A Socio-Technical Evaluation of the Danish Energy Transition for 2050

How will the Danish Energy System achieve fossil fuel independence by 2050?

By Jay Louis Farrar

SID: 200947619

Supervisor: Dr Lucie Middlemiss

SOEE3030: Environmental Research Project

University of Leeds, 2019

Word count: 13,174

ACKNOWLEDGMENTS

I am indebted to my supervisor, Dr. Lucie Middlemiss, who has supported me in the collection, analysis and refinement of this research process in Copenhagen and Leeds. Without her support and guidance, this research would be far less rewarding.

Special thanks also to Jesper Steenberg, Rasmus Helveg Petersen, Janne Wichard Henriksen, Esben Baltzer Nielsen, Marie Münster, Mark Augustenborg Ødum, Iver Høj Nielsen, Jesper Troelsgaard Werling and Stig Nørgaard Knudsens for taking the time to share your knowledge and expertise of *Energy Strategy 2050*.

I would like to thank my parents, Steven Farrar and Karen Meehan, for their boundless love and support throughout my life.

Finally, I would like to dedicate this research to my great aunt, Margaret Redick, an incredibly kind and attentive woman who I miss dearly.

"If a small country like Denmark*, who is responsible for less than 1% of total emissions of the world wants to influence her own future, then it has to be done by taking a lead, by developing technologies and integrating an energy system that underpins the political will of others to do their part"*

(Rasmus Petersen, 2018)

TABLE OF CONTENTS

ACRONYMS

BEVS - Battery Electric Vehicles

CHP - Combined Heat and Power

COP - Coefficient of Performance

DEA - Danish Energy Agency

DEM - Danish Energy Management & Esbensen

DH - District Heating

DHN - District Heating Network

DIPD - Danish Institute of Parties and Democracy

DPP - Danish People's Party

DKK - Danish Krone (current exchange rate: £1 = 8.57Kr)

DTU - Technical University of Denmark

EB - Electric immersion boiler

FIT - Feed-in Tariff

GHG - Greenhouse gas

HP - Heat Pump

HFCV - Hydrogen Fuel Cell vehicles

IDA - The Danish Society of Engineers

IEA - International Energy Agency

NZEBs - near Zero Energy Buildings

OOA - The Organisation for Information on Nuclear Power

OVE - Danish Organisation for Renewable Energy

PM - Prime Minister

PPM - Parts per million

PV - Photovoltaic

R&D - Research and Development

RE - Renewable Energy

RETs - Renewable Energy Technologies

SPOT - Elspot day-ahead market

TSO - Transmission System Operator

VSC - Voltage Source Converter

WTP - Willingness to Pay

UNITS OF ENERGY

W - Watt

KW – Kilowatt, or 1 watt x 10^3

KWh – Kilowatt-hours

KWh/m^2 – Kilowatt-hours per square metre

MW – Megawatt (1,000 kilowatts)

GW – Gigawatt (1,000 megawatts)

TW – Terawatt (1,000 gigawatts)

PJ – Peta Joule (energy unit equal to 1 million billion joule)

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Denmark has the highest share of wind power in the world and is a leader in many aspects of renewable energy transitions. In 2011, the Danish Government introduced *Energy strategy 2050*, the first energy strategy to incorporate all sectors (heat, electricity and transport) when targeting a 100% renewable energy system. Numerous studies have demonstrated that *Energy Strategy 2050* is both technically and economically feasible, but there has been little research into the social potentials of *Energy Strategy 2050*, and very few researchers in the UK have sought to learn from the Danish experience in first-person. Subsequently, whilst living in Copenhagen for the 2017/18 academic year on an Erasmus exchange, I conducted nine in-depth qualitative interviews with elites regarding the socio-technical aspects of *Energy Strategy 2050*. I used purposive sampling to secure interviews with elites working at a variety of organisations within Denmark's energy sector. Interviewing a broad array of elites enabled me to accumulate a wealth of expertise and knowledge associated with *Energy Strategy 2050* that is not easily, if at all, obtainable from other sources.
The data obtained from the interviews was analysed using mind mapping, free coding and axial coding methods. My results show that there are many challenges associated with *Energy Strategy 2050*, including; poor dissemination of storage and conversion technologies that can assist in the management of a high penetration of fluctuating wind energy, the unsustainable use of biomass stocks and a growing sense of frustration towards onshore wind turbines. However, my results also show that Denmark is extremely well connected with the continental and Nordic power systems, has a flexible district heating network, is a world leader in onshore and offshore wind developments and most importantly, has the political infrastructure and societal competencies to achieve a 100% renewable energy transition.

1.0 INTRODUCTION

1.1 RESEARCH AREA

The combustion of fossil fuels in the world's energy sector is responsible for roughly 68% of global greenhouse gas (GHG) emissions. A continuation of the fossil fuel dominant energy system we see today will exacerbate the impacts of climate change, driving the Earth's planetary systems into a dangerous operating space for humanity (Rockström et al. 2009; Araújo, 2017).

Denmark's energy related GHG emissions account for just 0.1% of the world's GHGs, so Denmark's climate and energy policies are without the scale or magnitude to influence global GHG emissions directly (DEA, 2018). However, through government-to-government cooperation with a number of leading economies in the Nordic and continental power systems, Denmark's progressive energy and climate policies can positively influence up to 2 billion energy consumers accounting for one-third of global GHG emissions (Danish Energy Agency, 2017).

1.2 INTRODUCING *ENERGY STRATEGY 2050*

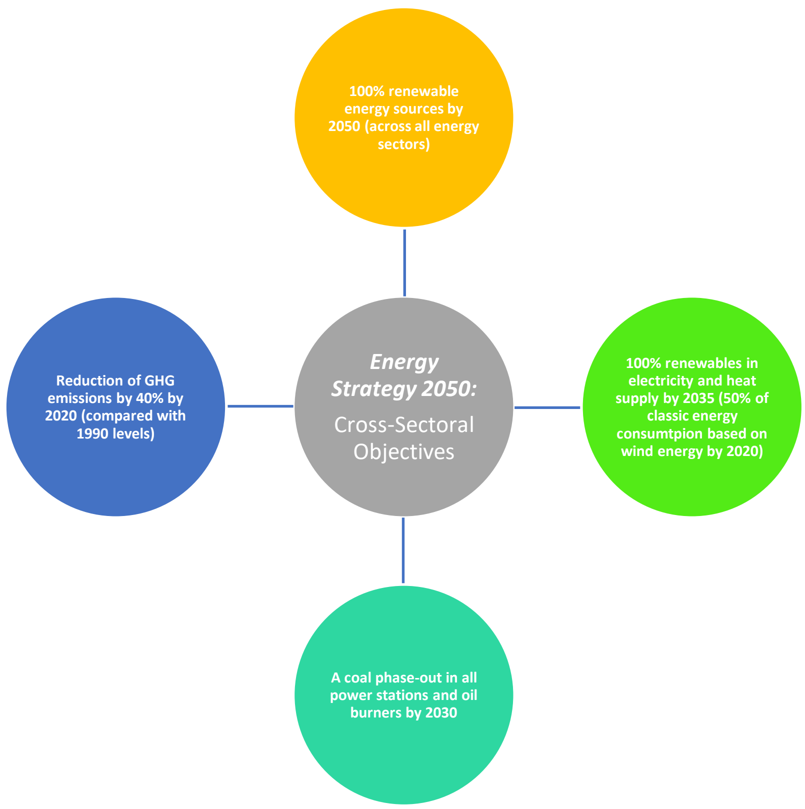
In the early 1970s, imported oil constituted for more than 90% of Denmark's energy mix, so when the oil crises of 1973 and 1979 struck, Denmark was extremely susceptible to the volatilities of international oil prices (Fawkes, 2013). In response to the energy security shocks of the 1970s, the Danish Government turned to nuclear power in the hope that it would resolve national energy security issues (Lund, 2010).

However, a decade long anti-nuclear movement led by several NGOs, as well as the emergence of a cooperatively owned wind industry meant that nuclear power was permanently axed from Denmark's energy plans in 1985 (Vasi, 2011; Houmøller, 2014; Araújo, 2017). Since the late 1970s, the Danish Government have introduced a number of policy instruments in support of the research and development (R&D) of renewable energy technologies (RETs), which has propelled Denmark as a world leader in many aspects of renewable energy transitions (Mendonça, 2007; Araújo, 2017).

In a speech to Parliament in October 2006, Danish Prime Minister (PM) Anders Fogh Rasmussen announced that the Danish Government had a long-term objective of a 100% fossil fuel independent energy system. At that time, no definitive path to fossil fuel independence was outlined explicitly, but Anders Rasmussen made it perfectly clear that nuclear power would have no role to play in the substitution of fossil fuels (Lund, 2010; Münster et al, 2012).

Then, in February 2011, a Venstre-Conservative Government, with Lars Løkke Rasmussen as PM and Lykke Friis as Climate and Energy Minister (both from Denmark's Liberal Party, *Venstre*) adopted *Energy Strategy 2050.* This comprehensive energy strategy was the first of its kind, both in Denmark and worldwide, as it was the first energy strategy to incorporate all sectors (heat, electricity and transport) with the overall aim of achieving a 100% fossil fuel independent system by the year 2050 (Agora Energiewende & DTU, 2015). In October 2011, a new, predominantly left-wing government led by Helle Thorning-Schmidt (*Socialdemokratiet*), introduced a number of cross-sectoral energy policy targets, thus strengthening the early momentum of *Energy Strategy 2050* (Agora Energiewende & DTU, 2015). Some of the core objectives of *Energy Strategy 2050* can be observed in *figure 1*:

Figure 1: Cross-Sectoral Objectives of Energy Strategy 2050.



1.3 RESEARCH AIMS

My interest in *Energy Strategy 2050* emerged whilst studying abroad at the University of Copenhagen on an Erasmus exchange. A preliminary investigation of *Energy Strategy 2050* highlighted that Denmark's 100% RE transition is technically feasible (Lund and Mathiesen, 2009; Lund et al., 2010; Mathiesen et al., 2015; IDA, 2015), but there is a research gap associated with the social aspects of *Energy Strategy 2050*.

In order to adequately address this research gap, I conducted nine qualitative interviews with elite individuals who work, or have worked, towards *Energy Strategy 2050* in some capacity. My research aim was to use the knowledge and expertise that they shared with me to produce a narrative account of *Energy Strategy 2050* from a socio-technical perspective.

It is crucial that we engage in knowledge sharing experiences with the elites who are responsible for carrying out the objectives of *Energy Strategy 2050* because there are many lessons we can learn from Denmark's RE transition. For instance, like Denmark, the UK has substantial onshore and offshore wind potentials and has the capacity to utilise vast quantities of excess heat in its district heating system (Wright, 2015; Cooper et al., 2016; IEMA, 2017; Ørsted, 2019). Ultimately, my research is part of a wider knowledge sharing process between Denmark and the UK associated with RE transitions.

In Section 2.0, I provide context for the study in light of previous research of energy transitions, smart energy systems theory and the characteristics of the Danish energy sector. In Section 3.0, I outline my research design and justify the use of in-depth qualitative interviews with elites as my primary data collection method. I also outline my data analysis process, which includes; mind mapping, free coding and axial coding. In Sections 4.0, I present my findings in a narrative format, using five sub-themes that emerged as a result of axial coding. Finally, in section 5.0 I discuss the significance of my results when evaluating *Energy Strategy 2050* from a socio-technical perspective.

2.0 LITERATURE REVIEW

In this section I provide a comprehensive overview of (2.1) Renewable Energy Transitions, (2.2) Smart Energy System and (2.3) how the Danish energy sector is characterised.

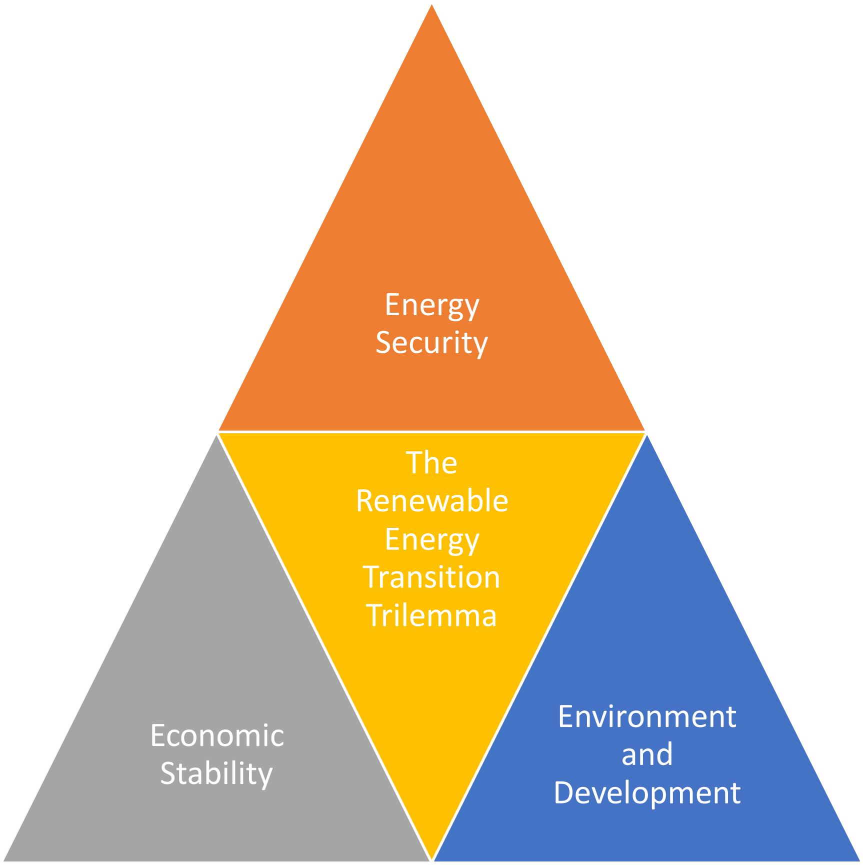
2.1 RENEWABLE ENERGY TRANSITIONS

Before addressing the importance of renewable energy transitions, some key definitions must be outlined. Firstly, renewable energy (RE) is energy that is derived from natural resources such as solar radiation, wind, rain, waves, tidal and geothermal heat. Unlike fossil fuels, renewable resources are replenished within the time span of a few years and produce zero emissions once in operation (Goodall, 2008; Lund, 2010). Secondly, *"energy systems are the interconnected networks of people, (infrastructure), and institutions engaged in the process of energy exploration, production, transformation, delivery and use within an enabling environment"* (Araújo, 2017: 9).

Furthermore, an energy transition is a change in the type, quality, or quantity of energy that is sourced, delivered and utilised (Lund et al., 2012; Araújo, 2017). More specifically, a RE transition (or green energy transition as terms are used interchangeably), is a configuration of the social and technical developments within a system that enable a high penetration of RE (Lund, 2010; Wright, 2015).

Broadly speaking, there are three political motivations for RE transitions (*see Figure 2*). One of the motivations is associated with energy security. A transformation of the world's energy system is desperately needed, with a greater focus on the phase-out of fossil fuels and a comprehensive integration of RE (Lund, 2010; Greenpeace, 2014; Mathiesen et al., 2015). The European energy sector relies on the import of fossil fuels for more than 50% of its energy needs, and a continuation of this trend could result in the import share of fossil fuels rising to 65% by 2030. Subsequently, unless the European energy system transitions towards renewable generation, the European energy system will become increasingly susceptible to terrorism and volatile fluctuations in the market price of fossil fuels (Münster et al., 2012; Fawkes, 2013; Bointner, 2014).

Figure 2: The Renewable Energy Transition Trilemma.



According to path dependency theory, developed economies in Europe are reliant on fossil fuels as a result of the co-evolutionary development of technological and institutional processes that have consistently resulted in market and policy failures, thereby inhibiting the integration of RETs; despite their environmental and economic advantages (Unruh, 2000). Araújo (2017) suggests that RE transitions provide an opportunity for developed economies to alleviate their path dependency on fossil fuels and move towards a more sustainable energy future. However, the common policy discourse that portrays energy systems planning as a burdensome bureaucratic process has slowed the pace of RE transitions throughout Europe (Wright, 2015).

Regarding the environment and development, concentrations of CO_2 have increased from roughly 280ppm (parts per million) in the pre-industrial age to more than 430ppm today, and the Earth's climate is moving into a dangerous operating space (Rockström et al., 2009; Wright, 2015).
The threat of climate change is inextricably linked to emissions of carbon dioxide (CO_2) in the energy

sector (Brundtland Commission, 1987; Fawkes, 2013). From a Danish perspective, around 74% of emissions are emitted from the energy sector. Subsequently, finding low carbon solutions in the energy sector has become a priority for Denmark (IEA, 2017).

The majority of Denmark's climate and energy objectives are consistent with that of the EU (European Union) and the United Nations (UN) (Lund and Mathiesen, 2009; AgoraEnergiewende and DTU, 2015). For example, Denmark, like all members of the EU, is targeting GHG emissions reductions of 80-95% relative to their respective 1990 levels (Parajuli, 2012; Drysdale and Mathiesen, 2018). Substantial emission reductions can be achieved by reducing energy demand, altering consumer behaviours, increasing energy efficiency through technological innovation and integrating a greater share of RE (Lund, 2010; Bointner, 2014). Thankfully, RE is on the rise throughout the EU; in 2016 RE provided 17% of gross final energy consumption, up from 9% in 2005 (Eurostat, 2018).

Finally, there are many economic advantages of RE transitions, including: job creation, industrial growth and improved balance of payments (Lund, 2010). According to the Risø National Laboratory for Sustainable Energy, greater RE integration can help reduce the fiscal insecurities of energy prices associated with a finite supply of fossil fuels. In addition, RE transitions correspond with *"new"* employment in the green energy sector (Parajuli, 2012; Christensen, 2015; IDA, 2015).

2.2 Smart Energy Systems

When considering how to integrate a large share of RE into an energy system, we must turn our attention to the *smart energy systems concept*, a topic of literature that has gained significant attention in recent years; particularly in a Danish context (Lund, 2010; Lund et al., 2012; Mathiesen et al., 2015; Schick and Gad, 2015; Lund et al., 2017; Drysdale and Mathiesen, 2018).

A smart energy system is *"an approach in which smart electricity, thermal and gas grids are combined with storage technologies and coordinated to identify synergies between them in order to achieve an optimal solution for each individual sector, as well as the overall energy system"* (Lund et al., 2017: 560). By combining the electricity, thermal and transport sectors, smart energy systems can improve system-wide flexibility, compensating for the intermittency of renewables such as solar and wind (Goodall, 2008; Mathiesen et al, 2015).

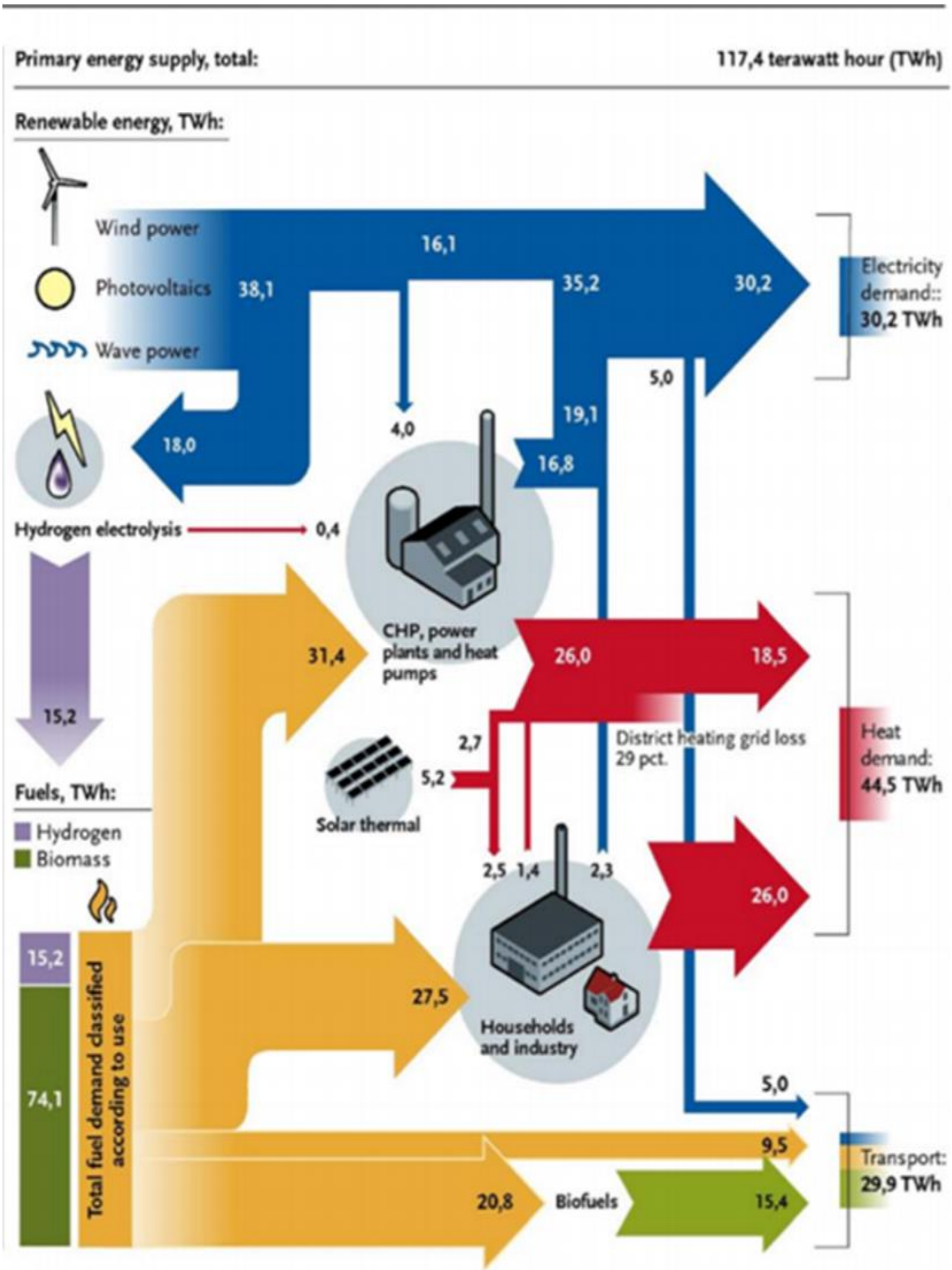
It is possible to trace the contemporary smart energy systems concept back to the environmental consciousness that emerged in the 1970s and 1980s. Seminal works such as *Limits to Growth* (Meadows et al., 1972) and *Soft Energy Paths: Toward a Durable Peace* (Lovins, 1977) were some of the earliest publications to address the importance of systems thinking; emphasising the need for a more strategic use of resources.

In 1980, a study by the Institute for Applied Ecology in Germany merged the environmental consciousness of these seminal publications with the concept of *Energiewende* or *"energy transition"* (Krause et al., 1982; Energiewende and DTU, 2015). This study was one of the first energy strategies to incorporate smart energy systems thinking, merging economic growth objectives with strategic resource use (Krause et al., 1982).

Although RE transitions are by no means a new phenomenon, Denmark was one of the first movers in implementing a RE transition across all sectors, aiming for a 100% fossil fuel independent energy system by 2050 (Lund, 2010; AgoraEnergiewende and DTU, 2015). There is now a broad consensus among energy system theorists in Denmark that the smart energy concept must be implemented for the 100% RE transition to succeed (Mathiesen et al., 2015; Lund et al., 2017).

Lund and Mathiesen (2009) designed a flow diagram of what Denmark's 100% RE system might look like in 2050 (see *Figure 3*), but it is virtually impossible to predict what the optimal energy strategy will look like in 2050 given the uncertainties regarding technological development, policy implementation and how Denmark's energy system will respond to a greater influx of RE in the future (AgoraEnergiewende and DTU, 2015; Lund et al., 2017).

Figure 3: Flow diagram of what Denmark's 100% RE transition might look like in 2050.



Source: Lund and Mathiesen, 2009.

2.3 OVERVIEW OF THE DANISH ENERGY SECTOR

In this section, I outline the key characteristics of the Danish energy sector when looking to evaluate *Energy Strategy 2050* from a socio-technical perspective.

2.3.1 Long-term drivers of Denmark's RE Transition

In the early 1970s, around 90% of Denmark's primary energy mix was fuelled by oil, obtained largely from the Middle East, and at that time, Denmark had not yet matured as an oil or gas producer in the North Sea (Lund, 2000; IEA, 2017; Araújo, 2017). Subsequently, when the first oil crisis of 1973 struck, petroleum imports for Denmark more than trebled in nominal currency terms (Moser and Schnitzer, 1985; Fawkes, 2013). In response to the oil crisis of 1973, Danish investors, scientists, environmentalists and communities rallied to develop alternatives to the costly importation of petroleum (Lund, 2010, Araújo, 2017).

Denmark's first national energy policy (*Danske Energipolitik*) was also released in 1976 in response to the first oil crisis. *Danske Energipolitik* prioritised fuel switching from oil to nuclear and coal, as well as targeting considerable energy conservation efforts in an attempt to insulate Denmark from the global energy crisis (Fawkes, 2013; Bointner, 2014). *Danske Energipolitik* also introduced high taxation on electricity as a fiscal income that would support the R&D of renewables (AgoraEnergiewende and DTU, 2015; IEA, 2017).

However, *Danske Energipolitik* was confronted by an alternative energy plan developed by a number of scientists from a host of Danish universities. The alternative plan (*Skitse til alternative energiplan for Danmark*) outlined a path of energy self-sufficiency based on RE production and not nuclear power (Lund, 2010; Araújo, 2017).

Alongside the alternative energy plan emerged a grass-roots movement against nuclear power (see *Figure 4*); headed by the Organisation for Information about Nuclear Power (OOA) and the Organisation for Renewable Energy (OVE) (Lund and Mathiesen, 2009; Bointner, 2014; Nyborg and Røpke, 2015). The OOA focused on preventing the approval of nuclear developments through; public debate, guidance of alternatives and advocating that energy related decision-making power should reside with parliament rather than with the central authorities. The OVE, an offshoot of OOA, was one of the earliest actors in demonstrating the feasibility of wind turbines through the publication of policy papers and early knowledge sharing exchanges at Old Danish Folk Schools (Greenpeace, 2014; Araújo, 2017).

Figure 4: A member of the OOA points a Danish power plant owner in the direction of a safe and sustainable energy future (Adapted from: Lund, 2010).

As the anti-nuclear movement gained the backing of scientists, engineers and a growing number of politicians, support for nuclear power diminished, and in 1985, nuclear power was eliminated from Denmark's future energy policy (Araújo, 2017). Bointner (2014) also points out that just a year after Danish Parliament vetoed nuclear power, the nuclear disaster at Chernobyl struck.

Together, the anti-nuclear movement and the alternative plan gave rise to a world leading and cooperatively owned wind industry (Vasi, 2011). From the mid-1970s onwards, local entrepreneurs, blacksmiths, farmers and mechanics voluntarily partnered together in the development of wind cooperatives. The early rationale for the cooperative ownership of wind turbines was that people could meet their own energy needs without relying on energy imports (Fawkes, 2013; Araújo, 2017).

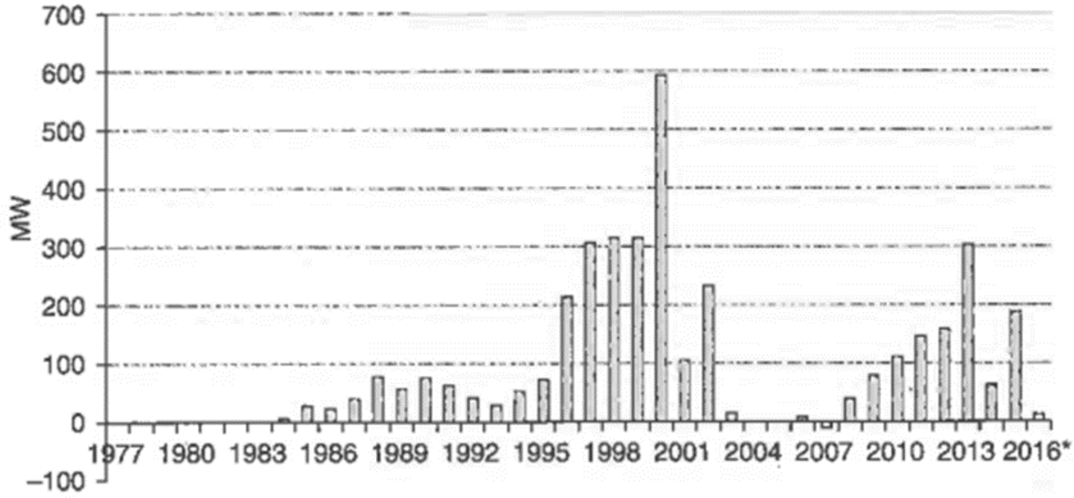
The earliest commercial wind developments in Denmark were designed and built by amateurs at the Tvind School of Western Jutland between 1975 and 1978. A partnership approach between scientists and volunteers at the Tvind School led to the successful construction of the 1MW Tvindkraft wind turbine, whilst the more scientific wind projects in the US and Germany failed (Greenpeace, 2014). The Tvindkraft turbine is still in operation today, and is *"a symbol of collective ingenuity and RE's ability to reduce energy dependency on foreign imports*" (Araújo, 2017: 152).

By 2002, wind energy cooperatives and individual farmers owned more than 6,300 wind turbines, and it was estimated that 150,000 Danish families were participating in wind energy production, a remarkable feat for a country with just 5.7 million inhabitants (IEA, 2017; Araújo, 2017).

Crucial to the success of cooperative wind turbine ownership and the year-on-year capacity increase of wind production has been Denmark's *sustainable democratic infrastructure* (Lund, 2010). With a relatively independent Parliament, the Danish Government have been able to introduce a number of policies that have challenged the dominance of the fossil fuel industry (Lund, 2000; Mathiesen et al., 2015; *Energistyrelsen*, 2017). As a society, we are often told that we don't have a choice, and that RETs are not reliable or cost-effective (Araújo, 2017), but Lund (2010) argues that the *sustainable democratic infrastructure* in Denmark allowed wind cooperative participants to feel as though they had a choice, and that they could, and can continue to, positively influence their own futures by investing in wind energy.

Furthermore, since the mid-1980s, the Danish Government has introduced a number of policy instruments that have granted priority market access to RETs. Perhaps the most successful of all policy instruments in speeding up the comparatively low-cost deployment of RETs was the fixed feed-in tariff (FIT) that was introduced in 1993 (Meyer, 2004; Mendonça, 2007; Lindboe and Werling, 2015; Lund et al., 2017). The fixed FIT model granted priority access to renewables and decoupled power purchasing price from existing electricity rates, ensuring that the price paid for electricity generated from wind turbines was set at 85% of the utilities and production cost, irrespective of wind conditions (IRENA, 2013). The introduction of a fixed FIT coincided with a dramatic rise in the annual capacity increase of wind turbine installation between 1994 and 2001, with 68% of total wind capacities installed in a 7 year period (see *Figure 5*).

Figure 5: Year-on-year onshore and offshore wind capacity change (MW).



Source: Araújo, 2017.

However the abonnement of the FIT in 1999 and subsequent implementation of a market-price premium approach resulted in wind developments stalling significantly between 2001 and 2008, as wind turbines were no longer guaranteed priority access (Mendonça, 2007; Lund, 2010; IRENA, 2013).

In the last decade, we have seen a noticeable shift towards offshore wind developments, as a growing number of citizens are becoming irritated by the density of onshore wind turbines; particularly in Jutland (Ladenburg, 2007; Wright, 2015; Mathiesen et al., 2015). Denmark was one of the first countries to go offshore with the completion of the 1991 Vindeby project (see *Table 1*), and it is unsurprising that offshore turbines are gaining in popularity in Denmark given that they are less likely to evoke NIMBY (not-in-my-back-yard) responses, and they are generally more efficient in terms of production output than their onshore cousins (Wright, 2015; Christensen, 2015; Lund et al., 2017; Buch and Kjaer, 2015; Elliot, 2019).

Table1: Offshore wind development over time.

Project	**Year of completion**	**Description**
Vindeby	1991	11 turbines, 5 MW
Tuno Knob	1995	10 turbines, 5 MW
Middlegrunden	2000	20 turbines, 40 MW
Horns Rev 1	2002	80 turbines, 160 MW
Samsø	2003	10 turbines, 23 MW
Rødsand	2003	8 turbines, 17 MW
Fredrikshavn	2003	3 turbines, 8 MW
Nysted	2003	72 turbines, 165 MW
Horns Rev 2	2009	91 turbines, 209 MW
Avedore Holme	2009	3 turbines, 11 MW
Sprogø	2009	7 turbines, 21 MW
Rødsand 2	2010	90 turbines, 207 MW
Anholt	2012	111 turbines, 400 MW
Horns Rev 3	2017	400 MW
Vesterhav Syd	Under development	180 MW
Vesterhav Nord	Under development	170 MW
Kriegers Flak	Under development	600 MW

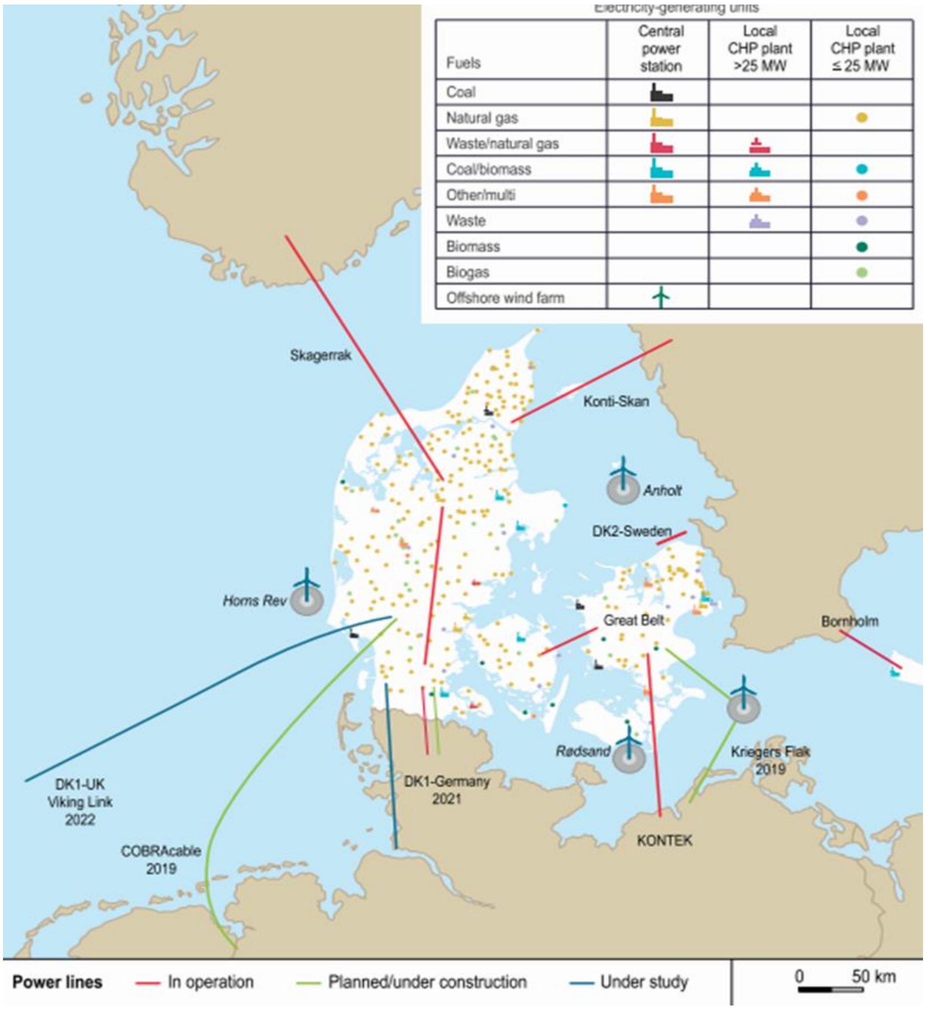
Source: Buch and Kjaer, 2015.

Most offshore developments in Denmark rely on a tendering procedure, where a fixed settlement fee is paid to the winning bid of the tender, the rationale behind this procedure is that offshore wind farms are constructed in the most efficient and cost-effective manner (AgoraEnergiewende and DTU, 2015). Equally, the DEA (Danish Energy Agency) is the sole authority for awarding contracts in this tendering process, so the process of awarding contracts is generally not very bureaucratic.

2.3.2 Grid Infrastructure

Denmark's transmission system operator (TSO), Energinet.dk, owns and operates the entire Danish transmission system and is responsible for the balancing of energy demand and supply. Somewhat unusually, Denmark's transmission system is divided into two distinct grids: DK1, the western grid, which covers Jutland and Funen, and DK2, the eastern grid, covering the islands of Zealand and Bornholm (*see Figure 6*) DK1 and DK2 are connected by the 600 MW Great Belt Power Link (Parajuli, 2012; Münster et al., 2012; Houmøller, 2014).

Figure 6: Present and future interconnectors between Denmark and the rest of Europe.



Source: IEA, 2017.

Denmark's transmission system also functions as an extremely interconnected hub between the Nordic and continental power systems. DK1 is synchronised with the German and continental energy system, and DK2 is synchronised with the Nordic power system (see *Figure 6*) (AgoraEnergiewende and DTU, 2015; *Energistyrelsen,* 2017). The combination of continental and Nordic interconnections means that Denmark has a total of 6.4 GW of export capacity, far exceeding its 5.7 GW of import capacity, thus having more than enough power to cover typical peak demand (Lund, 2010).

Figure 6 also highlights a number of new large-scale transmission projects. Noteworthy projects include: (1) the 700 MW high-transmission COBRAcable between the Netherlands and Denmark, (2) Kriegers Falk, a 600 MW offshore wind park, and (3) Horns Rev 3, an offshore wind project that has delivered some of lowest power production costs of offshore wind to date (Buch and Kjaer, 2015; Christensen, 2015; Shankleman, 2016; IEA, 2017). The main objective of these high-transmission projects is for Denmark to be able to transfer electricity almost instantaneously from grid networks in surplus to those in deficit (Goodall, 2008; Mathiesen et al., 2015).

2.3.3 The Nordic Power Market

Most countries are poorly connected to their neighbours, but Denmark is highly interconnected within the Nordic power market (Goodall, 2008; AgoraEnergiewende and DTU, 2015). The vast majority of Denmark's electricity flows are traded in the Nordic power market; primarily in the Elspot (SPOT) day-ahead market, but also in the Elbas intra-day market (Lund, 2010; Lindboe and Werling, 2015).

In the SPOT market, competitive auction begins at 12:00 CET on a daily basis, where electricity prices for each hour of the next day (24 hours) are estimated for each grid area participating in the power exchange, as well as an overall system price (Houmøller, 2014; Lindboe and Werling, 2015). Unlike many other auction systems where only a buyer submits bids, SPOT prices are unique in that they are determined by a double auction, where a buyer and seller submits bids (Houmøller, 2014).

Wind energy supplies 42.5% of Denmark's electricity consumption, and on a number of days, power production from wind turbines exceeds domestic demand for electricity (Münster et al, 2012; DEA, 2017). As a result of this high wind penetration, Denmark can routinely afford to export surplus electricity in the SPOT market, and the implicit double auction system ensures that Denmark's surplus wind energy is offered to markets with the highest WTP (willingness to pay). This is particularly advantageous for Denmark given that fellow Nord Pool participants; Norway, Sweden and Finland suffer from *"dry years",* where a lack of domestic hydrogen generation means that they have a high WTP for Denmark's surplus wind power in order to compensate for their lack of hydrogen (Lund, 2010; Houmøller, 2014; Lindboe and Werling, 2015).

The SPOT market also gives priority access to RETs, a market-based approach which has proved to be extremely successful in excluding fossil fuels from the Nord Pool (Jacobsen and Schröder, 2012; Houmøller, 2014). In addition, a recent Balmorel analysis of SPOT market prices in DK1 revealed that the price of onshore and offshore wind in western Denmark was roughly 8% cheaper than the average SPOT market price of electricity generation (Lindboe and Werling, 2015). This supports the notion that Denmark has some of the cheapest pure electricity prices (pre-tax) in Europe (Sovacool and Blyth, 2015).

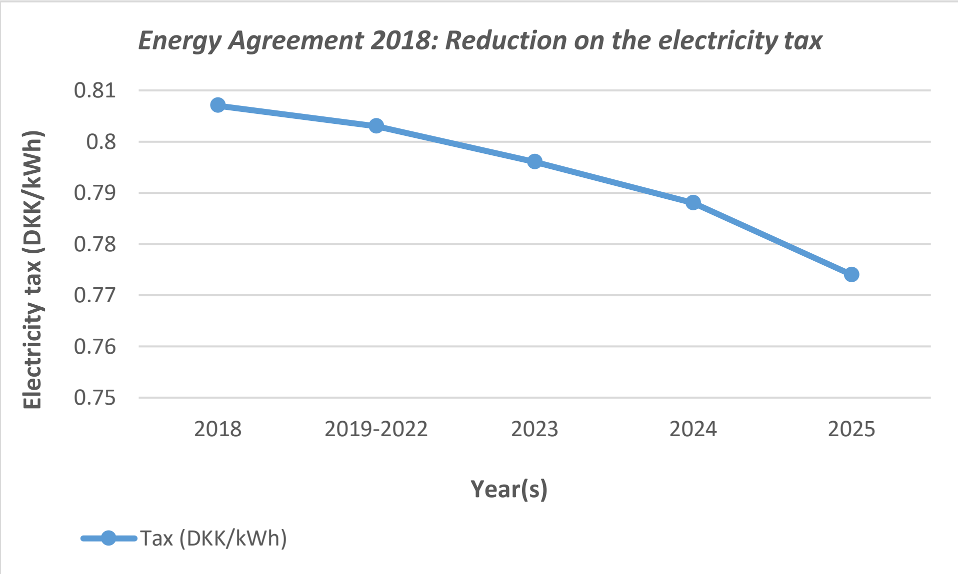
However, as wind production generally occurs at the same time throughout northern Europe, the SPOT market is becoming increasingly congested as the influx of wind power continues to rise (IDA, 2015). Unless the power market becomes more flexible, the marginal cost of investing in new wind turbine capacities in Denmark will soon outweigh the marginal profits, and the number of days Denmark experiences negative prices for wind generation will continue to rise (Lindboe and Werling, 2015; Lund et al., 2017).

2.3.4 The Electrification of Danish Society

In order to counter the storage related issues identified in the previous sections, the Danish Government are targeting substantial price reductions on the tax of electrical heat and electricity production as means of promoting the electrification of the Danish society (Nyborg and Røpke, 2015; *Energistyrelsen*, 2017; The Danish Ministry of Climate, Energy and Building, 2018).

As seen in *Figure 7*, in 2018, the electricity tax was .807 DKK/kWh, but this will be reduced to .774 DKK/kWh by 2025 (The Danish Ministry of Climate, Energy and Building, 2018). It is believed that by reducing the electricity tax, the demand for renewable electricity generation from wind and solar will increase (Lund et al., 2017).

Figure 7: Tax reduction on electricity.



Source: The Danish Energy Agency, 2018.

In addition, the tax on electrical heating will be almost halved by 2021, falling from .307 DKK/kWh in 2018, to .155 DKK/kWh (The Danish Ministry of Climate, Energy and Building, 2018). The aim of this tax reduction is to make electrical heating more attractive to consumers so that heating demand associated with the combustion of scare biomass stocks for heating purposes is reduced, or at least managed more sustainably (Gregg et al., 2014; The Danish Ministry of Climate, Energy and Building, 2018).

Furthermore, since Denmark is deprived of hydrogen storage capacities, and large-scale electric battery stores are expensive and unable to provide sufficient reserve capabilities for the back-up generation of wind turbines, it appears that Denmark should rely on conversion technologies such as heat pumps (HPs) for the electrification of society (Goodall, 2008; Bointner, 2014; Zvingilaite and Balyk, 2014; Nyborg and Røpke, 2015; Lund et al., 2017).

According to a recent EnergyPlan analysis of the entire Danish power system, whenever wind production exceeds 20% of annual electricity production in Denmark (which it does on a regular basis), there is a high feasibility for investing in flexible energy systems infrastructure such as the installation of large-scale HPs at combined heat and power (CHP) plants (Lund, 2010; Lindboe and Werling, 2015).

Danish engineered HPs are some of the most efficient in the world, with a co-efficient of performance (COP) value of 3:1, meaning that they give you three units of heat for every unit of work or electricity you put in. However, the dissemination of HPs at individual household level in Denmark has been incredibly slow due to insufficient user-interaction on the Government's behalf (Boyle, 1977; Moser and Schnitzer, 1985; Lund and Mathiesen, 2009; Nyborg and Røpke, 2015; Schick and Gad, 2015; Nielsen et al., 2015). In the discussion section I highlight a number of strategies that could be used to improve HP integration in Denmark (Schick and Gad, 2015; Nyborg and Røpke, 2015).

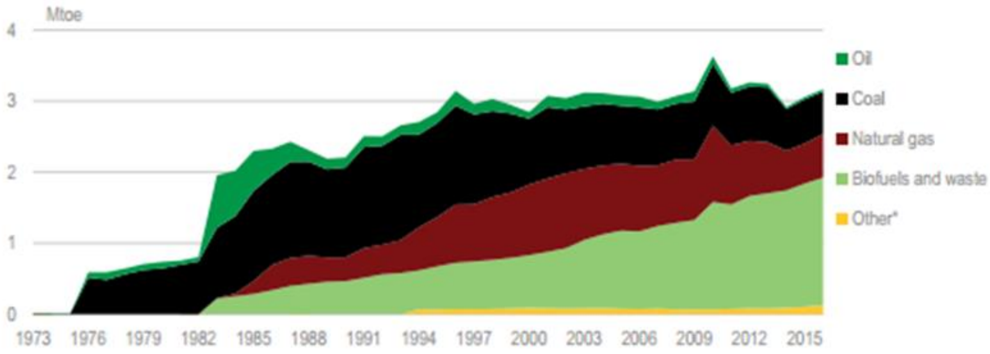
2.3.5 Heating and Transport needs

More than 60% of Denmark's heating needs are covered by 420 district heating networks (DHNs). Some of these networks are cooperatively owned, serving the heating needs of just a few hundred households, whilst 11 centralised networks account for 62% of total district heating (DH) needs (Goodall, 2008; Münster et al, 2012; Lindboe and Werling, 2015).

The supply of Denmark's DHN is remarkably flexible given that 80% of demand is generated by cogeneration at CHP plants (Münster et al, 2012). Denmark's DHN is also one of the most efficient in the world, with 90% of energy used in fuel typically converted into useful heat or electricity (Goodall, 2008; Fawkes, 2013).

The primary fuel source of DH in Denmark has changed significantly since the outbreak of the 1973 oil crisis, and this has huge implications for *Energy Strategy 2050* (see *Figure 8*). Biofuels, mainly in the form of waste; agriculture, forestry and crops currently account for 43% of DH needs, and this is a result of the large-scale conversion of CHP plants from coal to biofuels in recent decades (Münster et al, 2012; IEA, 2017; Drysdale and Mathiesen, 2018).

Figure 8: Fuel consumption in DH generation between 1973 and 2015.



Other includes solar, electricity (direct and in heat pumps) and industrial surplus heat.*
Source, IEA, 2017.

Although the conversion of CHP plants from fossil fuels to biofuels is generally regarded as a positive aspect of *Energy Strategy 2050*, there are very few bio-refineries in Denmark, therefore Denmark imports the majority of its biofuels (Münster et al, 2012). In addition, only 75% of biomass reserves in Denmark can be allocated for energy usage given the competition from other bio-based industries such as bioplastics (Drysdale and Mathiesen, 2018).

Nonetheless, Lund and Mathiesen (2009) suggest that if Denmark restructures its agricultural sector proficiently, Denmark could access 400 PJ of sustainable biomass by the year 2050. In order to accommodate such a gigantic increase in biomass production, the Danish Society of Engineers (IDA) have calculated that the total demand for DH will need to increase from 22.8 TWh in 2015 to 28.2 TWh in 2050 (IDA, 2015).

Another important characteristic of Denmark’s heating sector is the potential for efficiency improvements (Fawkes, 2013; Zvingilaite and Balyk, 2014; Drysdale and Mathiesen, 2018). The concept of near Zero Energy Buildings (nZEBs) has been put forward by Drysdale & Mathiesen (2018), but there is a broad agreement that the greatest potential for energy efficiency improvements is in existing building stock (Zvingilaite and Balyk, 2014; IDA, 2015; Drysdale and Mathiesen, 2018).

The average heat demand of an existing building in Denmark (built before 2015) is roughly 132 kWh/m^2, and although this ranks relatively high in efficiency terms in comparison with other European countries, the Danish Energy Agency (DEA) aims to reduce the average heat demand of existing buildings to 80 kWh/m^2 by 2050 (IEA, 2017; DEA, 2017; Drysdale & Mathiesen, 2018). However, a number of scholars are concerned that efficiency measures will be overlooked because they are not as photogenic as the construction of large-scale wind parks (Fawkes, 2013; Zvingilaite and Balyk, 2014).

There is also a growing body of literature concerned with the utilisation of excess heat from Danish industry. Bühler et al (2017) discovered that there is 2.37 TWh of accessible industrial excess heat that could supply 1.36 TWh of DH to consumers each year. A fundamental benefit of using excess heat from industry is that otherwise wasted heat is used productively (Fawkes, 2013; Lund et al., 2017). However, the use of excess heat from industry will be concentrated in the industrial hubs of Aalborg, Fredericia and Kalundborg, with very limited potential at a national scale (Bühler et al., 2017).

Finally, in regard to the transport sector, there is much uncertainty regarding the use of biofuels. Although biomass could supply around 47 PJ of bio-based electro-fuels by 2050 (IDA, 2015), many believe that Denmark should prioritise the electrification of the transport system given the scarcity of biomass (Lund, 2010; Lund et al., 2012; Sovacool et al., 2018). For example, Lund (2010) has suggested that by 2030, 80% of Danish vehicles weighing less than 2 tons should be replaced by a combination of battery electric vehicles (BEVs) and hydrogen fuel cell vehicles (HFCVs).

2.4 Literature Summary

Clearly, there are a number of social and technical challenges facing *Energy Strategy 2050,* including; a lack of electricity storage and conversion capabilities during periods of high wind penetration, a growing sense of NIMBY(ism) towards onshore wind turbines and the use of scarce biomass stocks for heating, electricity and transport needs.

In order to overcome the aforementioned challenges, Denmark must continue; investing in offshore wind capacities, expanding power links throughout Europe, targeting substantial reductions in the taxation of electricity and electrical heat, as well as investing heavily in HPs to facilitate the electrification of Danish society, thereby enabling a more efficient use of surplus wind power; in heating and transport. Equally, Denmark must remain in contact with its origins of cooperative ownership and bottom-up support of a RE transition.

In the results (4.0) and discussion (5.0), I combine the secondary data sources used in this literature review with the knowledge and expertise of nine elites working within the Danish energy sector to evaluate *Energy Strategy 2050* from a socio-technical perspective.

3.0 METHODOLOGY

In this section, I review the steps taken to conduct my research. Firstly, I outline and justify my research design (3.1). I then discuss the data collection (3.2) and data analysis process (3.3). Finally, I account for any ethical considerations (3.4), as well as the limitations of this research (3.5).

3.1 RESEARCH DESIGN

This research consists of nine in-depth qualitative interviews with elites working towards *Energy Strategy 2050* in some professional capacity. Qualitative interviews were used instead of surveys because they allowed for a more profound investigation into *Energy Strategy 2050* (Marshall and Rossman, 2006; Arksey and Knight, 2011).

More specifically, elites were interviewed because they hold, or have held, a position of power that has granted them unique knowledge or information on a given topic. Given the prestigious status of the elites interviewed in this study, it is possible that they have provided data that is not easily, if at all, obtainable from other sources (Natow, 2019).

To add depth to the study, and attract the attention of an array of stakeholders, I specifically designed the interview to include a variety of sections associated with *Energy Strategy 2050,* labelled *Parts A-F (*see *Appendix 1*):

- *Part A. Personal and Organisational outlook*
- *Part B. Political Stability / Public Attitudes and Behaviours*
- *Part C: District Heating and the use of Biomass*
- *Part D: Renewable Energy Technologies (RETs)*
- *Part E: Nord Pool Market*
- *Part F: Closing questions*

3.2 Data Collection

As seen in *Figure 9,* my data collection consisted of four stages: (1) purposive sampling, (2) emailing research agenda and consent forms, (3) negotiation stage and (4) conducting the interviews.

In light of the difficulties in gaining access to elite interviews, I was unable to use snowball sampling because it would have been naïve to assume that each elite interviewee would take the time to recruit other participants for my study (Mikecz, 2012; Kirchherr and Charles, 2018). Subsequently, I used purposive sampling, where my knowledge of a relatively visible elite population in the Danish energy sector guided the sampling process. Purposive sampling enabled me to identify a total of 60 potential interviewees, dismissing those who did not satisfy the research criteria (Tansey, 2007). Ultimately, I received interest from nine elites (see *Table 2*). The diversity of elites interviewed in this study permitted a multi-stakeholder perspective of *Energy Strategy 2050*, incorporating insights from the private and public sectors (King and Horrocks, 2010).

Figure 9: Data collection process.

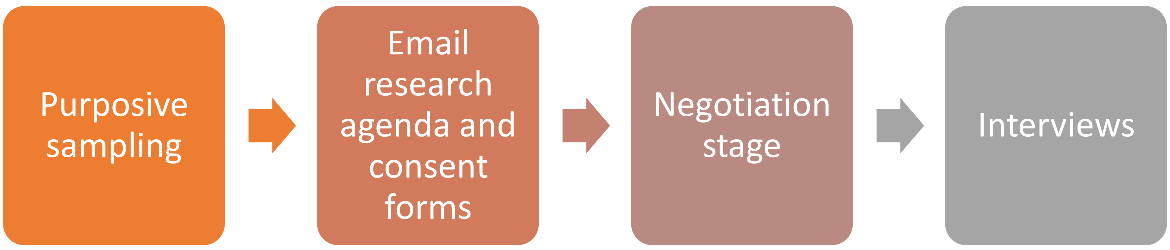


Table 2: Interview Participants

Organisation	Organisational Contributions to *Energy Strategy 2050*	Interview Date	Interview Duration (Hour/Min/Sec)	Interviewee	Position of Interviewee at Organisation
ENERGI & VAND – Greater Copenhagen Living Lab	The Greater Copenhagen Living Lab bridges sustainable city design through education, involvement, dissemination and research.	08.02.2018	00:46:51	Jesper Steenberg	Managing Director
Danish Institute for Parties and Democracy (DIPD)	Promotion of sustainable development practices in Denmark and around the world.	16.02.2018	01:03:07	Rasmus Helveg Petersen	Director of DIPD **Former Minister of Climate and Energy**
Energistyrelsen/ The Danish Energy Agency (DEA)	The DEA is responsible for the implementation of policies and measures related to the production, transmission and utilisation of energy and their impact on climate change.	08.03.2018	00:33:30	Janne Wichard Henriksen	Advisor: Energy Efficiency and Markets
Vattenfall	Investing heavily in low carbon developments in the Danish energy sector (e.g. offshore wind).	15.03.2018	00:45:01	Esben Baltzer Nielsen	Head of Media & Public Affairs
Technical University of Denmark (DTU)	Academic research helps inform strategic energy decision-making. Collaborate with industry, the public sector and international institutions in finding low carbon energy solutions.	12.04.2018	00:45:36	Marie Münster	Professor MSO: Systems Analysis & Sustainability
Better Energy	A leading solar energy company: developing, financing and building operating solar PV systems.	20.04.2018	00:36:11	Mark Augustenborg Ødum	Executive Vice President
State of Green	A not-for-profit, public-private partnership from Denmark that fosters relations with international stakeholders in the fields of energy, climate, water and environment.	20.04.2018	00:52:36	Iver Høj Nielsen	Head of Media and Public Affairs
Ea Energy Analysis	Using complex mathematical models (e.g. Balmorel) for the simulation of electricity and heat systems in a liberalised market. Use scenario techniques to estimate long-term possibilities of developing sustainable energy systems.	30.04.2018	00:41:15	Jesper Troelsgaard Werling	Partner, MSc Engineering
Danish Energy Management & Esbensen (DEM)	Help improve the energy performance of an organisations, buildings or industrial processes.	19.05.2018	00:42:24	Stig Nørgaard Knudsens	Head of Sustainable Building Design

Prior to conducting the interviews, each respondent received an email disclosing the details of my research agenda and an attached consent form (see *Appendix 3*). Once interviewees had agreed to participate in this research, the date and times of the interviews were negotiated. At this stage in the research, I had to remain extremely flexible and adapt to the busy schedules of the elites (King and Horrocks, 2010).

I also conducted a risk assessment (See *Appendix 4*), mainly because I was travelling independently to various offices throughout the Greater Copenhagen area (see *Figure 10*). I decided to conduct face-to-face interviews at the respondent's offices because elites are generally not willing to travel for interviews due to the time pressures of their working life (Marshall and Rossman, 2006). Additionally, if elites feel more comfortable meeting in their 'natural' working environment, they are less likely to feel threatened by the interview itself, and will therefore present a more insightful account of *Energy Strategy 2050* (Harvey, 2011; Mikecz, 2012). An example of the type of office visited can be seen in *Figure 11.*

Figure 10: Offices of interviewees visited throughout the Greater Copenhagen area.

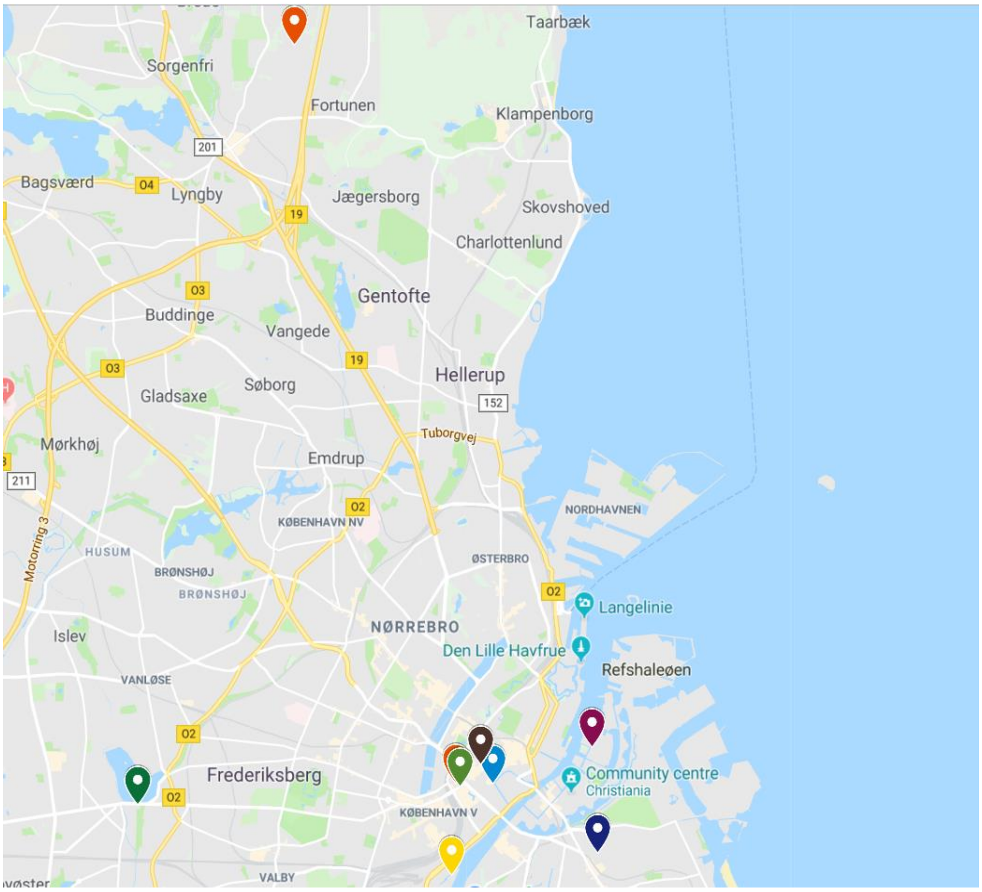
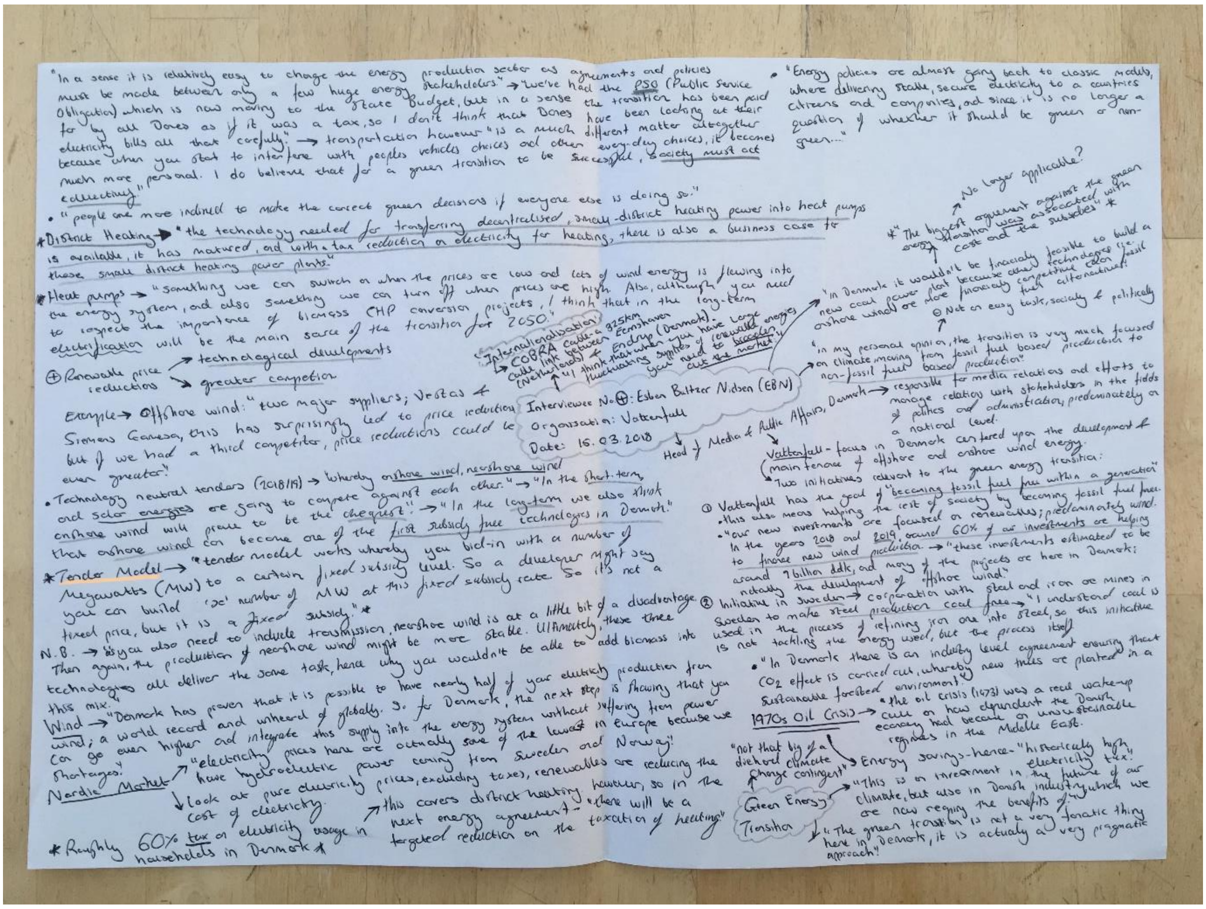


Figure 11: Axel Towers, the home of Better Energy. Source: Image is my own.

3.3 DATA ANALYSIS

After the interviews were transcribed (see *Appendix 5*), key information and quotes from each interview were mind mapped independent of one another (see *Figure 12*). Mind mapping data in free form facilitated the initial exploration of non-linear themes prevalent in each interview. The main benefit of using mind maps is that they encourage creating thinking throughout the data analysis process (Davis, 2010).

Figure 12: Figure 12: Mind map of information obtained from my interview with Esben Baltzer Nielsen.



I then began to free code, creating categories of codes by considering the themes emerging throughout all nine interviews (King and Horrocks, 2010). As a result, I began ordering the data for all nine interviews into five sub-themes of *Energy Strategy 2050*:

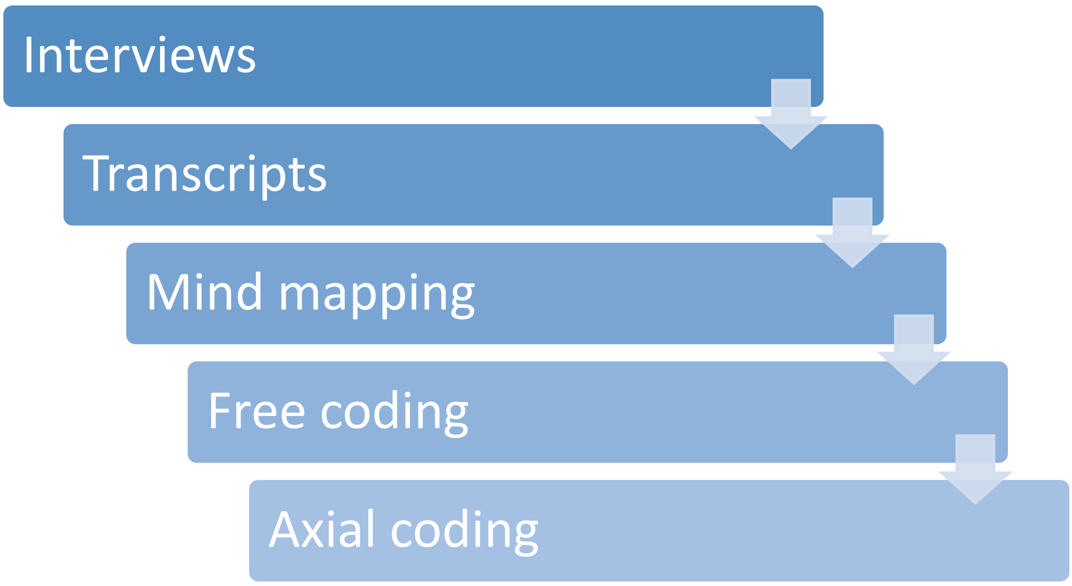
1. Political Stability & Social Acceptance
2. A Flexible Heat Sector

3. The Emergence of a Green Energy Cluster
4. Grid Expansion and Internationalisation
5. Continued support for the development and integration of Renewable Energy

The rationale for creating these five sub-themes is that they constituted as the main talking points during all nine interviews. In addition, these sub-themes are closely aligned to my research questions, allowing for a relatively smooth transition from research design to analysis.

Once the five sub-themes were established, I transitioned into axial coding, where I analysed the relationship between the different sub-themes. Axial coding allowed me to re-assemble the data that was fractured during the mind mapping and free coding stages of this analysis (Saldana, 2009). Ultimately, I conducted a thematic analysis of some of the most influential aspects of *Energy Strategy 2050*. *Figure 13* illustrates my data analysis process in full.

Figure 13: Data analysis process.



3.4 Ethical Considerations

As it is unethical to hide the research agenda of any study, before I started recording any of the interviews on my mobile device, I ensured that all interviewees were aware of the study objectives and how I intended to use the data obtained throughout the interview process (see *Appendix 1*). I also ensured that respondents felt no obligation to answer every question, and that they could cease answering questions or terminate the interview at any point (Harvey, 2011).

In addition, all nine interviewees signed a consent form to participate in this research, and although it was initially agreed that I would anonymise all participants, after consultation with my supervisor, Dr. Lucie Middlemiss, it was decided that I should name the elites who participated in this study. The main reason for not anonymising the elites in this research is that their prestigious status at their respective organisation makes it virtually impossible to ensure complete anonymity (Mikecz, 2012). As a result, I emailed all nine interviewees to inform them that I would be acknowledging their inclusion in this research, giving them an opportunity to retract their contribution to this research before final submission.

Interestingly, elites are thought to be more trusting of foreign researchers than their fellow compatriots. This is because foreign researchers are generally not considered to be a threat to the status and power of elites, especially if the results of the research are published in another country (Mikecz, 2012). Subsequently, the "*cultural gap*" between myself and the elites in this study allowed me to maintain a critical stance on their perception of *Energy Strategy 2050.*

3.5 Limitations of the Methodology

Interviewing elites presents a plethora of methodological problems. Although the elites in this study were relatively easy to locate through purposive sampling, gaining access, building trust and establishing rapport with them was much more difficult (Saldana, 2009; Mikecz, 2012). Furthermore, elites are trained on how to project their organisations to the outside world, so it could be argued that the data I have acquired is representative of public relations, rather than a more personal account (Mikecz, 2012). For example, the Head of Media and Public Affairs at State of Green, Iver Høj Nielsen, had to convey the organisations profit and non-profit interest throughout the interview, perhaps discouraging a more personal account of *Energy Strategy 2050* (Rapley, 2011).

There are also limitations associated with the validity of my data analysis. For example, mind mapping and free coding methods are often unable to detect more complex relationships between sub-themes. However, by using axial coding, I was able to counter such limitation by analysing the relationship between all five sub-themes (Saldana, 2009). It should also be noted that visual elements, such as interviewee body language, were omitted from this study because I was restricted to verbal recording only (Marshall and Rossman, 2006).

Finally, prior personal contacts have been found to be particularly useful when trying to interview elites (Kirchherr and Charles, 2018), so when considering that I had no contacts in Denmark when I moved to Copenhagen in August 2017, conducting nine elite interviews between January and May 2018 is testament to the quality of my research methods.

4.0 RESULTS

In this section, I evaluate some of the key aspects of *Energy Strategy 2050* using the primary data obtained from elite interviews. I have used the five sub-themes created during the free coding stage of my data analysis to connect the knowledge and expertise the elites shared with me into a narrative evaluation of *Energy Strategy 2050*.

4.1 POLITICAL STABILITY & SOCIAL ACCEPTANCE

Firstly, the political rationale for *Energy Strategy 2050* is that *"the main culprit emitting* CO_2 *into the atmosphere is the energy sector*" and *"if we (Denmark) are unable to solve the problem of emissions from the energy sector, then we are not going to succeed in the overall green transition"* and *"although it is not enough to focus on the energy sector alone, it is the obvious place to start*" (Interview: Rasmus Petersen, 2018).

Without political stability, *Energy Strategy 2050* would be *"null-and-void"* because *"stable policies are key to investor confidence in RETs".* In addition, since the inception of *Energy Strategy 2050*, *"only minor policy changes within the wider Danish energy transition framework have occurred"* (Interview: Rasmus Petersen, 2018), and it is this political desire to move in the same direction that has underpinned Denmark's RE transition success thus far (Interview: Iver Høj Nielsen, 2018).

Furthermore, the Managing Director of ENERGI & VAND's Greater Copenhagen Living Lab, Jesper Steenberg (2018), claimed that *Energy Strategy 2050* has helped establish a *"broad coalition among left wing environmental thinkers, a middle-section of society concerned with environmental health and energy security, and the right-wingers, who believe that the environmental discourse is good for business".* Jesper then went on to say that despite some opposition from the *Danish People's Party (DPP), "roughly 80% of parliament have agreed on the energy policy for the next line (Energy Agreement, June 2018), and not because they do it for the same reason"* (Interview: Jesper Steenberg, 2018).

Regarding social acceptance of *Energy Strategy 2050,* although Danes are often very forthcoming in communicating their *'green'* behaviours and attitudes (Sovacool & Blyth, 2015), one interviewee suggested that *"there is not a huge diehard climate change contingent in Denmark",* and that *Energy*

Strategy 2050 is *"not very fanatical"* but rather a *"pragmatic approach to energy and climate issues"* (Interview: Esben Baltzer Nielsen, 2018).

Somewhat surprisingly, a number of interviewees also suggested that many Danish citizens do not care whether or not energy is green, and merely care about how much it costs. For example, a senior Market Maker from DEM suggested that should green taxes on electricity increase to help finance *Energy Strategy 2050*, *"people will look to move away from the green energy transition"* (Interview: Stig Nørgaard Knudsens, 2018). In addition, according to Janne Wichard Henriksen (2018), a senior Advisor in the DEA's energy policy:

"Following the liberalisation of Denmark's electricity market almost fifteen years ago, people were promised that electricity prices would fall, but they haven't, they have increased because of tax amendments, tariffs and so on."

Should Denmark not reduce electricity prices in the near future, there is a danger that the less environmentally conscious members of society will distance themselves from *Energy Strategy 2050*. As a result, the system-wide objectives of *Energy Strategy 2050* could be at risk, given that *"for a green energy transition to be successful, society must act collectively"* (Interview: Esben Baltzer Nielsen, 2018). However, it should be noted that *"several studies have found that the Energy Strategy 2050 will only cost a few percentage of GDP"* (Interview: Marie Münster, 2018) and *"very few Danes look at their energy bills all that carefully"* (Interview: Esben Baltzer Nielsen, 2018).

Finally, it is imperative that Danish citizens remember that *Energy Strategy 2050* will allow them to enjoy the benefits of a fantastic welfare system "*without destroying the possibilities of future generations to have exactly the same opportunities"* (Interview: Janne Wichard Henriksen, 2018).

4.2 Smart Heating Solutions

Interviewing Marie Münster proved to be particularly useful in this section of my research thanks to her expertise in smart heating solutions (Münster et al., 2012). Marie informed me that DH is of particular importance to *Energy Strategy 2050* when evaluating the heat sector because DH accounts for 50% of household heating, and it has the potential to integrate a large influx of wind and solar energy, with the help of HPs for the conversion of surplus electricity into heat (Interview: Marie Münster, 2018).

Biomass, mainly in the form of waste; agriculture, forestry and crops - supplies around 40% of Denmark's DH needs (Münster et al, 2012), but all of the interviewees identified that biomass is a scarce resource and that there are climate induced implications from the combustion of biomass. One interviewee was particularly forthcoming in their criticism of Denmark's use of biomass for the production of heat and electricity:

"Biomass is certainly not a long-term solution in the way we are currently using it. Right now, the bulk of our biomass is used for the production of either heat or electricity, but it can be substituted by electricity, and it should be!"

(Interview: Rasmus Petersen, 2018)

However, for the next 10 or 20 years, Denmark is "*locked-in*" with the investment of converting CHP production from coal to biomass (Interview: Janne Wichard Henriksen, 2018). By 2030, Denmark anticipates that all coal producing units will have been completely phased-out, and the conversion of coal to biomass production is undoubtedly a great way to avoid stranded assets during this transitional period (Interview: Marie Münster, 2018).

In addition, Ea Energy Analysis recently conducted a Balmorel analysis of the entire Danish energy system, and they determined that sustainably sourced biomass could provide somewhere between 20-30% of Denmark's energy needs by 2030 (Interview: Jesper Troelsgaard Werling, 2018). However, these results are based on the assumption that Danish industry leaders will continue voluntarily carrying out re-forestation efforts in an attempt to utilise biomass stocks more sustainably (Interview: Esben Baltzer Nielsen, 2018).

In the near future, Denmark needs to upscale domestic biomass production to avoid energy security issues associated with the import of biomass. The construction of decentralised bio-refineries would allow for increased self-sufficiency of supply throughout Denmark, *"but the actors that need to come* *together (district heating and refinery sectors) continue importing biomass"* (Interview: Marie Münster, 2018).

Returning to the importance of energy conversion technologies mentioned earlier in this section, Jesper Steenberg (2018) said that, when combined, HPs and electric immersion boilers (EBs) can facilitate the large-scale transformation of surplus wind energy into heat which can then replace biomass, coal, natural gas and other less sustainable producers of heat.

Marie Münster (2018) also explained the two benefits of extensive HP and EB installation in Denmark's smart energy system:

- *The utilisation of low value heat sources*

"If you have 30°C lukewarm water coming out of an industry, HPs can increase the temperature of that water to something useful, since HPs allow you to up the temperature of water to around 80°C"

- *Integration with heat stores*

"When HPs are combined with heat stores (i.e. EBs), you can utilise the electricity whenever it is cheap. So even if you don't need the heat at that precise moment, you can send the heat to a heat store and then you can extract that heat out of the heat store whenever you should need it". In addition, *"EBs are cheap and use lots of electricity"* so if HPs are used in conjunction with EBs, *"they can help to integrate wind by converting electricity into heat and storing this surplus heat energy, because heat stores are much more cost-effective than other types of energy storage. Ultimately, investing in HPs and EBs will allow for a more flexible energy usage."*

Patently, HPs and EBs have a huge role to play in *Energy Strategy 2050,* whether that be in the utilisation of waste heat or converting surplus electricity into heat. Rasmus Petersen (2018) also acknowledged that countries such as the UK could learn from Denmark's utilisation of excess heat.

Finally, Denmark has an abundance of geothermal resources, which in the future could meet a large share of domestic heating needs with clean energy (Danish Ministry of Climate, Energy and Building, 2018). However, *"geothermal can only assist DH because the temperatures are not high enough to generate electricity"* and at present, there are very few geothermal power plants in Denmark, and those that are in operation are not working particularly well since *"geothermal is a very expensive and high risk technology to try and exploit"* (Interview: Marie Münster, 2018).

4.3 THE EMERGENCE OF A GREEN ENERGY CLUSTER

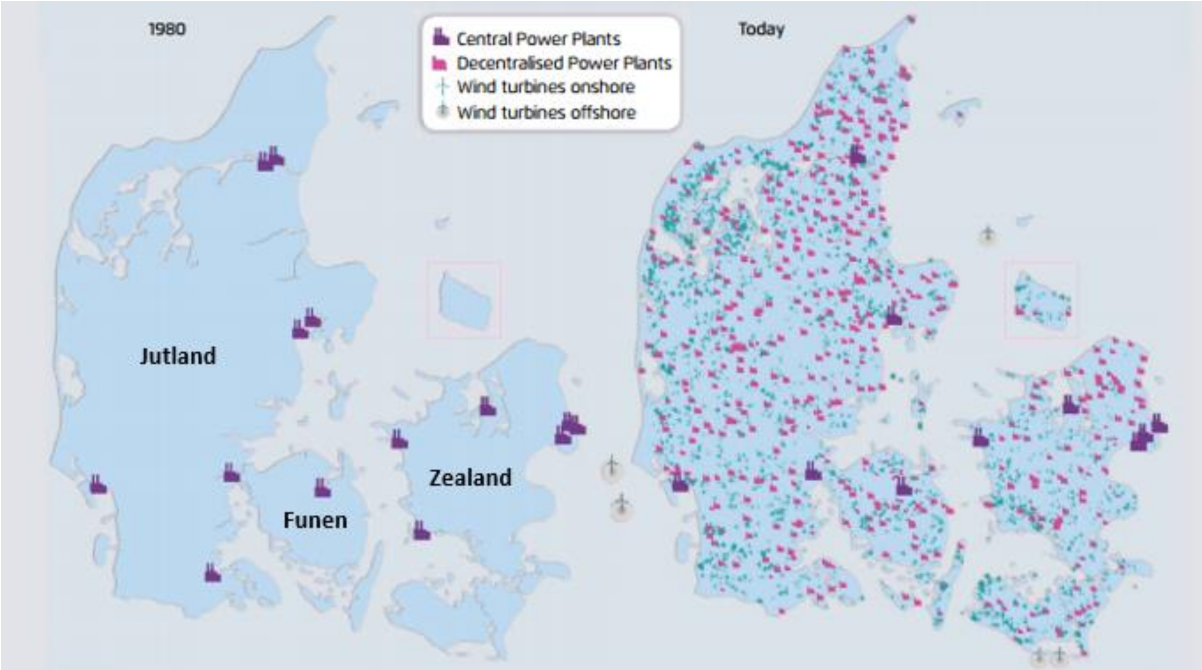
Broadly speaking, there is an acceptance from industry leaders in Denmark that *"the green energy transition is not only an investment in the future of our climate, but also in Danish industry"* (Interview: Esben Baltzer Nielsen, 2018).

Although Denmark's green energy cluster emerged in response to the energy security threats of the 1973 and 1979 oil crises (Lund, 2010; Fawkes, 2013), there is a palpable sense of pioneering entrepreneurship associated with *Energy Strategy 2050.* This notion is typified in the following extract:

> *"We (Denmark) do believe that we can make profit from this green energy transition. We are in a powerful position in the wind sector, we have some of the most efficient CHP plants and one of the most developed district heating networks in the world. So yes, we believe that we can make a shit load of money from the competencies that we can sell."*
>
> (Interviewee: Jesper Steenberg, 2018)

The vast majority of Denmark's green sector growth transpired in West Jutland during the 1980s and 1990s (see *Figure 14*). For decades, Danish entrepreneurs used the wind Atlas developed by scientists at the Risø Institute in 1981 to exploit areas of high wind productivity (Araújo, 2017). According to one interviewee, by the late 1990s, a staggering *"80% of all wind turbines were produced in Denmark"* (Interview: Mark Augustenborg Ødum, 2018).

Figure 14: Green sector growth over time.



Adapted from AgoraEnergiewende and DTU, 2015.

As well as generating clean energy, the emergence of a green energy cluster has had enormous societal benefits. For example, some of Denmark's traditionally most deprived and problematic areas in West Jutland now have *"zero unemployment"* as a result of the wind industry boom (Interview: Rasmus Petersen, 2018). Rasmus also said that he often refers to the green cluster workers in West Jutland as the "*Armoury of the Green Transition"* because they will be responsible for the mechanisation of *Energy Strategy 2050.*

However, there are concerns that in the coming years Denmark's green energy cluster will suffer from a *'brain-drain'*. Siemens Wind Power, a top-ranked wind development company in Denmark, recently merged with Gamesa, a Basque engineering firm, to form Siemens Gamesa; the world's largest wind provider (Tweed, 2016). Although Siemens upheld a 59% share of the merge, the HQ of Siemens Gamesa is located in Bilbao, so there are genuine concerns that Denmark is at risk of losing some of its expertise and workforce (Interview: Iver Høj Nielsen, 2018).

Nevertheless, Denmark remains a world leader in the development and integration of RETs, with Danish companies such as Ørsted at the forefront of offshore wind park developments throughout Europe (Buch and Kjaer, 2015). All interviewees acknowledged that Denmark must continue using its green energy cluster as an *international brand*, which in turn, will translate into political pressure through the EU and UN, thus encouraging other countries to adopt similarly ambitious energy strategies (Interviews: Rasmus Petersen, 2018; Janne Wichard Henriksen, 2018; Iver Høj Nielsen, 2018).

4.4 GRID EXPANSION AND INTERNATIONALISATION

Prior to joining the Nord Pool market in 2000, Denmark's approach to resolving energy and climate issues was largely internalised within national confinements (Interview: Jesper Steenberg, 2018). However, in 2000, Denmark joined Norway, Sweden and Finland in the Nord Pool, resulting in the full integration of the Nordic Power markets (AgoraEnergiewende and DTU, 2015).

According to Rasmus Petersen (2018), *"we all need to stop seeing energy systems as networks confined to national boundaries"* because it is much cheaper, safer and secure to generate energy cooperatively. Observations of SPOT market prices have shown that a greater influx of hydropower from Norway, wind energy from Denmark and other forms of RE from Sweden and Finland have resulted in the downward pressure of electricity prices in the SPOT exchange (Interview: Jesper Troelsgaard Werling, 2018). SPOT market prices have fallen so drastically in recent years, that *"if you are to look at pure electricity prices (pre-tax), renewables are reducing the cost of electricity"* to such an extent that *"electricity prices in Denmark are actually some of the lowest in Europe"* (Interview: Esben Baltzer Nielsen, 2018).

As well as bringing down peak prices (Interview: Rasmus Petersen, 2018), trading electricity in the Nord Pool is said to be the cheapest store of electricity for Denmark. This is largely because Norway, Sweden and Finland suffer from *dry years*, where they miss out on rainfall and are therefore reliant on the import of Danish wind energy (Interview: Esben Baltzer Nielsen, 2018). By the same token, *"Denmark can also buy hydropower from Norway when domestic wind resources are running low"* (Interview: Rasmus Petersen, 2018).

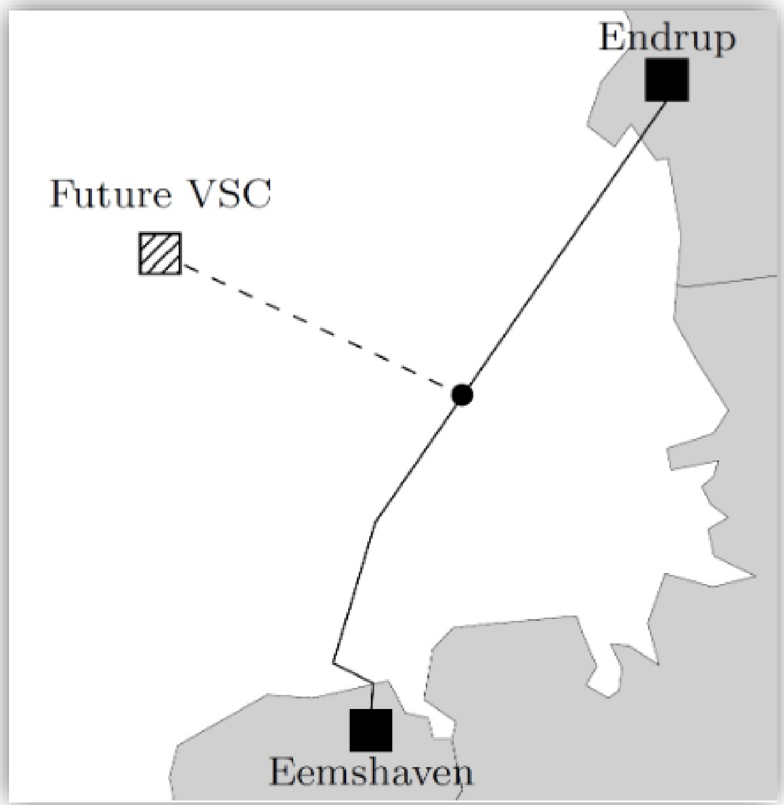
Although the Nord Pool's model of interdependence between countries producing in excess and those in deficit has served Denmark tremendously well, there are serious doubts about whether or not the same logic could be applied to a wider European framework:

“A number of EU member states want free energy markets, but local utilities want to protect their turfs and therefore don’t want an inflow of energy from neighbouring countries producing in excess.”

(Interview: Mark Augustenborg Ødum, 2018).

Despite such claims, we are starting to see a shift towards a European super grid. For instance, the 700 MW sub-sea COBRAcable between Eemshaven in the Netherlands and Endrup in Denmark is expected to be operational by July 2019 (see *Figure 15)*. The project is a partnership approach between the Dutch TSO, TenneT, and the Danish TSO Energinet.dk (Aalborg University, 2018). However, the COBRAcable is unique because unlike other interconnectors, it is designed with new technology, a Voltage Source Converter (VSC).

Figure 15: The COBRAcable interconnected with a VSC.



Source: Aalborg University, 2018.

The introduction of a VSC technology is crucial because it provides an option for directly connecting offshore wind farms to the COBRAcable. Thus, the COBRAcable is making huge strides in establishing an offshore grid in the North Sea, thereby strengthening the interconnectivity of the European transmission system (Aalborg University, 2018; Energinet.dk, 2018). From Denmark's perspective, the COBRAcable will help manage large fluctuating flows of wind energy (Interview: Esben Baltzer Nielsen, 2018).

4.5 Continued support for the development and integration of Renewable Energy

Traditionally, *"the biggest argument against RE was associated with costs, subsidies and the intermittency of supply"* (Interview: Esben Baltzer Nielsen, 2018). For instance, the first generation of wind turbines in Denmark were very expensive, *"perhaps five or six times more costly, but with the each generation the price of wind energy has fallen"* (Interview: Rasmus Petersen, 2018).

As a result of innovate subsidy schemes such as the fixed FIT (Mendonça, 2007), the price of onshore wind energy is generally the cheapest source of electricity in Denmark, and it has become apparent that:

> *"Wind turbines totally wreck the economics of coal generation"* because *"the economics of generating electricity through coal relies on base loads, which are not very flexible…*so *when you introduce both coal and wind into the electricity system, you realise that when the wind is blowing, the marginal price of wind energy is always lower than that of coal because the generation of an additional kilowatt is zero."*
>
> (Interview: Rasmus Petersen, 2018).

Despite the economic benefits of onshore wind generation, I was surprised to learn that *"there are very few onshore wind developments in Denmark at the moment because there is ongoing research into whether or not wind turbines have any cancer related impacts",* thankfully "*the intermediate* *answer to this research is that there are no cancer related impacts"* (Interview: Marie Münster, 2018).

Furthermore, the majority of Denmark's 5,000 or so onshore wind turbines were installed during the 1980s and 1990s and are much less efficient than their modern counterparts (Buch and Kjaer, 2015; IEA, 2017). Subsequently, as many of the older onshore models are decommissioned, we are starting to see a shift towards the more efficient offshore models (Interview: Iver Høj Nielsen, 2018).
The majority of Denmark's politicians are also very enthusiastic about offshore wind turbines because they generally provoke fewer NIMBY responses than their onshore cousins (Interview: Marie Münster, 2018).

When discussing RE in a Danish context, we must also refer to the rise of solar energy. According to the Vice President of Better Energy, *"the low cost of solar PV has become consensus in recent years"* (Interview: Mark Augustenborg Ødum, 2018). As a consequence of the falling price of solar PV, Denmark recently introduced a technology-neutral subsidy plan, whereby *"onshore wind, nearshore wind and solar energy will compete against each other"* (Interview: Esben Baltzer Nielsen, 2018).

The incentive for a technological-neutral subsidy is that in a few years, onshore wind capacities will be able to operate in the market without the assistance of subsidies (Interview: Mark Augustenborg Ødum, 2018). However, Janne Wichard Henriksen (2018) suggested that Denmark would be wise to take a strategic reserve pathway, having a few fossil fuel plants in reserves. Perhaps Janne's remarks are an indication that some elites are yet to be convinced that REs can compete with fossil fuels without subsidies?

Finally, a number of interviewees suggested that a greater electrification of the energy sector is required if Denmark is to integrate a larger of RE (Interviews: Jesper Steenberg, 2018; Janne Wichard Henriksen, 2018; Esben Baltzer Nielsen, 2018). This is because Denmark's main problem with wind energy penetration today is that there is often a surplus of supply, and without sufficient storage mechanisms, surplus wind energy is sold "*to Germany and the Netherlands at very low prices"* (Interview: Iver Høj Nielsen, 2018).

Ultimately, Denmark has demonstrated that it is technically and economically feasible to meet almost half of domestic electricity demand with renewables, but the next stage of *Energy Strategy 2050* is finding ways in which to store or utilise surplus wind power more efficiently (Interview: Esben Baltzer Nielsen, 2018). Although the road to 2050 will be a difficult one, all of the elites who participated in this study were confident that Denmark's energy system can achieve fossil fuel independence by 2050. Iver Høj Nielsen (2018) even highlighted that *"finding solutions to the world's sustainability challenges is exciting!"*

5.0 DISCUSSION

In this section, I discuss the significance of my results when evaluating *Energy Strategy 2050* from a socio-technical perspective. I also consider how certain aspects of *Energy Strategy 2050* might relate to the UK's energy system.

According to Iver Høj Nielsen (2018), the key to Denmark's RE transition success has been the political and societal desire to move in the same direction, but the origins of *Energy Strategy 2050* reside with the reactionary energy policies that were drafted in response to the oil crisis of 1973 (Fawkes, 2013; Lund; 2010; Araújo, 2017).

Danske Energipolitik (1976) was the Danish Government's first attempt at reducing fossil fuel imports, but rather than prioritising RETs such as wind turbines and solar PV, *Danske Energipolitik* focused on a comprehensive deployment of nuclear generating capacities (Lund and Mathiesen, 2009; AgoraEnergiewende and DTU, 2015). Subsequently, it would appear as though Denmark has not always had a political and societal desire to move in the same direction. Without the grass-roots activism of the OOA and OVE, as well as then bottom-up innovation of local wind cooperatives, Denmark's energy system might not have undergone a multi-decade RE transition fixed upon a high penetration wind energy (Araújo, 2017).

However, Denmark's *sustainable democratic infrastructure* has, and will continue, to play a major role in realising the cross-sectoral objectives of *Energy Strategy 2050* (Lund, 2010; AgoraEnergiewende and DTU, 2015; Lund et al., 2017). Without *sustainable democratic infrastructure*, the OOA, the OVE and local wind cooperatives would have failed to establish a political platform on which they could challenge the dominance of coal and oil, as well as proposals for nuclear generating capacities (Greenpeace, 2014; Araújo, 2017).

Ultimately, *sustainable democratic infrastructure* has allowed Choice Awareness theory to thrive in Danish society. Those who participated in early wind turbine cooperatives clearly felt as though they had a choice regarding energy and climate issues, and that they could shape their own future by investing in RETs (Meyer, 2004; Lund, 2010; Araújo, 2017).

Conversely, Esben Baltzer Nielsen (2018) believes that in contemporary Danish society, *"there is not a huge diehard climate change contingent",* and that *Energy Strategy 2050* is *"not very fanatical"* but rather a *"pragmatic approach to climate and energy issues"*. Despite such claims, literature on energy attitudes and behaviours in Denmark suggests that Danish citizens generally consider themselves as being eco-friendly (Sovacool and Blyth, 2015; Schick and Gad, 2015). However, Stig Nørgaard Knudsen (2018) emphasised that should green taxes on electricity and electrical heat increase as a means of generating fiscal income for *Energy Strategy 2050, "people would look away from the green transition".* This is a worrying statement given that over the last three decades, the Danish Government has worked tirelessly to secure a more sustainable energy future for Danish society (Lund et al., 2012; Araújo, 2017).

Despite Stig's comments, it would appear as though energy consumers in Denmark need not worry about rising energy costs because the Danish Government have targeted substantial tax reductions on the price of electricity and electrical heat for the first time since the liberalisation of the Danish energy sector at the start of the 21st century (Interview: Janne Wichard Henriksen, 2018).
In addition, according to Marie Münster (2018) *"several studies have found that Energy Strategy 2050 will only cost a few percentage of GDP".* Some of the studies Marie was referring to include: Lund and Mathiesen, 2009; Lund et al., 2010; Mathiesen et al., 2015; IDA, 2015, all of which I have made reference to in this research.

Like all of the interviewees in this study, I am confident that *Energy Strategy 2050* will succeed because *"there is a broad coalition among left wing environmental thinkers, a middle-section of society concerned with environmental health and energy security, and the right-wingers, who believe that the environmental discourse is good for business"* (Jesper Steenberg, 2018). Although the elites who participated in this research are working towards *Energy Strategy 2050* for their own individual reasons, all the elites I interviewed acknowledged that RE transitions such as *Energy Strategy 2050* are necessary if we are to successfully combat the imminent threat of climate change.

Regarding smart energy systems thinking, the Danish Government should increase the subsidies for HP and EB installations because they are efficient and flexible technologies, that when combined, can assist Denmark in the conversion of surplus wind energy into useful heat energy (Interviews:

Jesper Steenberg, 2018; Marie Münster, 2018). According to Lindboe and Werling (2015), whenever wind production exceeds 20% of annual electricity demand in Denmark, which it does on a regular basis, there is a high feasibility for investing in flexible energy systems infrastructure such as the installation of large-scale HPs at CHP plants. As well as assisting Denmark in the management of a fluctuating supply of wind energy, by electrifying the heat sector with the deployment of HPs and EBs, Denmark's reliance on finite biomass stocks will diminish (Zvingilaite and Balyk, 2014; IDA, 2015; Nielsen et al., 2015 Lund et al., 2017).

Although the benefits of HPs and EBs can be clearly observed in my results and in the wider smart energy systems literature, the dissemination of HPs in Denmark has been exceptionally poor in comparison with neighbouring countries such as Sweden and Finland (Nyborg and Røpke, 2015; Nielsen et al., 2015; DEA, 2018). In order to meet the DEA's quota of 300,000 HP installations in individual households by 2025 (DEA, 2018), Nyborg and Røpke (2015), have proposed the introduction of user-run internet forums, so that top-end technical assistance can be provided to individual homeowners interested in purchasing a HP for their home.

However, Schick and Gad (2015) claim that HPs are a special privilege for a minority who invest in smart storage technologies, and that in order to increase individual HP installations, tariff packages, similar to that of mobile phones should be introduced. For example, if a customer living in the periphery of rural Denmark wants to install a HP but cannot afford to, customers who offer greater flexibility (i.e. enabling an operator to turn the HP on and off between 17-25 °C rather than the more expensive 20-22 °C), should be rewarded with cheaper installation and running costs. It should also be noted that the installation of HPs requires the skills of several crafts, including plumbers, electricians and HVACs (Nyborg and Røpke, 2015), so just like wind turbine cooperatives, HPs offer an array of employment opportunities for individuals interesting in working within Denmark's green energy cluster.

Moving on, I have also discovered that there is much controversy regarding the use of biomass in the Danish energy system (Lund et al., 2012; Münster et al, 2012; IDA, 2015; Drysdale and Mathiesen, 2018). The conversion of CHP plants from running on coal to biomass is a great way to avoid stranded assets during the phase-out of coal, but biomass should be regarded as an intermediate solution in *Energy Strategy 2050* (Interviews: Janne Wichard Henriksen, 2018; Marie Münster, 2018).

Although Jesper Werling (2018) informed me that sustainably sourced biomass can deliver 20-30% of Denmark energy needs by 2030, Marie Münster (2018) from DTU has her reservations, mainly due to the lack of bio-refineries in Denmark. Without sufficient bio-refinery capabilities, Denmark's growing dependence on imported biomass for more than 40% of its DH needs could result in severe energy insecurities in the long-term, should political relationships with the suppliers of that biomass breakdown (Marie Münster, 2012; Gregg et al., 2014). One interviewee suggested that Denmark should exploit its large reserves of manure (mainly derived from pig faeces) for biomass production, but the required technological innovations for such methods are yet to be refined (Interview: Jesper Steenberg, 2018).

Like Denmark, the UK is heavily reliant on biomass imports. Although biomass accounts for 75% of the UK's RE production, just 30% of the UK's biomass is sourced domestically (Ward and Inderwildi, 2013). Some studies have suggested that as much as 10% of the UK's entire land mass would need to be dedicated for growing wood for fuel if biomass was to replace coal as the main source of heat in the UK. It goes without saying that such as substantial diversion of land-use would ignite conflict with food production and other interests groups such as the housing industry, particularly in a relatively densely populated country such as the UK (Goodall, 2008 Ward and Inderwildi, 2013; Gregg et al., 2014).

Another topic of interest in Denmark is the utilisation of industrial excess heat. According to Bühler et al (2017), 2.37 TWh of accessible industrial excess heat could supply 1.36 TWh of useful heat to Danish consumers every year. However, the bulk of Denmark's potential for greater thermal efficiencies in industrial heating is located in the industrial hubs of Aalborg, Fredericia and Kalundborg, with very limited potential in the capital region of Greater Copenhagen. Marie Münster (2018) explained that by installing large-scale HPs at these industrial hubs, the temperate of the lukewarm water coming out of industries can be pumped to temperatures of around 80°C, and therefore used to heat thousands of homes in a centralised area. Having centralised heating solutions is crucial to Denmark's energy mix given the predominately decentralised quality of wind turbine production (Interviews: Janne Wichard Henriksen, 2018; Mark Augustenborg Ødum, 2018).

Sadly, the UK's energy planning is extremely deficient in comparison with that of Denmark (Cooper et al., 2016). Whilst occupying the role of Minister of Climate and Energy, Ramus Petersen and the

District Heating Board of Denmark evaluated excess heat opportunities in the UK, and discovered that if waste heat energy in London was recovered efficiently, it could provide 80% of the London's entire heating needs. However, Rasmus revealed to me that very little is being done to make better usage of waste heat in the British capital.

The utilisation of waste heat is often overlooked by politicians because it does not present the same *ribbon cutting* opportunities as unveiling a 600 MW offshore wind park would do (Fawkes, 2013; Lund et al., 2017). The same can be also be said about efficiency improvements made in existing buildings. According to Zvingilaite and Balyk (2014), the greatest potential of all efficiency improvements in Denmark can be made in existing building stock, and this was reiterated by Stig Nørgaard Knudsen (2018), the Head of Sustainable Building Design at DEM. Stig informed me that "*perhaps 60% of all energy usage in Denmark occurs in old buildings, where we are yet to make efficiency improvements*". Intriguingly, although efficiency improvements are one of two key pillars in any RE transition (AgoraEnergiewende and DTU, 2015; Drysdale and Mathiesen, 2018), Stig was the only interviewee to explicitly mention their importance. Perhaps this is an indication that RETs are the dominant topic of conversation among elites in Denmark and that efficiency improvements are often neglected when discussing *Energy Strategy 2050.*

Furthermore, Denmark is in an advantageous position geographically, operating as an extremely interconnected hub between the Nordic and continental power system, using the SPOT market and large-scale interconnectors to distribute fluctuating flows of wind energy (Interview: Esben Baltzer Nielsen, 2018). However, my research findings suggest that Denmark must increases its overall interconnectivity throughout Europe to alleviate congestion in the SPOT market due to the large penetration of fluctuating RE (Interview: Jesper Troelsgaard Werling, 2018). Esben Baltzer Nielsen (2018) highlighted the importance of the COBRAcable between the Netherlands and Denmark for the whole of Europe, because this interconnector uses a VSC technology that is capable of directly connecting offshore wind farms. The inclusion of VSC technology means that the construction of the COBRAcable is the first of many development phases in establishing an offshore power grid out in the North Sea (Aalborg University, 2018; Energinet.dk, 2018).

For Denmark, establishing an offshore wind grid in the North Sea would prove to be extremely advantageous (Interviews: Esben Baltzer Nielsen, 2018; Mark Augustenborg Ødum, 2018). Many of

Denmark's onshore wind turbines are reaching the end of their lifetime and this presents an opportunity to replace these obsolete units with more efficient offshore turbines, such as the 10 MW units recently developed by Siemens Gamesa (Buch and Kjaer, 2015; Elliot, 2019). In addition, going offshore is also in the best interest of Danish politicians and society. Many communities in Jutland are starting to resent the sheer density of onshore wind turbines (Landenberg, 2007), and the Danish Government are awaiting the results of research into whether or not wind turbines expose local residents to cancerous radiation (Interview: Marie Münster, 2018).

From a UK perspective, it is crucial that we embrace the expert knowledge of Danish elites who specialise in the development of offshore wind parks and other RETs. Thankfully, there are some indications that the UK is working hard to establish strong relations with Denmark. For example, Ørsted, Denmark's largest energy company, was recently awarded the contract for the Hornsea Project One, a wind farm off the east coast of England that will generate a staggering 2,400 MW of electricity each year upon completion in 2020 (Ørsted, 2019). A combination of VSC technologies and high capacity offshore wind farms such as Hornsea Project One, will allow for a more flexible and sustainable power production between the UK and Denmark.

Ultimately, by engaging in business partnerships with Ørsted and other Danish companies who specialise in RE transitions, the UK can strengthen its government-to-government relations Denmark, and subsequently apply the lessons learn from *Energy Strategy 2050* in a UK context. However, the absence of *sustainable democratic infrastructure* in the UK following the 2016 EU membership referendum will prevent the UK from implementing energy and climate strategies as ambitious as *Energy Strategy 2050.*

6.0 Conclusion

The aim of this study was to evaluate how the Danish energy system will achieve fossil fuel independence by 2050. Although numerous studies have demonstrated that a 100% RE transition is technically and financially feasible in Denmark by 2050 (Lund and Mathiesen, 2009; Lund et al., 2010; Mathiesen et al., 2015; IDA, 2015), they have neglected the social components of Denmark's RE transition. In order to account for the social aspects of *Energy Strategy 2050*, I interviewed nine elites working in a variety of senior positions within Denmark's energy sector. I specifically targeted elites for this study because of their unique knowledge and expertise in this field study. I used the data obtained from the elites to produce a socio-technical evaluation of *Energy Strategy 2050* in a narrative format.

My results show that there are many challenges associated with *Energy Strategy 2050*, including; the poor dissemination of storage and conversion technologies that can assist in the management of a high penetration of fluctuating wind energy, the unsustainable use of biomass, congestion in the Nord Pool market and a growing sense of frustration towards onshore wind turbines. Although in the discussion section I recommended some solutions to these issues, all of these topics merit further investigation when evaluating *Energy Strategy 2050.*

Nevertheless, my results highlight that Denmark is in a strong position. It is well connected with the continental and Nordic power systems, has a flexible DHN, is a world leader in RE development and integration and most importantly, has the political infrastructure and societal competencies to achieve a 100% RE transition by 2050. I conclude that due to the *sustainable democratic infrastructure* prevalent in Danish society, the overarching aim of a fossil fuel independent energy system will be achieved by 2050. The stability of Denmark's political landscape has supported the emergence of a smart energy system, capable of integrating a large share of RE.

My experience of interviewing elites in the Danish sector was a very productive one. The elites who participated in this study are genuinely invested in *Energy Strategy 2050*, and their willingness to share in-depth knowledge and expertise with a foreign researcher was truly remarkable. I can only hope that other researchers from the UK will seek out the same knowledge sharing opportunities as I did because there is much we can learn from Denmark's elites when it comes to RE transitions.

References

Aalborg University. 2018. *COBRAcable*. [Online]. [Accessed 18 February 2019]. Available from: https://www.cobracable.et.aau.dk/about/about/

AgoraEnergiewende and DTU Management Engineering. 2015. *A Snapshot of the Danish Energy Transition: Objectives, Markets, Grid, Support Schemes and Acceptance*. [Online]. [Accessed 17 November 2017]. Available from: https://www.agora-energiewende.de/en/publications/a-snapshot-of-the-danish-energy-transition/

Araújo, K. M. 2017. *Low Carbon Energy Transitions: Turning Points in National Policy and Innovation.* New York: Oxford University Press.

Arksey, H. and Knight, P.T. 2011. *Why Interviews? Interviewing for Social Scientists*. London: SAGE Publications Ltd.

Bointner, R. 2014. Innovation in the energy sector: Lessons learnt from R&D expenditures and patents in selected IEA countries. *Energy Policy*. **73** (3), pp. 733-747.

Boyle, G. 1977. *Living on the Sun: Harnessing Renewable Energy for an Equitable Society.* 2^{nd} ed. London: Marion Boyars Publishers Ltd.

Brundtland Commission (WCED). 1987. *Our Common Future*. Oxford: Oxford University Press.

Buch, M. & Kjaer, E. 2015. *Offshore Wind Development*. Danish Energy Agency. [Online]. [Accessed 20 October 2018]. Available from: https://ens.dk/sites/ens.dk/files/Globalcooperation/offshore_wind_development.pdf

Bühler, F., Petrovic, S., Karlsson, K.B., Elmegaard, B. 2017. Industrial excess heat for district heating in Denmark. *Applied Energy.* **205** (1), pp. 991-1001.

Christensen, T.B. 2015. *Vattenfall skal opføre Horns Rev 3*. Energiwatch. [Online]. [Accessed 6 January 2019]. Available from: http://energiwatch.dk/Energinyt/Renewables/article7487416.ece

Cooper, G., Hammond, G.P., & Norman, J.B. 2016. Potential for use of heat rejected from industry in district heating network: A Great Britain perspective. *Journal of Energy Industry*. **89,** pp. 57-69.

Danish Ministry of Energy, Climate and Utilities. 2018. *Energy Agreement 2018*. [Online]. [Accessed 2 10 January 2019]. Available from: https://en.efkm.dk/media/12307/energy-agreement-2018.pdf

Davis, M. 2010. Concept mapping, mind mapping and argument mapping: what are the differences and do they matter? *Higher Education.* **62** (3), pp. 279–301.

DEA. 2018. *Energy – for a green Denmark*. [Online]. [Accessed 9 December 2018]. Available from: https://en.efkm.dk/media/11857/energiudspillet_eng.pdf

Drysdale, D. & Mathiesen, B.V. 2018. Transitioning to a 100% renewable energy system in Denmark by 2050: assessing the impact from expanding the building stock at the same time. *Energy Efficiency*. **12** (1), pp. 37-55.

Elliot, H. 2019. Siemens Gamesa launches 10MW wind turbine. Project Finance. London: Euro money Institutional Investor PLC.

Energienet.dk. 2017. *COBRAcable*. [Online]. [Accessed 20 October 2018]. Available from: http://www.cobracable.eu/

Energinet.dk.2019. *COBRAcable: Interconnectors to the Netherlands*. [Online]. [Accessed 18 March 2019]. Available from: https://en.energinet.dk/Infrastructure-Projects/Projektliste/COBRAcable

Energistyrelsen 2017. Energikommissionen. Anbefalinger til Fremtidens Energipolitik, pp. 78-79.

Eurostat. 2015. *Europe 2020 indicators - climate change and energy*. [Online]. [Accessed 3 March 2019]. Available from: https://ec.europa.eu/eurostat/statistics-explained/index.php/Europe_2020_indicators_-_climate_change_and_energy#Key_messages

Fawkes, S. 2013. *Energy Efficiency: The Definitive Guide to the Cheapest, Cleanest, Fastest Source of Energy*. Farnham: Gower Publishing Limited.

Goodall, C. 2008. *Ten Technologies to Save the Planet*. London: Green Profile.

Greenpeace. 2014. *Denmark's commitment to 100% renewable energy*. Greenpeace briefing. [Online]. [Accessed 16 December 2018]. Available from: http://www.go100re.net/wp-content/uploads/2014/10/GP-and-WFC_Denmarks-commitment-to-100-renewable-energy.pdf

Gregg, J.S., Bolwig, S., Solér, O., Vejlgaard, L., Holst Gundersen, S., Grohnheit, P.E., 2014. Experiences with biomass in Denmark. [Online]. [Accessed 23 March 2019]. Available from: http://orbit.dtu.dk/files/97912187/Experiences_with_biomass_in_Denmark.pdf

Harvey, W.S. 2011. Strategies for conducting elite interviews. *Qualitative Research.* **11** (4), pp. 431–441.

Houmøller, A.P. 2014. Scandinavian Experience of Integrating Wind Generation in Electricity Markets. In: Jones, L.E. *Renewable Energy Integration*. London: Elsevier, pp. 53-66.

IDA. 2015. *IDA's Energy Vision 2050: A Smart Energy System strategy for 100% renewable Denmark*. [Online]. [Accessed 29 October 2018]. Available from: http://vbn.aau.dk/en/publications/idas-energy-vision-2050(2439d020-cdb6-4526-a89c-4dfebd73b900).html

IEA (International Energy Agency). 2017. *Energy policies of IEA countries: Denmark review*. [Online]. [Accessed 15 October 2018]. Available from: https://www.iea.org/publications/freepublications/publication/EnergyPoliciesofIEACountriesDenmark2017Review.pdf

IEMA 2017. Wind energy prices hit record low. *Environment and Sustainability*, p.5.

IRENA (International Renewable Energy Agency). 2013. *30 Years of Policies for Wind Energy: Lessons from 12 Wind Energy Markets*. [Online]. [Accessed 20 February 2019]. Available from: file:///C:/Users/Jay/Documents/University%20of%20Leeds-Year%204/Danish%20Energy%20Transition%202050/Literature/30yrs%20of%20wind.pdf

Jacobsen, H. & Schroder, S.T. 2012. Curtailment of renewable generation: Economic optimality and incentives. *Energy Policy*, **49** (1), pp. 663-675

King, N. & Horrocks, C. 2010. *Interviews in Qualitative Research*. London: SAGE.

Kirchherr, J. & Charles, K. 2018. Enhancing the sample diversity of snowball samples: Recommendations from a research project on anti-dam movements in Southeast Asia. *PLOS One.* **13** (8), pp. 1-17.

Krause, F., Bossel, H., Muller-Reißmann, K.F. 1982. Energiewende: Growth and Prosperity without Oil and Uranium. Frankfurt: Fischer Verlag.

Landenberg, J. 2007. Attitudes on-land and offshore wind power development: Denmark; choice of development strategy. *Renewable Energy*. **33** (1), 111-118.

Lindboe, H.H & Werling, J. 2015. *Integration of wind power*. Ea Energy Analysis. [Online]. [Accessed 10 February 2019]. Available from: http://ea-energianalyse.dk/projects-english/1550_integration_wind_viking_link.html

Lovins, A. 1977. *Soft Energy Paths: Toward a Durable Peace*. San Francisco: Friends of the Earth International.

Lund, H. 2000. Choice awareness: the development of technological and institutional choice in the public debate of Danish energy planning. *Journal of Environmental Policy and Planning*. **2** (3), pp. 249-259.

Lund, H. 2010. *Renewable Energy Systems: The Choice and Modelling of 100% Renewable Solutions*. San Diego: Elsevier.

Lund, H., Andersen, A.N., Østergaard, A., Mathiesen, B.V., & Connolly, D. 2012. From electricity smart grids to smart energy systems - A market operation based approach and understanding. *Energy*. **42** (1), pp. 96-102.

Lund, H., Østergaard, P.A., Connolly, D & Mathiesen, B.V. 2017. Smart energy and smart energy systems. *Energy*. **137** (1), pp. 556-565

Lund. H. & Mathiesen, B.V. 2009. Energy system analysis of 100% renewable energy systems: The case of Denmark in years 2030 and 2050. *Energy*. **34** (5), pp. 524-531.

Marshall, C. & Rossman, G.B. 2006. *Designing Qualitative Research*. 4th Ed. California: SAGE Publications Ltd.

Mathiesen, B.V., Lund, H., Connolly, D., Wenzel, H, Østergaard, P.A., Möller, B. & Nielsen, S., Ridjan, I., Karnøe, P., Sperling, K. & Hvelplund, F.K. 2017. Smart Energy Systems for coherent 100% renewable energy and transport solutions. *Applied Energy*. **145** (1), pp. 139-154.

Meadows, D., Meadows, D., Randers, J., & Behrens III, W. 1972. *The Limits to Growth*. New York: Universe Books.

Mendonça, M. 2007. *Feed-in Tariffs: Accelerating the Deployment of Renewable Energy*. London: Earthscan.

Meyer, N. 2004. Development of the Danish Wind Power Market. *Energy and Environment*. **15** (4), pp. 657-673.

Mikecz, R. 2012. Interviewing Elites: Addressing Methodological Issues. *Qualitative Inquiry.* **18** (6), pp. 482–493.

Moser, F. & Schnitzer, H. 1985. *Heat Pumps in Industry*. Amsterdam: Elsevier Science Publisher B.V.

Münster, M., Morthorst, P.E., Larsen, H.V., Bregnbæk, L. and Werling, J. 2012. The role of district heating in the future Danish energy system. *Energy*. **48** (1), pp. 47-55.

Natow, R.S. 2019. The use of triangulation in qualitative studies employing elite interviews. *Qualitative Research.* **1** (1), pp. 1-14.

Nielsen, M.G., Morales, J.M., Zugno, M., Pedersen, T.E. 2015. Economic valuation of heat pumps and electric boilers in the Danish energy system. *Applied Energy.* **167** (1), pp. 189-200.

Nyborg, S. & Røpke, I. 2015. Heat pumps in Denmark - From ugly duckling to white swan. *Energy Research & Social Science*. **9** (1), pp. 66-177.

Ørsted. 2019. *Hornsea Project Three.* [Online]. [Accessed 15 March 2019]. Available from: https://hornseaproject3.co.uk/About-the-Project#0

Parajuli, R. 2012. Looking into the Danish energy system: Lesson to be learned by other communities. *Renewable and Sustainable Energy Reviews*. **16** (4), pp. 2191-2199.

Rapley, T. 2011. Interviews: *Qualitative Research Practice*. [Online]. 2nd Ed. London: SAGE Publications Ltd. [Accessed 6 March 2018]. Available from: http://dx.doi.org/10.4135/9781848608191

Rockström, J. 2009. Planetary Boundaries: Exploring the Safe Operating Space for Humanity. *Ecology and Society.* **14** (2), pp. 1-33.

Saldana, J. 2009. *The Coding Manual for Qualitative Researchers*. California: SAGE Publications Ltd.

Salgi, G. & Lund, H. 2007. System behaviour of compressed-air energy-storage in Denmark with a high penetration of renewable energy source. *Applied Energy*. **85** (1), pp. 182-189.

Schick, L. & Gad, C. 2015. Flexible and inflexible energy engagements: A study of the Danish Smart Grid Strategy. *Energy Research & Social Science*. **9** (1), pp. 51-59.

Shankleman, J. 2016. *The World's Cheapest Offshore Windfarm*. [Online]. [Accessed 2 February 2019]. Available from: http://www,bloomerg.com/news/articles/2016-06-02/vattenfall-accelerates-record-offshore-wind-project-in-denmark

Sovacool, B.K., Kester, J., Ruben, G.Z., & Lance Noel, L. 2018. Expert perceptions of low-carbon transitions: Investigating the challenges of electricity decarbonisation in the Nordic region. *Energy*. **56**, pp. 86-100.

Sovacool, B.K. & Blyth, P.L. 2015. Energy and environmental attitudes in the green state of Denmark: Implications for energy democracy, low carbon transitions, and energy literacy. *Environmental Science & Policy.* **54** (1), pp. 304-315.

Tansey, O. 2007. Process Tracing and Elite Interviewing: A Case for Non-Probability Sampling. *Political Science and Politics.* **40** (4), pp. 765-772.

Tweed, K. 2016. *Siemens and Gamesa Merge To Form Mega Wind Company*. New York: SyndiGate Media Inc.

Unruh, G. 2000. Understanding Carbon Lock-in. *Energy Policy*. **28** (12), pp. 817-830.

Vasi, I. 2011. *Winds of Change: A Comparative Study of the Politics of Wind Energy Innovation in California and Denmark*. Utrecht: International Books.

Ward, D.J. & Inderwildi, O.R. 2013. Global and local impacts of UK renewable energy policy. *Energy Environment*. **6** (18), pp. 18-24.

Weiss, R. 1994. *Learning from strangers: the art and method of qualitative interview studies*. New York: Free Press.

Wright. P.D. 2015. Renewable Energy and the Public: From NIMBY to Participation. 2nd ed. New York: Earthscan.

Zvingilaite, E. & Balyk, O. 2014. Heat savings in buildings in a 100% renewable heat and power system in Denmark with different shares of district heating. *Energy and Buildings*. **82** (1), pp. 173-186.

APPENDIX 1: INTERVIEW PROTOCOL AND STRUCTURE

Script to introduce interview and research agenda

- I am an undergraduate Sustainability and Environmental Management (BSc) researcher from the University of Leeds, but I am currently on a Study Abroad exchange at the University of Copenhagen.
- For my dissertation, I will be evaluating Denmark's Green Energy Transition or 'Grøn Omstilling' from a socio-technical perspective. Whilst living in Copenhagen, I will be conducting elite interviews with individuals from various agencies, companies and institutions within the Danish energy sector.
- I would like to spend roughly 30 minutes with you today, discussing the feasibility of *Energy Strategy 2050*. I would like to obtain your perspective on various aspects of the green energy transition in Denmark, including: how renewable forms of energy, political stability and public opinion might influence Denmark's green energy transition for 2050.
- Have you any questions or concerns regarding this research? (yes/no)
- Finally, do approve my usage of any information obtained in this interview when I write my dissertation? (yes/no)

The interview was split into six sections (labelled parts A-F), and I have justified the inclusion of each section:

Part A. Personal and Organisational outlook

This section established an understanding of the interviewee's background in Denmark's energy sector and how their work contributes towards *Energy Strategy 2050.*

Part B. Political Stability / Public Attitudes and Behaviours

This section encouraged interviewees to consider the political climate in which Denmark's energy sector has evolved over time. Since the interviews were semi-structured, interviewees were unrestricted in their response. As a result, the interviews were very open-ended (King and Horrocks, 2010). In the second part of this section, interviewees were asked if they believe that Danish citizens would be willing to pay more than what they are currently paying in energy costs to support Denmark's RE transition. Such questions were framed on the basis that household electricity prices in Denmark (29.8 eurocents/kWh) are among the highest in Europe (Sovacool and Blyth, 2015).

Part C: District Heating and the use of Biomass

An extensive literature review of the Danish energy sector revealed that DH and the use of biomass will play major roles in *Energy Strategy 2050*. This is mainly because DH is accountable for roughly 60% of Danish heating needs, and in most cases, DH can absorb heat regardless of how it is produced, allowing a relatively simple conversion of coal to biomass production (Münster et al, 2012). Subsequently, this section was designed to explore the more technical aspects of *Energy Strategy 2050*, including; the use of heat pumps (HPs) in DH and the role of biofuels in the transport sector.

Part D: Renewable Energy Technologies (RETs)

Denmark already enjoys a comprehensive penetration of wind energy, responsible for approximately 42.5% of total electricity demand (IEA, 2017). According to Araújo (2017) offshore wind developments are now leading the way in terms of new wind turbine installations, so this section was designed to identify future trends in the development and integration of wind turbine technologies when moving towards the 2050 objectives. This section also allowed interviewees to discuss the importance of other RETs such as solar photovoltaic (PV).

Part E: Nord Pool Market

In this section, interviewees had the opportunity to discuss the energy security and economic advantages of trading electricity in the Nordic Power Market (Nord Pool). However, to ensure that my questions were non-leading, interviewees also had the opportunity to identify any challenges associated with integrating a larger share of fluctuating renewable energy within the Nord Pool (Rapley, 2011). The main aim of this section was to determine how the interviewees perceived Denmark's role as an inter-connected hub between the Nordic and continental power systems.

Part F: Closing questions

Finally, interviewees were asked to identify what they consider to be the driving factor(s) in Denmark's green energy transition since the 1990s. Some interviewees challenged the premise of the question, stating that the transition began much earlier than the 1990s. However, by allowing interviewees to challenge the question, interviewees began to add more depth in their response.

To add a personal touch at the end of the interview, respondents were asked if they had any thoughts on how the green energy transition for 2050 might be improved. This was a fantastic way to end the interview because at this stage I had built trust and rapport with the interviewees, and they were confident enough to critique many aspects of *Energy Strategy 2050*, which they might not have done earlier in the interview process (Harvey, 2011; Mikecz, 2012).

APPENDIX 2: INTERVIEW QUESTIONS

Part A: Personal/organisational outlook

1. Firstly, could you tell me a little bit about your role at _____?

2. In your own words, what does the Green Energy Transition or Grøn Omstilling mean to you?

3. Do you believe that a 100% share of renewable energy supply, based on domestic resources, is technically and financially possible by the year 2050?

4. Can you identify any initiatives here at _____ which support the Green Energy Transition in Denmark? If so, please could you explain how they are helping to decarbonise the Danish Energy System.

Part B: Political Stability / Public Attitudes and Behaviours

1. Do you believe that there is a broad consensus in Danish politics towards a reduction in energy consumption & increased utilisation of renewable energy?

2. A recent study by Sovacool et al (2015) claimed that Danish people have a *"high acceptance of green taxes"*. Do you consider this statement to be true/false and please could you explain your answer?

3. Could you perhaps explain why household electricity prices in Denmark are some of the highest in Europe (approximately 29.8 Eurocents per KWh) and why CO_2 emissions per capita are also among the highest in the world?

4. Do you believe that Danes would be willing to *pay more* for the Green Energy Transition than what they are currently paying in energy costs?

Part C: District Heating and the use of Biomass

1. With three major national grids, the Danish Energy System is both diverse and decentralised. How important is it having a diverse energy mix?

2. District heating is accountable for roughly 60% of Danish heating and in most cases will absorb heat *"no matter how it is produced"* (Munster, 2012), but how do you think district heating would best adapt to a greater share of renewable generation?

- Large heat pumps-utilising the excess power production from wind turbines
- Conversion of coal-fired power plants into biomass/other renewables forms of heating
- Conversion of natural gas plants into district heating buildings
- Other?

3. How important is the use of biomass for *Energy Strategy 2050*?

4. Do you have any concerns with the deployment of biomass (if any)?

5. Although biomass could supply 10% of Danish transport by 2020, the petroleum industry continues to dominate the transport sector. What do you think could be done to incorporate more renewables into the transport sector?

Part D: Renewable Energy Technologies (RETs)

A) Onshore wind energy is the cheapest renewable technology in terms of production, but how important is the cost of renewable technologies in influencing future energy development trends?

B) Is it true that Denmark's capacity for wind generation has almost peaked?

Part E: Nord Pool Market

C) As more renewables enter the Nordic power system, electricity prices are set to rise. Can Denmark simultaneously integrate more renewables and prevent volatile electricity prices?

D) What can you tell me about *Markedsmodel (new market design)* and how that might help facilitate Denmark's Green Energy Transition?

- Clean price signals-improved framework for investment
- Strategic reserve in order to secure capacity in extreme situations
- Capacity market- implying a direct payment for capacity

Part F: Closing questions

E) What do you think is driving Denmark's 36% reduction in fossil fuel consumption since 1990?

- Efficiency improvements
- Policies/political stability
- Renewable uptake (biomass/wind/other)
- Grid expansion
- Public acceptance

F) Do you have any thoughts on how the Green Energy Transition could be improved?

G) Have you anything else to add in regards to the Green Energy Transition that we haven't previously discussed?

APPENDIX 3: LETTER AND CONSENT FORM

Research agenda and consent forms that were attached to the email invitations to participate in my research.

Letter

School of Earth and Environment
University of Leeds
Leeds LS2 9J5
Date

Dear ____

I am an undergraduate Sustainability and Environmental Management (BSc) student from the University of Leeds, but I am currently on a Study Abroad exchange at the University of Copenhagen.

For my thesis, I am evaluating how Denmark's Green Energy Transition or *'Grøn Omstilling'* might be achieved. My primary research method is conducting elite interviews with individuals from various agencies, companies and institutions within the Danish energy sector.

Subsequently, I would like to spend roughly 30 minutes with yourself discussing the role of renewable energies, political stability and public opinion in the decarbonisation of the Danish society.

Please find attached a copy of the interview protocol. If you trust that you or your organisation can contribute towards any aspect of my research, do not hesitate to contact me by ll14jlf@leeds.ac.uk or (+45) 7305488386 so that we can arrange an interview date and time.

Yours sincerely

Jay Farrar

UNIVERSITY OF LEEDS

Consent to take part in University of Leeds research

SOEE3030 Environmental Research Project: Elite Interview

	Add your initials next to the statements you agree with
I understand the purpose of this research project and the significance of my contributions in this environmental research. Additionally, I have had numerous opportunities to ask questions regarding the research process.	
I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason and without there being any negative consequences. In addition, should I not wish to answer any particular question or questions, I am free to decline.	
I understand that the data collected from me today will be anonymised, and that I will not be referred to directly in the assignment that the student produces as a result of this research.	

Name of participant	
Participant's signature	
Date	
Name of person taking consent	
Signature	
Date	

APPENDIX 4: RISK ASSESSMENT

*Please note, under page 6 of the risk assessment, I have attached a screenshot from Becki Thomas, confirming that my Academic Supervisor, Dr. Lucie Middlemiss and the Health and Officer at the University of Leeds were happy for me to conduct this research in Copenhagen.

UNIVERSITY OF LEEDS

Faculty of Environment

TAUGHT STUDENT DISSERTATION FIELDWORK RISK ASSESSMENT

Name	Jay Louis Farrar
Contact Details (email/ phone)	ll14jlf@leeds.ac.uk / 07305488386
School / Institute	School of Earth and Environment
Module Code	SOEE3030

ASSESSMENT

If you need any help in completing the assessment please refer to the supporting documentation or contact FOE-safety@leeds.ac.uk

Document Title	Reference Number	Version	Author	Issue Date	Status	Page Number
Faculty of Environment Taught Student Dissertation Risk Assessment	FOE4.5.6.1	1.0	SEB		Final	1 of 6

-

Faculty of Environment UNIVERSITY OF LEEDS

Summary of Project Proposal *Include a clear summary description of all the fieldwork data collection tasks, methodology and activities you intend doing.*	Research Question- How will the Danish energy system achieve fossil fuel independence by 2050? Aims of research: -How might this transition be achieved? (i.e. what forms of renewable energy will be deployed / policies in favour of renewable energy integration / the growth of a green energy cluster) Roughly ten semi-structure elite interviews will be held with senior employees at various energy agencies, companies and insitutions situated within Copenhagen, including: •Ministry of Climate, Energy & Building •The Danish Energy Agency •The Danish Electricity Saving Trust (Elsparefoden) •E.ON, Copenhagen •Green Tech Energy Sytems •Dong Energy •State of Green Interviews will be held with people directly involved in the Danish energy sector and will therefore indicate whether or not the Danish energy sector has the capacity for a 100% renewable energy share. Each interviewee will have the opportunity to express their views on the tranistion and explain what their company/agency are doing or perhaps not doing, to faciltate Denmark's green revolution. Additionally, questions will focus on different renewable forms of energy (i.e. biomass, hydrogen and wind), enabling the interviewee to differentiate between the most and least important forms of energy from a Danish perspective. Most of the Danish energy literature emphasises the importance of biomass but the interviewees might provide a greater insight into the value of other forms of energy.
Dissertation Supervisor(s) / Mentor(s) *Name and contact details*	Lucie Middlemiss (Supervisor): L.K.Middlemiss@leeds.ac.uk Jen Dyer (Mentor): j.dyer@leeds.ac.uk
Will you be working alone in the field?	Yes

Document Title	Reference Number	Version	Author	Issue Date	Status	Page Number
Faculty of Environment Taught Student Dissertation Risk Assessment	FOE4.5.6.1	1.0	SEB		Final	2 of 6

Name and contact details of your fieldwork buddy *Your buddy is someone who you can contact at any time while you are doing your work – preferably close to where you are working- they can be a friend, colleague or relative. A suitable call in / check in time should be considered if working in the field/ doing interviews (this will vary depending on what you are doing and where). Also consider what they will do should they be concerned, who they will call and when, and if out of university hours who they would call.*	Stine Kornbek is my flat mate whilst studying in Copenhagen and has lived in the Danish capital all her life. She is well acquintaed with the Greater Copenahgen area. Her contact number: +45 29822532 Stine has been given the address and conact number of my dissertation supervisor, Lucie Middlemiss. I have also infored Stine that I will phone her following any interviews I might have and she will phone the polcie should I go missing after an interview.
Details of other group members (where applicable) *Name and contact details*	N/a
School Contact whilst on fieldwork *Please see supporting information document*	Student Support Office 0113 343 1613 University Security 0113 3432222 Sarah Burdall: s.e.burdall@leeds.ac.uk Becki Thomas: r.j.harrison@leeds.ac.uk FOE-safety@leeds.ac.uk
What are your arrangements for supervision while carrying out data collection? *e.g. who are you going to contact when you return or in an emergency*	Lucie Middlemiss will be my first point of contact when I return to the University of Leeds or in the event of an emergency.
Is your medical form up to date?	Yes *If no please update here: Medical Form*
What is the location of the fieldwork? *Include specific locations, addresses, neighbourhoods or the nearest town / city; include maps and grid references for more remote locations.* *Do not just state for example "Leeds" or "France"* *If your research requires an overnight stay include the address and contact details of the accommodation.*	Interviews will be held throughout a host of neighbourhoods in and around Copenhagen. My address whilst living in Copenhagen for the 2017/18 academic year is Signalhuset Kollegium, 11 Arne Jacobsen Alle, 2300 Kobenhavn.
When are you doing the work? *Include start and end dates and where applicable times. NB a more specific itinerary can be submitted to your supervisor when it is confirmed or if it changes.*	Throughout the 2017/18 academic year, but interviews will conducted between January & June 2018.
Will you need to borrow field equipment from the School?	No *If yes please indicate what* Click here to enter text.
Does it involve any equipment not already identified above?	No *If yes please indicate what* Click here to enter text.

What are the risks associated with the equipment and how are you going to reduce them?	N/a
Will you be bringing samples back for laboratory analysis?	No *If yes please indicate what, when and how many samples* Click here to enter text.
What type of site are you working on? *This could be farmland, offices, town centre, workshop, cliffs, riversides etc.*	Offices/professional working environments.
What are the risks associated with the site and how are you going to reduce them?	Conducting interviews in offices includes risks such as: - Electric shocks/burns from using faulty electrical equipmet, e.g. faulty laptop charger port -Display Screen Equipment (postural problems, eye strains, headaches) -Fire hazards -Manipulation of elites? In order to reduce the potential of hazards, the condition of my electrical equiptment will be checked before and after every interview. Addionally, I will keep hydrated throughout all interviews, ensuring that fatigue, headaches and strains when working with eletriconic devices are less likely. Finally, before conducting any interview, I will make sure that I am aware of the site specific fire procedures and nearby exit routes.
Do you need permission to access the site?	Yes ***if yes do you have it?*** No *If yes please provide evidence of this* Access to offices will be arranged via email prior to the interviews.
How are you collecting the data? *Indicate the methodology(ies) being used*	Data from the interviews will be recorded using the microphone application on my mobile phone, after which it will be then transcribed into a Word document.
What are the risks associated with the data collection method and how are you going to reduce them?	Not all interviewees will want to be recorded and have their information used in my research. In order to prevent this, I will first ask for written permission to use the interview notes when writing my dissertation.
How are you travelling to and from the site(s)? *If you are travelling abroad please include flight details*	Predominately cycling, with the occasional use of the metro system.
What are the risks associated with the travel and how are you going to reduce them?	Although cycling in Copnehagen is relatively safe a helemet will be worn at all times & front and rear lights will be used when cycling in the dark too and from interview locations.

Are you transporting samples or chemicals? *If you are transporting chemicals please contact FOE-safety@leeds.ac.uk for support*		No *If yes how?* Click here to enter text.
If you are working in "the field" have you completed the online "Good Fieldwork Practices" training on the VLE?		No *If no please complete via the VLE* Good Fieldwork Practice
Are there any cultural considerations?		Yes *If yes what are they?* Although the vast majority of Danes speak English, some language barreirs could arise.
What are the risks associated with them and how are you going to reduce them?		Risk of communication breakdown but prior to the interview I will specify that it is to be conducted in English.
Is there a potential for violence *Due to the nature, time or location of the work*		No
How are you going to reduce the potential for violence or reduce the risks?		N/a
Does your work fall under the block ethics approval for the module? *Please see supporting documentation*		N/A
What is your plan for emergencies?		Contact my dissertation supervisor regarding academic emergencies but contact the local police in the event of immediate danger (+45) 112
Is there any additional information you think is relevant?		N/a
FOR OVERSEAS FIELDWORK		
University Travel Insurance number *It is recommended you take a copy of the policy summary cover with you (see additional information)*		100003814GPA
Do you need Vaccinations?		No *If yes, what are they and have you had them?* Please select. Click here to enter text.
What is the current FCO advice for the Country FCO Travel Advice		-Be vigilant and follow the instructions of local authorities when using public transport. -Crime such as pickpocketing exists, particularly in larger cities (Copenhagen*)

DECLARATION
I have answered the above accurately, if the project proposal or details change at any time during the project I will update my supervisor and if necessary update my fieldwork risk assessment.

Document Title	Reference Number	Version	Author	Issue Date	Status	Page Number
Faculty of Environment Taught Student Dissertation Risk Assessment	FOE4.5.6.1	1.0	SEB		Final	5 of 6

Faculty of Environment UNIVERSITY OF LEEDS

Name	Jay Louis Farrar
Date	15.11.2017

APPROVAL
The above assessment has been approved by the following from and academic and health and safety content respectively.

Name Academic Supervisor/ Module Lead	Click here to enter text.
Date	Click here to enter text.

Name Health and Safety Manager / Officer	Click here to enter text.
Date	Click here to enter text.

Document Title	Reference Number	Version	Author	Issue Date	Status	Page Number
Faculty of Environment Taught Student Dissertation Risk Assessment	FOE4.5.6.1	1.0	SEB		Final	6 of 6

BE Becki Thomas [EAR]
Mon 20/11/2017, 09:29

Hi Jay,

Thanks for the updated assessment – this looks OK now. Lucie has confirmed that she is happy with this, so you are OK to go ahead.

Best Wishes,
Becki
...

APPENDIX 5: SAMPLE INTERVIEW TRANSCRIPT

Interviewee: Rasmus Helveg Petersen (RHP)
Organisation: Danish Institute of Parties and Democracy (DIPD)
Date of interview: 16.02.18
Recording time: 01:03:07

JF: So just to start with, what is your role here at DIPD?

RHP: Well I'm the Director of the Institute, meaning that I'm the day-to-day manager responsible only to a board, but apart from that I'm the boss here. I am responsible for our strategy and I take whatever decisions might need taking (3). We have about twelve people employed here, and then we have offices in Nepal, Myanmar and Malawi among other places.

JF: All over the world then?

RHP: Yes, we are working in a total of thirteen countries and some of our engagements are really minor. We also do democracy promotion; helping to strengthen new democracies.

JF: That's really interesting.

RHP: It is, really.

JF: (3) So this is quite a broad question. In your own words, what does the green energy transition mean to you?

RHP: First of all, it's much broader to me than a 'green energy transition', because there's an overall green transition where we are trying to save the world. The main culprit in emitted CO_2 into the atmosphere is the energy sector, so if we can't solve the problem of emissions from the energy sector, then we are not going to succeed in the overall transition (4). But, it is not enough to focus on the energy sector, however, it is the obvious place to start.

JF: Yes!

RHP: And it was an obvious place to start for a country like Denmark, where we have no hydropower and no nuclear. Actually, you will find that only 20 years ago, Denmark was run almost entirely by coal.

JF: Which is really quite striking when you consider that roughly 40% of Denmark's electricity demands are satisfied by wind power.

RHP: Yes, easily, but back then coal dominated the energy sector here in Denmark, and now, the contribution of coal is marginal, less than 5% probably.

JF: A really impressive turn-around.

RHP: Yes, and the end-date of coal usage is set for the end of 2023.

JF: Yes, I think to phase-out coal that quickly is a remarkable achievement.

RHP: A dramatic change, and then when you look at the energy sector from a slightly longer perspective, you will see that it has changed a number of times. Prior to the oil crisis in 1973, Denmark used to run on oil and obviously that came to a halt very quickly (3). So from 1973 onwards, we had a transition from oil to coal.

JF: Do you think that's maybe part of the Danish success story so far then? Distancing yourself from oil, when other countries have become more reliant on it?

RHP: Maybe. I think it's a mix of many different things but economics plays a crucial role here. Since we have no fossil fuels, or at least we didn't until the North Sea discovery, we have always been completely reliant on energy imports.

JF: Yes….

RHP: And during the 1970s when the oil crisis struck home, it was really bad times economically, so it made a lot of sense to try and subsidies some of the energy imports with home produce (2). So you should never overlook that during the oil crisis, it was crucial that Denmark reduced energy imports for economic stability. You can see today, when you do dual generation (where you use heat and electricity generation at the same time), you maximise the energy you get out of coal, and where we are right now, in this very office, the heat is HOFOR heat from the world's largest integrated district heating system (4).

JF: Oh, interesting…

RHP: And all this started, not to minimise carbon footprints or anything of that nature, it simply started as a measure to limit energy imports.

JF: Okay, so this wasn't an efficiency measure, it was an economic measure?

RHP: It was very much an efficiency measure, in order to get an economic advantage (3). And at the same time, you would see a number of Danish companies starting up, like a number of insulation companies (4). We have a whole green energy cluster doing energy efficiency measures and this stems from the 70s, where the objective was initially savings on energy imports.

JF: I was never considering looking that far back into the 70s…

RHP: No, but it's an interesting thing and that very same logic has actually applied to a lot of the green transition. And when you see where we are today, it makes perfect sense to continue with the green energy transition from an economic perspective (4). And what you see regarding public acceptance is that you have joint forces of the; green energy cluster, industry, economists and to some extent idealist having a broad coalition. So when we talk about the green energy transition, we do not only talk about carbon footprints, we talk about; technological developments, the future of energy costs, the export orientated jobs created in the wind turbine industry etc. So the whole story is much broader than just making an impact on global warming. As for myself, I routinely tell that story because I know we need all those stakeholders on-board to manage the green transition, but as I say, the only reason we do this is to minimise our carbon footprint, all the rest is just tactics and trying to keep the coalition together.

JF: Fantastic. I really like your outlook on the broader green transition.

RHP: Thank you.

JF: So do you think a 100% share of renewable energy is possible by as early as 2050?

RHP. Yes, but it could be attained much sooner. Right now, it is only a matter of cost, the technology is there (3). We are very conscious of cost, and that is because you don't want to have stranded assets, they are simply way too costly. On the other hand, when planning energy sector strategies, you do 20/30 year horizons at a time, so you want to make long-term investments, and then renew investments when their lifespans are completed.

JF: Yes.

RHP: If you want to build something that fits into a long-term plan, this is only attainable alongside stable politics. However, the only real reason as to why we can't do it any sooner is that we have some facilities that are yet to see out their lifespan.

JF: For example, are you still phasing out coal?

RHP: Coal for example, yes.

RHP: (4) But anyway, you asked is this possible? Technologically I would say yes, this is no problem. We can do this. I don't think anyone in their right mind could envisage installing new power-generating capacity based on fossil fuels. No one in their right mind would dream of doing that.

JF: Promising, unlike in the UK where we still have ongoing fracking approval debates…

RHP: Yes, but if I may say so, the UK has been very deficient in their energy planning, and as Minister of Climate of Energy I was in London with the District Heating Board of Denmark looking at the opportunities of district heating in London. Waste heat energy in London amounts to about 80% of the heating needs of London.

JF: That's just incredible.

RHP: And if you took this waste heat or spent money on trying to cool it away, and then put it into people's homes, you would save a lot of energy used for heating and you wouldn't need to deal with it by cooling it away. Although this takes planning and investment, you will get free heat in exchange, which will bring back your investment in a very short time span (4).   Then again, some of our (Denmark) measures are considered to be very harsh by British standards. For instance, by law people must often join the district heating network even if they have their own heating source.

JF: Oh, okay…

RHP: And if you don't want to join, you'll have to pay anyway…

JF: That does seem quite harsh, but do most Danes realise that this is done for a greater cause?

RHP: Yes, there is a greater common-good here and people are simply obliged to be part of it.

JF: I suppose, in a sense, that's how society should operate?

RHP: That's an open question. It's a political question. I certainly agree with it in terms of energy planning because the alternative is a London situation where you take all of this heat and throw it away (4), sorry, I'm not taking digs at you…

JF: No, no. I don't take offence (laughs).

RHP: Good (2). Anyway, I'm struggling with the English translation of some of the Danish names, but under the Ministry of Energy, there is a body called *Energistyrelsen* (Danish Energy Agency).

JF: Okay, I think I have read about this agency on the internet (2).

RHP: Yes, I they are sort of the executive of the Ministry of Energy (2), the ones who actually do all of the studies and do all the planning and so on.

JF: Yes…

RHP: And they have made a roadmap for how to get to 2050, putting up four different pathways (2). And as I have said, whenever you need to remove an ageing investment or a piece of capacity, you need to have an overall plan.

JF: Yes, certainly.

RHP: You know, what is the energy system and what is the thing you want to have in the end? And if you don't have that in sight, well you can't make the right incentives and measurements.

JF: That is all very true.

RHP: Good (2). So there are these long-term plans, and the former government chose one of these pathways, which was called the wind pathway, but they could have opted for a biomass pathway or various mixes.

JF: Okay, so for example with the wind pathway, has the capacity of wind energy in Denmark almost reached optimal?

RHP: Well, erm (3), no. First of all, do you mean the possibility for generating?

JF: Yes…

RHP: No, no, no. We can generate almost infinite amounts of wind. Probably not so much on land….

JF: But offshore?

RHP: Offshore is almost infinite. Endless (2). But what we would want in the wind pathway is to use far more electricity than we do today (3).

JF: Yes, so you need to raise demand before integrating more renewables?

RHP: Yes, and raising demand would mean producing much more heat from electricity (2); by heat pumps and other measurements. But ensuring that electricity is used to generate heat, using the existing network of district heating. Right now the heating in this room is generated by a mix of waste incineration, biomass as well geothermal contributions.

JF: So a mixture?

RHP: Yes, a mixture of geothermal, biomass and waste incineration. And of course we expect there to be less waste in the future as we are all trying to minimise waste, and there is only a certain potential for geothermal in Copenhagen.

JF: Interesting indeed.

RHP: But the biomass bit could be very easily replaced by electricity with very large scale heat pumps (2), and that will be the next stage. Heat pumps are wonderful because they are flexible, and you can, for a few days, take them off-grid when the wind isn't blowing (2). And you can actually store heat in the system when there is an excess of wind so they form part of your buffer in an energy system reliant on wind, where you can store some of the excess electricity from wind as heat.

JF: And the storage of renewables is crucial for the next stages really…

RHP: Crucial (2). And that's an example of the components we need for a large / flexible energy system. Although this is only one component, it is one of the big ones because we have so much of this district heat it acts as a substantial buffer (3). But again, if you want to start from scratch, how do you do that? (2)

JF: Mmmmm…

RHP: So the thing is, it is very nice to have an integrated system which you can use as a buffer, but if you had to design it from scratch it would be an enormous investment.

JF: Yes, it certainly would!

TEMPORARY PAUSE- COFFEE BREAK [22:04]

RHP: Also of interest, is looking at how you integrate a green energy system. Denmark used to be solely focused on the generation of green electricity, and we started this by paying through our nose (2), so the electricity generated by the first generation of wind turbines was very expensive (2), perhaps 5/6 times more costly, but we had very little of it (3), so everyone said "ok, this is fine", and so we had these development efforts done through our energy system. From then on, with each generation, the price of wind energy has dropped, and has most probably, now dropped below the generating price of fossil fuels (4). And, wonderfully, wind turbines introduce entirely new economics into a system, where they utterly wreck the economics of coal generation.

JF: *laughs*

RHP: Which to my view is wonderful.

JF: Yes, completely.

RHP: And the economics of generating electricity through coal is through what you call base loads (2), which is not terribly flexible (2). You can to some extent meet a peak demand, but preferably if you know of it in advance (2). But when you introduce a mix of coal and wind into the system, you realise that when the wind is blowing, the marginal price of wind energy is always lower than that of coal because once the wind is there the cost of generating an additional kilowatt is zero (2). It will always be lower than the coal. Suddenly the bias of electricity will always prefer electricity to coal.

JF: If energy is both renewable and cheaper….

RHP: Yes, it is cheaper but many people don't care whether it is green or not. You have to enter the world of politics and economics to make all this work, you can't just argue 'hey, but it's green'.

JF: Yes, I fully understand as much.

RHP: Yes, so the battle will be, and was one having made a business case, as well as an environmental case for the green energy transition.

JF: This leads on quite nicely to the next question really…

RHP: Okay…

JF: Do you believe that there is a consensus in Denmark that working towards a greener society is accepted as a societal norm?

RHP: Yes, and I can back this up with numbers (3). First of all, all political parties are currently backing the current energy plan, meaning that when we recently had a change of government, we at least didn't have a change of policy (2). And even the long-term goals of the current administration (predominately right-wing) are considered fairly progressive by international standards (3). You will also see that the younger people are, the more likely they are to support the green transition (3).

JF: Oh, okay….

RHP: And the electoral parties know that if they do not address the green transition in their campaigns, then they are going to lose a lot of the younger voters (3). And obviously, the younger generation are stuck with the climatic conditions of global warming for a longer period of time…

JF: Exactly.

RHP: Oh, another interesting point is that although Denmark has traditionally been built on the export of bacon, so agricultural exports. The export of pork last year was about 13 billion ddk, whereas the export of wind turbines was 44 billion ddk, so wind turbines alone are well in excess of our exports of pork; and they are only part of the green cluster (2). So in financial terms, this is not as you say 'alternative energy', this is the bulk of Danish industry.

JF: Fantastic.

RHP: Also, some of the most problematic rural areas in Denmark now have zero unemployment.

JF: Because of the green energy transition?

RHP: It is a driver yes (2). You cannot find an electrician, blacksmith or a specialist fibre-glass worker in west Jutland anymore (because of the green energy sector now dominates the local economies).

JF: Really?

RHP: Yes, and at some points, west Jutland has been at the end of the road.

JF: Wow, okay.

RHP: I like to call these workers in west Jutland *The Armory of the Green Transition.*

JF: Haha, brilliant (3). Moving on now, could you perhaps explain why household electricity prices in Denmark are some of the highest in Europe, and why CO_2 emissions, per capita, are also some of the highest in the world?

RHP: Sure (2). If you look at the price paid by industry, that do not pay the tariffs paid in households then it is on par with the rest of Europe and actually lower than in Germany and the UK. So the price of electricity in Denmark is actually very low. On the other hand, we tax the hell out of electricity. The reason for this dates back to the 70s. Back then, electricity was generated by coal, coal was imported, so we needed a strong incentive to save energy and so it was taxed.

JF: It's a very high percentage of tax…

RHP: Very high! So when I use 1 kW of electricity, the cost of energy would be roughly 25-30 øre per kWh, so that's the actual cost for the production of energy, but then you have the distribution of energy; which is the wider maintenance of the system (2), and this is approximately another 20 øre per KWh. And then, you'd have another 10 øre per kWh, so the actual price of generating electricity per kWh in Denmark is about 50 øre per kWh, of which the cost of electricity is about 10% (3). And this tax, like any other tax is simply used to finance schools, highways, social wealth and so on. It has nothing to do with the cost of generating electricity.

N.B. The price of 1 kW of electricity in Denmark pre-tax is approximately 9p

JF: Well that's answered my question perfectly, thank you.

RHP: Good, but we were very conscious of this. As the cost of distribution should be seen as the overall price of energy.

JF: Yes, it shouldn't necessarily be regarded as something separate…

RHP: But we do, but we still look at the cost (2).

JF: Yes…

RHP: But when compared with the rest of Europe, there are very few countries who can do cheaper. One of those countries (with cheaper prices) is Sweden because they have had access to hydro-power for a long time.

JF: Yes, and is that the same for Norway as well?

RHP: Oh yes, and the question of Sweden and Norway is actually interesting because what we have now is increasingly a non-Danish energy system. We all need to stop seeing energy system as confined to national boundaries.

JF: Can I just hold you with that thought for one second. Building on this topic, what can you tell me about the *Markedsmodel* (new market design) and how that might help facilitate Denmark's Green Energy Transition?

RHP: So, the integrated Nordic Market Model is brilliant (3). Now, Norway at some point took the decision that they wanted to rely on hydro, but Norway has something called dry years.

JF: Okay…

RHP: Where they miss out on the rainfall. If you were to be completely reliant on hydro and have a dry year, then you have a real problem (2). So the Norwegians needed something to back up their hydro-reserves. So, now when it rains in Norway we can get cheap electricity, and when we have a storm here they can get cheap electricity. So whoever has the bad weather at least has the upper hand in terms of green energy supply.

JF: *laughs*, that's a good way to look at it.

RHP: And that also brings down peak prices. We get a much lower cost of back up electricity and a much better price during peak hours; both when we need it and when we export. So the whole economic system (*Markedsmodel*) is massively advantageous and it makes us far less reliant on our own weather conditions.

JF: Certainly.

RHP: So, you shouldn't look at a power supply as a domestic affair because it will cost you. It is much cheaper to do it jointly. And if you expand that logic to encompass first Europe and then the rest of the world, the same goes (2), it will make energy consumption: safer, more reliable and 'greener' for everyone.

JF: And that's the logic behind the Nordic Model then?

RHP: Yes, but we have also integrated our thinking in Nordic countries. Its' based also on trust, as you expect that during a crisis we would all share our resources together, equally. So it takes a whole lot of trust.

JF: Fantastic.

RHP: Also, by introducing a *Markedsmodel* system, conditions become almost impossible for fossil fuels to thrive.

JF: So this system is also a mechanism to help phase out fossil fuels?

RHP: Yes, completely (2). When you look across Europe right now, the *Markedsmodel* has been shattered by the introduction of green energy.

JF: Well I'm sure that won't please many oil companies…

RHP: No, but most of what I have said today concerns only electricity generation. It has to spill over into oil and will do so only by the introduction of electric vehicles, which is still some way away, but the electric revolution will come.

JF: In my lifetime hopefully.

RHP: Oh yes. We are talking, maybe 10 years.

JF: I do hope that is the case.

JF: Now moving onto district heating. With three major national grids, the Danish energy system can be seen as diverse and decentralised. How important is diversity to the Danish energy system on the whole?

RHP: It is very important (3). It has to be an energy system, rather than one technology. Of course there can be a dominant technology, in this case the wind turbines but that's in relation to where we are.

JF: I have to say, I get the sense from this interview that in your opinion there are almost no barriers to Denmark's 2050 green energy transition, is that correct?

RHP: Yes and that's because it will be successful. We are way beyond *'will we do this?'* or *'can this be done?'* it is something we are all planning for and it will be done.

JF: It's happening…

RHP: Yes and we are on track. The International Energy Agency (IEA) just assessed the Danish energy system (annual assessment) and they said that we are on track for the 2050 objectives.

JF: Good news!

RHP: And the perfect thing about this assessment from the IEA is that it provides political support for the uptake of green energy. When political discussions are taking place elsewhere in the world, the Danish case study can now be used as an example of green transition success. If a small country like Denmark, who is responsible for less than 1% of the total emissions of the world wants to influence her own future, then it has to be done by taking a lead by developing technologies and integrating an energy system that underpins the political will of others to do their part (3). If you don't do that, you are basically just doing it for fun.

JF: Yes, but would you also say that the green energy transition here in Denmark is also a way of taking some kind of moral high ground?

RHP: Yes, but let's say that avoiding global climate change is your number one goal, what would you do? You try to influence others by developing technologies, policies and translating this into political pressure by translating it through the EU and the UN (3).

JF: Yes…

RHP: Also, during my time in politics, we made had a very strong cooperation with a number of leading economics (2). For instance, deep inside the Chinese Ministry of Energy there is a thing called the Center for Renewable Energy which is funded by the Danish Government and it where we take all of our information regarding the integration of renewables into a grid.

JF: Interestingly, I think China will be crucial for the world's energy future. I think many countries around the world are looking at China and saying "come on manufacture renewable goods for us".

RHP: Well in China, we are trying to make all of the findings available.

JF: Almost planting a renewable seed in China's energy sector.

RHP: Yes, we are planting the seed.

JF: But with a population of 1.3 billion, the future energy demands of China will be staggering.

RHP: Yes, it really is frightening.

JF: Okay, moving on now. We have discussed biomass already in this interview, but do you have any concerns regarding the usage of biomass, and do you consider biomass to be an intermediate solution in Denmark's green energy transition?

RHP: It's certainly not seen as a long term solution in the way we currently use it. Right now, the bulk of our biomass is used for the production of either heat or electricity, but it can be substituted by electricity and it should be (3).

JF: Okay…

RHP: But in a future energy system I would still want to use all of the biomass available in Denmark, but more intelligently; mainly for aviation and heavy transport. So instead of just burning wood chipping, I would want to generate biofuels from the biomass.

JF: It's really interesting you say this because biomass is said to have the capacity to support 10% of energy requirements in the Danish transport sector by 2020…

RHP: Oh yes, easily, but if we look ahead to 2050, we will need to find alternative fuels for aviation and that could be with biofuels. Although biofuels are currently more expensive than fossil fuels in most scenarios, through a series of development steps we can make biofuels more competitive (3). Having spoken with some airlines, we could quite easily dilute current fossil-based jet fuels by 50-70% with the help of biofuels (2).

JF: Interesting…

RHP: So the first 50-70% of the way wouldn't even require technical investments in the aeroplanes.

JF: That's quite staggering really.

RHP: So when you have a system like our district heating system where you can just change the engine to run on 'green', it becomes much cheaper, so as in the case of wind turbines, focus needs to be on actually how to generate this biofuel; then later on you can target the final 30-40% whereby the common generations of air crafts will be changed and so on….

JF: Yes but the aviation companies will need to be bold and make those first steps.

RHP: Indeed they will.

JF: So one final question, what do you consider to be the most important factor in driving Denmark's >40% reduction in fossil fuels since the start of the 1990s?

RHP: Well none of this could have been done without stable policies, they are key to making it making technical developments and gaining investor confidence. Without political stability all of this would have been null-and-void and we would have made nothing of it (2).

JF: I find that to be really interesting. As for many developing countries with unstable political environments, how might they follow suit?

RHP: Yes, well having visited many developing countries I have seen the solar sector and a lot of new technologies expanding that are cheaper and more reliable than their fossil fuel alternatives. Denmark does cooperate with a number of developing countries regarding the uptake of green energy solutions; notably targeting regional heavy-weights. For instance, South Africa is a notoriously coal dependent country, but we showed them that South Africa has a large capacity for wind energy; and this alternative would be cheaper and faster than building new coal power plants (3). Wind turbines are actually the fastest way you can add renewable energy to the grid because there is no delay once the technology is erm….

JF: Operational?

RHP: Yes. Anyway, erm, what we did in South Africa was create a wind Atlas.

JF: A wind Atlas you say?

RHP: Yes. Some of the researchers at the Resu Wind Facility they are now experts at pin-pointing locations for optimum wind turbine generating capacity (3). With plenty of promising wind opportunities now identified to them, South Africa are now expanding their wind generating ability faster than almost anyone else in the world. Isn't that interesting?

JF: It certainly is, and it's a really positive note to finish on because it highlights that not only are Denmark striving to achieve their energy goals for 2050, they are also helping developing countries achieve more renewable outcomes also.

RHP: Yes, and now we have a clear pathway and can help others with their own transitions (3). But anyway, that's it for today.

JF: Excellent (2). Have you anything else to add or have I missed anything of note?

RHP: Oh plenty! But we haven't got the time today *laughs* (3). No, no, we have discussed the core elements of the transition.

JF: Oh well thank you very much for your time then.

RHP: My pleasure.

END OF RECORDING