cent, and flaring of unwanted gas by 25 per cent by 2020. Exxon was one of eight large oil companies, also including BP, Shell and Total, that last year committed to reducing releases of methane from their operations. In April of 2018, BP announced it would keep net GHG emissions from its operations flat until 2025 (Crooks, 2018f). BP's nomination of the former chief executive of Statoil, Helge Lund, as its new chairman shows BP's shift away from fossil fuels. At Statoil, Mr. Lund made progress for a lower-carbon future by diversifying into the offshore wind and was among the industry's earlier supporters for action to help mitigate climate change. Mr. Lund will not be pushing BP out of fossil fuels overnight but he understands the energy transition and technology (Lund, 2018). Shell has set an ambition to halve its net carbon footprint – including its own emissions from the use of its products – by 2050 (Ward, 2018). In addition to developing net carbon footprint, methane guiding principles and other important climate change actions, Shell has signed a joint statement with Climate Action 100+ (a group of 310 investors with more than $32 trillion), pledging to set firm three- to five-year carbon emission targets every year and link them to its executive pay (Shell, 2018).

3.5.3 Big trends in mobility

More than half of oil demand comes from the transport of people and goods, with more than a quarter from passenger cars alone. New challenges are emerging as the rise of renewables and EVs creates long-term threats to fossil fuel demand and presents oil groups a problem about whether to accept the green revolution (Lund, 2018). Carmakers are trying hard to produce cleaner vehicles to hit strict emissions targets that enter into force in the EU in 2020, with the majority of global efforts being flooded into battery-powered EVs (Campbell, 2018d).

According to BP's annual energy outlook main scenario, self-driving (autonomous) EVs will cause a revolution in transportation over the next two decades and, lead to global oil demand to peak by 2040. BP says there will be around 300 million EVs on the world's roads by 2040, many of them self-driving vehicles, operated as part of Uber-style ride-sharing fleets, reducing private car ownership (BP, 2018b). According to IEA, oil use or consumption in cars is set to peak in the mid-2020s due to the adoption of EVs and more fuel-efficient cars (IEA, 2018b). Brookings Institution estimated that in 2017, more than $80bn was invested in self-driving vehicles technology. Companies are testing hundreds of self-driving vehicles across the US and some are piloting fully driverless cars (Bradshaw, 2018).

Alphabet's Waymo has launched a fully autonomous taxi service (robo-taxis) in Arizona in 2018. General Motors (hereinafter: GM) will introduce robo-taxi service in 2019. Volkswagen says through its new ride-hailing service, Moia, the carmaker will make autonomous vehicles (hereinafter: AVs) available in 2021. Ford says it will be mass-producing fully AVs and ride-hailing service by 2021 and Renault by 2022. Toyota wants to have robo-taxis ready by the Tokyo Olympic Games in 2020. Volvo vows by 2025 one-third of its vehicles sold will have autonomous technology (The Economist, 2018a; Campbell, 2018b). The Chinese market is pivotal to AVs: surveys reveal that consumers are ready to embrace it and Germany's three largest carmakers, Audi, BMW and Mercedes-Benz have already started trials of autonomous technology in China (Hancock & Xueqiao, 2018).

According to UBS, the investment bank report, by 2030 Waymo will retain 60 per cent of the global autonomous taxi market, a degree of supremacy that will put the squeeze on many car companies to embrace its technology or get outdated. UBS estimates by 2030 global earnings from autonomous technology will be worth around $2.8tn, with Waymo being the global leader. Waymo is not building its own cars. It is developing the self-driving technology system and will install the technology on existing cars. UBS expects 12 per cent of cars sold in 2030 will be for autonomous taxi fleets, with a total of 26m robotaxis in operation. Private car sales will fall by 5 per cent as a result. UBS forecasts only a handful of carmakers, such as Daimler and GM, will be able to operate their own systems and compete with Waymo's technology (Campbell, 2018h).

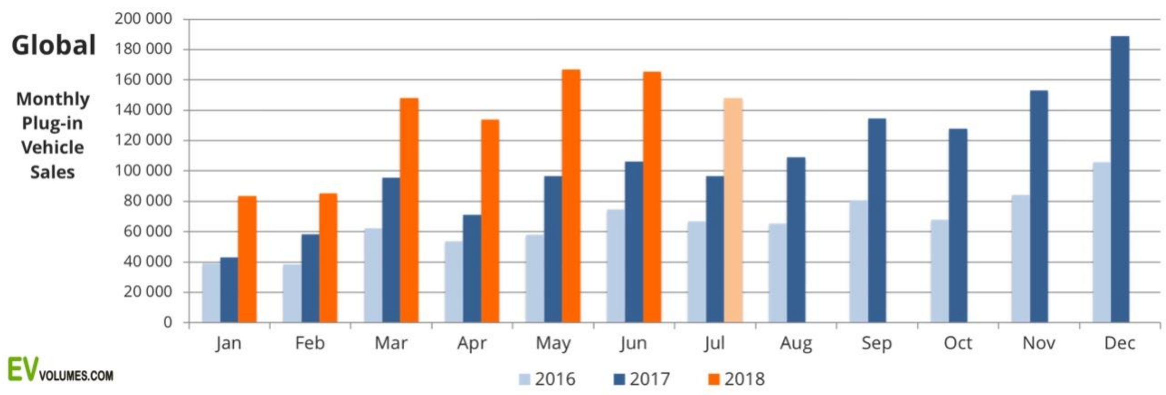
A number of carmakers have shown interests in ride-hailing groups in recent years as they seek to provide mobility services as well as producing cars to address declining car ownership. The potential for businesses in ride-hailing and autonomous driving is huge: according to a study by Intel and research group Strategy Analytics, the ride-hailing services and the autonomous driving market will generate over with $3tn in revenue by 2050 (Inagaki, Woodhouse, & Lucas, 2018).

Carmakers are racing to develop self-driving systems to enter the driverless ride-hailing segment that is expected to offset ownership in big cities (Campbell, 2018h). They are investing in ride-hailing services as a way of entering the fledgling transport services market, in which consumers pay per ride rather than owning a car directly (Campbell, 2018c).

Mercedes-Benz owner Daimler has been among the most active investors in ride-hailing and car-sharing (ride-sharing) services. In 2014, it acquired MyTaxi, a car-hailing service with 70m passengers in Europe; in 2017, it acquired Chauffer Prive in France, and it also owns car-sharing group car2go (McGee, Lewis, & Massoudi, 2018). In 2018, Daimler also took a stake in Estonian ride-hailer start-up Taxify in its latest investment in the growing world of ride-on-demand services (Campbell, 2018c). Volkswagen (hereinafter: VW) reported it plans to introduce a zero-emission car-sharing service in Germany in 2019. The VW brand will launch an international rollout in major cities as early as 2020. The car-sharing plan is one of many mobility plays among carmakers, who worry that car-sharing and car-hailing services could oust individual car ownership. PSA and Renault announced they would each begin electric car-sharing services in Paris soon (McGee, 2018b).

EVs are widely seen as the keystones of future transport. Traditional carmakers across the world are working to meet ever-tightening emissions regulations and pumping billions into electric technologies. This move will signal the beginning of the end for the internal combustion engine and also for oil. According to the Bloomberg forecast, by 2040 EVs would account for 54 per cent of all light-duty vehicle sales (Bloomberg New Energy Finance, 2017). Under the IEA's most ambitious scenario, in which 30 per cent of new car and truck sales are electric by 2030, with electricity displacing almost 4.8m b/d of petrol and diesel. Policy support, research and development and investment into charging infrastructure and technology spur use of EVs. Bans by individual cities also could accelerate EV take-up and have the potential to be more aggressive (Campbell & Raval, 2018).

Figure 6: Global monthly electric and plug-in hybrid vehicles sales, 2016 — 2018



Source: EV-volumes (2018).

In Figure 6, plug-in vehicles sales include all battery electric vehicles and plug-in hybrid electric vehicles. According to EV-volumes (2018), global sales volumes of plug-in vehicles for the 1st half of 2018 have been higher over the same period in 2017. According to the IEA's Global EV Outlook 2018, over one million EVs were sold in 2017. The IEA's Global EV Outlook reported that the number of plug-in vehicles on the world's road exceeded 3 million in 2017 (IEA: Global Electric Vehicles Outlook, 2018).

In the next few years, dozens of different EV models will be available, all from carmakers with the potential to surpass Tesla's production capacity. The existing electric models such as Nissan Leaf or BMW i3, do not match Tesla's technology. However, Jaguar's I-pace or Audi's e-tron mark the opening storm from the industry's current leaders (Campbell, 2018g). For example, between 2019 and 2021, Volvo will introduce five fully electric models and ensure the rest of all new models have an electric motor (a range of hybrid models) from 2019 (Vaughan, 2017). Toyota announced it would discontinue introducing new petrol and diesel cars by 2025. GM will introduce 20 all-electric models by 2023. Mercedes-Benz will sell electric options of all its models by 2022. Renault-Nissan-Mitsubishi will offer 12 more fully electric models by 2022 (Campbell, 2018e).

Volkswagen will build 150,000 EVs in 2020 while the multi-brand group, including Porsche and Audi, will spend €72bn on EV technology and by 2030 the group will make available an electric option of all its 300 models (McGee, 2018a). All BMW models will have an electrified version from 2020: it plans 12 all-electric models and 13 hybrid versions by 2025. PSA, which acquired Opel and Vauxhall brands from GM and also owns Citroen and Peugeot, will offer all of its models with an electric option by 2025. Rolls-Royce expects to produce solely EVs by 2040. The company aims to introduce its first electric vehicle within the next 10 years but will phase out its existing engines over decades. The Rolls-Royce chief executive, Torsten Muller-Otvos believes "electrification is the future." The company says the push towards battery power is driven more by legal requirements in the markets worldwide (Campbell, 2018f).

Governments across the world are drawing up rules that will govern how self-driving vehicles operate, in anticipation of the technology that is expected to disrupt businesses and transport over the coming decades. The European Commission is also drawing up measures to adopt a continent-wide framework on self-driving cars in an effort to catch up with China and the US. The measures include €450m of investment into roads, and telecoms networks needed to support driverless cars. The €450m comes on top of the €440m already set aside for investment, which has been used across 18 countries (Campbell, 2018a).

The next few decades are going to see some incredible innovations in transportation. Investors are pouring hundreds of millions of dollars into two-wheeled transport options such as electric bikes and electric scooters, which have quickly emerged as a cheap alternative for short hops around cities. Ride-hailing apps are taking people off mass transit systems and into cars (Ward & Hook, 2018). Electric bikes and scooters that can be rented cheaply via smartphone are seen as a replacement for cars on short urban journeys. The electric version is more grown-up than a push scooter, which is more commonly associated with kids than office workers (Bradshaw & Buck, 2018). Many cities have tried to encourage cycling by allowing app-based bike- and scooter-rental outfits to set up on pavements (The Economist, 2018b).

The IEA expects sales of electric buses and two-wheeled vehicles such as scooters to accelerate faster than passenger cars. Forty per cent of the world's two-wheelers may be electric determined by demand in China and India by 2030 (Campbell & Raval, 2018). Chinese cities are in the frontmost position of electric two-wheeled vehicles. In 2017, one in three bikes purchased in the Netherlands was electric. In Germany, 15 per cent of new bikes sold in 2016 were electric (The Economist, 2018c). The US tech start-ups, BirdRides and LimeBike, are the two pioneers of electric bikes and scooters rentals, now operate in more than 100 cities worldwide. In June 2018, Silicon Valley-based start-up LimeBike launched its electric scooters in Paris, denoting the beginning of an aggressive international expansion to the European market. The expansion of e-bikes and e-scooters is sped up by ride-hailing firms, such as Uber and Lyft determined to provide a wide array of urban e-mobility alternatives. In 2018, Uber acquired Jump, an electric bike-sharing service for around $200m and Lyft acquired, Motivate, an electric bike-sharing service for around $250m. Ford, the company that pioneered the motor car, has more recently bought California-based e-scooter rental start-up, Spin. The acquisition makes Ford the first carmaker to embark on the booming scooter rentals market and the carmaker plans to place fleets of electric two-wheelers in over 100 cities worldwide by 2020.

3.5.4 Green revolution of big oil groups

Automakers are not the only one active in diversifying their businesses. Big European oil companies are laying foundations for expansion into the electricity supply chain as focus turns to renewables. Big oil groups are showing interest in the tech behind changing patterns of transport, such as Uber-style ride-sharing and in the longer term, self-driving cars. The big European oil groups are investing in EV technology, giving them a position in EV tech that many analysts believe will eventually push oil demand into decline (Ward & Hook, 2018).

BP has declared it is looking to acquire more green energy firms. In June 2018, BP a) bought Chargemaster, the UK’s electric charging network, for £130m b) in May 2018, invested $20m in StoreDot, an Israeli developer of ultra-fast-charging batteries c) reached a partnership with NIO Capital, a Chinese private equity group, to venture in advanced mobility tech in China d) in January 2018, acquired a stake in FreeWire, a US group developing rapid-charging infrastructure for EVs (Ward & Hook, 2018). In 2017, BP spent $200m for a 43 per cent stake in Lightsource, Europe’s biggest solar developer.

BP is not alone. In 2017, Shell a) acquired NewMotion, a Dutch car-charging network, b) teamed up with Ionity, the electric car charging firm, c) acquired First Utility, a British gas and electricity supplier that already operates in Germany. Shell is also the majority owner of a UK start-up called FarePilot, which runs an app to help taxi and ride-share drivers identify areas of high demand (Ward & Hook, 2018).

In 2017, Total acquired a 23 per cent stake in the RE firm Eren for €237.5m. Besides, Shell and Total are setting up EV charging points in their web of petrol stations. In 2016, Total acquired Saft, a French battery maker, through which it is developing EV technology

(Ward & Hook, 2018). Total bought US solar company, SunPower and the largest vendor of natural gas and renewable power to the Belgium residential sector, Lampiris. In 2018, Total also acquired French electricity retailer, Direct Energie for €1.4bn. In 2017, through its Total Spring brand, Total set up the supply of gas and green energy to French households (The Economist, 2018d).

These investments into electricity supply chain are part of a push by European oil majors in expectation of renewable power becoming a bigger share of the energy mix at the expense of hydrocarbons. Entering the market for household power supply, which has been dominated by traditional utilities, is where oil majors see growth and also it is a hedge for these companies. Shell and Total have investments ranging from wind and solar farms to consumer electricity. These investments are designed to help the big oil groups acquainted with technologies with potential disrupt the conventional example of private car ownership (Ward & Hook, 2018).

Oil's dominance will decline in the 21st century. Low-priced natural gas, RE, EVs and a joint attempt by international governments to tackle climate change show that the energy source of selection will be electricity (The Economist, 2018e). Oil companies will need to change at the very pace as technology evolves around them (Ward & Hook, 2018). It is certain that heighten electrification is very likely to lead to disruption. Amid pressure to cut global warming and the development of renewables and EVs, the energy industry anticipate renewable electricity to grow a large amount of the world's energy mix during the next decades. The energy industry has already ploughed money into building natural gas businesses. The oil companies are also taking stakes in electric utility companies in deregulated markets (The Economist, 2018d).

3.5.5 Roadmap for decarbonisation

Many nations and private firms have already embarked on decarbonisation programs in various sectors such as transport and energy to cut their carbon emissions. While the transition between petrol and diesel cars and EVs is expected to take a couple of decades, there is a lot of political momentum for EVs as governments and cities around the world are considering the environmental implications and urging public adoption of EVs to curb carbon emissions. Several governments have set timelines for when they want older vehicles without electric power to be phased out. (Campbell & Raval, 2018). France, for example, will halt selling of petrol and diesel cars by 2040. Norway will only allow selling of fully electric or plug-in hybrid cars by 2025. The Netherlands has proposed banning diesel and petrol cars from 2025. The UK has pledged to halt selling of all petrol and diesel cars by 2040. Some federal states in Germany are keen on a 2030 phase-out (Chrisafis & Vaughan, 2017). China wants a fifth of new cars powered electrically by 2025 (Campbell & Raval, 2018). Also, cities around the world are looking to cut CO_2 emissions and enlarge their car-free zones. Oslo, for example, aims to forbid all cars by 2019. The city of London will ban diesel cars by 2020. All cars will be banned from Paris city center by 2030. Diesel cars will be disallowed in Copenhagen from 2019, while Oxford city has intended to outlaw cars from its center from 2020 except EVs (Business Insider, 2018; Jones, 2017).

Legislation that was recently approved in California, instructs two of the largest American pension funds, Calpers and Calstrs, to disclose the climate-related financial risk of their public market portfolio. The legislation defines risks as “the effects of the changing climate, such as intense storms, rising sea levels, higher global temperatures, economic damage from carbon emission and other financial and transition risks due to public policies to address climate change shifting consumer attitudes, changing economics of traditional carbon-intense industries” (Jaffe, 2018).

Besides, California became the first state in the US to require solar panels on all newly built houses and buildings after 1 January 2020. California’s decision reflects the transformation gripping the energy industry (Pfeifer, 2018). Over $42m has been invested so far on solar energy in California, and the mandatory solar panels will be expected to yield an additional increase to solar industry state-wide. In 2017, California generated nearly 16 per cent of its electricity from solar. California state law already requires the state’s utilities to source 60 per cent of all electricity from RES by 2030. It also states that all of California’s electricity should be sourced from RES by 2045 (BBC, 2018).

Despite Saudi Arabia's bullish view of peak oil, the actions of the state signal the threats for its barrels. The Saudi sovereign wealth fund, Public Investment Fund (hereinafter: PIF) bought a 5 per cent stake in Uber, for $3.5bn in 2016, and is an investor in Japan’s SoftBank $100bn Vision Fund (almost $45bn of SoftBank Vision Fund is Saudi money), which has ploughed billions of dollars into ride-hailing start-ups. As shared vehicles are increasingly electrified and eventually self-driving, some analysts see oil at risk of being cut out of the entire mobility value chain. In 2018, PIF signed a memorandum of understanding with SoftBank Vision Fund to create in Saudi Arabia the largest solar power generation project, aiming to spend $200bn by 2030. Saudi Crown Prince and SoftBank signed a preliminary deal for an output capacity of 200 GW solar farms, adequate to connect 150 million houses (Inagaki & Raval, 2018). According to Financial Times, in 2018 Saudi’s PIF spent $2bn to acquire almost 5 per cent of Tesla’s stock and invested $1bn in a US EV start-up, Lucid Motors (FT Reporters, 2018).

China has made a push to become the world’s champion in fully EVs by 2025. The government has justified pumping huge resources to encouraging domestic EV production based on the argument they are greener than combustion engine cars. Government measures developed to push EV production to consist of spending an estimated $60bn in subsidies between 2015 and 2020 and requiring carmakers to build very large numbers of EVs – between 2.4m and 2.7m passenger EVs per year by 2020 (Stacey, 2018b; Inagaki, 2018). China is critical, in terms of global emissions. China has pledged that emissions will peak before 2030, based on conservative projections of economic growth and changes to industrial structure (Hornby & Hook, 2018).

BlackRock, the world's largest asset management group with $6.3tn of assets, announced that it will explore fresh ways to invest in companies that do more with regard to RE and hunt for opportunities that arise from the shift to sustainable energy use. Investors are paying more attention to risks linked to fossil fuels and climate-related risks. Tougher environmental rules may lead to fossil fuel reserves being deemed unburnable, leading to asset write-downs. Besides BlackRock, there are other asset management groups such as BNP Paribas and State Street Global Advisors, already offer investors a low-carbon exchange-traded fund that focuses on companies with a low carbon footprint. This move highlights increasing interest in responsible investing and takes into account environmental, social and governance (hereinafter: ESG) factors by investors (Thompson, 2018).

Research published in the journal Nature Climate Change warned that between $1tn and $4tn could be erased from the global wealth due to 'stranded assets' – fossil fuel reserves that will not be burned because of improvements in energy efficiency. Climate-related risks include fossil fuel reserves being deemed unburnable because of environmental regulations and assets being subject to write-downs during a shift to RE (Nature Climate Change, 2018).

Above examples clearly point out one thing, that is, the end is clearly coming for the coal and oil industry and a clear shift from fossil fuel dependence to rely on RES or the gradual end of fossil fuels and how the transition to renewables will play out in the longer run.

4 RENEWABLE ENERGY

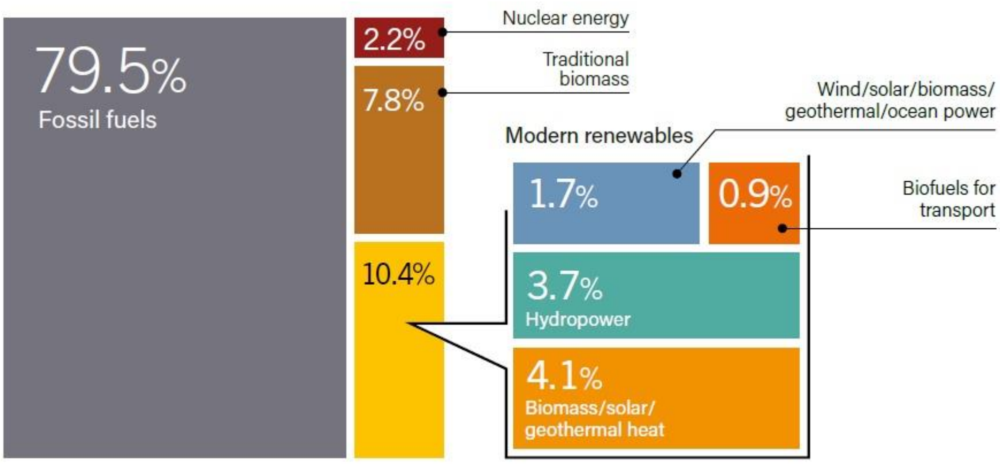
Fossil fuels are exhaustible and cannot be recycled. Currently, many industrialised countries depend on fossil fuels for their energy needs (Tietenberg & Lewis, 2015). The most important argument for using RE is to reduce global GHG emissions. Global CO_2 emissions will have to peak immediately and drop to almost zero by 2100. Emission reductions on this extent will require a transition to renewables. This means increasing investments in RE and energy efficiency significantly and reducing investments in fossil fuels. Above 170 countries had endorsed RE targets and over 145 had policies to assist RE. These policies have mainly focused on renewable electricity generation. Over 65 countries have policies to support renewable transport fuels (Peake & Everett, 2018a).

Renewable sources of energy are solar, wind, bioenergy, geothermal, tidal, and hydroelectric. In contrast to non-renewable fuels, renewable resources can replenish themselves; Renewables offer the possibility of an inexhaustible, carbon-free fuel (Schwarz, 2018). Most RES is derived from energy supplied by the sun.

Generating large amounts of low-carbon energy from RES is, together with dramatically improved energy efficiency measures, one of the two foundations for reaching the IPCC's emissions-cutting goals. This means generating energy at rapidly increasing rates for solar, wind, geothermal, clean bio-energy, and hydropower. It is realistic to expect that by 2050 clean renewables could supply around a third of all global energy resources. The main driver is the trajectory for prices and costs for renewables is becoming increasingly favorable (Pollin, 2015).

In 2014, electricity generation accounted for 40 per cent of global CO_2 emissions and two-thirds of the world's use of coal. Electricity is mainly generated in large gas, coal, or nuclear power plants. Renewable electricity sources have an important role in cutting global CO_2 emissions because of high levels of CO_2 emitted from fossil-fuelled generation (Everett, Boyle, Scurlock, & Elliott, 2018). The power sector is the biggest market for energy (in 2017, consuming over 40 per cent of primary energy) and is at the forefront of the energy transformation, as RES get bigger (BP, 2018a).

Figure 7: Global total final energy consumption in 2016



Source: Renewable Energy PolicyNetwork for the 21st Century (2018).

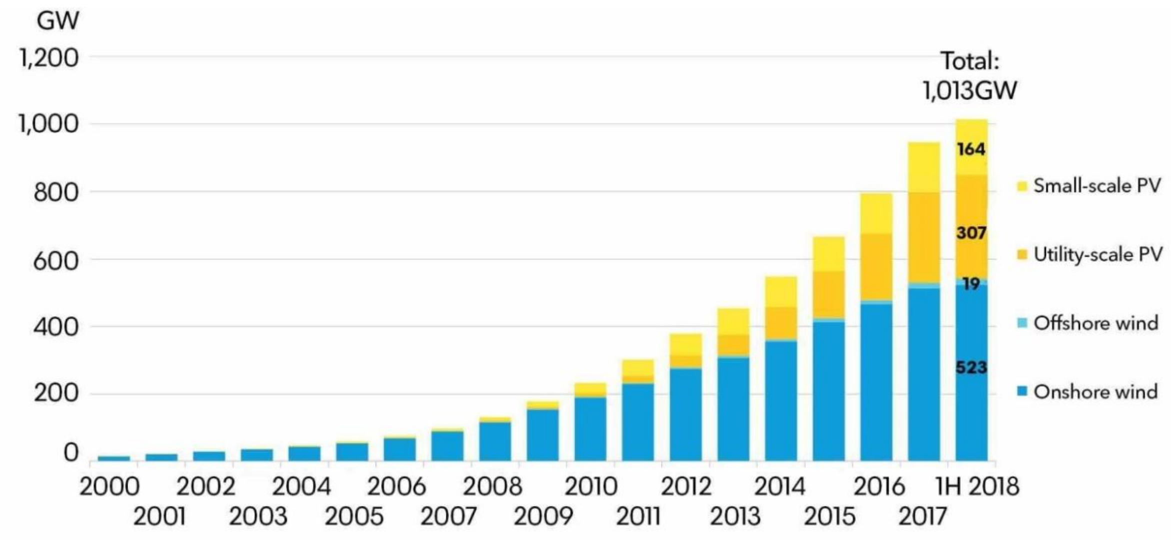
Figure 7 shows the RES contributed around 18.2 per cent of the world's total final energy consumption in 2016 (final or delivered energy means what the customer actually receives and pays for). Fossil fuels represent 79.5 per cent of the global total final energy consumption (REN 21, 2018).

Perhaps what is most striking about year by year changes in world RE supply is the extraordinary growth rates of some of the technologies, particularly those generating electricity. Between 2010 and 2016, world wind power output increased almost three-fold and solar PV output increased almost ten-fold (BP, 2017).

The sun is the most powerful energy source accessible and the world will need to exploit it more than it presently does to transition away from fossil fuels. The first concern is to decarbonise the electricity sector. This is because climate scientists agree that to limit climate change, carbon emissions from the electric power sector must drop between 80 and 100 per cent by 2050. Renewable solar and wind power are the most hopeful options to do the heaviest lifting. Decarbonising the electricity sector makes good sense because economical sources of clean electricity already exist. Also, electricity demand is expected to grow rapidly, driven by economic expansion, population rise and urbanization, and the rise of new sources of demand such as EVs. In other sectors, such as the industrial sector or the transportation sector (especially, aviation, trucks and ships), efficient and affordable options are limited and there are currently few substitute fuels economically practical (Sivaram, 2018).

In 2017, the power sector grew by 2.8 per cent globally. The growth in power generation was prompted by intense expansion in RES, caused by wind (17 per cent, 163 terawatt hours (hereinafter: TWh)) and solar (35 per cent, 114 TWh), which made up almost 50 per cent of the total growth in power generation. In 2017, Renewables' share of power generation grew from 7.4 per cent to 8.4 per cent. Wind supplied over 50 percent of renewables growth, whereas solar added more than a third. Solar capacity grew by around 100 GW in 2017, with China alone adding over 50 GW (BP, 2018a).

Figure 8: Global wind and solar installations, cumulative to June 30, 2018



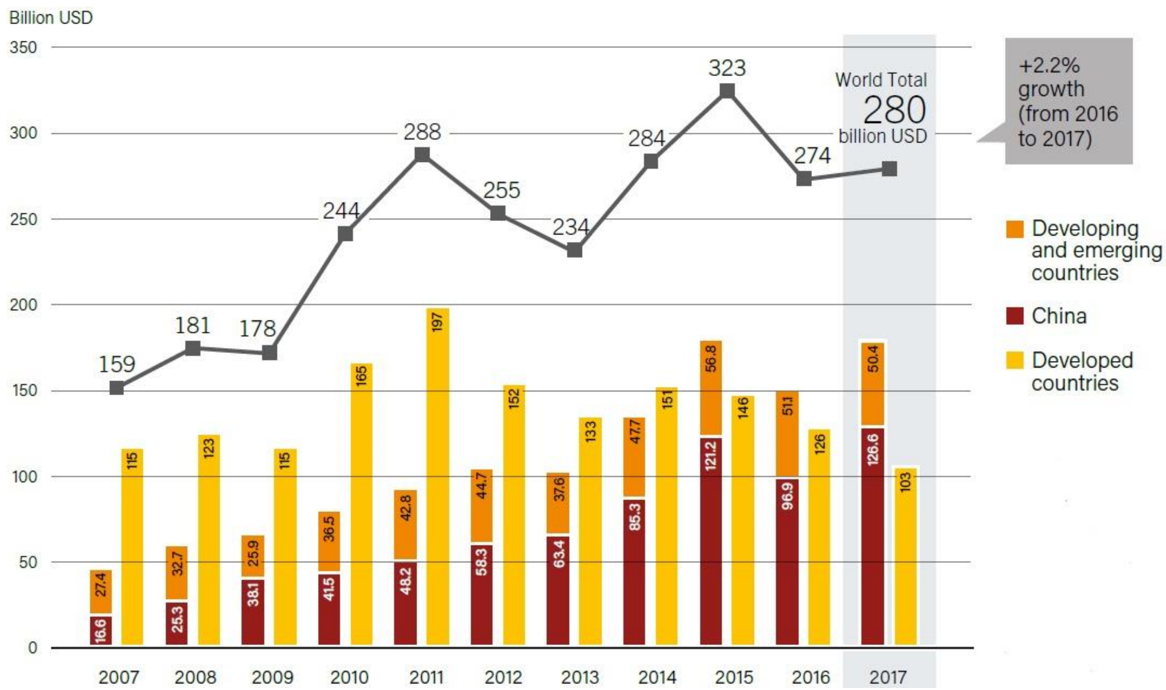
Source: Bloomberg (2018e).

Figure 8 shows there were 1013 GW of wind and solar PV generating capacity installed for the 1st half of 2018. According to the Bloomberg New Energy Finance (hereinafter: BNEF), the total combined capacity of wind and solar energy exceeded the notable one terawatt (hereinafter: TW) figure by the end of June 2018. According to BNEF's estimation, the first 1 TW of wind and solar required about $2.3 trillion of capital expenditure. And the BNEF estimate that the second terawatt of wind and solar will happen by mid-2023 and cost 46 per cent less than the first (Bloomberg, 2018e).

There has been an increasing interest in responsible investing and big investors now begin to take into account of ESG factors. Investors' interest in ESG comes as concern rises over climate change and the societal effect of companies. According to data from the Global Sustainable Investment Alliance, funds with responsible investing strategies managed $22.9tn of assets in 2016, up 25 per cent in two years. The rapid growth of funds with responsible investing strategies has spurred a push by investors for greater disclosure from companies. The market for environmentally friendly investment products is growing fast. According to recent research by credit rating agency Moody's, $77bn of green bonds were sold globally in the first half of 2018, and the agency expects that up to $200bn of green would be sold in 2018 – up from $155bn in 2017 (Allen, 2018b; Allen, 2018a).

Furthermore, financial services and insurance companies are putting their money into renewable energy projects such as solar and wind farms and hydro schemes. Germany's Allianz invested €5.6bn invested in RES at the end of 2017 and Axa upped its objective for low-carbon ventures from €3bn to €12bn by 2020 (Ralph, 2018b).

Figure 9: Global total new investment in renewable energy sources, 2007 — 2017



Source: Renewable Energy PolicyNetwork for the 21st Century (2018).

Figure 9 shows the global new investment in RES in developed, emerging and developing countries. The value of the investment is holding up: in 2017, it was around $280 billion. This represents an increase of just over 2 per cent compared to the previous year (REN 21, 2018).

However, there is a gap for investors to finance the transition towards renewables. According to the IEA's latest Energy Outlook report, over $2.3tn of annual investment in the global energy sector is needed to meet the sustainable development scenario. In 2017, only $1.8tn of public and private funding was spent in global energy. Nevertheless, many private investors have recognised an opportunity and are plugging funding in for green energy projects (IEA, 2018b). Green bonds have been popular with institutional investors. According to a report by the OECD, global green bond issuance has grown from $3bn in 2011 to $95bn annually in 2016 (OECD, 2017).

In recent years, a significant amount of investment has begun to flow into modern RE technologies, mainly solar PV, wind and hydropower. In 2015, for the first time, more than half of global total electricity capacity additions were from renewables – overtaking new investments in fossil-fuelled and nuclear-powered electricity generation (Peake & Everett, 2018b).

According to the credit rating agency, Moody's, emerging economies would get past developed countries with regard to the size of RES they set up in 2018. A great deal of the development would, in particular, originate from two of the biggest renewable energy markets: China and India. According to the IEA, in 2017 China added 50 GW of solar power capacity – equal to the solar capacity of France and Germany combined. Also, China added 15.6 GW of wind capacity in 2017. India installed around 9.5 GW of solar and is on target to reach 28 GW by 2018 (Stacey, 2018a).

An outstanding expansion in solar and wind is happening for many reasons, but the most important reason has been the decline of solar and wind prices by comparison to prices of fossil fuels. The decline in solar PV prices is caused by two drivers: developments in technology and the increased scale of manufacturing. Prices of wind are declining because of lower-cost wind turbines that account for better capture of wind resource, and thus greater performance (Heinberg & Fridley, 2016). Analysts attempting to calculate the percentage fall in cost from each doubling in accumulated global output of solar panels have almost all arrived at a figure of 20 per cent and the PV industry named this frequently observed, apparently highly predictable cost decline 'Swanson's Law' (Goodall, 2016). Expansion in the manufacture of renewable technologies has also produced dramatic cost reductions. These RE growth rates are likely to carry on, led by issues of global warming, and the local air pollution consequences of coal-fired electricity generation in China and India (Everett, Boyle, Scurlock, & Elliott, 2018).

4.1 Solar energy: photovoltaics

From the 'favelas' of Latin America and 'slums' of India to the cities of Europe, solar power offers electricity that is now competitive with all other energy sources. And it is becoming cheaper each month through predictable technological changes (Goodall, 2016).

The average solar power falling on the Earth is about 150,000 TW in total. This power is far larger than the world consumption in 2014 of 19 TW (Andrews & Jelley, 2017). The solar energy hitting the Earth's surface in an hour is bigger than all the energy used up in a year by the population of the world (Nersesian, 2016). The solar intensity on a clear sunny day is 1000 watts/m^2 (Andrews & Jelley, 2017). Approximately 30 per cent of the 5.4 million EJ per year of solar energy reaching the Earth is bounced back into space and the remainder of 70 per cent – approximately 3.8 million EJ – is available for use on Earth. In 2014, the total world primary energy consumption was 575 EJ. (Peake & Everett, 2018a).

Solar energy can be classified into two kinds: solar thermal energy and solar PV energy. Solar energy can be transformed into useful energy either directly or indirectly. Direct solar energy uses include solar thermal water heating using solar hot water panels (e.g. domestic hot water heating), passive solar heating of buildings (e.g. space heating, daylighting, Passivhaus design), and electricity generation using solar PV modules or concentrating solar power (hereinafter: CSP). Solar thermal energy is renewable energy that uses the sun's heat to warm a fluid, produce steam and generate clean electricity (Nersesian, 2016). Solar thermal collection methods are many and varied (Everett, 2018). Solar PV technology uses light energy from the sun, captured by solar cells, to generate clean electricity. Solar PV technology represents the most significant growth in RE at this time, beating out thermal solar and overwhelming other renewable sources. While wind power generates more electricity than solar, the growth in PV solar power is significantly higher than that of wind in recent years (Nersesian, 2016).

This thesis will only briefly touch on solar thermal-electric generation, known as CSP but mainly focus on a more direct method of generating electricity from the Sun’s rays, namely, photovoltaics.

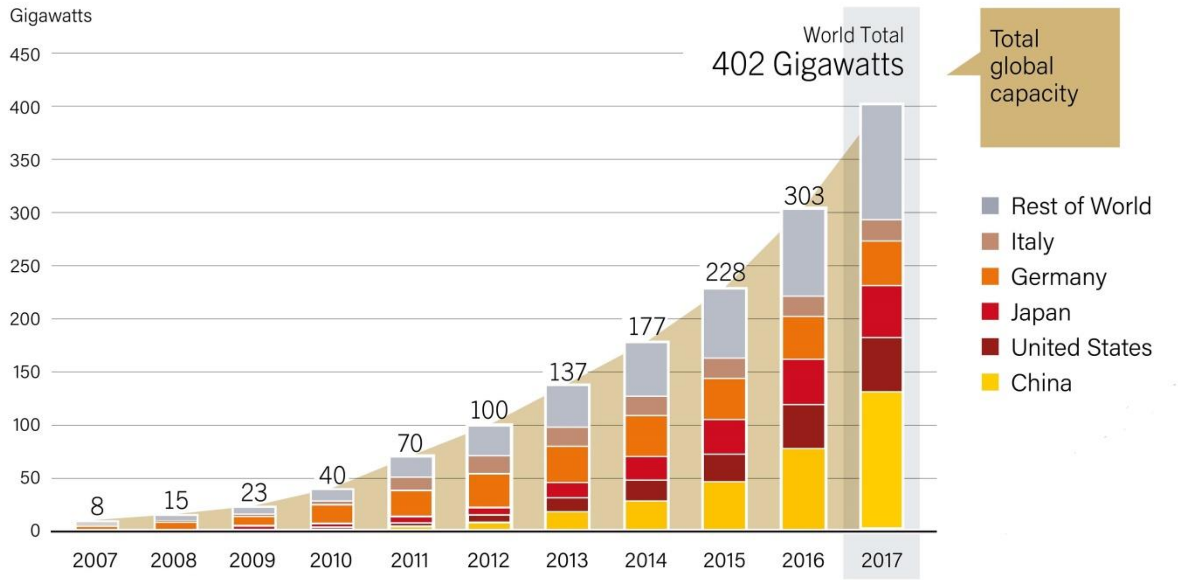
A PV or solar cell is the basic building block, small in size, and capable of producing 1or 2 watt of power (Nersesian, 2016). Solar cells are actually sold packaged into solar panels or modules, which produce 50-300 watt of power. A PV array is likely to consist of multiple modules connected in parallel each one supplying more current (Boyle & Everett, 2018). There are two main types of solar cells in production today: silicon ‘crystalline’ solar cells and thin-film solar cells. Crystalline silicon cells are produced either single monocrystalline (single crystal) or polycrystalline (multicrystalline) silicon cells (Andrews & Jelley, 2017).

Despite the fact that monocrystalline silicon PV modules are costly but very efficient (26 per cent). In 2015, this type still made up about a quarter of global PV cell production. Polycrystalline silicon PV cells are cheaper to produce, but not very efficient (21 per cent). Nevertheless, their price edge meant that their share of the market has been steadily increasing, to about 70 per cent of global PV production in 2015 (Boyle & Everett, 2018).

Silicon is not the only crystalline material suitable for PV applications. PV cells can also be made from ‘thin-films’ of various kinds. There are a number of materials that have good solar light absorption: in particular, gallium arsenide (GaAs), cadmium telluride (CdTe), copper indium gallium diselenide (CIGS), and amorphous hydrogenated silicon (a-Si:H) (Andrews & Jelley, 2017). These are often called second generation solar cells (Boyle & Everett, 2018).

Large scale PV module production since the 1990s has driven down prices. The learning curve during 1980 – 2015 for all PV technologies was 19.1 per cent, while during 2010 – 2015 it was 27 per cent for crystalline silicon and 23.5 per cent for thin film technologies. In 2015, 93 per cent of the modules produced were silicon-based modules, with the rest thin-film cells (Andrews & Jelley, 2017).

Figure 10: Solar PV Global Capacity, by country or region, 2007 — 2017



Source: Renewable Energy PolicyNetwork for the 21st Century (2018).

Between 2007 and 2017, total world solar PV capacity made headway at full speed, from 8 GW in 2007 to over 402 GW in 2017 as is shown in Figure 10 (REN 21, 2018).

There are many reasons to predict that the PV industry can continue its high growth rate despite the fact that just 1 per cent of the world's electricity had come came from PV in 2015. Here are the reasons: The cost of generating electricity by PV cells has now approached grid parity in many places; A large number of countries have incorporated PV objectives as an integral part of their carbon mitigation pledges; Both China and India are looking to PV for their local pollution problems; Countries such as India have pledged to give access to electricity in their more remote rural areas and PV technology could be the best answer; A number of Middle-Eastern nations have realised that diversification into solar is necessary (Boyle & Everett, 2018).

The essence of solar expansion has been of a cave in the cost of solar panels, due to improved technology and excessive supply in China.nAccording to the International

Renewable Energy Association (hereinafter: IREA), between 2009 and 2017, the price of solar panels had dropped more than 80 per cent, whilst the price of wind turbines had dropped down by almost 50 per cent (Stacey, 2018a).

Over the two decades leading up to 2016, global annual PV production grew at an annual pace of roughly 40 per cent. Solar now supplies more than 2 per cent of global electricity demand. According to BNEF, the cost of solar PV will plummet by two-thirds by 2040, and as a result, solar will account for 17 per cent of total electricity generation (Sivaram, 2018).

The expansion of PV throughout the world is spurred by the fast-growing success of PV in comparison with of fossil fuels, by governmental programmes, by its very low CO_2 emissions and lack of pollution, and by the increasing demand for electricity (Andrews & Jelley, 2017).

Some estimates in the academic literature are extremely optimistic about zero-carbon power sources supplying nearly all the world's electricity demand by 2050. The IEA's projection of what the global electricity mix needs to look like in 2050, in order to cut global warming to 2°C, solar power – a mix of solar PV and CSP plants - would provide just 20 per cent of the world's electricity. Adding the contribution of wind power would bring the total share to a little over one-third of the global electricity mix by 2050 (Sivaram, 2018).

Commercial solar PVs usually convert 15 – 22 per cent of the sun's energy striking it into electricity. But to meet solar's 2050 target of powering one-third of global electricity demand, solar must do more than attract investment in existing solar technology. Fortunately, exciting academic researches around the world are making good progress in tomorrow's solar panels. Solar cells made of perovskite have taken the forefront among emerging PV technologies. In June 2018, Oxford PV, a solar start-up, break the record with its perovskite-based solar cell: 1 cm^2 perovskite-silicon tandem solar cell has recorded a 27.3 per cent conversion efficiency. This exceeds the 26.7 per cent conversion efficiency of a single-junction silicon solar cell (Oxford PV, 2018). There are a couple more materials for solar cells, which may have future potential: organic PV and quantum dots (Sivaram, 2018). Furthermore, A new research by Chinese academics improved the efficiency of organic solar cells from 15 per cent to 17 per cent. This result is important because for example with 15 per cent efficiency and a 20-year duration of life, organic solar cells could generate electricity at a cost less than 7 cents per kilowatt-hour (kWh). According to the US EIA, the average cost of electricity in 2017 was 10.5 cents per kWh (McGrath, 2018b).

Solar energy can also be used when concentrated in a thermal power plant to generate electricity (Andrews & Jelley, 2017). CSP plants convert solar thermal energy into electricity by using mirrors or parabolic trough collectors or parabolic dishes to focus the Sun's heat onto a central receiver at the top of the tower or a horizontal pipe or central steam boiler. In the central receiver, either steam can be produced directly or a heat transfer fluid can be raised to a high temperature to be pumped away to generate steam. The steam then drives a turbine to produce electricity. Most of the currently proposed CSP plants are solar-fossil fuel hybrids where the steam turbine is powered by the Sun during the day, by stored heat in the evening and by natural gas at night. Also, most CSP plants use some fossil fuels to provide back-up when the Sun does not shine, and to speed up the start-up of the plant (Everett, 2018).

In 2010, the IEA predicted that CSP could provide about 10 per cent of the global electricity demand of 4.5 TW in 2050 with an estimate global CSP capacity of 150 GW by 2020. The IEA now thinks that this 150 GW capacity will be reached in 2030 (Andrews & Jelley, 2017).

4.2 Economics of photovoltaics and environmental impacts

There are four essential parts to the cost of electricity from any power generation station: initial capital costs, operation and maintenance costs, fuel costs, and final decommissioning costs. A widely used technique for making analogies between different various power generating stations is to determine a comprehensive levelized cost for the electricity in pence per kWh across the life span of the station (Boyle & Everett, 2018). There are large initial capital costs for many RE technologies but the fuel cost is zero (Boyle & Everett, 2018). The Levelized Cost Of Energy (hereinafter: LCOE) of PV is currently economical with fossil fuels in sunny countries, and likely to reach grid parity in numerous places by 2020 (Andrews & Jelley, 2017).

The cost of generating electricity by PV cells is made up of a mixture of costs: paying off the initial capital and the maintenance and operation costs. A grid-connected PV power system's capital cost contains the balance of system (hereinafter: BOS) costs (Boyle & Everett, 2018). In recent years, the cost of PV modules has plummeted notably and is about half of the total cost (Andrews & Jelley, 2017). The BOS costs are made up of a combination of costs: “the costs of the interconnection of modules to form arrays, the array support structure, the cost of cabling, switching, metering and inverters and if the array is not building-mounted, the land and foundations.” Small off-grid systems would also have to include extra battery capital costs (Boyle & Everett, 2018). But the balance of systems cost have also decreased, for example, through the use of robots for installation and maintenance, and optimising the output of modules (Andrews & Jelley, 2017).

Electricity cost from PV cells has plunged sharply throughout the course of the last few years and has currently reached grid parity in many places with a LCOE $60/MWh (Andrews & Jelley, 2017). According to Fraunhofer ISE researchers, the LCOE of PV systems currently range between €0.0371 and €0.1154 per kWh in Germany and on average, PV is the most cost-effective technology among all power plant types in Germany. The study confirms that newly constructed PV systems and onshore wind turbines at favorable locations are already cheaper than fossil fuel plants. According to the study, technological developments in PV will further reduce costs in the future (PV Magazine, 2018).

In operation, Solar PV systems produce no gaseous or liquid pollutants. Most PV modules make no sound. PV arrays have a little bit of visual impact: rooftop arrays may not be regarded as attractive. But PV cells can also be integrated into buildings: a number of firms have constructed unique PV modules in the shape of roofing tiles. Large, multi-megawatt PV arrays require a large area and there have also been objections to their construction on agricultural land but this issue can be solved by placing them on low-quality land. Even though PV modules are very long-lived devices, the EU recycling regulations require PV-makers to retrieve and reprocess 85 per cent of their PV modules for free at the end of their working lives.

The primary substance, which a large number of PV cells are made from, is silicon, and it is not naturally dangerous. Despite that, in the production process, some hazardous chemicals can be used, but the quantities are small and with effective safeguards and regulations the risks can be kept very small.

Energy is used to produce the PV modules and at present, it is largely from fossil fuels, and for this reason, there will be some attached GHG emissions. However, modern cells are more efficient and the emissions and the energy associated with manufacturing PV systems are small compared with the time required to produce this amount of energy (known as, ‘energy payback time’) in relation to the lifetime of solar cells, which is about 30 years (Andrews & Jelley, 2017).

4.3 Wind energy

The Sun is also responsible for wind energy, heating up the Earth’s atmosphere and causing air currents, which wind turbines then can convert to power (Sivaram, 2018). The amount of energy in the wind, across the whole of the globe including the oceans, is about 900 TW (Goodall, 2016). Winds are variable both in time and in location, with some parts of the world exposed to high winds and some to almost no wind (Andrews & Jelley, 2017). The wind blows more reliably offshore. Many countries in high latitudes will use cheap wind technologies for low-cost power, Denmark being a good example (Goodall, 2016).

Between 1980 and 2000, the cost of wind turbines plummeted at a steady rate. Nowadays, the advantageous and economical practices of electricity generation are from wind turbines. In light of ongoing plunge in price, efficiency advancements, and performance, in the coming decades wind energy will be a financially secure investment both onshore and offshore (Taylor, 2018; GWEC, 2018).

Present-day wind turbines are available in two primary designs: horizontal axis wind turbines and vertical axis wind turbines (Taylor, 2018). Most of the current designs are horizontal axis wind turbines. Wind turbines vary greatly in their dimensions: from smaller ones that generate a few hundreds of watts to huge ones generating a great deal as 10 MW (Taylor, 2018). A standard present-day 3 MW wind turbine can generate sufficient electricity to supply, for example, 1000 American homes (Letcher, 2017). Costs are going down because turbines are being built at higher elevations, meaning, longer blades in locations that have more wind, a combination that has more than doubled the capacity of a given turbine to generate electricity (Hawken, 2017).

Ongoing technical developments focused around wind turbines have made the sector possible to become one of the fastest growing RES (Taylor, 2018). In June 2017, global wind power capacity went past half a terawatt (1TW = 1000 GW) (Taylor, 2018). In 2017, over 52 GW of wind power was installed, arriving at a total of 539 GW globally (GWEC, 2018).

According to Global Wind Energy Council's (GWEC) Global Wind Energy Outlook 2016, wind energy could get to 2110 GW and provide around 20 per cent of electricity throughout the world by 2030. The report says wind energy could entice investment of around $200 billion yearly, and cut carbon emissions by more than 3.3 billion tonnes annually (GWEC, 2016). If the current rate of growth continues, wind energy could supply a third of all global energy by 2050 (Letcher, 2017).

The wind is a source of carbon-free energy and thus far wind farms produce and supply an impressive volume of electricity in many different countries throughout the world (Andrews & Jelley, 2017). In 2017, around 44 per cent of Denmark's electricity came from wind. In 2017, about 11.6 per cent of the EU's power came from wind energy. In Europe, Germany has been at the forefront of the wind energy revolution and by 2017, it deployed 56,132 MW. However, China has the world's largest wind energy capacity, with over 188,392 MW put in place by 2017. The USA has the next largest with over 89,077 MW positioned (GWEC, 2018).

4.4 Economics of wind energy and environmental impacts

The cost of generating electricity from wind energy is made up of a mixture of costs: the capital costs of building wind farms (wind turbines), the operations and maintenance costs, to name a few (Andrews & Jelley, 2017). The global average LCOE in 2015 from onshore wind was US$0.06 per kWh (US$0.045 – US$0.14 from fossil fuels). The LCOE from offshore wind, currently about €0.14 per kWh and there is an initiative to try and reach €0.10 per kWh by 2020 (Andrews & Jelley, 2017). The World Economic Forum calculated that the LCOE in 2016 was about $50/MWh ($0.05/kWh) (World Economic Forum, 2017b).

The cost of both solar and wind includes production tax credits. However, Goldman Sachs believes that the continuing decline in wind turbine costs will make up for the phasing out of tax credits in 2023. Bloomberg BNEF predicts that wind energy will be the lowest-cost energy globally by 2030. BNEF calculated that the cost of wind and solar power generation would be less than the cost of constructing and running new fossil fuel-fired power stations. (Hawken, 2017).

The costs of electricity from fossil fuel-consuming power stations depend on estimates of future oil and gas prices but electricity generated from wind farms have zero fuel cost (Taylor, 2018). Wind is now the most economical energy source in numerous countries, such as Australia, China, and Turkey, to name a few (Andrews & Jelley, 2017).

Wind farms are sources of RE that cause no global warming or any pollution and give energy security. The electricity generated from wind farms does not involve air pollution-related deaths. Furthermore, generating electricity from wind cuts the amount of fossil fuels used and thus lowers CO_2 emissions (Taylor, 2018).

Wind energy development has a few adverse environmental issues. Wind farms are reported as loud by opposers of wind farms, but improvements in blade design have reduced the noise from currently available modern wind turbines. Another concern that has been raised is their electromagnetic interference with TV and military radar due to signal reflections from the blades. Changes to the visual appearance of the landscape have caused public discussions about wind farm constructions. The space that wind farms occupy has also been raised as an issue, but it should be noted that the land between turbines can be used for grazing or for growing crops. There are also some concerns about the possible impact on the natural ecosystem: especially on the likely impact on migratory birds (Andrews & Jelley, 2017; Taylor, 2018).

European utilities are increasingly under pressure as they grapple with the effects of the transition to low-carbon energy and RE. The Danish energy company Dong (Danish Oil and Natural Gas) has undergone one of the biggest transformations of any European energy company in recent years, selling its oil and gas assets, concentrating on RE and renamed itself Orsted. Furthermore, the company is selling its power grid and residential distribution businesses as it expands investment in offshore wind projects, accelerating its transition to RE (Hook, 2018b). In 2018, the company also acquired the US-based Lincoln Clean Energy, a developer of onshore wind projects. The US wind market, which is second-largest globally in terms of annual new installations, has fluctuated because of uncertainties over the production tax credit. Lincoln Clean Energy was the largest non-utility developer of wind projects in the US and has developed wind projects in California, New Jersey and Texas (Hook, 2018c).

4.5 Challenges for renewable energy technologies

Tumbling prices for solar and wind energy technologies and rapidly increasing expansion in these sectors do not mean that the RE industry will be able to outmaneuver the fossil fuel industry overnight, but perhaps, in a few decades. That is because the RE industry has to overcome some significant challenges. Intermittency has been recognised as one of the challenges. Solar and wind power are accessible to Nature's conditions; they are not always available (Heinberg & Fridley, 2016). While solar and wind can complement each other, there can be significant gaps in availability. Also, solar and wind are both variable in output (Andrews & Jelley, 2017). For example, the intensity of sunlight varies depending on latitude – the sunlight is more intense closer to the equator (Heinberg & Fridley, 2016). In addition to variability, solar- and wind-generated electricity is more diverse, ranging from centralised and utility-scale to small and distributed, for example, solar on rooftops (Hawken, 2017).

The other challenge the renewable industry faces is energy storage. Energy storage reduces generation costs during periods of peak demand and enables the grid controllers to manage with unexpected variations in electricity demand or sudden losses in electricity production capacity until alternative generating units can be brought into action (Andrews & Jelley, 2017). For electricity, the options most often discussed are: "Pumped storage", "Batteries", and "Hydrogen storage". The fact is that there are some alternative choices, and further research and development on these and other options and more are already in progress (Heinberg & Fridley, 2016).

Increasing amounts of wind and solar PV are requiring new ways of operating grids that will involve smart grids and more back-up supplies (Andrews & Jelley, 2017). Integrating electricity from renewable sources remains a matter of some concern at present and will need some redesigning of electric transmission and distribution. The 20th century electric transmission systems were constructed to supply electricity from centralised power stations, mostly powered by coal, to final consumers. The electricity (from RES) of the 21st century will be distinct. For supply to become entirely or predominantly renewable, the grid needs to become more flexible and adaptable than it is today: in other words, we need a "smart grid" (Hawken, 2017). The abundance of cheap digital communication technology in the 21st century has opened up the possibility of two-way communication between the electricity consumer and electricity provider (Andrews & Jelley, 2017). The term "smart grid" refers to a series of interconnected technologies whose aims are to obtain a greater mastery of what is going on the grid with the intention to minimise electricity usage in the course of peak hours and include grid energy storage. Both of them have the ability to combine more solar and wind. According to Heinberg & Fridley (2016), the primary components of a smart grid are made of "integrated communications, sensing and measurement devices (smart meters, high-speed sensors), devices to signal the current state of the grid, and better management and forecasting software."

Also, ‘super grids’ can help with smoothing out the variability of supply from wind and solar farms and with the variability of demand. The term ‘super grid’ refers to a large grid, connecting the electricity supply across several regions or countries. Super grids can also distribute electricity from renewable sources in regions where conditions are favorable (Andrews & Jelley, 2017).

Solar and wind have shown very positive growth in recent times and the outlook for them are very promising and there are more RES such as bioenergy (from biomass), geothermal energy, hydropower, tidal power, and wave power, which the thesis did not focus on. The economics and outlook for these RES also look very encouraging and in the medium to longer term, they will undoubtedly play a huge role in transforming today’s fossil fuel-dominated power system. According to Heinberg and Fridley (2016), “Another way to reduce the impact of energy source intermittency is to add redundant generation capacity.” When there is no Sun or wind, just turn on alternative RES, which can be turned off whenever there is plentiful sunlight or wind. (Heinberg & Fridley, 2016). There are many different forms of RES. Different RES will have distinct desirable benefits consequently, a combination of RES will be required (Tietenberg & Lewis, 2015).

Corporate purchases of renewable electricity have recently soared and tech companies are racing to build their renewables portfolios to keep pace with rapidly growing electricity demand in the US. According to the latest figures from Business Renewables Center, corporate buyers in the US have purchased a total of 4.96 GW of RE as of October 2018 and the figure is expected to hit around 5 GW by December of 2018 (Business Renewables Center, 2018).

Alphabet (Google) bought enough RE in 2017 to match the needs of all of its data centers and global operations. Alphabet’s energy purchase contracts had resulted in more than $3bn of investment in wind and solar farms globally and the company has secured 3 GW of RE, making it the biggest corporate buyer of renewable power in the US, and according to BNEF, with Amazon and Apple second and third. Facebook plans to cover 100 per cent of its electricity use with RE purchases by the end of 2020, joining Citigroup and Ikea in setting that deadline for achieving its goal. In 2017, Facebook covered 51 per cent of its electricity usage by renewables. To guarantee reliable power, Facebook has signed ‘green tariff’ deals with local utilities, on the understanding that they will support new solar, wind and hydropower capacity (Crooks, 2018g; Hook, 2018a).

If there was ever any doubt that high-temperature heat for industrial processes - making of steel, cement, aluminum – pose the highest substitution hurdle for 100 per cent RES or electrifying high-temperature industrial processes are economically inefficient, then that uncertainty is also covered now. According to data from IPCC, the industrial sector is responsible for more than a fifth of global GHG emissions and the sector has struggled to reduce its emissions. Tech companies are not the only buyers of renewable power. The trend has now spread to heavy carbon-intensive industries. The Overturinen wind farm being built in the forests of central Sweden is a good example. The purpose of the wind farm is to supply power to the aluminum smelters of Norsk Hydro: the wind farm will sell power into the electric grid, which will then supply the aluminum smelters on the west coast of Norway. Other industrial sectors are beginning to make a similar move. Acwa Power, the Saudi Arabian power company, has started a wind project in Morocco that will supply electricity to three cement kilns. The cement-wind deal was driven by the low cost of energy produced by renewables. These underline that electrification of energy-intensive industries are now on the agenda and they no longer have to depend on fossil fuels in the future (Pooler & Hook, 2018).

According to the latest estimates published by the investment bank Lazard, in many parts of the US, the cost of new-build wind and solar power generation has fallen below the cost of running coal-fired plants. The calculations show that it can be profitable for US utility generation companies to close down working coal plants and replace their output with RES such as wind and solar. In the US, for example, the levelised cost of electricity from a new-build onshore wind farm is $29 – $56 per MWh, before any subsidies such as the US federal tax subsidies. The marginal cost of operating a coal plant is $27 – $45 per MWh. Add in the US federal tax subsidies, which can cut the the levelised cost of electricity from a new-build onshore wind farm to as little as $14 per MWh (Lazard, 2018).

5 POLITICS OF CLIMATE CHANGE

Climate change is a unique environmental concern for two reasons. It is a global externality created by people in the world in their daily actions, particularly the burning of fossil fuels; and it damages the future, exerting influence on the Earth and its inhabitants and natural systems for decades into the future (Nordhaus, 2013). Our remedy to climate change can be divided into three strategies: adaptation, mitigation, and geoengineering. This thesis will only focus on adaptation and mitigation.

5.1 Adaptation and mitigation strategies

Adaptation means responding to the catastrophic impacts of climate change - in other words, learning to live climate change. For example, if global warming contributes to sea level rise, an adaptive answer would be to build seawalls or relocate. For a long time, communities have embraced climate variability and change, for example, constructing dikes against floods in the Netherlands. ‘Planned adaptation’ in preparation for anticipated climate change is now happening. In the Netherlands, for example, there are floating and amphibious homes - the two methods the Dutch are using to fight against the threat of flooding.

There are several advantages and disadvantages to being dependent on adaptation as the main strategy to climate change.

Dessler (2016) notes the advantages of adaptation: since many of the perilous and destructive environmental effects of climate change will take place later in the century, adaptation permits us to hold back for a period of years before we go ahead adapting – in other words, it permits us to work out uncertainty on how climate will change and focus our efforts on the harmful impacts; Future generations will be wealthier than we are and more advantageous to support the costs of adaptation; Many of the adaptations needed to be done, will at the same instant be beneficial to society in other ways; Of all of the possible responses, adaptation involves the minimum obtrusion of government into the private lives of individual citizens.

However, Dessler (2016) criticizes that some of these advantages are mostly misleading. For example, delaying action until the effects of global warming are noticeable is considerably costly than adapting ahead in time. Furthermore, adaptation can be an entirely local solution, is widely untrue. Most individual communities cannot afford to build a sea wall and thus significant adaptation efforts need national governments or international institutions to provide funding.

Because adaptation needs a large number of resources and besides the impacts of climate change are most strongly faced by the poorest and most vulnerable, relying heavily on adaptation as our response is debatable. Consequently, the adaptation strategy is often seen as morally questionable as it leaves out the poorest inhabitants to the destructive environmental effects of climate change that they did not contribute.

Some future climate change is inescapable due to lags in the climate system and this warming cannot be stopped, we must adapt to it. For example, if heat waves become more common, people can install air conditioning. Adaptation is likely to be an essential and effective part of the portfolio of actions to lower the effects of climate change. It is a compliment not a substitute for mitigation.

According to Nordhaus (2013) adaptation denotes the adjustments that human or natural systems make in response to changes in environmental conditions. In some situations, adaptation might reduce the impacts of climate change to nothing. In other cases, adaptation may accomplish very little. Chapter two of the thesis has already covered what impacts of climate change can and cannot be managed.

Some adaptations happen without human involvement, for example, a species move to a friendlier environment in response to varying climate. In agriculture, adaptations occur with human assistance. Short-run adaptations by farmers include adjusting sowing and harvesting dates, changing crops and seeds, and altering production techniques. Long-run adaptations include abandoning infertile lands and moving to new ones, planting new varieties of seeds that are drought and heat resistant, building a water-efficient irrigation system and shifting land to other uses (Nordhaus, 2013).

In other areas, such as ocean acidification, melting of big ice sheets, sea-level rise, and threatened species and ecosystems, the necessary adaptations are very expensive or impossible. Therefore, adaptation is an insufficient answer to unmanageable systems. Particularly in areas that are managed by humans, such as agriculture and health care, adaptation can remove many of the impacts of climate change. But as we have seen, there are serious limitations to adaptation. The only sure way to avoid damaging impacts of climate change is to reduce CO_2 and other GHG concentrations (Metz, 2010; Nordhaus, 2013).

Mitigation denotes cutbacks in the production and discharge of GHGs, by that means stopping the impacts of climate change by fending off the climate from changing in the beginning. This is achieved by cutting emissions of GHGs, generally through policies that influence the transition from fossil fuels to RES.

It is important to make clear the size of the required reductions. The new report by the IPCC set the world a clear target: we must reduce emissions of GHGs to net zero (meaning, any remaining emissions would need to be sucked out of the atmosphere) by 2050 to have a fairly good prospect of restricting global warming to 1.5°C. The report recognises that the world is on course to go past the goals of the Paris agreement and heat up by 3°C by 2100. By contrast, a path that would prevent a rise of much more than 1.5°C would require CO_2 emissions to fall by about 50 per cent between now and 2030, and reach net zero emissions by 2050 (Stern, 2018). The IPCC report comes at a time when global carbon emissions have started to rise (Hook, 2018e). According to the annual UN Environment 'Emissions Gap Report 2018', global CO_2 emissions went up by 1.2 percent in 2017, after a three-year period of stabilisation (UN Environment Programme, 2018). At present human actions are releasing around 42bn tons of CO_2 every year and at that rate carbon budget (the accumulative quantity of CO_2 emissions officially allowed during the time to remain within a defined temperature threshold) would be exhausted within 20 years (Stern, 2018).

The factors that control emissions are the world's population, the world's consumption of goods and services, and GHG intensity. GHG intensity is equal to the energy intensity times the carbon intensity. Neither the world's population nor consumption has any chance of being reduced. So, it is the GHG intensity, in particular, the carbon intensity must be reduced in order to reduce emissions.

The carbon intensity reflects the technologies the society uses to generate electricity. Dessler (2016) explains that reducing carbon intensity is code for switching from the burning of fossil fuels to sources that do not emit GHGs – often referred to as carbon-free energy sources. Therefore, the key question of how to mitigate climate change is truly a question of how to persuade humanity to move off from fossil fuels to RES.

Chapter two of the thesis has explored in detail the policy options that governments can use to reduce GHG emissions. Carbon taxes, carbon trading and regulations are three mitigation policy instruments commonly recommended by economists and policymakers and currently used to control GHGs. The arguments for using market mechanisms rather than conventional ‘command and control’ regulation are almost entirely independent of the basis on which decisions are made about how much pollution control should be achieved. The one obvious exception is where the decision has been taken to cut emissions zero; in that case, an outright ban clearly makes the most sense, and there is little merit to thinking about taxes or trading alternatives (Smith, 2011).

Mitigation efforts at first will make a small impact on the climate due to the long lifetime of CO_2 but an effective mitigation scheme would enable us to prevent catastrophic climate changes. There are several alternatives for reducing GHGs. Chapters two, three and four of the thesis have looked into them in detail. Some technologies to reduce carbon intensity are achievable today such as fuel switching or gas-fuelled electricity plants. Others have not yet realised enough to make a commercial debut (at industrial scale) in the near term such as CCS technology (Dessler, 2016).

A realistic target threshold temperature for long-term climate policy would involve balancing greenhouse abatement costs (the costs of cutting the level of GHG emissions beyond the current level in order to slow future global warming) and greenhouse damage costs (the cost of not reducing GHG emissions beyond the current level). The trade-off between these two costs is fairly obvious since a higher abatement cost (an investment by current generation to future generations for projects that are intended to reduce GHG emissions) would be expected to cause a lower damage cost, and a lower abatement cost would have the opposite effect (Hussen, 2013).

The Global Commission on the Economy and Climate is calling for a price of \$40 – \$80 a tonne on CO_2 emissions by 2020. The commission is formed of business leaders and politicians. The commission also warns the world is not making enough progress in reducing GHG emissions to achieve the goals agreed at Paris climate summit (Crooks, 2018c). Currently the price of carbon allowances or credits in the EU’s ETS – introduced by the EU to curb pollution by companies in the trading area - is around €20 – €25.

5.2 Kyoto, Paris and other international environmental agreements

Climate change first made its entry into the international arena in treaty terms at the Rio Summit in 1992, with the UNFCCC. Its goal is to stabilise GHG concentrations in the atmosphere that would stop hazardous human-generated intervention with the climate system. The UNFCCC officially came into action on 21 March 1994. The UNFCCC held no binding agreements, except on reporting their current and projected emissions, and ‘the parties’, have been meeting annually at the COPs at which they would set targets and make commitments. The notable COPs was the one that took place in Kyoto in 1997, and which gave rise to the Kyoto Protocol (Maslin, 2014; Dobson, 2016).

A degree of a scientific agreement had been reached through the first IPCC report on 1990 – what was lacking was a policy response from governments (Dobson, 2016). The IPCC was founded in 1988 and the role of the IPCC has been to periodically assess the shape of climate science as a basis for intelligent policy actions. These assessments are done based on experts' peer-reviewed and published scientific literature (Hussen, 2013). The IPCC has until now published five assessment reports and the reports are broadly acknowledged by governments and the evidence in those reports are used in the climate change negotiations (Dobson, 2016).

Unlike the UNFCCC's nonbinding emissions reductions, the Kyoto Protocol required emissions from participating industrialised (high-income) countries, pledging to a small objective of cutting emissions by 5 per cent during 2008 – 2012, relative to 1990 levels (FitzRoy & Papyrakis, 2016). Developing countries had no emissions reduction requirements. The Kyoto Protocol formally came to a legally binding treaty on 16 February 2005 (Dessler, 2016). The Protocol incorporated several provisions to allow flexibility in how countries met their emission limits. Emissions-reduction obligations could also be exchanged between countries through various mechanisms. Kyoto set important standards by separating between Annex 1 (developed) and non-Annex 1 (developing) countries, placing the responsibility to act on Annex 1 countries and by developing the concept of common but differentiated responsibilities – it means, all countries must participate in solving the climate change problem but not necessarily the same way. It established three market-based mechanisms for reducing emissions: a trading regime allowing Annex 1 countries to buy and sell emission credits among themselves; a Joint Implementation method by which Annex 1 countries could implement carbon savings in other Annex 1 countries in exchange for emission credits; and a Clean Development Mechanism whereby Annex 1 countries get emission credits by funding carbon-saving projects in developing countries (Dessler, 2016; Dobson, 2016). The Kyoto Protocol reflected a more top-down approach (defining particular policies and measures that countries must undertake). Although it gave parties flexibility in deciding how to implement their emissions targets, the targets themselves were internationally negotiated rather than nationally determined (Bodansky, Brunnee, & Rajamani, 2017).

Barrett (2013) states a persuasive worldwide treaty for climate mitigation must do three things: "it must get countries to participate; it must get participants to comply; it must get countries to participate in and to comply with an agreement in which global emissions are to be reduced substantially." Barrett (2013) said that the Kyoto Protocol did not do the three things.

In 2001, the Protocol suffered a massive blow when the US pulled out. The former US president George W Bush said implementation of the treaty would seriously harm the US economy: because the Protocol does not require developing countries such as China and India – two of the world's biggest producer of GHGs – to commit to emissions reductions. Kyoto failed to reduce emissions substantially and it expired at the end of 2012.

In 2015, the world community came together in Paris in order to build a global response to climate change. The adoption of the Paris Agreement was a historic moment globally. An agreement to curb the increase in global average temperature to less than 2°C by 2050 was reached in Paris. After years of talks, all 197 countries agreed to keep global temperatures "well below" 2°C and "to pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels". The Paris Agreement pulls together all the world's nations in a single arrangement on tackling climate change. On 4 November 2016, it entered into force. As of this date, 181 countries have ratified the Paris Agreement (UNFCCC, 2017).

The key measures in the Paris Agreement are:

- To keep global average temperature rise below 2°C and to continue with efforts to curb it to 1.5°C,
- To cut the volume of GHGs released by human action to the same levels that the natural world can normally soak up, and achieve a balance in the second half of this century,
- To evaluate every country's input into curbing emissions every five years,
- For rich nations to support poorer countries by offering $100 billion a year in climate finances to adapt to climate change and switch to RE (Briggs, 2017).

Only some elements of the Agreement will be legally binding such as presenting emissions cutting target and the frequent evaluation of that target. Every nation will lay down its individual emissions target, starting in 2020 when the Paris agreement takes effect and then choose a fresh target for reductions every five years. Some aspects will not be legally binding. The national targets by nations to limit emission are optional (Briggs, 2017).

The Paris agreement reflects a hybrid architecture, containing both bottom-up (allowing each participating state to define its commitments) and top-down elements. The bottom-up element comprises the nationally determined contributions (NDCs) of parties. The top-down elements comprise the five-year cycles of global inventory to evaluate common progression toward permanent goals (Bodansky, Brunnee, & Rajamani, 2017).

The latest of the UN's annual climate summit, known as COP 24, in Katowice signatories to the Paris climate pact agreed on a single set of rules to regulate how all countries report emissions, replacing former design that had different rules for developed and developing countries. The rule book will regulate how countries' GHG emissions are reported, monitored and verified by the UN (UNFCCC, 2018).

The latest IPCC report was clear that if today's national climate policies or pledges by governments that were tabled before the Paris agreement in 2015 continued, the global average temperature would be closer to 3°C by 2100. However, the report recognises that curbing global warming to 1.5°C or well below 2°C could still be technically feasible if there is strong political will, leadership and immediate response from governments. Temperatures can be stabilised only when net global carbon emissions fall to zero (Stern, 2018; Intergovernmental Panel on Climate Change, 2018). Governments can make policies that influence what companies and individuals can do to curb the global temperature rise to 1.5°C.

5.3 EU climate change policies

The EU has emerged as one of the leading advocates for reducing emission targets and already has some of the most ambitious carbon emission reduction targets in the world. The climate and energy policy in the EU is characterised by several targets and pricing and regulatory instruments. They consist of the so-called 20-20-20 targets: a 20 per cent reduction in the EU GHG emissions relative to 1990 levels, a 20 per cent share of renewables, and a 20 per cent improvement in the EU's energy efficiency (Schenker & Löschel, 2017).

Between 1990 and 2017, the EU has cut carbon emissions by 22 per cent and has pledged to curb emissions by 40 per cent by 2030. However, the EU's climate action and energy commissioner is pressing member states to follow a new set of carbon reduction targets. Under the new target, the EU would increase its carbon emissions reduction target to 45 per cent by 2030, up from the current target of 40 per cent, relative to 1990 levels. Also, with new legislation, at least half of the EU's electricity will come from renewable sources by 2030. Reaching the new energy and climate change targets would require a mixture of public and private investment of €379bn a year between 2021 and 2030, as well as a 50 per cent increase in the amount of new renewables installed each year (Toplensky & Hook, 2018).

In 2016, 17 per cent of the EU's final consumption of energy came from renewable sources. The EU's aim is to secure 20 per cent of the energy in the final consumption of energy from renewable sources by 2020 (Eurostat, 2018). In June 2018, the EU raised its target for the amount of energy it consumes from renewable sources to 32 per cent by 2030, up from the previous target of 27 per cent (Vaughan, 2018b).

Almost a quarter of the EU's carbon emissions comes from transport. Transport is the only sector in which GHG emissions are still higher than they were in 1990. The EU has pledged to the Paris Agreement to reduce its GHG emissions by 40 per cent by 2030. In 2018, the EC announced plans to set standards for CO_2 emissions from lorries, buses and coaches (known as heavy-duty vehicles (hereinafter: HDVs)) in the EU for the first time. The EC proposed an interim CO_2 emission reduction target of 15 per cent by 2025 for all HDVs compared to 2019 levels. By 2030, HDVs will have to emit 30 per cent less CO_2

than 2019. Canada, China, Japan and the US already have emissions standards for HDVs (Toplensky, 2018).

In 2017, the EC also published proposals aimed at reducing CO_2 emissions for cars and vans for the period after 2020 to fight global warming and air pollution. In 2018, the EU governments and the European Parliament reached a deal that would aim to reduce CO_2 emissions from new cars by 37.5 per cent by 2030 compared with the 2021 limit. Under the agreement cars will have to emit 15 per cent less CO_2 by 2025 compared with 2021 levels (Stearns, 2018) and carmakers that miss the targets will face penalties (Campbell, 2018b). From 2021, carmakers in the EU will have to make sure that across their fleets, average CO_2 output is no higher than 95 grams of CO_2 per kilometer – down from 130g/km in 2015. Such aggressive emission targets will transform carmakers to accelerate plans around electrification. The problem is that emissions regulations are getting much tighter. The only option for carmakers is to scale up fully electric and hybrid cars' output in the wake of the new EU emissions targets.

Also, the European Commission's recently proposed strict rules to prevent climate change from causing catastrophic economic damage are set to be imposed on asset managers, pension funds and insurance companies. Investment managers will have to examine the effect that climate change could have on their investment portfolios and reveal how future returns may be influenced by climate change. Environment risks are widely mispriced across Europe's energy, transport and agriculture sectors. This proposal is planned as the basis of a European single market for sustainable investment (Flood, 2018).

However, the current EU policies are not enough to encounter the temperature targets of the Paris Agreement and the EU's new climate strategy roadmap indicates that new policies in line with 1.5°C of global warming would be about twice as costly as policies in line with 2°C of warming. Lowering carbon emissions to net zero by 2050 in line with the recent IPCC report would require up to €290bn a year in additional investment in energy infrastructure in Europe (Hook & Toplensky, 2018, p. 4).

6 CASE STUDIES

By studying climate change policies of Germany and Norway, the thesis will try to understand how our dependence on fossil fuels, resulting in global warming can be remedied through more promising policy interventions by governments.

6.1 Germany

Germany, a country unknown for its sunny climate, is a champion in solar energy (Schwarz, 2018). The solar boom in Germany, driven by regulatory measures and generous public support scheme, saw the country emerge as the solar leader in the early part of the

2010s. As part of the government's Energiewende initiative, Germany has been committed to supporting renewables: the government of Germany is trying to move away from fossil fuels and nuclear power to a clean alternative by 2050. Germany's climate targets have been upheld by every German government since 2007. Germany's determined energy transition intends for at least 80 per cent of the country's gross power consumption to come from renewables and it has pledged to reduce its GHG emissions up to 95 per cent by 2050 relative to 1990. Since 1990, GHG emissions have fallen 28 per cent. The vast majority of that reduction came as a result of the failure of East German industry after reunification. Germany aims to lower carbon emissions by 55 per cent by 2030, relative to 1990 (Buck, 2018). In 2011, Germany announced that it intends to close down all its nuclear power stations by 2022 (Schwarz, 2018).

The Energiewende has led to a substantial increase in the number of wind and solar plants across Germany, raising renewables from 6 per cent of total power generation in 2000 to 36 per cent in 2017 (Buck, 2018). In Germany, the German Renewable Energy Sources Act passed in 2000 introduced a large-scale Feed-in Tariff system (the owner of the installation could sell solar power to a utility) that proved extremely effective at stimulating a range of renewable energies and successfully completing the "100,000 Roofs Programme" (Zhao, Wang, & Zhang, 2018). In 2004, the PV tariffs were adjusted to make up for the end of the German 100,000 Roofs Programme, offering payback periods of about 8 – 10 years. It gave rise to an explosive growth of solar PV deployment: a large amount of PV panels were mounted on domestic and commercial buildings, farmers erected PV on farm buildings and in farmlands and a large number of PV power plants were authorised (Fthenakis & Lynn, 2018). Germany's generous policy support would make it the world's largest solar market and almost singlehandedly fund the global PV manufacturing industry's growth. By 2010, Germany made up almost half of the global market for solar deployment (Sivaram, 2018). In 2011, 14 per cent of Germany's energy came from renewable sources that have been accredited to the success of its comprehensive feed-in tariff system. Germany's experience in promoting PV deployment from the aspects of policymaking, management, and technologies has been the model for several other countries (Zhao, Wang, & Zhang, 2018).

Germany's distinctive renewables subsidy scheme let out a stream of private investment: according to data from BNEF, investors have contributed more than $250bn into the German renewables sector in the past decade. The major part of the private investment has come from funds, co-operatives and individual owners of homes and land. The growth of renewables in Germany has surpassed the initial forecasts, the cost of wind and solar has fallen drastically and Germans have also become better at devising an energy market that functions. The cost of that press has been monumental. Subsidies directed at increasing the use of renewables have accounted for around €200bn so far, with another €200bn allocated for the years in the future (Buck, 2018).

Feed-in tariffs (a policy mechanism designed to accelerate investment in RE technologies) particularly have been key to promoting the distribution of solar power, and in 2015, they were the most well-liked policy instrument to support RE in the world. But around the world, countries are changing feed-in tariffs with reverse auctions, in which solar developers bid against one another to offer the lowest price for which they will agree to sell solar power for the next fifteen to twenty years. Even Germany, which pioneered feed-in tariffs, has switched to reverse auctions (Sivaram, 2018).

In 2016, there were sufficient solar PV panels to provide a quarter of Germany's power if all the panels generated at full output synchronously. But considering the number of hours during the day when solar produces little or no power, solar panels accounted for 7 per cent of Germany's annual electricity. German politicians envision that the share of electricity generated by solar PV will increase to 30 per cent by mid-century. That increase would lead to huge swings in the instant power supply to the grid whenever clouds happen to roll in. To make up for the rise in fluctuating RE, Germany has set up a fleet of expensive stand-in plants to keep grid reliability. In the next few years, consumers will pay more as Germany spends $20 billion in setting up transmission lines, upgrading local distribution grids, and installing smart grid technology, to accommodate more RE.

A report by the Fraunhofer research institute said Energiewende could inflict additional costs of as much as €30bn a year up to 2050. One challenge is Germany's power grid: much of RE is produced in the windier north – far from the energy-consuming industrial stronghold in the south. Constructing new power infrastructure to connect the two will need around €80bn (Buck, 2018).

In standard practice, a solar developer signs a power-purchase agreement contract with an electric utility or an industrial power user. Under this contract, the electric utility agrees to buy power from the solar developer at an agreed-upon price for many years. The solar developer profits from the guarantee of cash flows, and the guarantee also makes it easier to increase capital from investors to pay for the up-front bill. The electric utility benefits from locking in a long-term power price. To ditch the power-purchase agreement and operate a solar farm as a merchant plant, which sells its power at a price that varies every hour in the marketplace (known as the wholesale power market), is solar madness. The power-purchase agreement contract structure has protected solar from fluctuating power prices (Sivaram, 2018).

In Germany, rising levels of solar electricity have cut the bottom lines of fossil-powered sources rather than undercutting solar revenues. A 2016 study clearly concluded that the rise in RE is the largest driver of the plunge in wholesale power prices. Germany's wholesale power prices have fallen by two-thirds since 2008 as more RE has come online. This plunge is fatal for other power plants that depend on higher power prices to pay for fuel (coal and gas plants). But solar power is protected in the German power market by incentives that boost solar income even as revenues from wholesale power markets fall. As a result, German power utilities, which have traditionally owned fossil-fueled, have experienced major financial distress.

When there is an over-supply of solar and wind power, power prices sometimes even go negative. Germany's enormous investment in renewable electricity is beginning to throw up a few surprises – consumers are sometimes paid to use power. On the 1st of January 2018, Germany crossed a symbolic milestone for the first time: by briefly providing almost 100 percent of electricity use with renewables. For a short period of time on that day electricity prices dropped into negative territory, as RES supplied a large amount of electricity into the grid that supply surpassed demand. Such negative prices are not typical in Germany but they are infrequent, as a result of Germany's effort to encourage investments in low-carbon forms of power generation (Amelang, 2018).

To limit catastrophic climate change, the world is likely going to need solar power to provide at least a third of all electricity by 2050. Across a range of different assumptions, the most economical way to decarbonise the power sector is for solar power to contribute at least one-third of global electricity. A global target for solar to provide one-third of the electricity mix is roughly equal in percentage terms to Germany's 2050 target. Whereas Germany needs to quadruple its solar penetration to hit its target, the rest of the world would have to boost its solar penetration from below 2 per cent in 2016 to upward of 30 per cent by 2050 (Sivaram, 2018).

In Germany, decarbonisation is also happening in the transport sector. According to BNEF, Germany is on its way to becoming the world's third-largest market for battery electric and plug-in hybrid electric cars by 2018, surpassing long-time European leader Norway. The government has stepped up measures too: since 2016, buyers of electric cars get €4000 rebate, while owners of plug-ins hybrids get €3000 subsidy (Vaughan, 2018a). There is also a €300 million budget to boost the build-out of charging infrastructure. Even car makers are chipping in as part of their €40 billion splurges on electric technology budgeted for the next few years. Long-time rivals VW, BMW AG, Ford and Mercedes have come together and started construction of a fast-charging network along Europe's highways (Behrmann, 2018).

A government-appointed task force is set to release a plan on ending the use of lignite (brown coal) that accounts for around a quarter of electricity generated in Germany. The task force is made up of representatives of Germany's energy industry, politics and environmental groups, and its mandate is to ensure the country's energy sector meets its 2030 climate targets, that is, cutting GHG emissions by just over 60 per cent relative to 1990.

6.2 Norway

Nowadays, Norwegians are slowly turning away from fossil fuels and surely embracing an electric future. The Norwegian government has scheduled 2025 as the "target year" for all new cars to emit zero emissions. Norway will only allow selling of fully electric or plug-in hybrid cars by 2025. In other words, the government aims to end sales of petrol and diesel cars by 2025. Norway is one of the leading countries in the electrification of its transport sector. However, such boisterous acceptance of EVs by Norwegians is not all due to environmental concerns but something simpler – extremely generous subsidies and restrictions on fossil fuel vehicles. According to data from BNEF, as of June 2018, 47 per cent of all new cars sold were either plug-in hybrid or battery-powered EVs (World Economic Forum, 2018). It took Norway about a decade to reach 6 per cent EV sales but then only five years to go from 6 per cent to 47 per cent (Bloomberg, 2018c). In 2017, pure electric and hybrid cars accounted for 52 per cent of all new cars sales. While motorists are usually exposed to high levels of taxation, those who buy EVs in Norway are compensated by the government offering them with a generous amount of incentives and perks worth thousands of dollars a year as a way of achieving its climate change targets. EV owners do not pay road taxes, road tolls, ferry fees, city emission charges. They can park in public places and avoid congestion by driving in some bus lanes. Running costs are cheaper because electricity is cheaper than petrol and diesel. Importantly, Norway's EVs run on the nation's hydropower. So the source of electricity is clean. Buyers avoid heavy import duties or high purchase taxes and are free from 25 per cent value-added tax (VAT). EV owners can charge their cars for free in public places. Also, the world's fastest-charging stations, capable of charging up to 28 cars at a time in around half an hour, are in Norway (Jones H., 2018). Norway is the third-largest market for EVs in the world behind the USA and China. But with a population of just 5.35 million, Norway is by far the undisputed world leader with the highest market share for EVs by capita globally (Portvik & Christiansen, 2018).

According to BNEF, cumulative global EV sales hit 4 million in 2018. This includes fully electric cars and plug-in hybrid cars. Around a million EVs are sold every six months across the world and the number is growing fast (Bloomberg, 2018b). According to EV-volumes, there are more than one million EVs are in Europe and the cumulative total is expected to hit 1.35 million by the end of 2018 (EV-volumes, 2018). But there is a long way to go. Hybrid and EVs only make up around 1 per cent of the total market in Europe. Norway continued to lead the pack. However, EV growth is speeding up in Germany and it is set to overtake Norway by the end of the year for total sales (Vaughan, 2018a).

In Norway, 98 per cent of all electricity production comes from renewable sources. Hydropower is the source of most of the electricity production. Both wind and thermal energy are also instrumental in Norway's electricity generation. Norway produced 134 TWh of electricity in 2013. To put this number in perspective, Oslo consumes around 9 TWh each year. This puts Norway in a unique position: having flexibility in electricity generation makes it possible to both export and import power from neighboring countries. Norway and Sweden's grids have long been connected Norway's grid is also connected to Denmark and the Netherlands. There are proposed projects for electricity cables between Norway and Germany and also between Norway and the UK (Government.no, 2016).

Norway already has a number of laws aimed at cleaning up the air. For example, when pollution rises in Oslo, diesel cars are banned from the city's roads. Oslo, for example, aims to forbid all cars by 2019. Norway will also ban the use of heating oil, including gas oil, kerosene and paraffin to heat buildings (new and old buildings, private homes and businesses) as of January 1, 2020. Ministry of Climate and Environment is now considering additional measures which could include restrictions on the use of natural gas for heating (Bloomberg Environment, 2018). Norway ratified the Paris Agreement in June 2016. Under the Paris Agreement, Norway consented to cut GHG emissions by 40 per cent below 1990 emission levels by 2030. It hopes to eventually become a carbon-neutral nation by 2050, in quantitative terms, defined as a reduction in GHG emissions by 80-95 per cent below 1990 emission levels (The Climate Action Tracker, 2018).

Norway has been well known for its green endeavors and very active in promoting electric mobility solutions. The country has pledged that all of its short-haul flights will be on electric aircraft by 2040. Norway's terrain is mountainous, which means there are many short-haul flights and that air travel is more efficient. Its shortest flight route takes only 12 minutes, but the journey would take several hours in a car. Norway wants aircraft makers to launch a 25-to-30 seat electric aircraft with the first of them brought into service as early as 2025. According to consultants Roland Berger, aviation emissions could reach 10 per cent of the total by 2050. Norway's plan has attracted the interest of both Airbus and Zunum (Washington-based aircraft developer, partly financed by Boeing). Zunum has plans to bring a 12-seat short-haul hybrid electric aircraft to market by 2022 and a 50-seat aircraft with a range of 1000 miles by 2030. Avinor, Norway's state-run airport operator, which has been working on its electrification plans for the past three years, aims to be the first in the world to make the switch to electric air transport (Hollinger, 2018; Beale, 2018; Dowling, 2018).

Norway's airports are leading efforts to limit its growing carbon emissions. Avinor is putting emphasis on its determined attempt to actively support the mixing of biofuels with jet fuel. A special blend of jet fuel mixed with biofuels is already made available to all aircrafts at two of Norway's busiest airports, namely, Oslo and Bergen. Besides, in 2016 Oslo airport became the first airport to offer biofuels to all airlines (World Economic Forum, 2017a). Airport constructions aren't usually green nor environmentally responsible and resource-efficient but the new terminal expansion at the Oslo airport focused on obtaining environmentally friendly building materials and innovative energy efficient solutions to minimise the carbon footprint. The design of the building takes advantage of passive solar energy, natural lighting (sunlight) and natural thermal energy for heating in winter and coupled with the idea of superinsulation has helped the building achieve

PassivHaus standard. Also, in winter, snow is gathered and kept in a storage place, enveloped by sawdust for insulation. In summer, meltwater from the snow is put to use to air-condition the building, cutting down the amount of energy consumption during peak hours (Ros, 2017).

The Norwegian oil firm Statoil, has abandoned its name given to it almost 50 years ago, and taken up a new name, Equinor as it attempts to stretch out its influence beyond oil and gas production. The change came just a few months after Norway's $1tn sovereign wealth fund shocked the world in proposing to divest all of its oil and gas stocks, arguing that given the country's overall exposure to oil, it did not make sense to tie up financial assets in the petroleum sector. Norway as a whole is also seeking to reduce its reliance on petroleum production (Bloomberg, 2018a).

Norway's sovereign wealth fund is the world's largest sovereign wealth fund and has put ethical issues and sustainable business practices at the core of what it does. In 2017, the Norwegian central bank recommended its government it should divest its shares in oil and gas companies. The Norwegian central bank made the proposal to get ahead of a debate they could see coming as investors around the world face pressure to adapt their portfolios to climate change. Although, a government-commissioned report in 2018 advised the government to stay invested in energy stocks and now Norway's parliament will make the final decision whether the world's largest sovereign wealth fund should divest or not. Norway's sovereign wealth fund on average owns 1.4 per cent of every listed company globally and 2.4 per cent of each European business on the stock market. The fund has major holdings in international energy companies, including $6.14bn in Shell, followed by billions of dollars invested in BP, Chevron, ExxonMobil, and Total. It has smaller stakes in the Italian oil firm Eni, the US oil firm ConocoPhillips and the US oil services group Schlumberger (Milne, 2018; Vaughan, 2018c). In 2015, Norway's parliament decided on ethical grounds to force the fund to divest any mining company or power producer that derived more than 30 per cent of its revenues or operations. The fund has barred more than 70 companies from its portfolio in line with the ethical guidelines. To help it secure more information on climate risks, the fund has developed its own proprietary tool: the tool gives the portfolio managers information on carbon emissions of the companies.

CONCLUSION

The future world will need a lot of energy. On the one hand, fossil fuels are what made the 20^{th} century possible but on the other hand, if we do not curb their impact, they risk destroying the future world. This thesis is not about trying to predict the exact moment of death of fossil fuels. This is because natural gas will have a role as a transition fuel in the medium-to-longer term. Switching from coal to gas reduces emissions fast. The shale renaissance in the US will add to global supplies: by 2022, the US will turn into an important LNG exporter. Natural gas will eventually squeeze oil out of the energy mix.

There are no simple and obvious formulas for hurrying the transition away from fossil fuels. Nevertheless, significant transformations are in progress for the global energy industry, from growing electrification to the expansion of renewables. Some clean energy technologies such as solar PV, offshore wind, EVs and battery storage have made immense headway in recent years, paving the way towards a low carbon future. The economics of energy are greatly shifting in favor of clean energy. The global energy industry (coal, oil and gas companies) is accountable for over 50 per cent of energy-related GHG emissions globally. Decarbonisation of the power sector, which accounts for about a quarter of global emissions, will define the success or failure of the low carbon future since it is fundamental to decarbonising heat, transport and industry. Stricter climate policies, pressure from institutional investors and the falling cost of renewables have sent coal into decline in most of the developed world and are pushing coal-fired electricity plants aside. Shifting electricity generation from coal to natural gas and other RES is one option for reducing GHG emissions. Falling cost of renewables is on course to construct new solar and wind farms more economical than keep going with current coal stations.

In the case of Germany, Germany’s determined energy transformation programme intends for at least 80 per cent of the country’s total power consumption to come from renewables by 2050. Germany, a country not known for its sunny climate, is a leader in solar energy. In 2000, Germany passed landmark legislation that offered substantial incentives for new solar installations and as a consequence, the country has been investing heavily in renewables. Germany’s pioneering renewables subsidy regime also released a flood of private investment. The government’s Energiewende initiative, coupled with feed-in tariffs will eventually force out fossil fuels. It shows that stricter local, regional and national government climate change policies, whether in the shape of government targets, government regulations, government subsidies for renewables, and guaranteed prices such as feed-in tariffs for producers of renewables, are needed in order to curb GHG emissions. Governments must develop policies and regulatory environments that change businesses' behavior.

More than half of oil demand comes from the transport sector, with more than a quarter from passenger cars alone. The energy industry is confronted by a serious challenge: whether to invest in oil at a time when climate change concerns could see oil demand peak sooner than expected and the adoption of EVs grows more rapidly. Big institutional investors believe that business models of global oil companies are on a path towards 3°C and that a continued push by governments to cut emissions to meet Paris agreement targets will trigger a transformation of these oil companies that would make a huge number of oil projects uneconomic. Driven by investor pressure, the big oil groups invest more capital into shorter-term projects, such as shale projects, as well as RE.

Wood Mackenzie has forecast that global oil demand will peak in 2036. Wood Mackenzie’s thinking was propelled by the impact of EVs and AEVs. According to BP, self-driving EVs will cause a revolution in transportation in the next two decades, prompting global oil demand to peak by 2040. BP says there will be around 300 million self-driving EVs by 2040, reducing private car ownership. Carmakers are racing to develop self-driving systems to enter the driverless ride-sharing segment that is expected to offset car ownership. Governments across the world are drawing up rules, in anticipation of the technology that is expected to disrupt businesses and transport over the coming decades. Emissions regulations are getting tighter in many key markets. As a result, a big push towards electrification is already underway. Traditional carmakers across the world are working to meet ever-tightening emissions regulations that enter into force in the EU in 2020 and pumping billions into electric technologies.

In the case of Norway, the government has announced an outright “ban” on combustion engines by the year 2025, signaling to the carmakers to move to zero emission vehicles. Norway’s dominance on EVs is the direct result of good government economic incentives, as a way of meeting its Paris climate targets. These policy measures are producing the desired effect - decarbonising Norway’s transport sector. Markets alone will not solve the climate change problem. We need local and national governments to work together on climate change policies. Across all regions and fuels, the selection of policy choices made by governments around the world will decide the shape of the energy system of the future. The EU has emerged as one of the leading advocates for reducing carbon emission targets in the world. The EU’s aggressive CO_2 emission targets will transform the auto industry. It will force all of the major car manufacturers to speed up plans around electrification and launch a variety of electric and hybrid cars in the coming years. These policy incentives are set out to persuade businesses to embrace technologies such as EVs, and energy efficient technologies.

According to the IPCC report, the governments of the world have just 12 years to take the necessary steps to curb global warming to the inevitable 1.5°C target and that emissions must fall by 45 per cent by 2030 to stand a chance of getting there. Institutional investors have an awesome power to decide where tens of trillions of dollars will be invested. Betting on coal, oil and gas is betting on a future of increased human suffering and economic losses. Shareholders must divest from the past and invest in the future, or they are clearly complicit in climate change and its impacts. Also, investors could do more, if they pushed governments into creating a policy that would bring certainty about how energy companies should operate.

To encourage the adoption of clean technologies, governments must provide subsidies to consumers who buy solar panels, wind turbines, and EVs. Different designs of feed-in tariffs and other renewable support policies must be implemented, in order to increase the share of renewables. Decision-makers outline economic incentives with the intention of persuading consumers to take on innovative technologies that cut environmental damages. Economic incentives may consist of price subsidies, rebates, tax credits, sales tax exemptions, and subsidised financing. Policymakers at various positions of governance - from national to international - must find ways and means of assisting adaptation and mitigation technologies in reply to climate change, as well as working out what economic policy instruments are fitting. Policymakers can do more to stimulate demand for RES: a lot more could be done through public-private partnerships to attract more capital to sustainable investment projects.

Due to geopolitics, in the short term oil prices may fluctuate but not in the medium and long term. Oil price volatility is a cyclical process: in the global energy industry, price volatility is often connected to supply and demand issues and it will unsettle major oil and gas companies. But what these companies should be concerned about is the long term threats that the industry will face in a couple of decades. As prices rise, so do the incentives for technical innovations. Firstly, high prices dent demand and they also motivate the search for alternative sources of supply. Current technological progress on a scale not seen in electricity generation, transport and other sectors is already transforming these sectors, with radical implications for big energy companies, OPEC and the rest of the producers. Secondly, when fossil fuels prices tumble, it is critical for governments to put creative incentives and economic policy instruments in place (for example, using the opportunity to increase the carbon price by a carbon tax or emissions trading).

Low-priced natural gas, RES, EVs and a joint attempt by international governments to tackle climate change show that the energy source of selection will be electricity. It is certain that heighten electrification is very likely to lead to disruption. Electricity will transform transport, the core of the current oil demand. Electricity will also transform heating and cooling. Big energy majors should weigh up a future where oil demand stops growing as the world moves towards cleaner fuels. Energy companies should seek to move their core businesses from fossil fuels to renewable sources of energy and the industry anticipate renewable electricity to grow a large amount of the world's energy mix during the next decades. The energy industry has to plough money into building natural gas businesses and renewables for cleaner power generation.

Holding climate change under control will demand a transition to renewables well before the depletable fossil fuels are completed. Eventually, our energy needs will have to be managed from RES because the environmental costs of burning fossil fuels will become costly in comparison with that of RES. Substitution of fossil fuels is needed to sustain humankind while mitigating environmental impacts and clean forms technologies (renewables) offer an effective way of achieving this goal. Technological developments in renewables will offer a range of technical solutions for improving energy efficiency. There is considerable technical potential for energy efficiency improvements from electricity generation, energy storage, electric grids and transportation. Given that by 2040 there could be a disruption in energy markets as renewables become cheaper than fossil fuels, it makes sense now to switch towards renewables.

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APPENDICES

Appendix 1: Povzetek (Summary in Slovene language)

Podnebne spremembe so globalne, dolgoročne in bolj negotove kot katera koli druga okoljska težava. To je ena od največjih težav 21. stoletja in številni menijo, da je to najresnejša okoljska težava, s katero se je človeška družba kadar koli spopadala.

Znanost je jasna – človeške dejavnosti vplivajo na podnebni sistem, tako da pripomorejo k povečanju globalnih povprečnih temperatur, obsežnemu taljenju snega in ledu ter k višanju povprečne globalne morske gladine (IPCC, 2007). Obstaja vse več znanstvenih dokazov, da globalno segrevanje povzročajo pretežno človeške dejavnosti, zlasti povečana uporaba fosilnih goriv od začetka industrijske revolucije (Hussen, 2013). Med znanstveniki, ki delujejo v okviru IPCC (Mednarodni panel za podnebne spremembe), obstaja soglasje, da se koncentracije toplogrednih plinov v ozračju povečujejo in da povzročajo dvig temperatur zaradi učinka 'tople grede', ki pa naj bi se povečeval zaradi emisij toplogrednih plinov človeškega izvora. Najbolj smiseln pristop za preprečevanje najhujših učinkov prihodnjih podnebnih sprememb bi bil zmanjšanje toplogrednih plinov (Pollin, 2015). Zaradi človeških dejavnosti se v ozračje vsako leto sprosti približno 42 milijard ton ogljikovega dioksida. Največji delež se sprosti zaradi zgorevanja fosilnih goriv in v industrijskih procesih, preostali delež pa je treba pripisati krčenju gozdov in drugim spremembam rabe tal (Juniper & Shuckburgh, 2017).

Praktično vse človeške dejavnosti zahtevajo zgorevanje fosilnih goriv, kar povzroča emisije ogljikovega dioksida v ozračje. Ogljikov dioksid spreminja podnebje Zemlje in ima posledično številne škodljive vplive (Nordhaus, 2013). Nastajanje toplogrednih plinov ne prizadeva le globalnega podnebnega sistema, temveč tudi povečuje kislost oceanov, posega v gozdove in druge ekosisteme, vpliva na kmetijske pridelke in škoduje zdravju ljudi. Te spremembe lahko resno posežejo v številne okoljske procese, gospodarske dejavnosti in zgrajene strukture, na katerih temelji človeška družba (Baker, 2016).

Od industrijske revolucije so človeške dejavnosti pripomogle k dodatnim emisijam toplogrednih plinov v ozračje. Glavni dejavnik, ki je prispeval k povečanim emisijam, je ogljikov dioksid, ki nastane pri zgorevanju fosilnih goriv. Stopnja emisij ogljikovega dioksida, ki jih povzroča zgorevanje fosilnih goriv na celotnem planetu, se je od leta 1950 izjemno povečala. Rezultat tega je bil, da se je koncentracija ogljikovega dioksida v ozračju povečala z 280 delcev na milijon (ppm) sredi 19. stoletja na 405 delcev leta 2017, poleg tega pa trenutno raste za približno 3 ppm na leto (Peake & Everett, 2018a).

Po konferenci pogodbenic v Parizu leta 2015 v okviru Združenih narodov se je skupaj 195 držav zavezalo, da bodo omejile svoje emisije toplogrednih plinov 'v skladu z ohranjanjem naraščanja povprečne globalne temperature krepko pod 2° C nad predindustrijskimi ravnmi in ob prizadevanju, da se naraščanje temperature omeji na 1,5°C nad predindustrijskimi ravnmi'(UNFCCC, 2015).

Znanstveniki novega poročila IPCC opozarjajo, da je svet na poti, da prekorači cilje Pariškega podnebnega sporazuma in se do konca stoletja segreje za 3 °C ter da bi se morale globalne neto emisije ogljikovega dioksida za ohranjanje povprečne globalne temperature pri 1,5°C do leta 2030 zmanjšati za 45 odstotkov glede na raven iz leta 2010 in do leta 2050 doseči neto ničlo (IPCC, 2018).

Podnebne spremembe že povzročajo škodo: velike poplave, suše, vročinski valovi in požari so po celem svetu vse pogostejši. V skladu z zadnjim poročilom Svetovne meteorološke organizacije je bilo 20 najbolj vročih dni zabeleženih v zadnjih 22 letih, pri čemer so bila štiri leta od 2015 do 2018 rekordna (Svetovna meteorološka organizacija, 2018). V skladu z zadnjim poročilom organizacije Christian Aid je deset dogodkov, ki so imeli največje finančne posledice zaradi podnebnih sprememb, zabeleženih v letu 2018, pri čemer je ob vsakem dogodku nastala več kot milijardna škoda, štirje dogodki pa so terjali vsak po več kot 7-milijardno škodo (Christian Aid, 2018).

Izziv, s katerim se spopada svet, je zagotoviti energijo, ki jo družbe potrebujejo za povečanje svojega življenjskega standarda, hkrati pa korenito zmanjšati našo odvisnost od fosilnih goriv. Občutno bomo morali povečati svoje zaloge obnovljivih virov energije, zlasti zaloge električne energije, cena obnovljivih virov energije pa mora postati nižja od energije, pridobljene iz fosilnih goriv. Obnovljiva energija naj bi bila način, da se lahko izognemo resnim škodljivim okoljskim vplivom zaradi zgorevanja fosilnih goriv (Maslin, 2014).

V številnih državah energija, ki je potrebna za transport, ogrevanje in elektriko, izvira pretežno iz fosilnih goriv. Vlade po vsem svetu so se kot odgovor na podnebne spremembe zavezale, da bodo zmanjšale svojo odvisnost od teh virov energije in da bodo povečale uporabo nizkoogljičnih virov energije (Devine-Wright, 2011). Med letoma 2010 in 2016 se je zelo povečal obseg različnih tehnologij obnovljivih virov energije: proizvodnja vetrne energije na svetovni ravni se je povečala za skoraj trikrat, proizvodnja fotovoltaične sončne energije pa za skoraj desetkrat (BP, 2018a). Širitev uporabe tehnologije obnovljivih virov energije v proizvodnji je prav tako občutno znižala stroške. Ta porast uporabe obnovljivih virov energije se bo verjetno nadaljevala, kar dodatno spodbujajo zaskrbljenost zaradi podnebnih sprememb ter posledice lokalnega onesnaženja zraka zaradi proizvodnje električne energije na premog na Kitajskem in v Indiji (Everett, Boyle, Scurlock, & Elliott, 2018).

Načrt v zvezi s podnebnimi spremembami (dekarbonizacija) in uvajanje novih tehnologij v celotnem energetskem sektorju, zlasti v proizvodnji električne energije – nove tehnologije za skladiščenje, prenos in distribucijo – ter hitro spreminjajoča se tehnologija na področju električnih vozil bodo sčasoma izrinili fosilna goriva (Helm, 2017).

Politiki po vsem svetu so zaradi vse večje zaskrbljenosti glede podnebnih sprememb na novo razmislili o emisijah toplogrednih plinov v svojih državah. Glavne politične možnosti za zmanjšanje emisij so dobro znane: davki na ogljik, s tem povezano trgovanje z dovoljenji za izpuščanje ogljikovega dioksida, predpisi, kot so omejitve emisij iz vozil ali uvajanje standardov ogrevanja, in subvencije za obnovljive vire energije.. Vsi ti ukrepi bodo zmanjšali povpraševanje po fosilnih gorivih. Vsaka oblika določanja cen za emisije ogljika bo povišala ceno goriva za končnega potrošnika, zato se bodo spodbujale naložbe v obnovljive vire energije. Prihodki od davkov na ogljik se lahko uporabijo tudi za subvencioniranje čiste tehnologije (FitzRoy & Papyrakis, 2016). Skupna značilnost teh politik je, da cilje zmanjšanja emisij toplogrednih plinov v gospodarstvu, kot običajno, postavljajo v nedoločeno prihodnost (Garnache, Merel, Lee, & Six, 2017). Trgovanje z emisijami je v številnih državah postalo temeljni kamen politik, povezanih s podnebnimi spremembami, in sicer z izvajanjem programov po načelu 'omeji in trguj'.

Da bi se povečal delež obnovljivih virov energije, so se v različnih državah začeli izvajati različni modeli tarif za dovajanje toka in druge politike za podpiranje obnovljivih virov energije. Obstaja široko politično in znanstveno soglasje, da morajo imeti obnovljivi viri energije pomembno vlogo na poti do nizkoogljičnih virov energije (Schenker & Löschel, 2017).

Proizvodnja električne energije se vse bolj obsežno preusmerja s fosilnih goriv na obnovljive vire energije. Nekatere čiste tehnologije, kot so fotovoltaična sončna energija, vetrne elektrarne na morju, električna vozila in baterijsko skladiščenje, so v zadnjih letih izjemno napredovale, s čimer utirajo pot proti nizkoogljični prihodnosti.

Svet prihodnosti bo potreboval veliko energije. Fosilna goriva so zaznamovala 20. stoletje in skušnjava, da bi to preteklost preslikavali na prihodnost in na leto 2050 gledali na nekoliko drugačno različico današnjega dne, je skrajno nesmiselna. Cilj te magistrske naloge ni predvideti natančnega trenutka smrti dobe fosilnih goriv. Zemeljski plin, ki je najčistejši med fosilnimi gorivi, bo namreč srednje- ali dolgoročno imel vlogo prehodnega goriva. S prehodom s premoga na plin se hitro zmanjšajo emisije. Revolucija skrilavca v ZDA bo dodatno prispevala k svetovnim zalogam: UZP postopoma postaja del globalnega gospodarskega okolja. V določenem trenutku bo plin naposled izpodrinil nafto iz obstoječega nabora virov energije.

Pri proizvodnji električne energije nastane največ emisij ogljikovega dioksida. Porast obnovljivih virov energije ter strožje politike v zvezi z onesnaževanjem zraka in podnebnimi spremembami izpodrivajo elektrarne na premog. Prehod s proizvodnje električne energije na premog na proizvodnjo električne energije na zemeljski plin in druge obnovljive vire je ena od možnosti za zmanjšanje emisij toplogrednih plinov. Strmo nižajoči se stroški obnovljivih virov energije bodo kmalu omogočili gradnjo novih parkov za pridobivanje vetrne in sončne energije, ki bo cenejša od gradnje obstoječih elektrarn na premog.

V ZDA elektrarnam na premog grozi zaprtje zaradi velikih zalog cenovno ugodnega zemeljskega plina, ki je postal razpoložljiv zaradi ameriškega razmaha pridobivanja plina iz skrilavca. Kitajska se zdaj gospodarstvo ponovno preusmerja stran od energetsko intenzivnih industrij ter postaja energetsko učinkovitejša in uporablja več obnovljivih virov energije. V zadnjih letih Kitajska izstopa med državami v razvoju po tem, da se bori proti gostemu smogu, ki je posledica elektrarn na premog. Kitajska strategija za prehod s premoga na zemeljski plin ima tudi pomemben vpliv na trge UZP.

Strožje podnebne politike in nižajoči se stroški obnovljivih virov energije so povzročili upad uporabe premoga v večini razvitega sveta. Nemčija je na primer priznala, da bo morala opustiti premog, če bo želela izpolniti svoja zelena prizadevanja. Nemčija si je zastavila ambiciozen cilj, da bo do leta 2050 vsaj 80 odstotkov njene skupne porabe električne energije izviralo iz obnovljivih virov energije. Ta država, ki ni ravno znana po sončnem podnebju, je vodilna po sončni energiji. Leta 2000 je Nemčija sprejela pomembno zakonodajo, ki je dala znatne spodbude za nove sončne obrate, posledično pa je ta država začela veliko vlagati v obnovljive vire energije. Nemški pionirski sistem subvencij je poleg tega sprožil poplavo zasebnih naložb. Nemški načrt v zvezi s podnebnimi spremembami (Energiewende) skupaj z modeli tarif za dovajanje toka bo sčasoma izpodrinil fosilna goriva. To samo kaže, da so za obvladovanje emisij toplogrednih plinov potrebne strožje politike lokalnih, regionalnih in nacionalnih vlad, bodisi v obliki vladnih ciljev, vladnih predpisov ali vladnih subvencij za obnovljive vire energije bodisi v obliki zajamčenih cen, kot so tarife za dovajanje toka za proizvajalce obnovljivih virov. Vse več evropskih in ameriških bank, pokojninskih skladov, zavarovalnic in drugih institucionalnih vlagateljev je napovedalo prepoved naložb v premog, da bi se podprli globalni napori za spopadanje s podnebnimi spremembami.

Več kot polovica povpraševanja po nafti izvira iz prevoznega sektorja, pri čemer več kot četrtino predstavljajo samo osebna vozila. Energetska industrija je pred resnim izzivom: ali naj vlaga v nafto v času, ko bi se lahko povpraševanje po nafti zaradi zaskrbljenosti spričo podnebnih sprememb ustavilo hitreje, kot je pričakovano, medtem ko vse bolj raste uporaba električnih vozil. Naftna industrija, ki je pod pritiskom vlagateljev, je večinoma prenehala vlagati v tako imenovane mega projekte. Vlagatelje skrbi, da bi lahko ukrepi za spopadanje z globalnim segrevanjem energetskim podjetjem povzročili velike izgube. Velike naftne korporacije vlagajo več kapitala v kratkoročnejše projekte, kot so projekti, povezani s skrilavcem in obnovljivo energijo. Večja energetska podjetja se spopadajo z resno grožnjo, ki jo predstavljata globalno opuščanje naložb v fosilna goriva in hitro šireče se gibanje za čisto energijo.

Wood Mackenzie je napovedal, da se bo globalno povpraševanje po nafti ustavilo leta 2036. Wood Mackenzie meni tako zaradi vpliva električnih vozil in samovozečih električnih vozil. Po navedbah družbe British Petroleum bodo samovozeča električna vozila v naslednjih dveh desetletjih povzročila revolucijo na področju prevoza, tako da naj bi se globalno povpraševanje po nafti ustavilo leta 2040. Družba British Petroleum navaja, da bo do leta 2040 na cestah po celem svetu 300 milijonov samovozečih električnih vozil, ki bodo upravljana kot del platforme za skupno uporabo vozil, podobno kot Uber, kar bo zmanjšalo število lastnih osebnih vozil. Proizvajalci vozil tekmujejo pri izdelavi samovozečih sistemov, da bi se prebili v segment skupne uporabe vozil brez voznika, ki naj bi po pričakovanjih nadomestil lastne avtomobile v velikih mestih. Številna avtomobilska podjetja so si prilastila delež v skupinah za skupno uporabo vozil, tako da poleg proizvodnje ponujajo prevozne storitve.

Vlade po vsem svetu oblikujejo pravila, ki bodo urejala delovanje samovozečih vozil, saj se pričakuje, da bo tehnologija v naslednjih desetletjih naredila preobrat v gospodarski dejavnosti in na področju prevoza. Predpisi o emisijah se poostrujejo na številnih ključnih trgih. Tradicionalni proizvajalci po vsem svetu si prizadevajo za izpolnitev vse strožjih predpisov, ki bodo začeli veljati v EU leta 2020 in ki bodo električni tehnologiji prinesli milijardne dobičke. Velika prizadevanja EU, da bi zmanjšala emisije ogljikovega dioksida, bodo spremenila avtomobilsko industrijo. To bo vse večje proizvajalce avtomobilov prisililo k pospešenemu uresničevanju načrtov v smeri elektrifikacije in hibridnih avtomobilov v prihodnjih letih. Namen teh političnih pobud je spodbuditi podjetja, da se preusmerijo k tehnologijam, kot so električna vozila in energetsko učinkovite tehnologije.

Na Norveškem je vlada napovedala popolno prepoved vozil, ki imajo motor z notranjim zgorevanjem, do leta 2025, s čimer je proizvajalcem avtomobilov dala jasen znak, da preidejo na vozila brez emisij. Norveška je vodilna na področju električnih vozil, saj jih je vlada podprla s širokim naborom izdatnih spodbud, da bi tako dosegla izpolnitev svojih ciljev podnebnih sprememb. Ti politični ukrepi so dosegli želeni učinek – dekarbonizacijo norveškega prevoznega sektorja. Norveška je nesporno v samem svetovnem vrhu z največjim tržnim deležem za električna vozila na prebivalca globalno. Sami trgi ne bodo rešili problema podnebnih sprememb. Odločanje o politikah za preprečevanje globalnega segrevanja morajo usklajevati in voditi nacionalne in lokalne vlade.

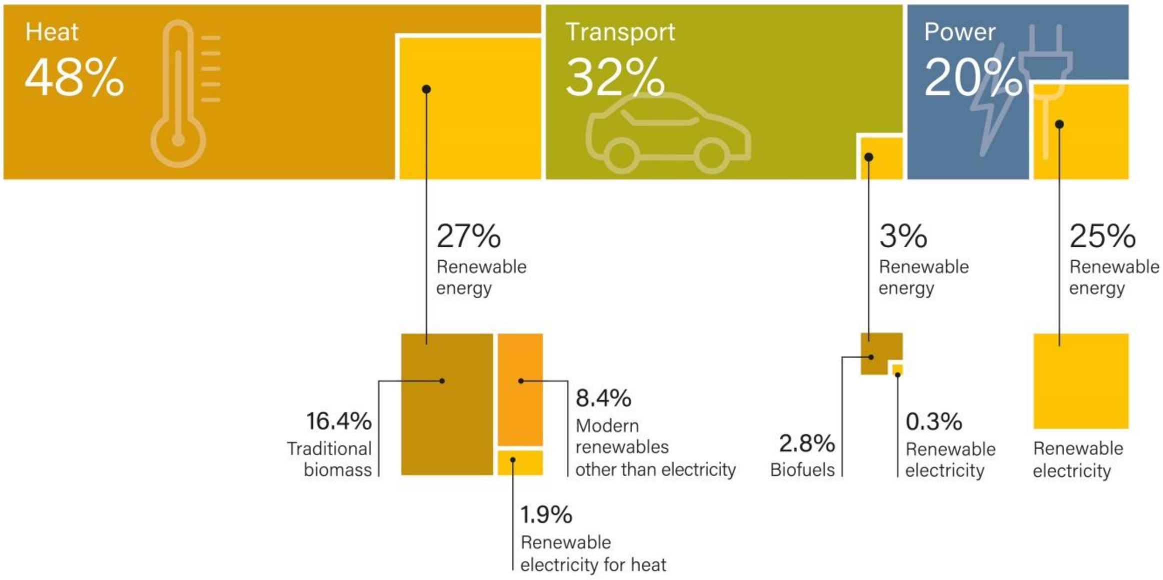
Vlade za spodbujanje prehoda na čiste energije zagotavljajo subvencije kupcem, ki se odločijo za sončne kolektorje, vetrne turbine in električna vozila. Za povečanje deleža obnovljivih virov energije so se v nekaterih državah začeli uporabljati različni modeli tarif za dovajanje toka. Oblikovalci politik snujejo javne spodbude, katerih cilj je kupce spodbuditi k odločitvi za inovativne tehnologije, ki zmanjšujejo okoljsko škodo. Take spodbude lahko vključujejo cenovne subvencije, rabate, davčne odbitke, oprostitve prometnega davka in subvencionirano financiranje. Sistem EU za trgovanje z emisijami je tržna politika, ki temelji na spodbudah. Višja cena ogljika bi morala zmanjšati emisije in verjetno spodbuditi prehod na čistejša goriva. Oblikovalci politik na različnih ravneh odločanja morajo najti načine za podpiranje tehnologij za prilagajanje in za zmanjševanje emisij kot odgovor na podnebne spremembe, poleg tega pa morajo določiti, kateri instrumenti gospodarske politike so ustrezni.

Zaradi geopolitike lahko cene nafte kratkoročno nihajo, vendar to ni mogoče srednje- ali dolgoročno. Nihanje cen bo vznemirilo večja naftna in plinska podjetja, ki si prizadevajo za znižanje stroškov in porabe. Proizvodnja skrilavca v US je trenutno šibka zaradi logističnih omejitev, vendar bi se morala proizvodnja skrilavca do leta 2019 povečati, tako da cena nafte ne bo več tako odločilna. Kakor koli, s tem ko cene rastejo, obenem rastejo tudi spodbude za tehnične inovacije. Prvič, visoke cene zmanjšujejo povpraševanje in hkrati spodbujajo iskanje alternativnih virov energije. Drugič, kadar cene fosilnih goriv padajo, je ključno, da vlade zagotovijo kreativne spodbude in uvedejo kreativne instrumente gospodarske politike (na primer, da to priložnost izkoristijo za zvišanje cene ogljika z davkom na ogljik ali trgujejo z emisijami).

V 21. stoletju bo vpliv nafte vse manjši. Cenovno ugoden zemeljski plin, porast obnovljivih virov energije, električna vozila in usklajeni napori za spopadanje z globalnim segrevanjem skupaj pomenijo, da bo izbrani vir energije elektrika. Jasno je, da bo povečevanje elektrifikacije povzročilo preobrat. Električna energija bo spremenila področje transporta, na katerem je največ povpraševanja po nafti. Električna energija bo spremenila tudi segrevanje in ohlajanje. Velika energetska podjetja poskušajo svoje osnovne dejavnosti preusmeriti s fosilnih goriv na obnovljive vire energije ter pričakujejo, da bo proizvodnja električne energije z nizkimi emisijami ogljikovega dioksida v naslednjih nekaj desetletjih zavzela veliko večji delež svetovnega nabora virov energije. Ta podjetja so že izvedla velike naložbe v vzpostavitev podjetij za proizvodnjo zemeljskega plina in obnovljivih virov energije za čistejšo proizvodnjo električne energije.

Sčasoma bo treba naše energetske potrebe pokriti z obnovljivimi viri energije, saj je okoljska cena zaradi uporabe fosilnih goriv postala previsoka v primerjavi z obnovljivimi viri. Nadomestitev fosilnih goriv je potrebna za zadostitev energetskim potrebam človeštva in hkrati ublažitev okoljskih vplivov, pri čemer čiste tehnologije ponujajo učinkovit način za doseganje tega cilja. Tehnološki razvoj na področju obnovljivih virov energije ponuja in bo ponujal širok nabor tehničnih rešitev za izboljšanje energetske učinkovitosti. Obstaja precejšen tehnični potencial za izboljšanje energetske učinkovitosti na področju proizvodnje električne energije, njenega skladiščenja, električnih omrežij in prevoza. Ker bi lahko do leta 2040 prišlo do preobrata na energetskih trgih, saj obnovljivi viri energije postajajo cenejši od fosilnih goriv, je smiselno zdaj preiti na obnovljive vire energije.

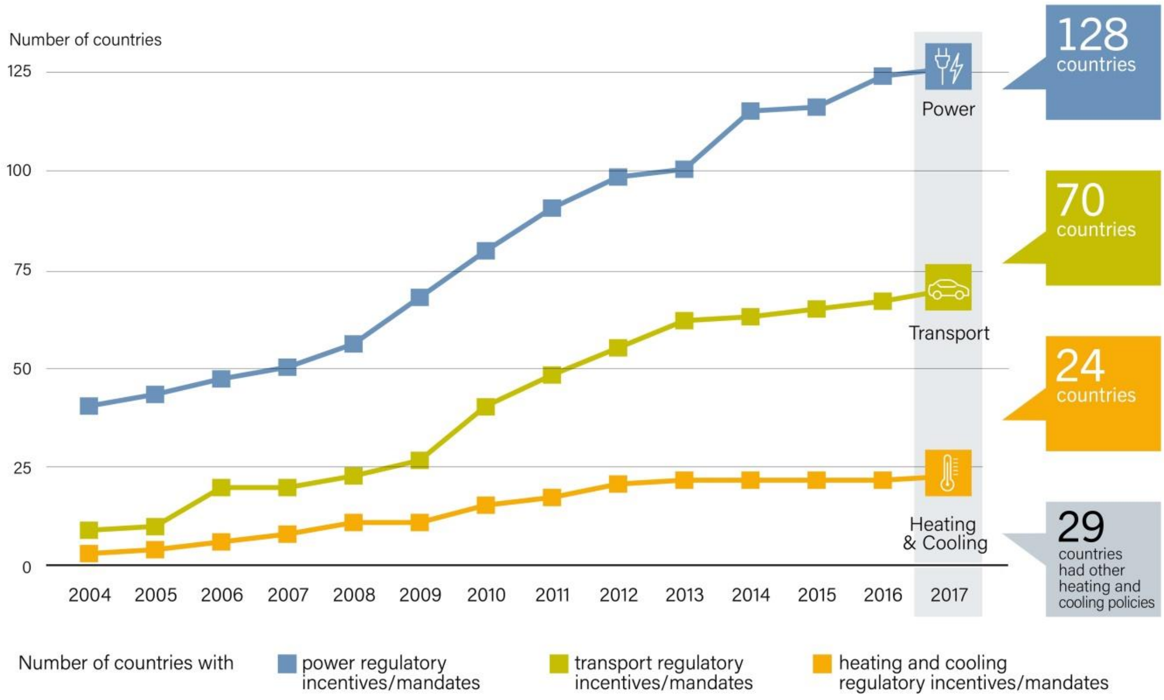
Appendix 2: Renewable energy in total final energy consumption, by sector, 2015



Source: (REN 21, 2018)

Since 2015, heating and cooling made up 48 per cent of total final energy consumption; transport accounted for 32 per cent; power (electricity) consumption represented 20 per cent (REN 21, 2018).

Appendix 3: Number of countries with renewable energy regulatory policies



Source: (REN 21, 2018)

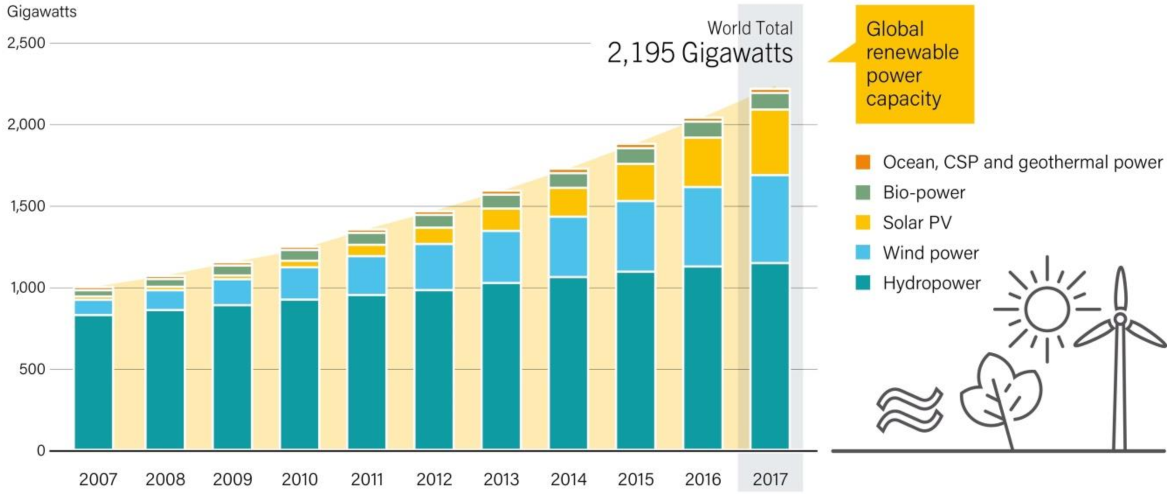
A country is taken into consideration to have a policy when it holds at the minimum one (policy). The figure above does not display every single one of policy kinds in operation. In numerous cases, nations have passed supplementary tax incentives to assisit RE.

Power regulatory policies contain feed-in tariffs, auctions and tendering schemes for RES, net metering and renewable portfolio standards.

Heating and cooling regulatory policies made of solar heat obligations, renewable heat feed-in tariffs, to name a few.

Transport regulatory policies cover biodiesel obligations, ethanol obligations and non-blend mandates, to name a few (REN 21, 2018).

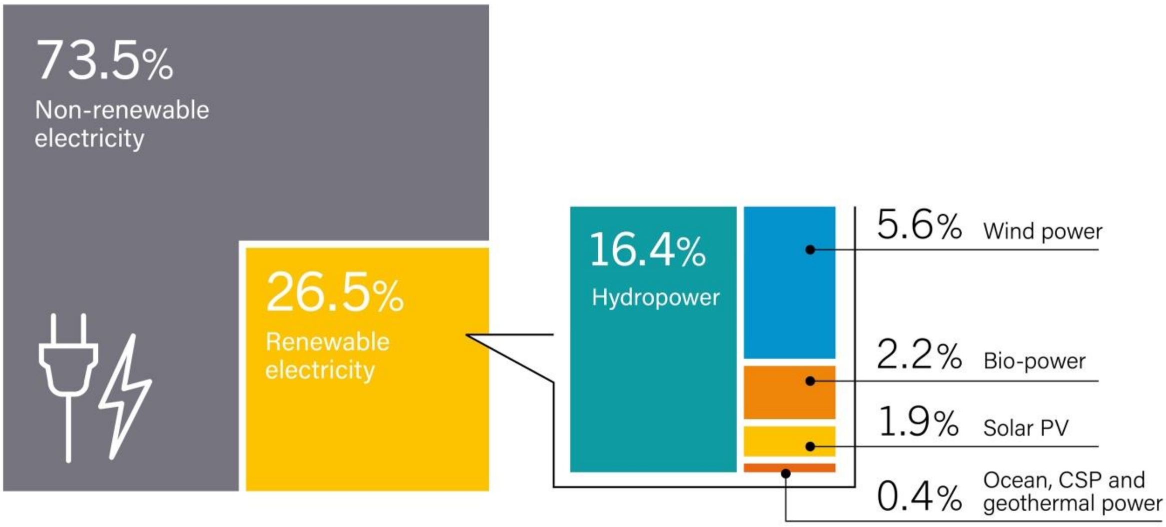
Appendix 4: Global renewable power capacity, 2007 – 2017



Source: (REN 21, 2018)

According to REN 21 (2018), "From 2007 to 2017, total global renewable power capacity more than doubled. In 2017, renewable power generating capacity witnessed its biggest expansion, with an estimated 178 GW deployed globally, lifting total capacity by almost 9 per cent over 2016. Solar PV made up almost 55 per cent of newly deployed renewable power capacity. Wind and hydropower formed most of the remaining renewable capacity additions, accounting for more than 29 per cent and almost 11 per cent, individually" (REN 21, 2018).

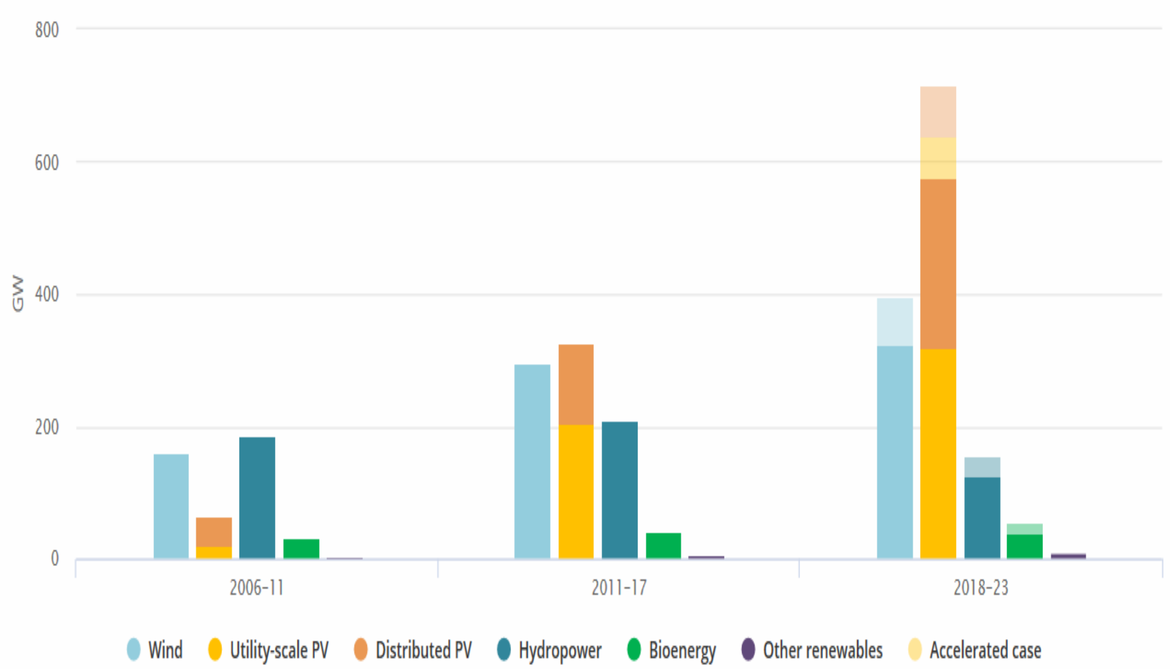
Appendix 5: Estimated renewable energy share of global electricity production



Source: (REN 21, 2018)

By 2017, global renewable power capacity totalled around 2,195GW – globally providing an estimated 26.5 per cent of (renewable) electricity, with hydro power accounting for 16.4 per cent; with wind power accounting 5.6 per cent; solar PV accounting 1.9 per cent (REN 21, 2018).

Appendix 6: Net renewable capacity additions, 2006 - 2023



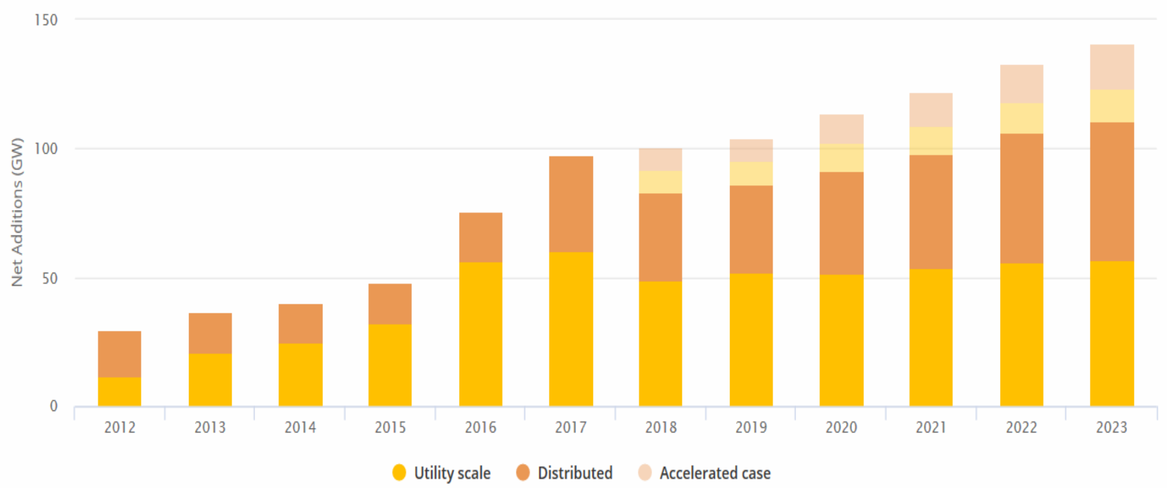
Source: (IEA, 2018a)

According to the IEA's market analysis and forecast from 2018 to 2023 on renewable energy and technologies:

"In the *main case* forecast, which takes into account of current market and policy structure, renewable capacity is believed to increase by over 1 TW, a 46 per cent growth over the period 2018 to 2023." (Wind: 324 GW + PV: 575 GW + Hydro: 125 GW + Other renewables: 8 GW =1069 GW)

"In an *accelerated case* forecast, which illustrates how some market and policy enhancements could affect renewable deployment, the growth in renewable capacity to 2023 could be 25 per cent higher than in the main case, reaching 1.3 TW, provided that governments address policy, regulatory and financial challenges before 2020." (1069 GW + Wind: 74 GW + PV: 139 GW + Hydro: 19 GW + Other renewables: 3 GW = 1335 GW) (IEA, 2018a).

Appendix 7: Net solar PV capacity additions, 2012 - 2023

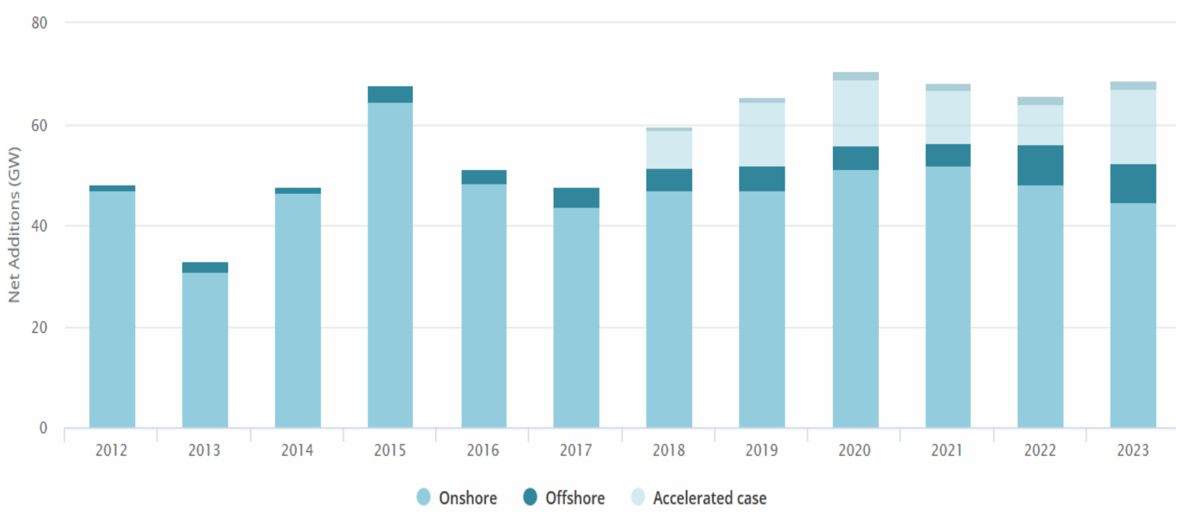


Source: (IEA, 2018a)

According to the IEA's market analysis and forecast from 2018 to 2023 on renewable energy and technologies: "Solar PV dominates renewables capacity growth in the next six years (from 2018 to 2013), with 575 GW of new capacity expected to become operational in the main case forecast over that period."

Driven by faster cost reductions, annual additions of solar PV are expected to reach 140 GW in the accelerated case forecast from 2018 to 2023. (IEA, 2018a).

Appendix 8: Net wind capacity additions, 2012 – 2023



Source: (IEA, 2018a)

According to the IEA's market analysis and forecast from 2018 to 2023 on renewable energy and technologies: "Wind capacity is forecast to grow by 324 GW in the main case over that period. Onshore wind adds around 50 GW of capacity per year in the main case forecast." (IEA, 2018a).