Oil and Shale Gas depletion estimates. Can Renewable Energy replace Fossil fuels in the UK?

Daniel Dickson

Supervisor: Fabienne Marret-Davies
Work-based Supervisor: Stuart McBain

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MSc Environment & Climate Change

Declaration

I hereby declare that the following dissertation is based on the results of investigations conducted by myself, and that this dissertation is of composition. This dissertation has not, in whole, or part, been previously submitted, to any university of institution for any degree, diploma, or other qualification. Work other than my own is clearly indicated in the text by reference to the relevant researcher or publications.

Signed: D.Dickson

Date: 08/09/2017

The work presented in this dissertation is the work of the candidate. Conditions of the relevant ordinance and regulations of the University of Liverpool have been fulfilled.

Executive Summary

I. Fossil fuels play a pivotal role in the modern world and is crucial for energy production. The UK has historically been dependent upon North Sea oil and on shore coal mines to meet its energy needs. However, the demise of the coal industry and falling North Sea reserves have resulted in UK imports of energy surpassing 50% in 2013, with the UK now heavily reliant upon imported sources of energy.

II. The UKCS oil extraction has previously seen two peaks, in the 1980's and the late 1990's. Subsequently extraction rates have been in decline in the 21st century, with further extraction declines estimated after 2020. This in turn has led to renewed interest into non-traditional fossil fuels; primarily shale gas, as well as an acceleration of the UK's renewable energy sector.

III. This report was undertaken in order to calculate the estimated depletion times for the UK's oil reserves, focusing on the North Sea, as well as its potential shale gas reserves. This was accomplished using an updated Donald Klass model. The report also highlights renewable energy in the UK and its potential to meet the UKs energy needs in the future.

IV. The UK has minimal oil reserves due to the previous exploitation of the North Sea, with reserves likely to be depleted by 2033 at current extraction rates. Predicted drops of extraction rates after 2020 as major oil companies transition away from the North Sea due to lack of recoverable resources. As a result, the UK is likely to increase its dependence upon oil imported from foreign sources which will have several implications. It will drastically effect the UK's energy security as it becomes reliant upon foreign oil.

V. The UK has considerable shale gas reserves, which could meet the UK demand for natural gas for the next 55 years. The development of the UK's shale gas resources could help improve the UK's energy security, while acting as a stop gap fuel to allow the UK to develop its renewable energy industry. However, there is considerable opposition to a fracking industry in the UK, mainly due to the environmental risks associated with the extraction process.

VI. Renewable energy in the UK is currently undergoing massive growth, as the UK looks to reduce its carbon footprint in order to combat climate change, as well as increase its energy security. The UK has the highest wind potential in Europe and as such is currently pursuing an aggressive strategy of developing off-shore wind farms. The move to off-shore is in part due to the nimbyism movement against onshore wind farms. Solar and hydroelectric power are also experiencing growth to meet UK demand for energy. Further development in the future could see renewables provide 100% of the UK's energy needs, however further investment is required.

VII. A number of recommendations have been made to help the UK increase its energy security as well as transition to a low carbon economy. An expansion of the renewable sector could replace oil and gas in the long term to meet the UKs energy needs, however it is likely a shale gas industry will be required to meet energy needs while renewables continue to develop in the UK.

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Daniel Dickson

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Glossary

CCS-Carbon Capture and Storage

CO_2- Carbon Dioxide

EU ETS- The EU Emissions Trading System

GHG – Greenhouse gas

GW- Gigawatts

HAP's – Hazardous Air Pollutants

MW -Megawatts

OGA – Oil and Gas Authority

RSPB – Royal Society for the Protection on Birds

TWh- Terawatt-hour

TCF- Trillion Cubic Feet

UKCS – United Kingdom Continental Shelf

VOC's – Volatile Organic Compounds

1. Introduction

1.1 Background

Fossil fuel reserves, such as oil and gas, are vital resources in the modern world; responsible for powering homes, transport and business. Therefore, fossil fuel depletion time is a fundamental question which much be answered. Understanding how long conventional fossil fuel reserves will last is of key importance to help develop and prepare for when fossil fuel resources are diminished (Campbell and Laherrère 1998). The UK has long been dependent upon hydrocarbon deposits in the North Sea, with oil and gas making up the majority of the UK's energy generation since the demise of the coal mining industry in 1970s and 80s. However, a decline in the extraction of fossil fuels from the North Sea since the beginning of the 21st century, due to falling reserve amounts, has resulted in the UK becoming a net importer of fossil fuels. Thus the UK is reliant upon overseas imports to meet its energy requirements (Bolton 2013). Subsequently the UK has begun exploring alternative fuel sources such as shale gas to meet its energy needs.

The increased risk of anthropogenic climate change, along with dwindling North Sea fuel reserves has seen an increased focus upon renewable energy generation in the UK, in order to decrease dependency for energy on foreign countries, as well as to meet several climate change targets set out by the UK Climate Act 2008 and the Paris Climate Agreement in 2015. The UK wind energy potential is often ranked as the best in Europe, and one of the best worldwide locations for wind energy generation. The UK generated more electricity from wind power than from coal in 2016, with further increases in wind energy planned in the future (Kelly 2007).

1.2 Oil

Oil is the lifeblood of the industrialised world, and has becomes the world's most important source of energy since the mid 1950's (Tsui 2011). Since this period the importance of oil has seen dramatic increases, with its products underpinning modern society. However, as a fossil fuel, oil is a limited, non-renewable source of energy, and therefore understanding how long reserves last is of vital importance to the world, both on a regional and worldwide scale (Brown *et al.,* 2011).

The importance of oil cannot be understated, while mainly used for energy, oil is used in the manufacturing of goods which are used in everyday lives, from rulers and crayons in schools, contact lenses and deodorants at home, to PC's and football boots. The worlds demand and usage of oil has increased exponentially in the 21st century despite attempts to reign in usage as a result of falling supplies. Estimates suggest that worldwide oil reserves will only last a further 50 years at current production levels (Shafiee and Topal 2009).

The UK's natural oil supplies therefore are strategically important. The North Sea, a marginal sea, forms part of the European continental shelf and is a vital area for the UK, as it contains much of the UK's oil reserves. The North Sea Oil Province development is characterised by transient thermal doming during the middle Jurassic, which along with halokinesis, allowed for the formation of hydrocarbon bearing sediments, mainly mudstones, from which most of the oil reserves are extracted (Johnson *et al.,* 2005).

1.3 Shale Gas

The 21st century has seen shale gas become one of the most important potential sources of natural gas. The processes of hydraulic fracturing, allowing for natural gas stored in shale formations to be extracted, is not a new technique, however recently large deposits of natural gas, contained within shale formations, has seen an exponential growth in the shale gas industry (Shelly 2005). While several countries are currently exploring their shale gas potential, the US has a large shale industry, responsible for over 20% of the USA's natural gas production in 2010, up from 1% in 2000. While shale gas is currently not commercially extracted in any other country outside North America, the US's 40,000 shale gas wells have demonstrated to the world the potential of shale gas in meeting energy needs. The growth of the shale gas industry in the US has led to a shale gas revolution, with over 40 countries including the UK currently considering jump starting their own shale gas industry to meet natural gas needs (Jenkins and Boyer 2008).

The UK is currently investigating its own shale gas potential in order to meet its energy needs. With falling oil and gas extraction rates from the North Sea due to dwindling supplies, the UK is in dire need of another fuel source while it continues to develop its renewable energy sector (Mair *et al.,* 2012). Several studies have placed the UK's shale gas deposits as some of the highest in the world, mainly focused in the Howland-Hodder formation in England, with the UK's deposits estimated to total over 1,000 TCF (Andrews 2013).

Shale gas has faced considerable opposition due to its environmental effects, with several high-profile protests held against shale gas in the UK around exploration drilling wells. Concerns over methane emissions, water contamination, and earthquake risk has result in a sizeable public opposition to the development of an on shore shale gas industry. However due to the UKs need to be energy self-sufficient, as well as its potential as a transitional fuel, the government continues to push ahead and actively promote the shale gas industry in the UK (Stevens 2012).

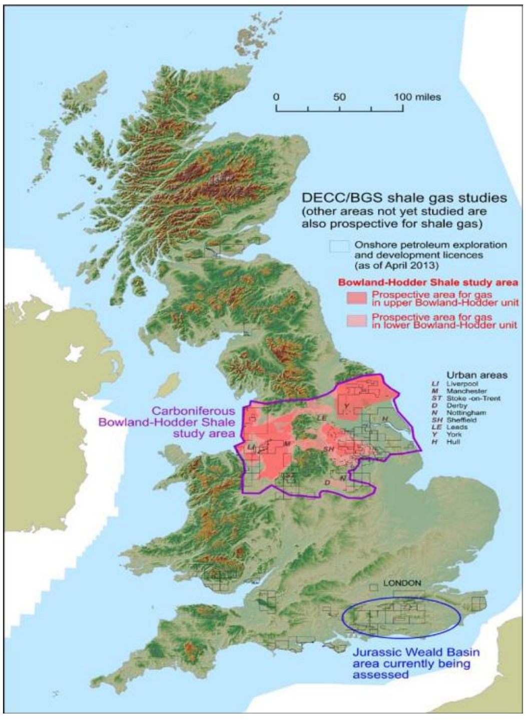

Figure 1-Map highlighting the Bowland-Hodder Shale formation site, as well as the Jurassic Weald Basin. Both areas contain the majority of the UK's Shale gas potential. (Source: Andrews 2013)

1.4 Renewable Energy

To combat and mitigate the effects of climate change, renewable energy is set to play a vital role in the future of the world's energy market. While fossil fuels have powered the modern world since the industrial revolution, in the future renewable technologies are set to take over once fossil fuels reserves are finally diminished (Asif and Muneer 2007). Several international agreements such as the Paris Agreement actively promote an increase in green energy generation in response to anthropogenic climate change, with the aim of reducing GHG emissions. Renewable energy in the 21st century has undergone several technological advancements which have made renewable energy cheaper and more efficient, overcoming many of the issues green power had during the 20th century (Klassen *et al.,* 2005).

The UK has seen its renewable sector boom since the beginning of the 21st century, with the UK Climate Change Act 2008 aiming to achieve 80% cut in GHG emissions by 2050 from the 1990 baseline level, a process that would involve renewable energy sources becoming the overwhelming source of the UK's energy needs (Challinor *et al.,* 2016).

Wind energy is set to become the major source of UK energy as the 21st century continues. As a result, the majority of renewables in the UK are constituted of wind; with wind energy generating more electricity in the UK than from coal in 2017 (Kelly 2007). Due to the NIMBY movement, the UK's wind farms are being positioned off-shore, with the government aiming to produce 25% of the country's energy needs from off-shore wind farms by 2020. While the UK has tremendous wind energy potential, the slow rate of building and transitioning into a greener economy means scepticism still exists, whether renewable sources can replace the UKs dependency upon fossil fuel reserves in the future (Devine-Wright 2005; Sinden 2007). Solar and hydroelectric power have also seen increased funding and development in the past 20 years, providing alternative renewable energy sources.

1.5 Aims and Objectives

1.5.1 Aims

This report, using government data, will attempt to predict how long traditional fossil fuel reserves of the UK will last, focusing upon both on and off shore hydrocarbon deposits. It will also analyse the potential of wind energy as a viable replacement for traditional fossil fuels and evaluate perceptions regarding renewable energy as a viable replacement for fossil fuels.

The aims of the report are outlined below:

- To investigate the current UK fuel reserves of oil and shale gas
- Estimate how long reserves of oil and shale gas may last
- Discuss and analyse the implications to the UK in the future because of diminishing fuel resources
- Produce a holistic overview of renewable energy resources, and evaluate if they can replace traditional fuel sources in the UK

1.5.2 Objectives

- To investigate current UK fuel reserves, including known reservoirs available to the UK, and predict how long these reserves will last using a Klass model
- Critically analyse the potential future implications for the UK energy market as a result of the depletion of its natural oil resources

- Critically analyse the potential for a shale gas industry in the UK, and its role in replacing oil to meet the UK's energy needs
- Produce a holistic overview of renewable energy in the UK and evaluate the potential to replace traditional fuel sources in the UK

2. Methodology

A modified Donald Klass formula was used in order to calculate the depletion time estimates for UK oil and shale gas reserves (Klass 1998). The original Klass formula assumed a constant extraction rate for fossil fuels, and did not take into account growth in extraction rates into the future. In order to take into account growth of extraction rates into the future, particularly for shale gas, an updated formula was used, as proposed by Shafiee and Topal (2008), and is detailed below.

The formula uses data obtained from UK government data. The oil data contains estimates for proven oil reserves, 349 million tonnes, as well as a maximum possible oil reserves which stands at 727 million tonnes. The shale gas reserves are estimates produced by the UKGS during an exploration drilling investigating shale gas reserves. Presuming only 10% of the available shale gas will be extractable, a low, medium and high reserve estimate was produced which stood at 100 TCF, 150 TCF, and 400 TCF respectively. An extraction rate of 5 million TCF was assumed for an operational fracking industry. A low extraction value was chosen as a baseline extraction rate for a shale gas industry which is starting production.

Eq. (1) demonstrates fossil fuel consumption over time, while the second model then calculates the ratio of world consumption to reserves:

$$TFC = \sum_{i=1}^{n} FC_i = R \qquad (1)$$

$$FC_n = FC_1\, e^{(n-1)g} \qquad (2)$$

TCF in the above equation is the total fossil fuel consumption, *FC* the fossil fuel consumption, *N* representing the year and *R* for total fossil fuel reserve and *g* representing the annual continued growth of extraction. As can be seen in the above equations, *TCF* is assumed to be consumed in *"n"* years.

In order to calculate "n" Eq. (3) is derived from Eq. (1) and Eq. (2);

$$n = \frac{Ln[(R/FC_1)(e^g - 1) + 1]}{g} \qquad (3)$$

In addition, 450 questionnaires were also conducted in order to gauge public opinion on the oil, shale gas and renewables industries in the UK. These questionnaires were conducted in two manners. Firstly, an online questionnaire was posted on the Environmental Science forum on Reddit, with participants invited to complete the questionnaire. Questionnaires were also conducted in three locations, Liverpool, Blackpool and Wrexham. Participants were selected using a random sampling technique.

3. Results

Table 1-Reserve size for oil and shale gas as well as estimated depletion times. Reserve sizes obtained from government data available from OGA website, with proven and maximum possible oil reserves used. Source data within appendix. Shale gas reserves based upon UKGS estimates for low, medium and high shale gas reserve estimates, found in appendix. Under current extraction rates North Sea oil depletion time's estimates at 7 years for proven reserves and 16 for maximum possible. Shale gas reserves depletion time estimated at 53, 55 and 60 years for low, medium and high estimated reserves respectfully.

	Proven Oil (Million Tonnes)	Maximum possible Oil reserves (Million Tonnes)		Low Estimate (TCF)	Medium Estimate (TCF)	High Estimate (TCF)
Reserves	**349**	**727**		**100**	**150**	**400**
Depletion Time in Years	**7**	**16**		**53**	**55**	**60**

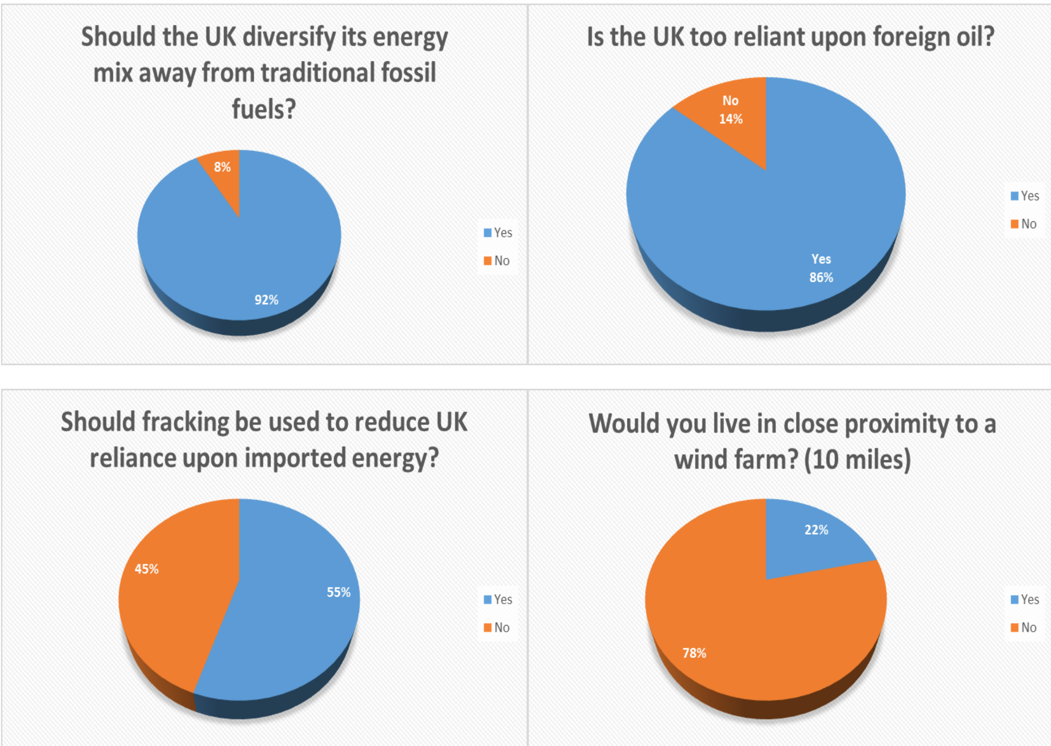

Figure 2-Results from the questionnaires conducted. (Top left) indicates 92% of those polled, believe the UK should diversify its energy mix away from fossil fuels. (Top right) indicates 86% of those polled, believe the UK is too reliant upon foreign oil. (Bottom left) indicates 55% of those polled suggest the UK should use fracking to allow the UK to reduce reliance upon imported energy. (Bottom right) indicates the majority of those polled (78%) would be unwilling to live within 10 miles of a wind farm.

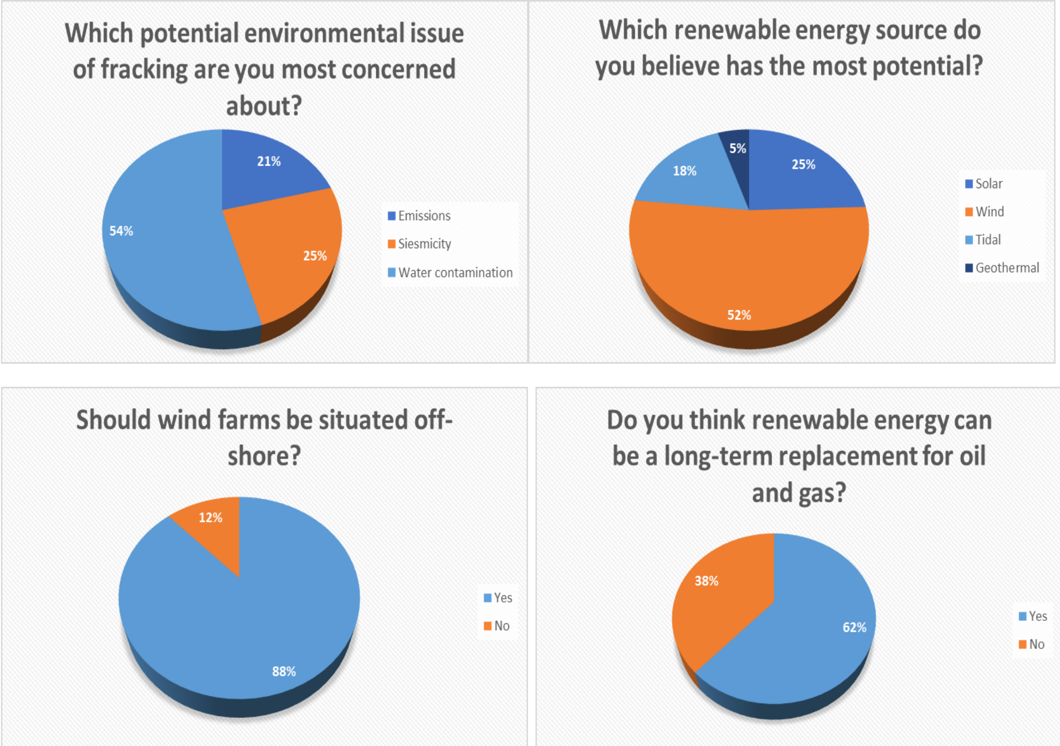

Figure 3-Results from the questionnaires conducted. (Top left) indicates the majority of those polled are most concerned with water contamination as a result of fracking, with 25 regarding seismic events as the most concerning while 21% are most concerned regarding emissions. (Top right) 52% of those polled highlight wind energy as the renewable energy source with the most potential. 25% believe solar energy has the most potential, while 18% believe tidal while just 5% indicate geothermal has the most potential in the future. (Bottom left) indicates 88% of responses agree that wind farms should be situated off-shore. (Bottom right) indicates only 38% of those polled believe renewable energy cannot be a long-term replacement for fossil fuels.

These new results raise major questions regarding the future of the North Sea oil reserves and the UK's ability to be energy self-sufficient. At current extraction rates North Sea oil will be depleted in the next 20 years, with proven reserves depleted in 7 years and maximum possible reserves depleted in 16 years at current extraction levels. This will have several significant consequences for the UK in the future as North Sea oil depletes.

The shale gas depletion time paints a more positive picture, with shale gas resources predicted to last at least 50 years under all possible resource estimation scenarios. While a relatively small extraction level was used, an increase in extraction rates over time helped ensure accuracy of the results.

The questionnaire results show the UK's public attitude towards oil and shale gas has a strong emphasis towards transitioning towards renewable energies. While a majority of those polled believe the UK is currently too reliant upon imported oil, with 92% of responses stating the UK should transition away from fossil fuels, with low public support for fracking. The majority of those polled are highly critical of fracking, especially concerning the environmental impacts the process has, with the majority favouring a switch to renewable energy sources. While 52% of people see wind as having the most potential, 88% feel wind farms should be situated off-shore, suggesting a strong NIMBY sentiment remains amongst the UK population.

4. Oil

4.1 Implications

The North Sea has been an important strategic fuel source for the UK for generations. As a small island nation, access to the North Sea oil reserves has provided the UK with a local source of petroleum based products cheaper than the imported costs of foreign oil (Forsyth and Kay 1980). In 2008 three quarters of the UK's primary energy was delivered via oil and gas, with 98% of the oil produced by the UKCS satisfying almost all the UK's domestic consumption. However, concerns have been raised about the amount of oil remaining to the UK as imports have steadily risen since the second peak of North Sea oil extraction in the late 1990s (Aleklett *et al.,* 2010).

It is highly likely reserves will last past the depletion estimates produced as falls in extraction continue to occur in the future, with the OGA predicting major extraction decreases after 2020, due to rising costs. Oil extraction from the North Sea could continue until 2050, with significant cut backs in extraction, with medium and small size oil firms continuing extraction of smaller wells. Future price increases of oil in the future as worldwide resources diminish could also see a return to large scale extraction in the North Sea, as higher worldwide prices of oil allow for extraction of more difficult and costly reserves. However due to the amount of oil remaining, only small oil producers will see any benefit.

4.2 Future of the UKCS

As oil operations continue to be reduced, it is vital to consider the future of the UKCS in the coming decades. The UKCS supports a considerable number of jobs, particularly in Aberdeen where the oil and gas industry of the UK is located. 450,000 jobs in the UK were directly supported by the UKCS in 2008, 34,000 directly employed by oil companies, the rest from the wider supply chain. The job market surrounding the UKCS continued to grow after 2010, with a further 45,000 jobs created in 2013 due to new technology allowing for marginal fields to become viable for extraction (Noreng 2016). While a large number of jobs were lost during the oil price slump of 2014, around 65,000, a considerable workforce is still supported by the UKCS, with every billion pounds spent on the UKCS supporting 20,000 jobs. However, in the future, as extraction rates continue to decline, job losses are set to increase as large companies move staff and production to over-sea fields (Elvind 1992). Over 40% of the jobs directly supported by the UKCS are situated in Scotland, with future job losses severally impacting the Scottish economy, as well as the economy of the UK. While job losses are likely to be incurred directly due to falling extraction rates, jobs could also be created in the future as companies begin the decommission and clear up of oil platforms after production has ceased (Dickey *et al.,* 2011).

As the oil resources of the North Sea are depleted in the future, it could help the UK's ability to combat climate change. CO_2 emissions from oil exploitation in the North Sea is considerable, with 17 million tons of CO_2 emitted in 2007. However, as production levels have fallen since the onset of the 21st century, consequently resulting in a fall in emissions, with 2007 emissions seeing a 10% reduction from 2000 (Kunstler 2007). UK oil installations also participate in the EU ETS, allowing them to offset some of the emissions. However, as production continues to fall in the future, further reductions in emissions will make it easier for the UK to meet its CO_2 reduction targets. The future of the UKCS could also help via CCS schemes. While no working model exists to store captured emissions within geological formations on a large scale, technological improvements could make it a reality in the future, with the best natural repositories for captured carbon being depleted oil fields, several which already exist in the North Sea (Newman *et al.,* 2009). As large companies such as Shell continue to scale back their oil extraction in the North Sea as it is no longer economically viable, their knowledge of the geology of the UKCS, and their existing pipeline transport system and reservoir management could allow for the world's first working CCS scheme.

4.3 Energy Security

Energy security has become an increasing concern in the UK over the past several decades, particularly as energy imports have risen, predominantly in the 21st century. The UK net energy imports surpassed 50% in 2013, and the UK is currently heavily reliant upon imported oil and gas to meet its energy generation needs in the face of growing demand and population increases, resulting in the UK becoming a net importer of energy (Macleavy and Harris 2013). Access to cheap energy is an essential part of any modern-day economy, and since the 1970s the North Sea has provided a considerable portion of the UK's oil needs as well as providing substantial economic benefits.

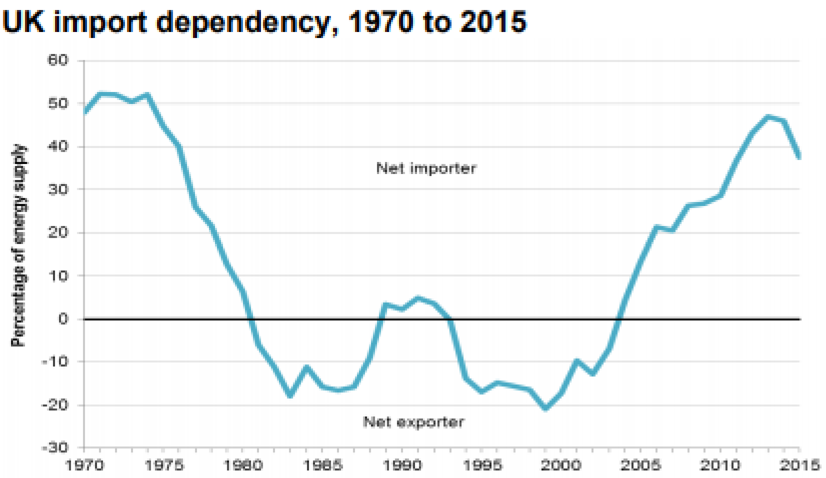

Figure 4-UK import dependency from 1970-2015. The two peaks in North Sea oil extraction can be seen during the early 1980's and the late 1990's which allowed the UK to be a net exporter of energy. However since 2000 falling reserves have seen the UK become a net importer as extraction levels reduce. (Source Harris and MacLeay 2015).

However, while the North Sea has provided much of the UK's fuel reserves since the first commercial wells in the 1960s, more than half of the North Sea oil reserves have been extracted, with the UK extraction of oil in the North Sea peaking between the mid-1980s and the late 1990s (Owen *et al.,* 2010). Subsequently since the peak in North Sea oil extraction, reductions in the extraction rate, along with limited reserves available to the UK in other areas has resulted in a fall in the extraction of North Sea oil. This fall in the rate of extraction from the UK's natural oil reserve has seen an increased reliance upon imported fuel, particularly from Norway (AEO 2013). This has further raised energy security questions as Norway is also largely reliant on the North Sea for its oil, although it does have access to wells situated in the Arctic. As a result, in the future the UK is likely to see imports of oil increase from the Middle East, particularly Saudi Arabia and the United Arab Emirates.

Dependence upon foreign sources of oil is already a major concern in the UK, with 86% of those polled believing the UK is already too reliant upon foreign oil (figure 2). Due to the importance of oil to the UK's overall economy, the UK must maintain the supply into the future for the time being. The UK first began exploiting North Sea oil and gas reserves in response to the 1974 oil crisis, with its energy security being one of the main reasons for the focus on North Sea oil (Winzer 2012). Future increased dependence upon the Middle East for oil could once again see oil used as a political weapon against the UK, while another crisis like 1974 could have enormous consequences upon the UK economy.

Diversification of oil import sources will play a major role in the UK's oil security in the coming decades. While the UK is currently largely dependent upon Norway for oil imports, diversifying the number of countries it imports oil from could help to reduce its dependence (Cohen *et al*., 2011). Having a varied supply chain of oil from a number of countries will spread the risk, allow for more reliable imports of resources to meet its needs in the future.

The falling extraction levels of the oil industry in the UK has led to renewed efforts by the government to explore alternative sources of energy, particularly shale gas and renewable sources. The reductions in the extraction level, and rising dependence upon foreign countries for its energy supply, has hastened the need for the UK to transition away from traditional fossil fuels and further push it towards a low carbon economy (Kuzemko 2014). The reduced availability to oil as a result of the depletion of North Sea oil reserves could trigger another energy revolution in the UK, allowing it to reduce its demand upon imported fuel sources.

4.4 Case Study-Canada Oil Sands

Canada is regularly rated as having the third largest reserves of oil worldwide, the fourth largest oil exporter and the fifth largest oil producer. However, the majority of its oil reserves are contained in oil sands deposits, with its conventional oil production peaking in the 1970's, with oil sand only recently being considered part of the world's oil reserves, as technology has allowed for their extraction.

With the peak of Canada's traditional oil extraction in the 1970's, the country became heavily reliant upon imported oil to meet its needs, while also continuing to extract oil from offshore sources. The decline after the 1970's peak in extraction is similar to the present situation in the UK. The technological advances which allowed for Canada to take advantage of its oil sand deposits has allowed for the country to reduce its dependence upon foreign oil as well as reap significant economic benefits.

Canada's exploitation of a non-traditional fossil fuel is a prime example to the UK. By using a non-traditional source of fossil fuels, it has allowed the Canadian oil industry to continue to flourish and grow, with over 100 new wells spudded in Alberta alone to extract from the oil sands. The UK is at a critical point, due to its falling oil reserves, and may have to take advantage of non-traditional fossil fuels in the future to increase its energy security.

5. Shale Gas

5.1 Implications

Organic rich carboniferous marine shales are present across a large part of Britain, with the largest formation consisting of the Bowland-Hodder formation in Central Britain. The shale formations in the UK, such as the Bowland-Hodder, are organic rich and as such are deemed to be excellent source formations for shale gas (Selley 2012).

The UK has a significant shale gas potential with a BGS study suggesting 82 to 228 TCF with a mid-estimate of 150TCF of technically recoverable reserves in the UK, with the mid estimates able to supply UK natural gas needs for the next 55 years (Table 1) As a result, Britain has one of the highest shale gas potentials in Europe, and due to the size and quality of the shale formations it is highly likely a shale gas industry will be developed in the UK by 2020. While the amount of shale gas resources in the UK is considerably higher than those quoted above, only 10-20% of proven reserves may be technically recoverable (Stevens 2012).

5.2 Benefits of Shale Gas

A future shale gas industry could provide significant benefits for the UK in the future. Perhaps the biggest potential benefit is increasing the UKs energy security. The UK, like much of Europe, is reliant upon imported Russian natural gas. As a result of turbulent politics between the western world and Russia, the UK is in dire need to increase its own energy security. The results show that shale gas has the potential to reduce its dependence upon Russia through the development of its own shale gas industry (Cotton *et al.,* 2014). Natural gas currently makes up 30% of the UKs electricity needs, and with government plans to close all coal fired powerplants by 2020, natural gas is of vital importance to the UK for its economy and electricity needs. Security of its own energy supply in a troubled world is therefore of paramount importance.

A developed shale gas industry could also lead to significant job creation across the country as the industry develops. In addition, a shale gas industry in the UK is likely to decrease and stabilise the natural gas price in the UK. The UK has some of the highest natural gas prices in the world, with US citizens paying less than a third of what their British counterparts pay, partly due to its current shale gas revolution which has added billions to the country’s economy, increased its energy security and created jobs (Christopherson and Rightor 2012).

5.3 Environmental effects

5.3.1 Water Issues

The environmental effects of fracking are a major concern to the UK government and public, and none more so than the impact fracking may have upon water sources in the future. The fracking processes require a tremendous quantity of water in order to fracture the shale deposits, allowing for gas extraction. Each fracking well will, on average, use over 2 million gallons of water per year, increasing strain on the UK’s water supply (Jenner and Lamadrid 2013).

The fracking process also results in a significant quantity of wastewater as a by-product, approximately 25-75%, which is often stored in open pits near the wells. While the wastewater is required to be taken away from the site and treated, the potential still remains for contamination of the surrounding areas from wastewater due to accidents, spills, and improper storage techniques. Spills of fracturing fluid could pose a bigger risk that hydraulic fracturing itself due to the number of chemicals contained within the fluid (Zeng *et al.,* 2013). Contamination of wastewater of the surrounding area could have devastating effects on local flora and fauna in areas surrounding wells, many of which are situated in or close to natural parks (Rahm and Riha 2012). Contamination of local water sources such as rivers could also lead to significant health impacts for local human populations as many of the chemicals used in the fracking process are carcinogenic and have associated health risks.

Methane seepage into groundwater and aquifers is also a major concern. Natural gas primarily consists of methane, with concerns raised of groundwater contamination as a result of well cracks and failures. It could also pose a number of health hazards, particularly if contaminated water also contaminates aquifers (Stamford and Azapagic 2014). Several groundwater sources close to existing fracking wells in the US have reported increased concentrations of methane, causing widespread condemnation (Yang *et al*., 2013). However, several studies have shown increased dissolved methane concentrations in drinking water do not pose a significant threat to local population well-being however this is still disputed (Osborn *et al.,* 2011; Kappel and Nystrom 2012).

While water contamination is a major risk of a fracking industry in the UK, with 54% of polled people highlighting water contamination as the biggest environmental concern from fracking, effective management strategies can be put in place to reduce the risk of water contamination. Fracking near groundwater sources is regulated under the Water Framework Directive, with the environmental regulation responsible for deciding if fracking possess a contamination risk to local groundwater sources and can set restrictions to reduce the risk of groundwater contamination, while in the UK it is not permitted to fracture below freshwater aquifers (Selley 2012). Regular well integrity checks are essential to avoid aquifer contamination, with the UK government suggesting checks every 3/6 months to ensure well integrity.

Table 2- Chemicals used during the fracking process and purposes for each substance. Table highlights the main chemicals used and their purpose in the fracking (Source Burton et al., 2014)

Functional Category	Purpose	Example of Chemical used
Diluted Acids	Improve injection and penetration. Dissolves minerals and clays to reduce clogging, open pores and aid gas flow	Hydrochloric acid
Proppant	Holds open fractures to allow gas to be released from shale formations	Silica, glass beads
Scale control	Prevents minerals scale formation which can clog wellbore and block fluid and gas flow	Ethylene glycol

5.3.2 Air Quality and Methane Emissions

Another key potential environmental impact from a large-scale fracking industry concerns methane emission from fracking wells. Natural gas has a high methane content, and during the extraction processes methane is released into the atmosphere. While shale gas extraction produces less CO_2 than traditional fossil fuel extraction methods used for oil, methane emissions from fracking could be twice as high, which will raise concerns over the climatic impact of the practise (Howarth *et al.,* 2011). While much of the focus regarding GHG emissions focuses on CO_2 as the dominant GHG, methane is a potent GHG, and over a 20-year period methane is 84 times more potent than carbon dioxide, and 21 times more potent over its lifetime. While a shale gas industry would help the UK to reduce part of its CO_2 emissions, particularly as it would replace coal fired powerplants, it would substantially increase the UKs methane emissions (Stamford and Azapagic 2014). This could lead to a short-term increase in the rate of regional climate change.

Air quality concerns have also been raised, with well documented impact on air quality in areas with active fracking wells. Several studies concern US wells have shown increases in emissions of not only methane, but VOC's and HAP's, particularly benzene (Broderick *et al.,* 2011). The increases benzene around fracking wells is a major concern, posing a potential cancer risk to those living nearby fracking wells. While the exploration wells currently under development in the UK are not in close proximity to major urban centres, wind borne benzene can pose a risk to local populations. However, this can be easily management through traditional air quality control methods.

5.3.3 Induced Seismicity

Human induced seismicity can also occur as a result of fracking for shale gas. The process of injecting high-pressure water into shale formations to allow for the release of natural gas does cause small earthquakes to occur, due to the sheer stress placed upon the rocks to allow for the gas extraction, combined with the high-pressure water injected into the rock increasing strain on existing fault lines (Rutqvist *et al.,* 2013). As a result, a number of the protests against fracking which have focused upon the potential risk of major earthquakes as a result of fracking for shale gas. Many of the protests surrounding Cuadrilla Resources exploration drilling in Blackpool at the Preese Hall drilling site have particularly focused on the earthquake risk after two earthquakes were caused in 2011 due to the company's fracking exploration (Clarke *et al.,* 2014). Both seismic events, magnitudes 2.3 and 1.5, occurred close to the drilling site, with the BGS suggesting the quakes were caused by the fracking activities, something later accepted by Cuadrilla following its own investigations, with the fracking process at the well site triggering earthquakes along a known seismic fault-line which has caused historic Blackpool earthquakes (Westaway and Younger 2014).

While fracking has been shown to cause seismic events, such as the two earthquakes which occurred as a result of Cuadrillas operations, the earthquakes caused by fracking are often small, local events not felt on the surface. When larger earthquakes do occur, such as those in Blackpool, the quakes are no larger than other earthquakes which have been felt in the area. However, the risk still remains for further seismic events as the industry develops in the coming decades (Rutqvist *et al.,* 2015).

The risk of fracture induced earthquakes can be reduced via a traffic light system, which was developed in the USA to address seismic concerns. The traffic light system stops all activities at a drill site once microquakes are detected, reducing the risk of a major seismic event occurring. The detection of microquakes, which act as preludes to major seismic events, and subsequent shutdown of activity can stop a major quake from occurring if caused by fracking activities.

5.4 Case Study – Fracking in the USA

Shale gas in the USA is a thriving industry, and continues to show rapid growth as an alternative source for the USA's natural gas needs. While shale has been providing the US with a source of natural gas since the 1825's, falling reserves and lower extraction costs has resulted in a shale gas revolution since 2000 (Kerr 2010). Largely due to shale gas discoveries, the estimated reserves of natural gas in the United States in 2008 were 35% higher than in 2006 (Jenkins and Boyer 2008).

The US contains some of the highest estimated shale gas reserves on the planet, with the EIA in 2012 estimating 482TCF of technically recoverable shale gas reserves in the USA, including the Marcellus Shale Complex. However, several studies suggest the true shale gas potential of the US could be considerably higher, and technological advancements in the future may see a greater proportion of the US total shale gas being technically recoverable. The US has experienced rapid growth in the extraction of its shale resources, which in 2009 grew 54% to 3.11TCF per year. The boom in the industry has consequently seen shale gas makes up 23% of total US gas production in 2010, and is expected to rise to 49% by 2035 (AEO 2013).

The development of shale gas in the US has brought about significant benefits. The US is now much less reliant on overseas countries as a result of its shale gas industry and in particular has allowed it to reduce its gas imports, increasing its energy security (Jacoby *et al.,* 2011).

Due to the rapid growth of shale gas in the USA, and with the industry regulation left to each individual state, reports of malpractice and corner cutting are widespread (Rahm 2011). Several studies have found low level methane contamination of groundwater and aquifers close to fracking wells, suggesting contamination as a result of fracking which has raised health concerns. In Pennsylvania, wastewater from fracking has been released into rivers and has resulted in condemnation and protests (Olmstead *et al.,* 2013).

Fracking in the UK could provide a number of benefits to the economy as well as reducing the dependence of the UK on imported natural gas. The shale industry in the USA has highlighted the benefits of shale gas. However, the environmental risks associated with shale gas are a major concern. The USA is a prime example of poor regulation resulting in severe environmental impacts and may explain the considerable resistance to shale gas seen in the UK. Despite not having a fully developed shale gas industry in the UK, regulations are already in place to help avoid many of the pitfalls and negative impacts of shale gas, however how successful they will be remains to be seen. As a result of falling oil reserves and increasing dependence upon imported fuel reserves, there is a strong likelihood for a shale gas industry in the UK in the coming decades to take advantage of the resources available.

The UK government is actively promoting a shale gas industry in order to reduce its dependence on imported fuel and see shale gas as a stop gap option as it transitions to a low carbon economy as required by the UK Climate Act 2008. Natural gas was responsible for 30% of UK electricity generation in 2015, and 35% in 2016 as coal fired power plants began to shut down following a government commitment to phase out coal as a fuel source by 2020 in light of the Paris agreement. As a result, the amount of natural gas used and required by the UK government is set to increase dramatically as coal is cycled out of the

UK's energy mix. Shale gas therefore could substituted for coal in the future while renewables continue to be developed and built (Chi *et al.,* 2009).

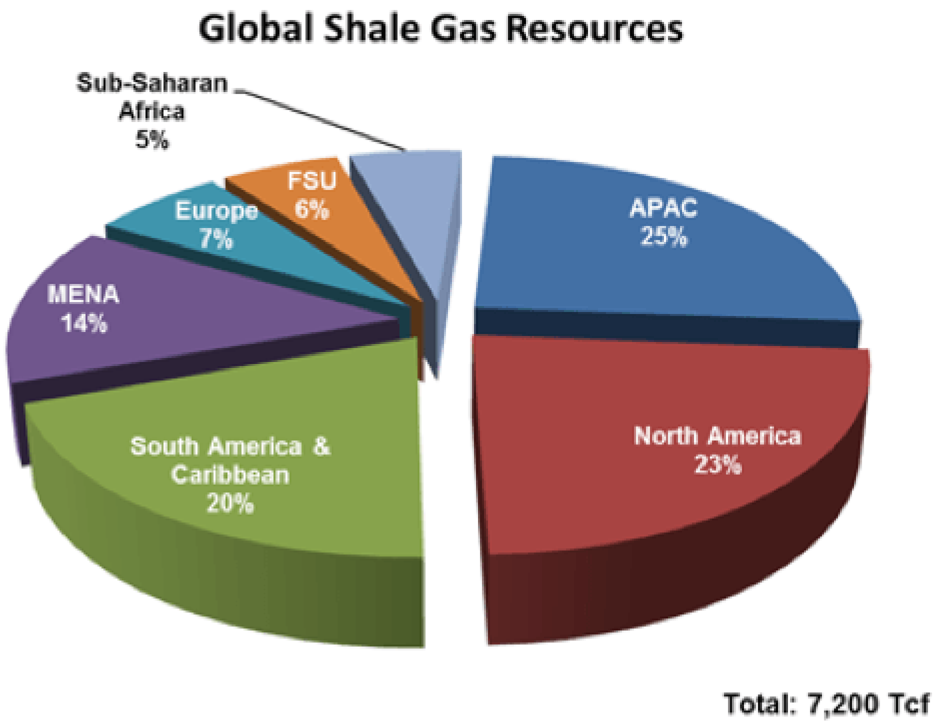

Figure 5- Global Shale gas resource per region. North America has the second highest estimated reserves of shale gas, behind Asia-Pacific (APAC), with the majority of shale gas in North America concentrated within the United States. Middle East and North Africa (MENA), Europe, Former Soviet Union (FSU) and Sub-Saharan Africa all have sizeable shale gas reserves. (Source: AEO 2013)

6. Renewables

6.1 Wind energy

While fracking could act as a stop gap fuel, the UK's aim is to become a low carbon economy, with the majority of its power derived from renewable sources. The United Kingdom has one of the highest wind energy potentials in the world, and is by far the best in Europe (Strachan *et al.,* 2006). Since the Strategic Environmental Assessment in 2007, wind energy has undergone massive growth in the UK, today generating over 15% of the UK's electricity (Burton *et al.,* 2011).

Wind power is increasingly becoming a key source of energy generation of the UK consisting of 7,613 wind turbines and a total installed capacity of 15.6 GW. The majority of the wind turbines which make up the UKs wind energy sector are situated onshore, with 10,275 MW generated from onshore farms, and 5,356 MW generated from off-shore wind farms (Kaldellis and Zafirakis 2011). With an overall capacity of 15.6 GW, the UK is currently the world sixth largest producer of wind power, previously overtaking France and Italy in 2012 (Bell *et al*., 2013). Since 2010 wind energy has seen massive growth in the UK, achieving double digit increases on installed capacity since 2011, with a 12% increase of installed capacity in 2014 (Perez-Collazo *et al.,* 2015). Public support for future growth in wind generation is also high, with 65% of the public supporting a further growth in wind energy.

While historically wind farms have been situated onshore, the past several years have seen wind farms being moved off-shore to take advantage of its considerable off-shore potential. The UK is already the world leader for offshore wind power generation and has been since 2008, pioneered by the 175 turbine London Array wind farm. Located off the Kent coast, the London Array is the largest off-shore wind farm in the world, as well as the largest wind farm in Europe (Glasdam *et al.,* 2014).

The development of off-shore wind farms in the UK has occurred in three major stages:

Round 1, which includes the Teesside Wind Farm and North Hoyle Wind Farm was completed in 2013 with 12 wind farms in total with a maximum power generating capacity of 1.2GW (Feng *et al*., 2010).

Round 2 learnt lessons from the first round of off-shore wind farms, particularly regarding the difficult obtaining planning consent for offshore wind farms, as well as issues raised regarding the visual impact of wind farms as well as to avoid impact on the feeding ground of sea birds (Bhattacharya *et al*., 2013). Round 2 saw 15 projects approved for construction including the London Array, and the Triton Knoll wind farm which is still currently in development (Heptonstall *et al.,* 2012).

The next stage, Round 3, began site allocations in June 2008, and aims to be the largest so far. While Round 1 and 2 allocated 8 GW of sites for off-shore wind farms, Round 3 aims to deliver 25GW of wind energy in the future, with 9 sites having been approved. All 9 sites are currently under construction (Greenacre *et al.,* 2010; Tavner 2012).

The wind industry in the UK has undergone considerable growth in the past decade, and highlights the UK's need to reduce its energy dependence upon fossil fuels in order to combat climate change as well as meet international agreements. The development of its wind industry is also allowing the UK to transition away from fossil fuel power generation, particularly coal fired power plants, which are currently being phased out by 2020.

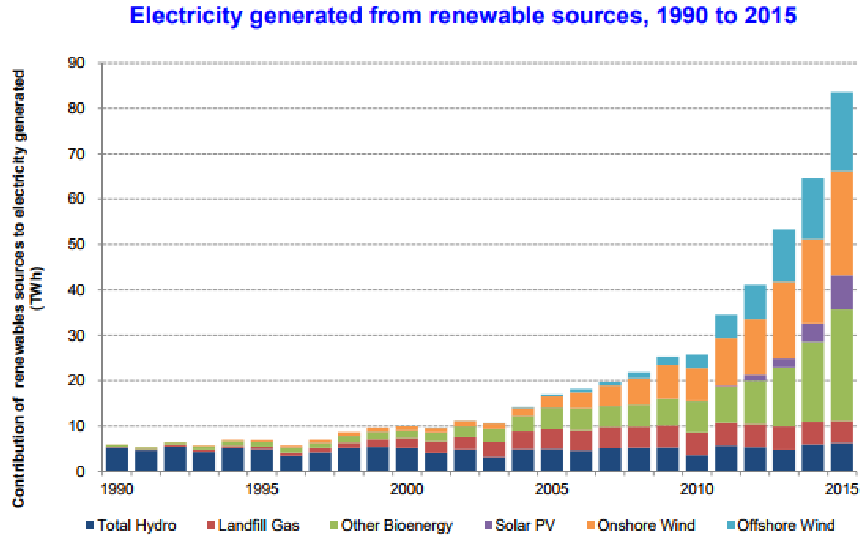

Figure 6-Electricity generated from renewable sources, 1990 to 2015. Hydroelectric power constituted the majority of the UKs renewable energy source in 1990, before the expansion of wind power in the 21st century. While wind power was concentrated on-shore at the beginning of the century, off-shore wind saw drastic growth after 2010. Solar PV energy expansion has also helped increase the renewable energy share of the UK power mix. The growth in renewable energy generation reflects UK government efforts to increase renewable power. (Source Harris and MacLeay 2015)

6.1.1NIMBY

One of the biggest hurdles to further development of wind generation in the UK is the NIMBY movement. Nimbyism is not a new philosophy, and can occur in protest to a number of projects ranging from oil wells to youth hostels. However, the growth of onshore wind farms has resulted in a new wave of environmental nimbyism opposed to onshore wind generation. The renewed hostility to onshore wind farms as a result of the nimbyism movement was partially responsible for the renewed focus on off-shore wind farms in the UK, with onshore wind farms granted permission falling to just 33% in 2014 (Devine-Wright 2005, 2014).

Aesthetics of wind turbines play a major role in the opposition to onshore wind turbine development. The aesthetical look of wind turbines has often had a significant role in the evaluation of prospective turbine developments, with many perceiving wind turbines as ugly and a menace upon the natural beauty of the British countryside (Bell *et al.,* 2013). While some people do find wind farms pleasant or as symbols of a renewable energy revolution, a large majority of people find turbines unsightly, especially as a result of turbines often being situated in the countryside and across British mountains (Van der Horst 2007). While offshore windfarms have greater potential due to constant wind speeds, and are increasingly being developed, aesthetical concerns are still raised by local communities due to their visual impact.

Nimbyism has also raised concerns regarding birds with the development of windfarms both on and offshore. The impact of wind energy on birds is complex and hard to manage. Wind turbines can directly impact bird populations as a result of deaths from flying into turbine blades, or indirectly due to habitat degradation (Erickson *et al.,* 2001). However, while wind turbines have contributed to bird deaths, many studies used as evidence focus on bird deaths and fail to take into account bird mortality. Conventional fossil fuel mining and fossil fuel plants have resulted in significant bird mortality reductions due to toxic deposits and acid raid which have damaged and poisoned nesting and feeding grounds. Wind turbines deaths can be high; however, they may be as much as 20 times less than fossil fuelled power plants, suggesting a switch to wind energy may help reduce bird deaths in the long run when compared to conventional fossil fuel plants (Sovacool 2013). The RSPB has concluded that wind farms, when positioned correctly, do not pose a significant hazard, and that wind energy can help protect birds in the long term by combating climate change (Langston 2010).

While the UK public agrees there is a greater need for renewable energy sources in the UK to help combat climate change, and increase the UKs energy security, a large majority are opposed to living close to on shore wind farms. While 65% of those polled supporting a further growth in the wind industry in the UK, and 52% highlighting wind as having the most potential of all renewable energy sources, 78% would not live in close proximity to a wind farm (figure 2). This further highlights the connotation that UK residents support and believe the need for the development of wind farms in the UK, but they should be further away, in this case off-shore. These results mirror the results of several studies which have demonstrated a high level of Nimby opposition to wind farms in the UK, particularly in rural areas where find farms are often concentrated.

6.2 Other Renewable Sources

The UK renewable industry as a whole, taking into account all sources of generation, exceeded 25% in 2015, surpassing coal generation for the first time (Foley and Olabi 2017) Renewable energy as a whole is undergoing growth across the UK and is not restricted to wind energy, albeit wind energy is the largest contributor.

Solar energy in the United Kingdom has historically been responsible for a small part of the UKs electricity generation, largely due to the cost and efficiency concerns regarding photovoltaic panels. Since 2010 technological advances have allowed for greater efficiency as well as a reduction in the cost of solar panels, and as a result solar power now contributes 3.4% of the UKs power generation in 2016, with a capacity of 12,000 MW, placing the UK sixth in worldwide total installed capacity for solar energy (DECC 2015). The reduction in the price of solar panels have seen a rise in their use to power domestic homes, often situated upon the roofs of urban buildings. However, unlike wind power, the UKS solar power generation is concentrated in the south, as well as being more expensive than wind energy in the UK (Bahaj and James 20007). Despite this solar energy has significant potential in the future, with estimations suggesting 4 million homes will be powered by solar energy across the UK by 2020 (Walker *et al.,* 2007).

Hydroelectric is another renewable energy will which play a role in the future as the UK transitions to a low carbon economy. 2% of the UK’s total electricity generation is the result of hydroelectric power, which makes up 18% of the renewable energy capacity, and accounts for around 1.8 GW (DECC 2015). While the UK has adequate hydroelectric potential, with the potential for up to a further 3,000 MW of hydroelectrical power stations in the UK. However due to the geography of Britain many of the locations ideal for hydroelectric power are located close to natural parks and areas of natural beauty, and would face considerably environmental concerns should they go ahead. The proposed Swansea Bay Tidal Lagoon, which could provide energy for 150,000 Welsh homes has undergone repeated delays as a result of concerns of its effect upon fish and wildlife (Gruffydd 2017). However, should the project go ahead, it would be the first operational tidal lagoon plant in the world.

6.3 Can renewable energy meet the UKs electricity demand?

Perhaps the biggest question surrounding renewable energy, and one which has caused considerable disagreement in government and energy circles, can renewable energy provide 100% of the UK's electricity demand? As the UK transitions away from traditional fossil fuels, renewable energy will have to be able to generate the electricity needs of the UK.

Historically, due to variability in renewable sources such as wind and solar, scepticism has been high about renewable energy ability to meet the UK's demand requiring variable forms of energy in the sun and wind (Edenhofer *et al.,* 2011). However, in recent years, particularly due to the development of large off-shore wind farms, as more turbines are connected over greater distances, the average power output becomes less variable (Sinden 2007). Therefore, spreading thousands of turbines over several different sites around the UK, in different wind regimes, could smooth out the variations in wind energy produced, and providing the UK with a normal distribution of power.

There is no longer any doubt that renewable energies can meet the UKs energy demand, as renewable technology develops in the future (Hoffert *et al.,* 2002). However, the transition to a renewable energy sector faces further issues. While renewable energy continues to develop, due to the development and construction time, fossil fuels will be required to ensure cheap energy for the UK (Gross *et al.,* 2007). This could further reinforce the need for a fracking industry in the UK in the future, allowing time for the UK to transition to 100% of its energy from renewable sources while maintain its energy supply in the short term while development of renewable energy continues in the coming decades. However, many environmentalists believe the investment into a shale gas industry in the UK would be better invested into the renewable industry allowing for a faster rate of development without the environmental consequences of fracking (Gruffydd 2017).

6.4 Case Study- Renewable Energy in Germany

Germany is at the forefront of pioneering renewable energy and is often referred to as the first major renewable energy economy. The adoption of *Energiewende*, energy transition, has led to a significant change in the countries energy policy since its implementation in 2011, with Germany's ultimate goal to transition to a low carbon energy supply (Couture and Gagnon 2010).

Germany currently generates 29.5% of its total power requirement from renewable sources, with wind and biomass energy generation making up the largest portion. The development of the renewable sector in Germany as resulted in 23,000 wind turbines, as well as 1.4 million solar systems being distributed across the country (Sadorsky 2009). Since 2011 the Germany government has also begun to actively develop its off-shore wind potential to further increase its renewable energy generation. Germany also has one of the fastest solar energy industries in Europe, and has help develop technologies which resulted in the price of solar photovoltaic systems decreasing by 50% since 2006 (Quaschning 2016).

The German strategy of *Energiewende* is aimed at changing energy views in Germany, focusing more upon the supply chain as well aiming to help improve energy efficiency and reduce energy waste. An important focus of *Energiewende* is to reduce primary energy consumption by 50% by 2050, which is in stark contrast to the UK which predicts a demand increase over 70% by the same year (Schmid *et al.,* 2016) The policy also includes aims to reduce GHG emissions by a minimum 80% by 2050 from the 1990 baseline. The policy has resulted in the phasing out of all existing coal-fired generation, with one of the major goals of the policy also phasing out all nuclear reactors in the country by 2022. This will allow for a massive increase in funding for new renewable energies, primarily off-shore wind and hydroelectric power. In addition, a €1.5 billion fund per year exists to fund energy research in order to help solve technical issues involved with the transition to a low carbon economy (Hake *et al.,* 2015).

As a result of its energy transition Germany has seen a number of significant landmarks highlighting its progress towards becoming the world's leader in renewable energy. May 2016 saw renewables provide over 80% of the country's electricity demand for over an hour, mainly due to solar energy, with solar energy predicted to produce up to 25% of the countries required electricity by 2050. A new raft of off-shore wind farms due to be finished by 2020 could also see Wind energy provide over 20% of the country's total energy needs (Jacobs 2012).

Germany's transition to a low carbon economy is in full swing and serves as a blueprint for the UK to follow in the coming decades. Its commitment to renewable technology has allowed it to be seen as the world's first renewable energy economy, with further goals to further increase its renewable market as well as see a dramatic increase in its energy efficiency in the future. The UK should also be following the example of Germany in the future to also allow it to transition to a low carbon economy.

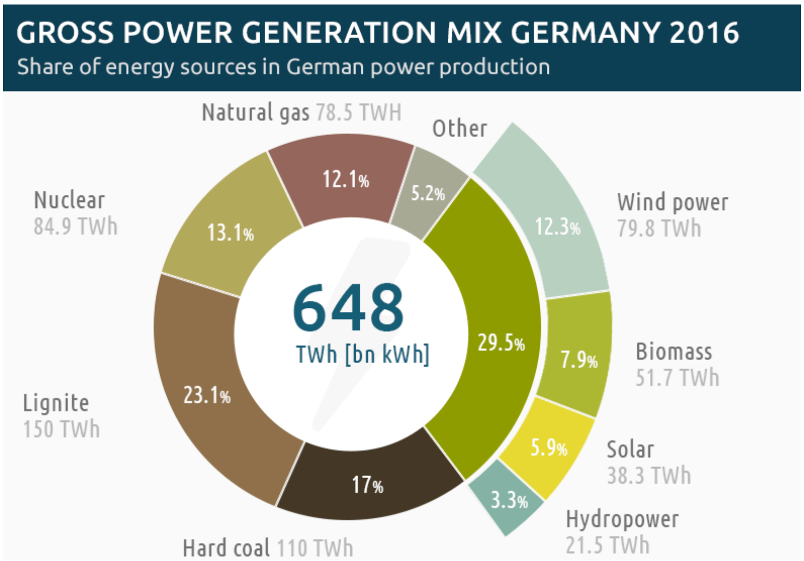

Figure 7-Gross power mix for Germany at the beginning of 2016. Renewable energy provides 29.5% of Germany's energy needs, with wind contributing 12.3% or 79.9 TWh. Biomass, Solar and hydropower provide the rest of the renewable sectors energy contribution, providing 7.9%, 5.9% and 3.3% respectively. (Source Quaschning 2016)

7. Conclusion and Recommendations

7.1 Conclusion

The UK is at a critical point regarding its energy industry. The results highlighted above demonstrate the UK is quickly diminishing its traditional fossil fuel stores, particularly North Sea oil. While North Sea oil was once the driving force of the UK economy and able to meet the majority of the oil needs of the UK, today falling reserves and extraction rates could be the beginning of the end for the North Sea oil industry.

The falling reserves of the North Sea, and the rising dependence of the UK upon imported fuel sources, has seen a renewed interest into alternative sources of energy. While the oil price slump of 2014 resulted in shale gas taking a back seat, shale gas is once again coming to the forefront. The UK has considerable shale gas reserves and it is highly likely an industry similar to the USA's but on a smaller scale will grow in the coming decades, despite the potential severe environmental impacts.

The long-term goal for the UK has always been to transition to a low carbon economy, with the majority of its energy produced from renewable sources. Renewables offer the UK a unique opportunity to meet its climate change goals, while providing the energy it needs, however the industry requires more support and greater expansion in the future. Renewables could also hold the key to the UKs energy security, delivering energy independence if renewables continue to grow at the same rate they have since 2000.

7.2 Recommendations

I. UK policy in the future should aim to source oil from a number of countries to reduce dependence upon one major country as a source of oil. As North Sea extraction rates continue to decline, diversifying the oil source will increase the UK's energy security and reduce the risk of a potential oil crisis in the future. Additionally, the UK should also look to source oil from more politically stable countries such as Canada, and not be dependent upon Middle East oil due to geopolitical turmoil in the region.

II. The UK government and oil companies should actively explore ways to maintain jobs in the UKCS as oil extraction continues to decrease in the future. The oil industry is a major income source for the UK government via tax and supports thousands of jobs and households in the UK. Scrappage operations and the potential for a CCS scheme in the North Sea could help ensure job numbers into the future while providing an environmental benefit.

III. The UK should follow the direction of Canada and begin to explore its alternative energy sources, most likely shale gas. Due to the size of the reserves and the ability to drastically increase its energy security, it is highly likely a shale gas industry will emerge in the UK in the future. While regulations already exist, and are harsher than the regulations of shale gas in the US, regulations must be reviewed and standardised to ensure the industry takes every step possible to reduce to environmental risks associated.

IV. Greater public awareness surrounding shale gas is required in the UK. A large proportion of the UK public is firmly against fracking in the UK, partly due to the smear campaign against the industry. While the environmental impacts are considerable, several mechanisms can be put in place to limit and reduce the

impacts. The public confidence in the industry and the benefits it brings must be improved in the future.

V. Shale gas should be used as a stop gap fuel in the future to give the UK time to transition to a low carbon economy. It is crucial investment into shale gas does not take away from renewable energy development. Instead shale gas should be used to provide the UK with a cheap fuel source while development and investment continues into renewable energies to allow for renewables to meet the UKs future demand and transition the UK into a low carbon economy.

VI. Off-shore wind energy should continue to be developed to meet the energy needs of the UK. Taking advantage of its high wind energy potential is key for the UK to meet its energy demands in the future. The spreading of turbines around the UK shore can reduce variability in the energy generated. Investment into all forms of renewable energy should increase in the future to accelerate their development and integration into the UKs energy grid.

VII. The UK requires an energy transition policy similar to that currently occurring in Germany. Developing a range of renewable sources will help to meet the countries energy demand and provide clear aims as the UK becomes a low carbon economy. Further steps must also be taken to increase the energy efficiency of the UK.

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Appendix 1.

Emails
Fabienne Marret-Davies

Date	Recipients	Subject	Outcome
25/05/17	Daniel Dickson	Dissertation Meeting	Meeting arranged for 1/06/2017
1/06/2017	Daniel Dickson	Payment Request	Attached expenses form for travels related to the dissertation
7/06/2017	Daniel Dickson	Records of Meetings	Detailed requirements for the appendix. Also details word count and general information.
2/07/2017	Daniel Dickson and Fabienne Marret-Davies	Dissertation Meeting	Confirmation and time of meeting at 10am on 4/07/2017
14/07/2017	Fabienne Marret-Davies and Rob Duller	Depletion Time Equation	Issues experienced in computing the equation-Rob helped to guide and compute the equation.
07/08/2017-11/08/2017	Fabienne Marret-Davies	First Draft	First draft sent for review. Feedback detailed in returning email
04/09/2017	Fabienne Marret-Davies	Results Section	Results section included after guidance results section was required.
04/09/2017	Daniel Dickson	Instruction Document	Changes to the instructions for the layout of the thesis

Stuart McBain

Date	Recipients	Subject	Outcome
29/05/2017	Stuart McBain	Dissertation Meeting	Meeting for the following week arraigned. Outlined the dissertation and estimates for completion of each stage

16/06/2017	Stuart McBain	Dissertation Update	Update on progress on the dissertation.
1/08/2017	Stuart McBain	Dissertation Update	Update on progress on the dissertation
1/09/2017	Stuart McBain	First Draft	First draft sent for feedback and any requested changes

Appendix 2

Meetings

Date	Attendees	Topic	Outcomes
1/06/2017	Daniel Dickson and Fabienne Marret-Davies	Dissertation Update	Provided general guide upon the dissertation. Questions answered regarding first draft deadline
4/07/2017	Daniel Dickson and Fabienne Marret-Davies	Dissertation Update	Questions focusing upon the data collection. Agreed upon deadline for first draft
5/06/2017	Daniel Dickson and Stuart McBain	Dissertation Update	Update on progress as well as detailing when first draft would be available for review
7/09/2017	Daniel Dickson and Stuart McBain	First Draft Feedback	Feedback from first draft.

Appendix 3

Questionnaire Template

UNIVERSITY OF LIVERPOOL

Fossil Fuel, Shale Gas and Renewables Questionnaire

The purpose of this study is to examine public perception and views of fossil fuels, shale gas and renewables and their use in the UK. This study is being conducted as part of a master's thesis with the University of Liverpool as part of the Environment and Climate Change MSc. This questionnaire asks about your personal views on the usage of fossil fuels, shale gas and renewables in the UK as part of the country's energy mix. Your responses will be anonymous and will never be linked to you personally. Your participation is entirely voluntary. If there are items you do not feel comfortable answering, please skip them. Thank you for your co-operation.

Part 1: BioData

Please tick the most appropriate response.

1. Gender ☐ Male ☐ Female ☐ Rather not say
2. Please write your Age: ______________________________
3. Location: ____

Part 2: Fossil Fuels

1. The UK is too reliant upon fossil fuels for its energy needs. How much do you agree with this statement?

Do not agree
Completely Agree

1	2	3	4	5	6	7	8	9	10

2. Is the UK too reliant upon foreign oil?

☐ Yes ☐ No

3. How concerned are you about falling UK oil reserves?

Not concerned Very
concerned

1	2	3	4	5	6	7	8	9	10

4. How concerned are you about the UK's dependence on overseas source of energy?

Not concerned Very
concerned

1	2	3	4	5	6	7	8	9	10

5. Should the UK diversify its energy mix away from traditional fossil fuels?

☐ Yes ☐ No

Part 3: Shale Gas

1. How likely are you to support a fracking industry in the UK?

Not likely
Very likely

1	2	3	4	5	6	7	8	9	10

2. How likely are you to oppose a fracking industry in the UK?

Not likely
Very likely

1	2	3	4	5	6	7	8	9	10

3. Should fracking be used to reduce UK reliance upon imported energy?

☐ Yes ☐ No

4. How concerned are you with the environmental impacts of a potential fracking industry?

Not concerned Very
concerned

1	2	3	4	5	6	7	8	9	10

5. Which potential environmental impact of fracking are you most concerned about?

☐ Methane Emissions ☐ Seismicity ☐ Water contamination

Part 4: Renewables

1. Which renewable energy source do you believe has the most potential?

☐ Wind ☐ Hydroelectric ☐ Solar ☐ Geothermal

2. Would you live in close proximity to a wind farm? (10 Miles)

☐ Yes ☐ No

3. Should windfarms be situated off-shore?

☐ Yes ☐ No

4. Do you think renewable energy can be a long-term replacement for oil and gas?

☐ Yes ☐ No

5. How would you rate the UK government's policy on renewable energy?

Very poor
Excellent

1	2	3	4	5	6	7	8	9	10

6. Which energy source should be increased in the UK?

☐ Coal ☐ Oil ☐ Hydroelectric ☐ Vind ☐ ar G☐thermal Oth☐

Appendix 4

Results Spreadsheet

Workbook Views | Show | Zoom | Window | Macros

B61

	B	C	D	E	F	G	H	I	J	K	L	M	N
1		1	2	3	4	5	6	7	8	9	10		
2	1. The UK is too reliant upon fossil fuels for its energy needs. How much do you agree with this statement?	11	4	1	8	7	12	146	46	97	118	450	
3													
4		Yes	No										
5	2. Is the UK too reliant upon foreign oil?	387	63									450	
6													
7		1	2	3	4	5	6	7	8	9	10		
8	3. How concerned are you about falling UK oil reserves?	94	24	39	67	72	51	47	12	1	43	450	
9													
10		1	2	3	4	5	6	7	8	9	10		
11	4. How concerned are you about the UK's dependence on overseas source of energy?	0	0	0	78	49	0	88	156	43	36	450	
12													
13		Yes	No										
14	5. Should the UK diversify its energy mix away from traditional fossil fuels?	412	38									450	
15													
16		1	2	3	4	5	6	7	8	9	10		
17	1. How likely are you to support a fracking industry in the UK?	103	67	35	28	0	6	87	69	52	3	450	
18													
19		1	2	3	4	5	6	7	8	9	10		
20	2. How likely are you to oppose a fracking industry in the UK?	3	12	34	58	6	12	25	32	70	198	450	
21													
22	3. Should fracking be used to reduce UK reliance upon imported energy?	Yes	No										
23		248	202									450	
24													
25	4. How concerned are you with the environmental impacts of a potential fracking industry?	1	2	3	4	5	6	7	8	9	10		
26		0	3	11	8	12	46	81	82	87	120	450	
27													
28	5. Which potential environmental impact of fracking are you most concerned about?	Other		Emissions		Siesmicity		Water contamination					
29		0		95		110		245				450	
30													
31	1. Which renewable energy source do you believe has the most potential?	Solar		Wind		Tidal		Geothermal					
32		110		235		82		23				450	
33													
34	2. Would you live in close proximity to a wind farm? (10 Miles)	Yes	No										
35		97	353									450	
36													
37	3. Should windfarms be situated off-shore?	Yes	No										
38		396	54									450	
39													
40	4. Do you think renewable energy can be a long-term replacement for oil and gas?	Yes	No										
41		278	172									450	
42													
43	5. How would you rate the UK government's policy on renewable energy?	1	2	3	4	5	6	7	8	9	10		
44		32	42	46	32	49	54	68	45	53	29	450	
45	6. Which energy source should be increased in the UK?												
46		Coal	Oil		Wave	Wind	Solar	Other					
47		4	25		75	296	42	8				450	
48													

Sheet1

Appendix 5

Participant's information sheet

Participant Information Sheet

(11/07/2017)

Title of Study

My name is Daniel Dickson and I am conducting this research as a student in the Environment and Climate Change MSc programme at the University of Liverpool. The title of the study is:

Fuel reserves of the UK; Depletion Times and future Implications.

Invitation

You are being invited to take part in this research project. Before you decide to do so, it is important you understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part. Thank you for reading this.

What is the purpose of the study?

The purpose of this study is to research into the remaining UK fuel reserves, focusing on oil and gas, and estimate their depletion times. The study will also produce a holistic overview of renewable energy in the UK and if it is possible for renewable energy to replace fossil fuels in the future.

.

Why have I been chosen to take part?

The aim of the study is to investigate fuel reserves of the UK and public perception of each. You have been asked to participate in this study because of your involvement in the opposition to the fracking industry.

Do I have to take part?

Taking part in this research is entirely voluntary. It is up to you to decide whether or not to take part. If you do decide to take part you will be able to keep a copy of this information sheet and you should indicate your agreement to the consent form. You can still withdraw at any time. You do not have to give a reason.

What will happen if I take part?

The research will last until the 15th September 2017. As a participant you will be involved in the research until the 4th August 2017, when the data collection and data analysis part of the thesis will be completed.

Are there any risks in taking part?

There are no risks anticipated with participating in this study. However, if you have any queries following participation you are encouraged to inform the researcher and contact the principal investigator using the details provided at the end of this sheet.

Are there any benefits in taking part?

Whilst there are no direct benefits for those participating in the research, you may find participating interesting and if you are interested in obtaining a copy of the thesis then I am happy to send a copy once the research timeframe is completed.

What if I am unhappy or if there is a problem?

If you are unhappy, or if there is a problem, please feel free to let us know by contacting the Principal Investigator, Fabienne Marret-Davies and we will try to help. If you remain unhappy or have a complaint which you feel you cannot come to us with then you should contact the Research Governance Officer at ethics@liv.ac.uk. When contacting the Research Governance Officer, please provide details of the name or description of the study (so that it can be identified), the researcher(s) involved, and the details of the complaint you wish to make.

Will my participation be kept confidential?

- The data collected for this study will be stored securely and only the researchers conducting this study will have access to this data.
- Hard copies of interview data will be kept in a locked cabinet.
- At the end of the study, hard copies will be destroyed, unless the University states otherwise.
- The typed version of your interview will be made anonymous by removing any identifying information including your name if you wish. Direct quotations from your interview may be used in the reports or publications from the study. Contact the researcher at sgddicks@liverpool.ac.uk to state your preference.
- Your responses to the questions will be used for the purpose of this research only.

What will happen to the results of the study?
The results will be summarised and reported in a thesis paper and may be submitted for publication in an academic or professional journal.

What will happen if I want to stop taking part?

Participants have the right to withdraw at any time, the data they provided will not be used and any notes will either be returned or destroyed.

Who can I contact if I have further questions?

If you have any further questions about any aspect of this study, you can contact:

Principal Investigator:
Dr Fabienne Marret-Davies
Roxy Building, room 714
University of Liverpool
+44(0) 151 794 2848
fmarret@liverpool.ac.uk

Thank you for taking time to read this information sheet and for considering taking part in the study

Appendix 6
Consent form template

UNIVERSITY OF LIVERPOOL

Committee on Research Ethics

PARTICIPANT CONSENT FORM

Title of Research Project: Oil and Shale Gas depletion estimates. Can Renewable Energy replace Fossil fuels in the UK?

Researcher(s): Daniel Dickson — **Please initial box**

1. I confirm that I have read and have understood the information sheet dated for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily. ☐

2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason, without my rights being affected. In addition, should I not wish to answer any particular question or questions, I am free to decline. ☐

3. I understand that, under the Data Protection Act, I can at any time ask for access to the information I provide and I can also request the destruction of that information if I wish. ☐

4. I agree to take part in the above study. ☐

Participant Name	Date	Signature
Name of Person taking consent	Date	Signature

Researcher | Date | Signature

Principal Investigator:
Dr Fabienne Marret-Davies
Roxy Building, room 714
University of Liverpool
+44(0) 151 794 2848
fmarret@liverpool.ac.uk

Student Researcher:
Daniel Dickson
Roxy Building, room 714
University of Liverpool
07769214993
sgddicks@liverpool.ac.uk

Please

Additional statements
initial box

- The information you have submitted will be published as a report; please indicate whether you would like to receive a copy.

- I agree for the data collected from me to be used in future research and understand that any such use of identifiable data would be reviewed and approved by a research ethics committee.

- I would like my name used and I understand and agree that what I have said or written as part of this study will be used in reports, publications and other research outputs so that anything I have contributed to this project can be recognised.

Appendix 7
Llyr Gruffydd consent form

Committee on Research Ethics

PARTICIPANT CONSENT FORM

Title of Research Project: Oil and Shale Gas depletion estimates. Can Renewable Energy replace Fossil fuels in the UK?

Researcher(s): Daniel Dickson

Please initial box

5. I confirm that I have read and have understood the information sheet dated for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily. LlG

6. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason, without my rights being affected. In addition, should I not wish to answer any particular question or questions, I am free to decline. LlG

7. I understand that, under the Data Protection Act, I can at any time ask for access to the information I provide and I can also request the destruction of that information if I wish. LlG

8. I agree to take part in the above study. LlG

Llyr Gruffydd	2/08/2017	Ll. Gruffydd
Participant Name	Date	Signature
Daniel Dickson	2/08/2017	D.Dickson
Name of Person taking consent	Date	Signature

Daniel Dickson	2/08/2017	D.Dickson
Researcher	Date	Signature

Principal Investigator:
Dr Fabienne Marret-Davies
Roxy Building, room 714
University of Liverpool
+44(0) 151 794 2848
fmarret@liverpool.ac.uk

Student Researcher:
Daniel Dickson
Roxy Building, room 714
University of Liverpool
07769214993
sgddicks@liverpool.ac.uk

Please

Additional statements
initial box

- The information you have submitted will be published as a report; please indicate whether you would like to receive a copy.

LIG

- I agree for the data collected from me to be used in future research and understand that any such use of identifiable data would be reviewed and approved by a research ethics committee.

LIG

- I would like my name used and I understand and agree that what I have said or written as part of this study will be used in reports, publications and other research outputs so that anything I have contributed to this project can be recognised.

LIG

Appendix 8

Depletion time spreadsheet

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	OIL							Fracking							
2			Proven Reserves	349000000					Central Es	1.5E+11		Low Estimate	1E+11	High Estimate	4E+11
3	Production Rate	45000000	Maximum oil reserves	727000000					FC	500000					
4	Growth	0.001							G	0.2					
5															
6										Low estimate	53.49162				
7	Depletion Time-Proven	7.729485								Central estimate	55.51891				
8	Depletion Time-Maximum	16.0344								High estimate	60.423				
9															
10															

Appendix 9

Llyr Gruffydd Interview transcript

Interview- Llyr Gruffydd-AM for North Wales Region
Interview conducted at Llyr Gruffydd offices in Ruthin Wednesday 2nd August 2017

Daniel; Hi Llyr, thanks for taking the time for meeting with me, would you be able to quickly provide some background to who you are and your current role?

Llyr; I am Llyr Gruffydd, Welsh Assembly Member for the North Wales region and currently the Shadow Minister for Education, Children, Skills and Lifelong Learning. However, in the past I have also served as Plaid Cymru party spokesmen for energy up until 2016 when I took up my current role. As such I was also involved in Plaid Cymru's opposition to fracking in Wales, particularly in Wrexham which forms part of my constituency.

D; What are your views concerning fracking and its potential development in the coming decades?

L; The focus on future energy should be on renewables, embracing fracking in the future is moving away from that and moving in the wrong direction. As a country, the aim should be decarbonising the country to help combat climate change, and not moving towards an energy generation industry which will lead to further climatic impact. Fracking and gas extraction is not the way to go, especially with the ample renewable technology available. Renewables should be the main driving force into the future, with renewables allowing for the potential for Wales and the UK to be self-sufficient in its energy needs. Renewable energy can produce more electricity than needed, and it is critical we use natural resources in a sustainable manner going forward. Plaid Cymru has put forward several co-ownership energy schemes with will deliver clean renewable energy as well as provide social benefits. Such schemes should be encouraged and expanded across Wales and the UK.

D; Scotland have made significant progress in its renewable energy industry in the past several years, and in August 2016 managed to produce more power than needed just from wind energy alone. Is this an example Wales aims to follow in the future?

L; Absolutely. Scotland is a fantastic example of a country embracing its natural resources in a sustainable way, particularly in regard to energy. We share similar targets with Scotland, with Wales having set a 2036 target for 100% sustainable energy. The majority of this would be from wind generation, both on and offshore. We also have hopes for further development of Wales hydroelectric potential, with a proposed tidal lagoon power plant set to be constructed in the Swansea Bay. Projects similar to this highlight Plaid Cymru's continued support for the development of green energy for Wales. The project is one fully supported by the party and campaigned for by us.

D; What do you believe is the biggest potential environmental impact of fracking?

L; Water issues are the number one concern. The amount of water used in the fracking process is astronomical, with the potential for contamination of the surrounding areas due to large amounts of waste water. The process also poses a high risk of methane water contamination and the overall price of fracking is too high for the industry to be allowed to develop. Alternative energy options do not carry the same level of environmental risk that fracking does, with the money put into developing the fracking industry should be used to further develop renewable technologies. While fracking has seen success in the US, population density in the UK make it a much risker concept. While the UK has large space to allow for fracking away from major cities, here in Wales, our higher population density means fracking will occur under homes, and calls into question moral citizens' rights if the processes is approved in the future.

D; How much does the public in Wales oppose the fracking industry? And would you say there is widespread public opposition in Wales to Fracking?

L; There is vast support in Wales for a total ban on fracking which is being driven by local councils. Local people do not want fracking in their communities, especially in Wrexham. We had a popular opposition to fracking despite the welsh government allowing for exploration drilling to happen. Councils, along with protests from Plaid Cymru has resulted in tremendous pressure which resulted in a Welsh moratorium of fracking. However, the Welsh government only passed this in order to appear to be seen to be doing something.

While Plaid Cymru has campaigned against fracking, and I personally organise the opposition to fracking in Wrexham, energy is not devolved at all, with Westminster seeing the issues as too important to devolve energy generation powers, therefore most of the powers are still in Westminster. While the Welsh Assembly were able to introduce a fracking moratorium, this can be overruled by Westminster if they desire.

D; One of the biggest reasons for the exploration of a fracking industry in the UK is to increase our energy security, with the UK now a net importer of energy. Do you agree for the need of a fracking industry to address energy security concerns?

L; Fracking is not the answer to the energy security concerns many government officials have. The development of a fracking industry will cost billions, money which should go into helping increase energy savings as well as developing renewable energy. Renewable energy can increase our energy security just as easily as fracking can, and without the environmental impacts. Plaid's stance has always championed an increase in renewable energies to increase our energy security and ensure environmental wellbeing.

While we need fossilised energy in the short term, the focus should not be on looking at developing new forms of developing fossil fuels, but at progressing and moving towards a renewable future. The nation's energy supply is currently too concentrated upon fossil fuels and needs new energy forms to progress in the future in a sustainable way. Wales and the UK need a cultural shift in order to forget about the old energy of yesterday and progress to the energy of tomorrow and embrace renewable technology to decarbonize the country.

D; Finally, do you think renewable energy can meet the populations energy demand?

L; Currently renewables can meet energy demand however only occasionally. We are getting there but the renewable industry in Wales and across the UK needs more investment in order to become more reliable. Hydroelectric needs to be looked at more. While a lot of the current funding focuses on wind due to the UK's high wind potential, hydro has seen very little funding or investment and should be investigated to provide a good energy mix by source. We are not far off, energy storage is improving and a smarter energy future for Wales is needed. We need a clear path to renewables and less focus on alternative energy such as fracking. Wales is falling behind other countries. Germany are predicted to reduce their energy demand by 2050 where Wales is set to increase by over 50% and is the most energy inefficient country in Western Europe. The time to invest into renewable energy was ten years ago. The second best time is now, we have to follow examples set by other countries such as Germany and allow for technology to develop while implementation continues.

Appendix 10

Oil reserves and extraction raw data

Estimates of UK Oil Reserves and Ultimate Recovery at 31 December 2015[1][2]

[figures in brackets for end 2014]

Oil Reserves units - million tonnes	Proven	Probable	Proven & Probable	Possible	Maximum[3]
Fields in production or under development[4]	349 [374]	217 [255]	566 [630]	161 [312]	727 [942]
Other significant discoveries where development plans are under discussion	0 [0]	0 [86]	0 [86]	0 [32]	0 [118]
Total Oil Reserves in million tonnes[4]	**349 [374]**	**217 [342]**	**566 [716]**	**161 [344]**	**727 [1,060]**
Cumulative Oil Production to end 2015[5]	**3,668 [3,623]**				
Estimated Ultimate Recovery in million tonnes	**4,016 [3,997]**	**217 [342]**	**4,234 [4,339]**	**161 [344]**	**4,395 [4,683]**

[Please note “Other significant discoveries where development plans are under discussion” were counted as Reserves for end 2014 but are shown as zero this year.]

Review of UK Oil Reserves and Contingent Resources

The change in UK oil reserves during 2015 arises from a combination of: changing the category of other significant discoveries from probable and possible reserves to contingent resources only; production during the year; reserves additions from new field developments including those resulting from recent exploration success; reserves revisions in established fields.

Annual oil production was 45 million tonnes in 2015.

From the Oil Table it can be seen that the central estimate of oil reserves (i.e. 2P reserves) based on proven plus probable reserves now stands at 566 million tonnes which is a decrease of 150 million tonnes compared to last year. Taking annual oil production of 45 million tonnes into account this gives an apparent proven plus probable reserves loss of 105 million tonnes. However this is mainly due to changing the category of significant discoveries to contingent resources where the best estimate now stands at 134 million tonnes.

Proven oil reserves at the end of 2015 stand at 349 million tonnes, which is 25 million tonnes less than at the end of 2014. After accounting for annual production, there has been a net transfer of 20 million tonnes from probable to proven reserves. The main contributing factor to this was the reallocation of probable reserves into the proven category resulting from the development approval during 2015 of five new oil and condensate fields including Crathes, Scolty, Edradour, Glenlivet and Culzean.

Probable oil reserves now stand at 217 million tonnes and possible oil reserves at 161 million tonnes. These apparent losses are again mainly due to changing the category of significant discoveries and EOR potential to contingent resources.

Maximum oil reserves (i.e 3P reserves), combining proven plus probable plus possible reserves figures, appear at first sight to have decreased by 333 million tonnes to 727 million tonnes. This is again mainly due to changing the category of significant discoveries and EOR potential to contingent resources where the high estimate now stands at 268 million tonnes including 82 million tonnes for EOR potential. After taking this change and annual oil production of 45 million tonnes into account this gives the maximum reserves loss due to other factors such as reserves revisions and low oil price as 20 million tonnes.

Appendix 11

Shale gas raw data (total estimated reserves)

	Total gas in-place estimates (tcf)			Total gas in-place estimates (tcm)		
	Low (P90)	Central (P50)	High (P10)	Low (P90)	Central (P50)	High (P10)
Upper unit	164	264	447	4.6	7.5	12.7
Lower unit	658	1065	1834	18.6	30.2	51.9
Total	822	1329	2281	23.3	37.6	64.6

Appendix 12

Interview Schedule

Date	Attendees	Location
2/08/2017	Daniel Dickson Llyr Gruffydd	Ground Floor Birch House Business Centre Hen Lon Parcwr Ruthin LL15 1NA