

Encouraging Regional Accountability in the Supply and Distribution of Renewable Electricity

By

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Abstract:

Traditional methods of electricity generation and distribution within the UK have developed around the notion of a highly centralised system, based on the extensive use of fossil fuels. These fuels present a number of challenges; including the depletion of resources, negative environmental impacts, socio-economic barriers and political obstructions. As a result, the development and integration of renewable technologies is imperative in the creation of an energy system which is fully sustainable in the long term. This study investigates the level of planned renewable infrastructure in the UK and the likely increase in electrical generation capacity which will result from the completion of all planned projects. The regional distribution of this generation is explored, in addition to the proportion of electricity demand within each region which can be met by renewable sources of generation under a variety of future scenarios. Overall, there is a high level of variation in the proportion of electricity demand which can be met through renewable generation in each region, with two regions (Yorkshire and Scotland) displaying sufficient planned infrastructure to meet greater than 100% of future energy demand, whilst other regions illustrate low levels of increased generation - the lowest of which is seen in the London region, where a maximum of 3% of electricity demand is estimated to be met through renewable generation in the future. Overall, it is suggested that encouraging regional accountability for the supply and distribution of renewable electricity will enable increased sustainability and efficiencies in the energy system, and increase the likelihood of establishing a fully sustainable energy system in the UK in the future.

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1.0 Introduction:

Despite many improvements in efficiencies and technology, the global demand for energy continues to rise at an unprecedented rate (IEA, 2011), driven by rapid population growth and a continual search for economic development (Jackson, 2009). Traditionally, fossil fuels have dominated the energy market, however the age of conventional generation is widely considered to be nearing its end, due to the finite nature of resources (Mohr et al. 2015; McGlade and Ekins, 2015), the environmental consequences of their extensive use (O'Rourke and Connolly, 2003; Peduzzi and Harding Rohr Reis, 2013; IPCC, 2014) and an evolution of societal values (Spence et al., 2010; Demski et al., 2013). In contrast, the age of renewables is well and truly upon us, with rapid developments in technology and an increasing acknowledgement of the need to create an energy system based on clean sources of generation (Moriarty and Honnery, 2016). Within the UK, progress in this area has been slow, with policies designed to meet EU targets as opposed to embracing new methods of generation. This study is designed to investigate the level of planned renewable infrastructure in the UK, and will explore how a regional approach could stimulate sustainability and efficiencies in the supply and distribution of electricity on a national scale.

A number of studies have previously investigated the possibility of 100% renewable energy systems across a range of countries (Lund and Mathiesen, 2009; Mason et al. 2010; Mathiesen et al. 2011; Cosic et al. 2012; Fernandes and Ferreira, 2014; Safian, 2014; Trainer, 2013). Traditionally, these studies have been approached with an outcome perspective, by quantifying the level of required investments to reach a fully sustainable energy system. The approach used here differs slightly, by reversing the traditional outcome approach. The study first quantifies the level of planned renewable generation in place throughout the UK and the total renewable electricity generation which is likely to be realised as a consequence. Discussion surrounding the further action which will be required to reach a fully sustainable system following the completion of this planned infrastructure is then provided, with a view to exploring the notion of developing a fully sustainable electricity network in the UK.

2.0 Literature Review:

2.1 The Existing Power System in the UK:

Figure 1 (House of Lords, 2015) illustrates the current electricity system in place in the UK. The system is made up of four main components; a high voltage transmission network, fourteen lower voltage distribution networks, generating units and (not labelled on the Figure) consumer demand. This network is highly centralised, with thirty large plants (>1GWe) providing the bulk of total generation (Alderson et al. 2012). Generation is often located away from large centres of population where demand is concentrated, resulting in the need for a transmission network capable of transporting large amounts of energy over long distances. This transmission network, also referred to as ‘the grid’, transports energy at a high voltage (400kV) to minimise losses and is owned and operated by the National Grid (House of Lords, 2015). Distribution networks then connect the grid electricity with consumers at a significantly lower voltage (130kV-230V). In total, there are 14 distribution networks located across the UK, composed of over 800,000km of cable (Alderson et al. 2012).

Figure 1: The Electricity System

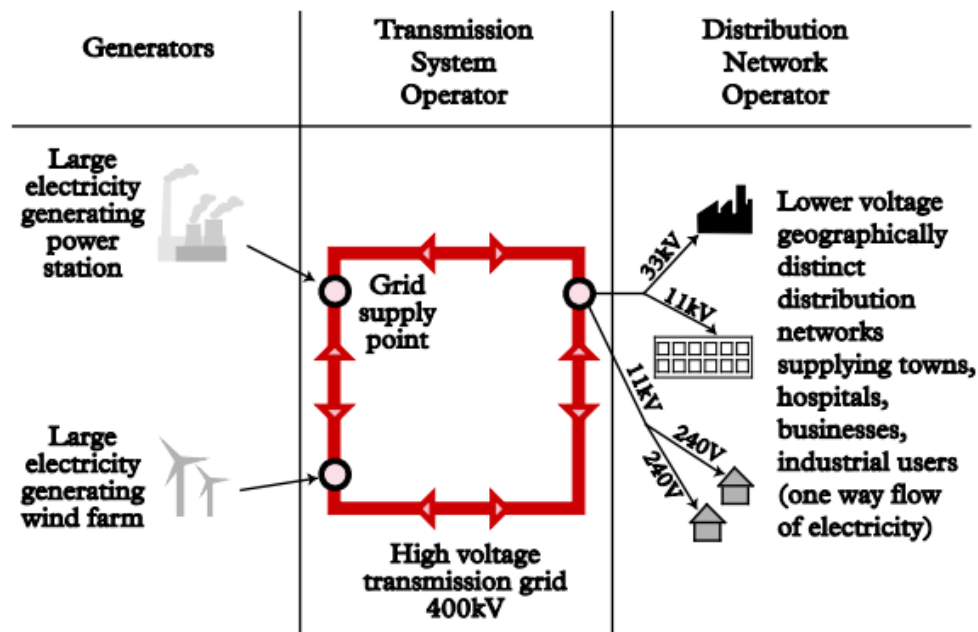


Figure 1 – The current electricity system in the UK (from: *The Resilience of the Energy System*, House of Lords, 2015).

Much of the current electricity system was designed and constructed in the 1950's and 60's and is now nearing the end of its design life (Strbac, 2008; Alderson et al. 2012). As we move further into the 21st century and renewable methods of generation become

increasingly widespread, it is likely that the structure of the grid will change somewhat to accommodate distributed generation. This will require a two way electricity flow on distribution networks alongside the need to balance demand at a local, as well as national level (NAO, 2010). Careful planning and consideration will be necessary to design a grid which can successfully distribute energy from a geographically disperse network of generation in a robust and sustainable manner.

The total electricity consumption demanded by this system in 2013 was 290TWh (DECC, 2015a). This was provided predominantly by fossil fuel generation – with 63.6% of energy met by coal, oil and natural gas. The remaining 36% was met by a combination of nuclear (19.7%) and renewable sources (15.7%) (House of Lords, 2015). As a result of this carbon dominant generation landscape, the UK total greenhouse gas emissions amounted to 569.9MtCO₂e in 2013, 463.4Mt of which was CO₂ (DECC, 2014). Whilst the UK has seen a steady decline in emissions since 1991, a substantial change in the main electricity generation technologies will be needed to meet the national target of an 80% decrease in greenhouse gas emissions by 2050 (Climate Change Act, 2008). This binding agreement is likely to compound the challenges facing current grid infrastructure as a shift away from large fossil fuel powered plants becomes necessary to sufficiently limit emissions to within this range.

2.2 Challenges facing the Existing Power System:

Whilst the current system has been delivering power to UK customers for over fifty years, it is likely that as the system nears the end of its design life, it will come under significant stress due to increasing energy usage per person and a rapidly expanding population. When coupled with environmental pressures associated with the existing methods of generation, it becomes apparent that contemporary methods are not sustainable in the long term. The various challenges associated with traditional methods of electricity generation will now be explored in more detail.

2.2.1 Environmental Damage and Global Climate Change:

No form of energy production is entirely without an effect on the local environment, however, the extensive use of fossil fuels has had a profound effect on the natural environment on a global scale. The nature of this environmental damage is – despite a biased focus on climatic effects in the media and literature – multi-faceted, with both direct and indirect environmental impacts across a spectrum of natural systems.

The extent of global reliance on fossil fuels can be illustrated by the huge growth in global demand for coal, oil and natural gas, which has risen from 26,200MBOE in 1965 to 80,300MBOE in 2012 (Butt et al. 2013). This reliance comes at a heavy environmental cost, with both local and larger scale effects becoming increasingly widespread. Locally, the exploration, drilling and extraction of fossil fuels has a network of negative effects. O'Rourke and Connolly (2003) examined these effects in detail, in relation to the extraction of oil. They note that the major impacts of extraction extend through many systems, including; deforestation, ecosystem destruction, chemical contamination of land and water, long term harm to animal populations, human health and safety risks for both workers and the local community, catalysts of military conflicts, and the displacement of indigenous communities. When considering that there are over 40,000 oil fields worldwide (a figure which is continuously increasing), the impact of oil on the natural environment is profound (O'Rourke and Connolly, 2003). Whilst this study focussed on the environmental impacts of oil extraction alone, the extraction of other fossil fuels carries many of the same impacts. It has been estimated that the remaining total reserves of fossil fuels which are already in possession of energy companies stands at 2795Gt, sufficient amounts when burnt to assure dramatic climate change (Dalby, 2013). Furthermore, it is posited that the environmental effects are to be exacerbated if we need to utilise unconventional reserves in the future (Peduzzi and Harding Rohr Reis, 2013).

Whilst it is important to consider all aspects of environmental damage associated with the widespread use of fossil fuels, by far the biggest challenge which their exploitation

has raised is the phenomenon of anthropogenic climate change. Though the earth's climate has varied significantly throughout history, recent analysis has shown that the release of greenhouse gases through anthropogenic actions is causing a positive radiative forcing within the Earth's atmosphere. This in turn is driving an increase in average global temperature at an unprecedented rate, with the potential to cause significant harm to natural global systems (IPCC, 2014). The current fossil fuel dominated energy landscape will continue to drive this unparalleled warming and cannot realistically be sustained without having a significant and potentially devastating effect on the natural environment.

2.2.2 Finite Resources:

Though the negative environmental effects previously highlighted represent a significant barrier to the sustained usage of current power systems, potentially equally limiting is the fact that fossil fuels represent a finite resource. All deposits of fossil fuels are limited either physically or economically (Hook and Xu, 2013), therefore stocks will not be replenished on a time scale which will continue to allow their inexhaustible extraction by this generation. As a result, it is imperative that we develop our energy systems to continue producing electricity when existing stocks of fossil fuels have been diminished.

Due to the widespread reliance on fossil fuels, many estimates have been made as to how long we can continue using these resources before we are likely to run out (Mohr et al. 2015; McGlade and Ekins, 2015). When investigating the remaining quantity of fossil fuels it is useful to consider the amount of ultimately recoverable resources (URR), defined as the total amount of fossil fuels that can be recovered from the resource prior to production (Mohr et al. 2015). Estimates of URR can then be used in conjunction with Hubbert Peak Theory to attain estimates of the remaining lifetime of a given resource. The expected lifetime of oil and gas is considered relatively short, with an estimated lifetime for each fuel type of roughly 130 years. World coal production is estimated to have a longer lifespan, with remaining resources thought to be capable of meeting consumption rates for another 250 years (Maggio et al. 2012). In reality, estimating the remaining lifetime of such resources produces a wide range of estimates and is dependent upon future discoveries and technology developments, which are difficult to predict. For this reason, whilst it is useful to have an estimate of likely remaining lifetime, we do not know for certain how long we will be able to continue to exploit these resources. This, in addition to the considerable environmental effects of pursuing the extraction of increasingly unconventional fossil fuels, suggests the need for a cautious approach and encourages the search for an alternative source for future electricity generation.

2.2.3 Security of supply:

Further to the environmental challenges and the finite nature of our fossil fuel resources, it is widely theorised that the use of fossil fuels in energy systems can affect national and international security by providing an incentive for conflict (Koubi et al. 2013; Colgan, 2014; Mansson, 2014). Indeed, the very presence of fossil fuels within countries is thought to have an effect known as the 'resource curse', which has been shown to affect the economy, politics and foreign policy of a number of resource rich nations (Colgan, 2014).

The international security threats that are associated with fossil fuels can be illustrated through the US (and other Western states) intervention in the Middle East over recent decades. Whilst it is evident that these conflicts have been driven by a complex interaction of socio-political factors, energy systems are thought to have added incentive to the engagement in these areas (Johansson, 2013). Mansson (2014) looks deeper into the ways in which energy systems can increase the rate of conflict, including; the secure and control system structure of energy systems, competition for resources, deliberate reductions in flow from the supplier, disturbance from a third party, the national resource curse, environmental degradation, reduced security of supply and interactions with social well-being and food prices. The resulting conclusion being that conflicts do not occur in isolation, but in a political, economic and social context, with energy systems providing an underlying incentive for instigation (Mansson, 2014). Given that fossil fuel resources lie at the centre of global industrial development and economic activity (O'Rourke and Connolly, 2003), it is perhaps unsurprising that they are often intertwined with global conflicts on a number of levels.

The impact of fossil fuels on security is not only an interstate cause of aggravation, with an abundance of fossil fuels often identified as a source of instability on an intrastate level (Johansson, 2013; Koubi et al. 2013; Colgan, 2014; Mansson 2014). Colgan (2014) investigated the relationship between oil and domestic policies in a variety of petro-states, highlighting that many are subject to the 'resource curse' phenomenon. Under this, such states are subject to pervasive corruption, wasted public spending, volatile economic growth, and more frequent civil wars and domestic conflict (Colgan, 2014). Further work on natural resources has also posited that rebellion is much more likely in resource rich regions due both to the financial incentives and opportunities that they offer (Collier and Hoeffler, 2004), and the weak governance often in place in these states (Koubi et al. 2013).

Overall, whilst conflicts relating to energy systems do not occur in isolation from complex political, economic and social interactions (Mansson, 2014), the link between the incidence of conflict and an abundance of natural resources should not be ignored. Recent

military interventions in the Middle East, civil wars in Nigeria and even recent terror attacks in Paris have been highlighted as driven – in part – by the fight for fossil fuels (Solnit, 2014). Whilst there is uncertainty over the impact of natural resources on the resource curse (Johansson, 2013), fossil fuels have a violent history which only strengthens the argument for a move away from traditional methods of generation.

2.2.4 Demand Management – Or Lack Thereof:

The dependency which has developed surrounding the use of fossil fuels arguably stems from the nature of these resources to be widely distributed and readily available to large swathes of global population. As a result, particularly in more economically developed countries such as the UK, we have become accustomed to using energy in an unsustainable manner, and our energy infrastructure has developed in a way which reflects this. The efficiency of the energy system in the UK is subject to variation in generation efficiency, which is dependent on the level of demand (Freris and Infield, 2008). As a result, the system operates at an average of 55% of total generating capacity, to allow a generous margin for an increase in power generation and transmission at times of peak demand (Strbac, 2008). An energy system designed to follow the demands of population creates an environment whereby people do not have to be cautious about the amount of energy they consume – an attitude reflected in the everyday energy heavy lifestyles led by the majority of the UK population. Managing demand across the power system would allow us to utilise existing infrastructure in a more efficient and sustainable way and as such represents a sensible first step towards creating a sustainable energy system.

As demand for electricity is increasing globally, the argument for managing demand becomes increasingly convincing, as it removes the need for costly investments in further generating capacity. It has been estimated that 40% of the EU's Kyoto Protocol obligations could be met through an increase in energy efficiency, in addition to reducing overall demand by 18% (Freeman, 2005). Demand side management therefore constitutes a substantial economic and environmental opportunity for world leaders. In addition, reducing the need for new infrastructure would reduce further habitat destruction (O'Rourke and Connolly, 2013), help to suppress the anthropogenic release of greenhouse gases (IPCC, 2014) and improve security of supply, with a less heavy reliance on fossil fuel generating countries. Whilst energy efficiency is not solely linked to the use of fossil fuels, inefficiency and unlimited access to electricity have added to the unsustainable nature of these resources and need to be improved regardless of the fuel choice moving forwards.

2.2.5 Compounding Factors:

Whilst each of the previously described challenges represent significant barriers to the continued exploitation of fossil fuel resources at present, these problems are likely to be exacerbated further as global population grows, and less developed countries improve their energy infrastructure. Ehrlich and Ehrlich (2012) highlight the severity of these compounding factors, stating;

“The industrial revolution set civilization on the road to collapse, spurring population growth, which contributed slightly more than overconsumption to environmental degradation. Now population combined with affluence growth may finish the job.” (Ehrlich and Ehrlich, 2012)

Population growth is a phenomenon which challenges many aspects of humanity, due to the simple notion that the presence of more people creates a higher demand for natural resources, services and goods, within an ultimately finite system. Current global population stands at almost 7.5 billion and continues to grow at a rate of 1.13% per year, with population estimated to reach 9 billion by 2038 (Worldometer, 2016). Given that leading research in to the ecological footprint suggests that humanity uses the equivalent of 1.6 planets to provide the resources we use and capture the waste we produce (GFN, 2016 – See Fig. 2), further increases in population are likely to lead to a large strain on natural resources, of which fossil fuels are a key element.

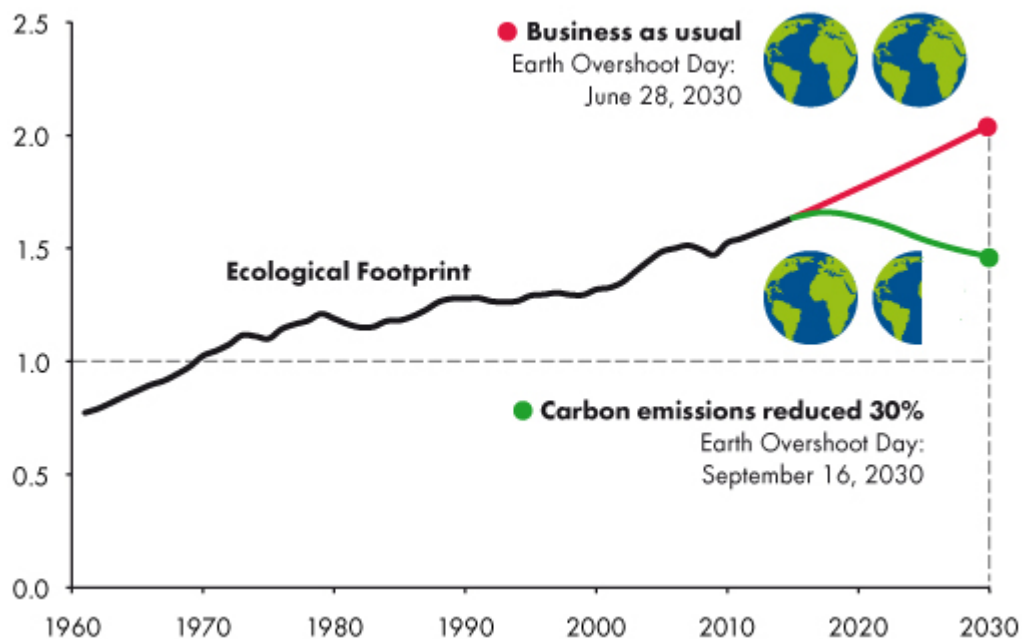


Figure 2 – ‘How Many Earth’s does it take to Support Humanity?’ A graph to show the amount of planets humanity requires if it is to keep consuming resources and producing waste at current rates. Taken from http://www.footprintnetwork.org/en/index.php/GFN/page/world_footprint/ [online].

A fundamental challenge raised by the combined impact of a rising population and the associated strain on resources is the location in which the greatest population growth is occurring. Large population expansion in less economically developed countries has led to an 84% growth in demand within these countries, in contrast to a 14% rise in more economically developed countries. This is key because within less economically developed countries, 1.5 billion people currently live without electricity in their homes, but as development progresses this figure will fall significantly (Wolfram et al. 2012; Lan et al. 2016), leading to large increases in global energy demand. The International Energy Association (IEA) have estimated that as electricity is delivered to these people, demand will at least double (Freris and Infield, 2008). Many of these countries are in the early stages of development and view fossil fuels as key to industrial development (O'Rourke and Connolly, 2003), and more favourable than less easily accessible renewable sources of energy. The use of fossil fuel resources at this scale is likely to; increase environmental challenges through the release of more greenhouse gases and local ecosystem degradation (Butt et al. 2013), increase the strain on global remaining resources due to a higher rate of extraction and use (Hook and Xu, 2013), and potentially induce new security threats associated with the shifting influence of power producing countries (Johansson, 2013). If the more economically developed world can demonstrate the use of effective renewable energy systems, it is more likely that developing nations will see this as a realistic future development strategy, contributing to the alleviation of issues associated with fossil fuels on a global scale.

Within the UK, the links between energy use and population growth are relatively well documented. Recently, the UK has seen a decrease in overall energy demand, with primary energy consumption (on a temperature correct basis) falling by 17 per cent between 2000 and 2014 (DECC, 2015b). This has been reflected in the domestic energy market, where demand has fallen by 19% per household, despite a 9.7% growth in population (DECC, 2015c). It is, however, likely that this decrease in demand per household has been driven by an increase in energy efficiency, the benefits of which will not outweigh population trends for much longer. The UK population is predicted to increase substantially over the next quarter of a century, with population estimated to increase by around 10 million by 2030 (ONS, 2014). Should population reach these estimates, it is likely that demand will increase to meet the needs of a growing population. This is reflected in the estimates of future electricity demand used in this study, which all predict (excluding the SEA scenario) a greater total electricity demand than is currently experienced (National Grid, 2015 – See *Table 1*).

2.2.6 Summary – Existing Power System:

Overall, the extensive use of fossil fuels is having a significantly harmful impact on a global scale. When conducting a global environmental review, Dunlap and Jorgensen (2012) state;

“Current populations and lifestyles are exhausting non-renewable resources like fossil fuels; creating shortages of renewable resources such as fresh water, fisheries, and forests; and generating accumulating levels of pollution, particularly hazardous wastes.” (Dunlap and Jorgensen, 2012)

Though this is not in direct reference solely to the extensive use of fossil fuels, it is reflective of the existing energy system. Fossil fuel reserves are being rapidly depleted despite widely documented impacts on the environment, international politics, domestic relations, and in spite of the fact we know that this system cannot be sustained in the long term. As a world leader in economics and scientific research, the UK has a huge opportunity. As the design life of our existing energy system comes to an end (Strbac, 2008; Alderson et al. 2012), the choices we make moving forwards could set in motion a green energy revolution, which others can follow. Or as Cosic et al. (2012) state when investigating the future of the energy system in Macedonia, it is a matter of making the right decisions today to shape tomorrow.

2.3 The Potential of Renewable Electricity Generation:

The challenges associated with traditional methods of electricity generation have been examined in detail, with the opportunity for the UK to become a future leader in sustainable generation highlighted briefly. To understand the opportunity which lies in renewable energy generation, it is useful to first examine how they can help to alleviate the challenges posed by the existing system of power generation. Technology developments over the past few decades mean that renewable methods of generation are becoming increasingly commercially viable (Renewable UK, 2015). As a result, now is the time to invest in technologies which will pave the way to a sustainable, successful and self-sufficient power system in the UK which can compete with major players in the modern economy. The benefits of renewable energy generation in contrast to the challenges of fossil fuel generation will now be discussed.

2.3.1 Sustainable Development:

To assess the extent to which renewables offer a solution to the environmental and finite resource challenges, it is useful to examine the case for sustainable development. Following the Brundtland Report (World Commission on Environment and Development, 1987), sustainable development has been widely defined as development which meets the needs of the present without compromising the ability of future generations to meet their own needs (IPCC, 2014). Key to this is the acknowledgement of tension between development and sustainability (Jabareen, 2008), which is vital as it raises concerns that whilst we need to do our best to preserve ecosystems for future generations, we also have a moral obligation to aid development on a global scale if we are to move forwards as a species. In an energy context, sustainable development has to account for inevitable growth in demand as developing countries expand their power systems to reach those currently without electricity. Current estimates of future energy demand will not be met in a sustainable manner using current methods of generation (Dunlap and Jorgensen, 2012) due to the challenges discussed in the previous section. As it is not acceptable to reduce demand by keeping families in poverty (Wolfram et al. 2012), a new system of generation, which alleviates the challenges posed by expansion of the existing fossil fuel dominated system, will be necessary to create a sustainable energy future which supports economic development. In contrast to conventional methods of generation, renewable energy is obtained from natural and persistent flows of energy occurring in the immediate environment (Twidell and Weir, 2015). Consequently, if harnessed successfully, renewable energy sources could offer a solution whereby increased demand can be supplied, enabling continued development, whilst imposing minimal negative consequences upon natural systems.

2.3.2 Geographically dispersed and abundant:

Further to being a persistent, self-replenishing source of power, renewable energy sources are available in a variety of forms, across an extremely wide geographical area. Globally, there is enough renewable energy potential to meet demand per person, it is simply a matter of harnessing this energy successfully (Twidell and Weir, 2015). The naturally dispersed nature of renewable energy provides additional advantages as, in contrast to conventional centralised methods of generation, it allows the delivery of electricity to remote areas (Freris and Infield, 2008). This has the potential to aid the electrification of remote developing regions, which may have previously suffered due to a lack of connectivity to national grid systems. As 1.5 billion people worldwide live without electricity in their homes (Wolfram et al. 2012), this could have huge impacts on global development and poverty alleviation. Similarly, countries which have previously been dependent on fossil fuel producing nations will have the potential to harness resources within their own nation. Consequently, these countries may develop a stronger domestic economy and an increased sense of national security as they become increasingly self-sufficient.

This abundance of natural resources has formed the basis of a number of studies which have investigated the potential of energy systems based on 100% renewable energy generation across many nations (E.g. Lund and Mathiesen, 2009; Mason et al. 2010; Mathiesen et al. 2011; Cosic et al. 2012; Fernandes and Ferreira, 2014; Safian, 2014; Trainer, 2013). The majority of these studies highlight that the implementation of a 100% renewable energy system is possible, but will require improvements in infrastructure (Mason et al. 2010; Fernandes and Ferreira, 2014), increased energy efficiency (Mathiesen et al. 2011; Cosic et al. 2012) and pro-active decisions by policy makers. The repeated suggestion that countries could theoretically sustain a power system based on 100% renewable generation suggests that the limitations to full scale adoption of renewable generation lie outside of the supply domain. When considering factors outside of the supply domain, some authors (E.g. Trainer 2013) have found that a 100% renewable energy system would not be sustainable across continental landmasses. However, this may be a reflection of the increasing need to specialise energy systems based on local environmental conditions and will be discussed further in chapter 2.5.

2.3.3 Encourages Intelligent Energy Usage:

Whilst the use of energy is not presently dictated by the way in which power systems operate, it is possible that in future this change will need to be implemented. Often when referring to the large scale adoption of renewable generation technologies, the variability of generation is seen as a major limitation to their use (E.g. Del Rio, 2011). This variable nature

is certainly true, renewable energy generation is based on the natural flow of energy through the environment and is therefore subject to variation on a range of time scales. Whilst some of this variability is largely uniform and highly predictable (e.g. Tidal), other forms are much more difficult to predict and intermittent in nature (e.g. Wind Power) (Twidell and Weir, 2015). However, this should not necessarily be viewed as a limitation, as the scarcity of resources can alter the approach to which people utilise them (Bridge, 2009), which could lead to a change in the public perception of energy use, leading to decreased energy demand in the future.

As previously mentioned, the energy system in the UK is largely dependent on the level of demand (Freris and Infield, 2008), creating an environment in which demand is allowed to fluctuate, and the energy system does its best to keep up. This is not a successful model for a sustainable energy system as it does not place any controls on the amount of energy which consumers can demand. If the UK were to move to a power system based around 100% renewable generation, a revision of the way power systems are designed and operated will be necessary (Freris and Infield, 2008). Whilst the associated infrastructural costs have been seen largely as an economic barrier, this could also be seen as a huge opportunity for a modernisation of the energy system in the UK. The conventional national grid system has reached the end of its design life (Strbac, 2008; Alderson et al. 2012), and the UK now faces a choice – between improving the old system and being content with utilising an energy system designed over half a century ago, or to modernise and restructure the power system in a way which encourages consumers to think about the way in which they use energy. Arguably, shifting the way in which the power system operates, from a demand based generation approach to a generation based consumer approach should be the first step towards reducing both carbon emissions, and environmental challenges posed by the extensive human consumption of energy, regardless of whether or not a move is made to renewable sources of generation. In this context, the variability of generation associated with renewable generation techniques should not be seen as a barrier to their implementation, but rather an opportunity to re-model the way in which we use energy, and the value which we place in our natural resources.

Key to this will be the need to alter energy use to match patterns in supply, through the adoption of demand side management (DSM) and localised distribution networks (Strbac, 2008; Freris and Infield, 2015). A detailed assessment of how DSM and grid structure can be combined to create an ideal power system for the integration of renewable technologies will be given in chapter 2.5.

2.4 Barriers to the Widespread use of Renewable Energy Sources:

Whilst the benefits of the use renewable sources of electricity generation are clear, renewable energy remains a small part of the global energy mix (Stigka et al. 2014). The public perception of renewable generation, in addition to costs, infrastructural challenges and the unpredictable nature of supply, continue to present barriers to the widespread implementation of renewable techniques. We have reached a stage whereby there are very few technical limits to the integration of renewable technologies across the range of existing energy systems worldwide (IPCC, 2011). As a result, it is worth examining the barriers to the use of renewable generation technology, to assess whether the socio-economic and environmental costs of the current system outweigh the costs of investing in energy reform. Overall, the barriers to renewable energy are fundamentally perceived barriers, which are essential to overcome if we are to mitigate the global challenges presented by current methods of generation.

2.4.1 Policy and public opinion:

Public opinion of renewable generation techniques is often considered to be hostile due to the widespread opposition to local development of renewable infrastructure (Devine-Wright, 2007). However, on a national scale, there is strong support for renewable technologies as a replacement for fossil fuels, and an increased awareness that a significant change is needed to the existing energy structure in the UK (Devine-Wright, 2007; Demski et al. 2014; Stigka et al. 2014). Underlying this support for an alternative method of power generation, three main drivers of public opinion have been identified. These are; affordability in terms of household bills, ensuring a long term supply to avoid shortages of power, and negative environmental consequences of fossil fuel usage (Spence et al. 2010; Demski et al. 2014). Perhaps unsurprisingly, the largest concern amongst the domestic market surrounds issues of affordability (Demski et al. 2014). Many people are aware of the volatility associated with fossil fuel prices and worry that these will escalate as resources continue to move towards exhaustion. Spence et al. (2010) note that more unexpectedly, there are surprisingly high levels of concern regarding security of supply. Overall, despite widespread acknowledgement that renewable sources of generation represent an opportunity to mitigate environmental damage caused by fossil fuels, this is considered a secondary energy concern by the UK population. When promoting a move to renewable methods of generation, it should not be overlooked that renewable sources provide a balance of economic, technical and environmental opportunities (Stigka et al. 2014), as the scientific message of anthropogenic climate change is not accepted unequivocally by all members of the public (Spence et al. 2010). As a result, it should be noted that public opinion no longer

represents a serious barrier, and with a well-led targeted approach the majority of people will likely support a move to renewable sources of power in future.

Despite this widespread public acknowledgement of a need for significant change to the existing energy system in the UK, this is not currently reflected in infrastructural development, and will need to be acknowledged through policy if a significant change is to occur. Current UK energy policy states three fundamental objectives; energy security, decarbonisation and affordability (DECC, 2012), which unsurprisingly align with the greatest concerns highlighted in public opinion (Spence et al. 2010; Demski et al. 2014). Whilst this appears to create an opportunity for the development of a successful renewable policy framework, a short sighted view of the affordability of fossil fuels is often the dominant government driving force and recent actions, such as cuts to the renewable sector (Carrington, 2015) and cash injections to the UK oil and gas industry (DECC, 2016), contradict the notion of creating a sustainable energy future in the UK. Whilst public opinion is widely in support of a move to renewable sources of power generation, pro-active policy making is needed to ensure that this is achieved on a national level. Until this is achieved, it is unlikely that there will be any significant changes to the fossil fuel dominant energy landscape in the UK.

2.4.2 Economic costs of Renewable Energy Systems:

Whilst public perceptions of renewable energy are an important aspect in shaping government policy, a greater driving force lies in the economic costs of an energy reform, especially in the aftermath of the financial crisis in 2008. Traditionally, renewable energy generation has been seen as a risky investment due to the relative infancy of technology and uncertainty in the amount of energy which can be generated in this way. However, it is increasingly clear that we are reaching a turning point whereby the age of cheap, seemingly endless supply of fossil fuels is coming to an end (Safian, 2014). This presents a challenge to world energy management, with the need to meet increasing levels of global electricity demand whilst moving away from conventional sources of power generation and reducing the cost implications of doing so.

Many studies designed to investigate the potential of 100% renewable energy systems have highlighted that one of the main challenges preventing the instigation of such systems is upfront capital investment costs (Mathiesen et al. 2011; Cosic et al., 2012; Trainer, 2013; Fernandes and Ferreira, 2014). Differing natural resources within or available to each country will dictate the amount and type of renewable generation which is both technically and economically realistic (Mason et al. 2010) and as a result, the costs of electricity reform will differ between countries. When taking an aggregate approach across

a continental scale, Trainer (2013) found that the costs of a 100% renewable energy system in Europe would not be affordable. However, other studies have looked into the costs of imposing a 100% renewable energy system on a national level and found that moving to such a system in the long term is feasible due to the relatively low maintenance and operating costs associated with renewable energy systems (e.g. Cosic et al., 2012; Fernandes and Ferreira, 2014). This is supported by the Stern Review (2007) which highlights that whilst costs of renewable energy are high at present, this is likely to decrease substantially in future as the technologies develop (Stern, 2007). Further to this, a move to 100% renewable energy systems has the potential to create jobs which are not based on the notion of an abundance of fossil fuels and offers additional societal benefits such as a positive effect on human health (Mathiesen et al. 2011).

Though the long term economic benefits of a move to renewable energy are becoming increasingly apparent, the large initial investment in renewable technologies remains a significant barrier to their widespread adoption. Despite the fact that much of the UK population agrees that a reorganisation of the existing power system is necessary (Devine-Wright, 2007; Demski et al. 2014; Stigka et al. 2014), concerns of cost continue to determine policy. This may help to keep domestic energy prices low in the immediate future, however it is not likely to be sustainable in the long term. In order to successfully encourage necessary investments in renewable technology, the lifetime cost benefits of renewable technology must be considered. A combined approach of increased efficiency and demand management could create a renewable energy future which is economically attractive to the consumer. Increasing awareness of this will help to drive necessary investments and policy which will become a crucial aspect of mitigation during the 21st century.

2.4.3 Variable Electricity Output:

As previously discussed, a key characteristic of the existing energy system in the UK is its configuration as a demand driven model of electricity generation (Freris and Infield, 2008). This is achievable when using fossil fuel generation as resources can be stored and burned as necessary. Renewable energy generation is based on the natural flow of energy through the environment (Twidell and Weir, 2015). Consequently, renewable generation is variable and relatively unpredictable (Freris and Infield, 2008), and therefore is not able to respond to alterations in demand in the same way. In addition, the seasonal nature of renewable generation provides further challenges (Pereira et al. 2014), particularly for wind and hydro generation which generally have higher capacities during the winter months in the UK, and much lower generation capacity in summer months. Without careful planning, this imbalance could lead to an excess of power generation in the winter or potential shortfalls in summer months.

Overall, the variable nature of renewable electricity generation presents a challenge predominantly to the behaviour of consumers in the existing power system. If an increased awareness of energy usage can be spread, alongside careful planning considerations and increases to energy efficiency, there is no reason why this variability challenge cannot be overcome, especially as technology and storage solutions improve and become increasingly commercially viable.

2.4.4 Difficulty of Incorporating Renewable Energy Sources in the current Power System:

The variable nature of renewable electricity generation also presents a challenge to the incorporation of renewable sources of electricity into the current grid system. The addition of renewable sources of generation is fundamentally and technically not too dissimilar from that of connecting conventional fossil fuel generators to the grid (Freris and Infield, 2008; Twidell and Weir, 2015). The difference lies in the nature of the resources being utilised in each case. Renewable sources have two key characteristics which differentiate them from fossil fuel generation techniques – a geographically dispersed nature and a variable output which cannot be controlled by the operator. As the existing electricity system in the UK is built around an idea of a limited number of large plants providing the bulk of generation in a centralised and controllable system (Alderson et al. 2012), the addition of renewable resources will clearly initiate a change to the existing network.

Renewable sources of generation can be largely split into two groups; dispatchable sources such as biomass and hydroelectricity, and non-dispatchable sources such as wind, tidal and solar (Boyle, 2007). This second group of renewables rely on natural flows of energy to determine electrical output and as a result the level of generation from these sources will vary over a variety of time scales (Denholm and Hand, 2011). Consequently, many scientists propose that the successful high level implementation of renewable sources of electricity generation will require an aggregated approach which makes use of the complementarity of a mixture of different sources of generation, to smooth power output and prevent energy shortages (e.g. Boyle, 2007; Ribeiro et al. 2014). Other scientists have taken this further and suggest that expanding existing networks through the interconnection of grids on a large scale (Denholm and Hand, 2007; Renewable UK, 2015) will be necessary to provide a closer match between supply and demand. However, the blind expansion of energy systems may not be conducive of a sustainable energy future and will be discussed further in chapter 2.5.

Variability represents a challenge to the existing network of generation, however this has moved beyond a technical limitation to a behavioural limitation, and the issue is much less of a technological barrier to renewable resources than sceptics have previously alleged

(Twidell and Weir, 2015). However, as Scheer (2012) has highlighted, the difficulties of incorporating renewable sources of generation into the grid also extend into the political sphere, with the influence of major power producers being key. Due to the structure of the existing power system, the removal of conventional plants and replacement with renewable generators creates a loss of income for the major power producers, and consequently energy companies will not invest in these technologies as it is not in their commercial interest to do so. Renewable systems have a completely different set of requirements to the existing system – from techniques, applications and locations, through to industrial priorities, company structures and political frameworks. As a result, any move towards renewable energy generation is damaging to the existing system and the major players within it. The transition to renewable energy needs to be rapid to mitigate the major challenges of our existing power system. To ensure this happens, the drive forwards will need to come from those who are least involved with the power industry, as those currently wrapped up in it are prisoners of their own system (Scheer, 2012). This presents a big challenge for future power systems as there is increasing need to alter the way in which power networks operate as a whole. This will involve huge levels of investment and face the opposition of hugely powerful global energy firms, but will be necessary if we are to ensure the security of future energy supply.

2.5 Energy Solutions for Future Growth:

As global demand for energy increases, we are faced with a choice. We can expand systems of power generation to meet the increasing needs of consumers, or we can alter the way in which we use energy, to make more of the resources we already have. Boyle (2007) frames this effectively by stating that in a world where we are constantly reminded that energy efficiency is cheaper than energy generation, the first response should be to delay or turn off a load, rather than starting another generator. The two responses – expanding generation infrastructure and intelligent use of energy – are discussed further in this chapter.

2.5.1 Expanding Systems and Unsustainable Growth:

As previously discussed, recent estimates of future energy demand will not be met sustainably through current methods of generation (Dunlap and Jorgensen, 2012), however we continue to have a heavy dependence on fossil fuel resources, and carry on extracting them at a rate which is damaging to natural ecosystems. Juan Enriquez (2007) has addressed this issue in a talk centred on bio-energy. Here, Enriquez compares the current expansion of the fossil fuel industry to that of the development of agriculture. In a similar style to that of agricultural expansion, we continue to use brute force to extract more fossil fuel resources, at the cost of the local environment across large portions of the Earth's surface. However, as found with agriculture, there comes a point whereby we can't get any more from the Earth system than we are already getting, yet demand for food (and energy) continues to grow. The agricultural response to this was to use biology to increase productivity from the same area of land. Enriquez argues the same is possible with energy, by applying biology to coal seams, we may be able to increase energy yields from existing resources and increase the efficiency of the power system as a whole (Enriquez, 2007). Whilst this does not address all aspects and challenges associated with the current energy system, it offers a short term bridging solution which could aid the transition to renewable generation systems by limiting further environmental damage whilst continuing to meet global demand. In short, it represents a way in which we can be smarter about the resources we use, as opposed to a continuation of the mindless brute force approach which is both environmentally destructive and economically short sighted.

The recent discussion of the creation of large super-grids is illustrative of this brute force approach. In response to an increasing need for renewable generation, governments have actively considered applying the characteristics of our current energy system to renewable forms of energy, only on a greater scale. Given the failings of our current system, which presents a major threat to the environment, is a driver of national and international conflict, and induces a system of greed and uneven development; it is surprising that

governments see it as an acceptable model on which to base future electricity generation. Scheer (2012) discusses the issues surrounding the super-grid project proposed across Northern Africa and Europe. This project, Scheer argues, would have direct consequences for the entire transition to renewable energy systems and represents a reluctance of big power producers to move away from a centralised (and arguably outdated) network of power generation. The largest risk with this form of development is that it ignores all opportunities for linking natural resources with regional energy demand, an opportunity which encompasses a greater level of economic and social rationale (Scheer, 2012), whilst simultaneously overlooking the security benefits of local generation and the environmental consequences of a constantly expanding energy footprint.

The unfortunate reality is that we are facing a world in which conventional sources of fossil fuels are diminishing (Pедуzzi and Harding Rohr Reis, 2013), and as a result the environmental boundaries we are willing to cross to reach unconventional sources is moving increasingly further from a sustainable limit. This is not an issue which is limited to the energy sector, with the growth centred focus of governments leading to a range of environmental, societal, political and economic challenges, all of which are compounded by an economy which is fundamentally broken. Jackson (2009) highlights how each of these issues have been created by a society which is fixated on an outdated notion of growth leading to prosperity. However as explained in the concluding remarks;

“The economic crisis presents us with a unique opportunity to invest in change. To sweep away the short-term thinking that has plagued society for decades. To replace it with considered policy capable of addressing the enormous challenge of delivering a lasting prosperity.” (Jackson, 2009)

Though Jackson (2009) is reflecting here on a wider societal structure than the global power system, it is very much relevant to the nature of global energy production. As the excessive usage of energy is a driving force behind many of the challenges facing humanity, reducing the negative impacts of this will be key in the design of a sustainable future. In the UK we have an opportunity to restructure our power system, not only to minimise growth and environmental impacts of fossil fuel generation, but to increase energy security, to become increasingly self-sufficient, to boost our national economy, and to ensure the well-being of our population for many decades to come. A move to a grid system dictated by generation as oppose to demand, and an effort to shift behaviour and attitudes towards energy use will be key to this restructuring and are discussed further below.

2.5.2 Micro Grids, Smart Grids and Demand Side Management:

In contrast to the option of increasing the generating capacity of current power networks, improving the way in which we perceive and use energy provides an opportunity to meet demand whilst mitigating the negative consequences of the existing system. There are a number of ways in which we can do this, which is arguably a reflection of the inefficiencies of the existing power system. Key to each of these methods will be the transition from the passive role of consumers in the energy network to an increasingly active role (Freris and Infield, 2008; Gangale et al. 2013), which should encourage a move away from the traditional model of a cascading energy flow from generator to consumer and break the common misconception that energy will always be available to meet demand (Crispim et al. 2014).

As the level of renewable electricity generation in the UK increases, heightened regional penetrations mean new ways of designing and operating systems will evolve (Freris and Infield, 2008). Two of the most predominant avenues which have been explored in terms of grid developments are Smart Grids and Micro Grids. Smart Grids are essentially intelligent electricity networks which can integrate the behaviour and actions of all users who are connected to the system in a cost effective manner (Crispim et al. 2014). The focus here is on the additional technology which is implemented in the grid system, which helps to facilitate multi-directional flows of energy between consumers and producers, and hence promote the more efficient use of energy already within the system. Micro Grids represent a change in the nature of networks, to move from large scale grids spanning wide geographical areas, to localised networks where there is a set number of consumers and generators, located in close proximity, with minimal transmission losses (Freris and Infield, 2008). Both grid systems aid the integration of renewable resources into grid networks and present opportunities for scaling down electricity production to reduce the energy footprint, provide improvements in energy efficiency, and create sustainable, reliable power networks. Whilst these technologies are in the early stages of research they offer an opportunity to revolutionise the amount of energy which we use and the types of generation from which it is derived, whilst simultaneously challenging conventional perceptions of energy availability. This is therefore a key area of research in the present energy context.

Finally, it should be noted that demand side management offers a method of reducing energy demand and facilitating the integration of renewable generation without the requirement to make changes to existing grid infrastructure. Demand side management refers to a number of techniques designed to create a system which is driven by the amount of energy available, as opposed to the amount of energy required. This can include all actions on the demand side of an energy system, from exchanging incandescent light bulbs

to compact fluorescent lights, to wholesale attempts to incorporate grid scale load management systems (Palensky and Dietrich, 2011). Ofgem (2016) incorporate demand side management in their discussion of demand side response and energy system flexibility, arguing that by being flexible with how and when we consume and produce energy, we can ensure generation always matches supply. Previously, the energy industry has attempted to ensure supply always matches demand, but our energy system is changing to accommodate dispersed renewable generation sources, and consequently, continuing to rely on supply-side solutions alone would be expensive and unrealistic (Ofgem, 2016). Many other studies have stressed the benefits of demand side management to the UK system as a whole (e.g. Bradley et al. 2012), with some studies adding that the UK has led successful demand side management campaigns in the past and should continue to do so in the future (Warren, 2014). In the face of energy security challenges and high costs of investment in renewable generation, managing demand is likely to become a vital aspect of system design in the future.

2.5.3 Summary:

In the UK, we have a unique opportunity to build a future proof system of electricity generation, which will ensure a reliable supply of electricity in the future, generated from sources which are sustainable and have minimal negative impacts on the natural environment. The current system was designed in the 1950s and 60s to accommodate concentrated generation technologies heavily reliant on coal mining (Crispim et al, 2014). Since this point, renewable technology has improved hugely, and many of the barriers to its use lie in an incompatibility with current distribution networks. The intermittency of renewable electricity generation should not be viewed as a flaw. An attempt to integrate modern technology into a grid designed to support vintage technology is bound to raise some challenges, but to discount modern technologies based on this would be foolish and wasteful (Freris and Infield, 2008). Renewable technologies have evolved and are technically capable of supporting systems of 100% renewable generation on a national scale (E.g. Lund and Mathiesen, 2009; Mason et al. 2010; Mathiesen et al. 2011; Cosic et al. 2012; Fernandes and Ferreira, 2014). Changing grid systems may be key to creating a sustainable energy future for the UK and political focus should be centred on creating grids which aid the behavioural shift of consumers from a demand driven mind-set to an engrained notion of matching demand to the energy which is available. Studies have shown that the public are willing to accept these changes (Spence et al. 2010; Demski et al. 2014), it is now a matter of creating effective and clear policy and infrastructure to create the energy system that will be in the best interest of the UK public, the country as a whole, and if it sets a benchmark for other nations, ultimately the best interests of the entire planet.

2.6 Aims and objectives of the study:

2.6.1 Justification of Research:

“The World’s energy management has reached an important turning point - the age of cheap, seemingly endless fossil fuel sources is approaching its end, while global energy demand is rising.” (Safian, 2014)

The above quote serves to illustrate one of the greatest challenges that faces humanity in the 21st century – the need to provide affordable and reliable energy to an ever increasing global population, in a sustainable manner. The climatic limitations and finite nature of current resources mean that continuing current methods of generation at an increased scale is not a sustainable option for meeting this demand. The IPCC (2014) have highlighted that the continued emission of greenhouse gases will cause long-lasting climatic consequences, increasing the likelihood of severe, pervasive and irreversible impacts on natural and human systems. As a result, it is imperative that we find a way to incorporate the widespread use of renewable electricity generation into global energy systems

Within the UK, the global challenges of the current energy system are compounded by a need for greater self-sufficiency and the need for economic revival following the financial crash of 2008. The current electricity system in the UK was designed and built over 50 years ago, to accommodate centralised power from the rapidly expanding coal mining industry (Crispin et al. 2014). The design lifetime of the existing network now draws to an end (Strbac, 2008; Alderson et al. 2012), providing an opportunity to develop new networks, capable of integrating modern technologies in a reliable and efficient way. This will help to meet the rising demands of the developing economy whilst mitigating the negative effects of the previous carbon dominated energy system. Current UK energy policy states three fundamental objectives; energy security, decarbonisation and affordability (DECC, 2011). Whilst traditional policy has focussed solely on the affordability aspect, future policy will need to create a change in the structure of UK electricity networks if all three objectives are to be met. It is only with a detailed understanding of the nature of future energy generation that we can make informed plans of how to structure the supporting network. As a result, this study represents a crucial insight into planned levels of generation which will aid the creation of effective plans for the UK energy system in the 21st century.

2.6.2 Research Question:

“To what extent does the planned regional renewable energy infrastructure support the notion of developing a fully sustainable electricity network in the UK?”

The focus of this study is on the regional differences in present and future renewable energy generation within the UK. The current level of renewable generation is examined in each region, followed by an analysis of the level of generation which will be realised upon completion of all planned infrastructure. The resulting total generation, in addition to the technological composition within each region, is then considered in relation to estimated regional demand, and used in the discussion of future network options within the UK. Hopefully, this will give a deeper understanding of the nature and distribution of future electricity generation in the UK and help to make informed decisions regarding the future of the electricity system which will serve to benefit all aspects of society.

3.0 Methodology:

3.1 Sources of Data:

Due to huge challenges facing the government in terms of energy security, economics and anthropogenic climate change, a wealth of data concerning both the demand for electricity and the future planned infrastructure is available and accessible online. The main data set used to obtain regional electricity consumption statistics in this study was the '*Sub-national electricity sales and number of customers 2005-2013*' data set produced by the Department for Energy and Climate Change (DECC) (DECC, 2015a). This data provided the total annual electricity consumption (GWh) at a sub-regional level for all regions of the UK since 2005. This dataset was useful both as a reference of current consumption figures nationally, but also provided a regional breakdown which indicated the geographical distribution of electricity demand. Consumption was used as the basis for estimating regional electricity demand and from here demand will refer to figures derived from current consumption levels.

In addition to consumption data, DECC also provided the key dataset, '*Renewable Energy Planning Database*' produced jointly by the DECC and Eunomia on a monthly basis (DECC and Eunomia, 2015). This data set tracks the progress of renewable electricity projects from inception, through planning, construction, operation and decommissioning. The resulting datasheet is therefore a timeline for planned renewable infrastructure, with details of whether the planned infrastructure is likely to be developed or if plans have been forced into submission. As the datasheet also provides details of the planned size of renewable generation projects (Installed Capacity, MW) it has been a useful tool within the study for predicting the likely future generation of power by renewable electricity sources within each region of the UK. To align these predictions with the demand estimates derived from '*Sub-national electricity sales and number of customers 2005-2013*' (DECC, 2015), the future installed capacity in each region was converted to GWh using the following formula:

$$\frac{(\text{Total Installed Capacity (MW)} * \text{Technology Efficiency Factor}) * 365 (\text{days}) * 24 (\text{hours})}{1000}$$

As a result, direct comparisons could be drawn between estimates of future regional electricity generation (GWh) and future regional demand estimates (GWh), to allow an estimation of the amount of electricity demand which can be met with renewable electricity generation in the future.

Population data were derived from the '*2012-based Subnational Population Projections for England*' published by the Office for National Statistics (ONS, 2014). The data represent the most recent estimates of regional population totals (2012), alongside estimates of future regional populations in 2022. The population trends given in this dataset were projected forwards in order to estimate the future regional population totals throughout the UK. Unfortunately data for Scotland and Wales were not available for these estimates, therefore whilst these regions feature in early stages of analysis, they were not included in the scenario development used in further analysis.

3.2 Scenarios:

In an attempt to create robust estimates of future regional electricity demand, a range of possible future energy scenarios were examined in this study. Firstly, scenarios from the National Grid 'Future Energy Scenarios' publication (National Grid, 2015) were used as a basis for future demand projections. Following the initial analysis using these scenarios, the study created three further scenarios based on regional population and demand changes. Each of the scenarios are outlined below.

3.2.1 National Grid Future Energy Scenarios:

The National Grid provide four future energy scenarios; Gone Green, No Progression, Slow Progression and Consumer Power. An overview of the parameters associated with each scenario is provided in Table 1, and full details can be found in the National Grid publication mentioned previously (National Grid, 2015). Understanding the underlying principles behind each of the scenarios is vital if we are to draw meaningful conclusions from predictions made in this study. An overview of each scenario is therefore given below.

Table 1 – Key parameters associated with each of the national grid future energy scenarios (adapted from National Grid 'Future Energy Scenarios' publication (National Grid, 2015))

Scenario	Parameter	2020	2030
Consumer Power	Annual Demand (TWh)	334	342
	Peak Demand (GW)	60.7	62.6
	Average Renewable Generation (%)	~12	~19
No Progression	Annual Demand (TWh)	335	333
	Peak Demand (GW)	60.5	60.8
	Average Renewable Generation (%)	~10	~11
Gone Green	Annual Demand (TWh)	329	362
	Peak Demand (GW)	59.3	66.1
	Average Renewable Generation (%)	~15	~30
Slow Progression	Annual Demand (TWh)	335	332
	Peak Demand (GW)	60.3	59.4
	Average Renewable Generation (%)	~13	~22

Gone Green is a scenario in which there are high levels of prosperity, many technological developments and increasing green ambition throughout society. A gone green world is harmonious, with a political focus on long-term environmental progress accompanied by high levels of capital to support investment and development in this area.

Under this scenario, annual electricity demand is estimated to reach 329TWh in 2020, a relatively low estimate when compared to the other National Grid scenarios, due to increasing levels of green ambition. The estimated annual demand then increases to 362TWh in 2030 due to increasing levels of electricity usage for transport in an attempt to reduce the level of emissions from this sector.

The No Progression scenario outlined by the National Grid is illustrative of a world in which the primary concern lies in achieving the greatest security of supply at the lowest possible cost. Low economic growth ensures the continued reliance on traditional sources of energy, with little innovation or improvement in the way in which we use energy. Under this scenario, demand decreases slightly alongside improvements in efficiency between 2020 and 2030 (335TWh and 333TWh respectively). Whilst this scenario gives a relatively low estimate of future demand, it provides a pessimistic view of future conditions, with a continued reliance on fossil fuels driving a continuation of emissions which may threaten climatic stability.

Similar to the No Progression scenario, the Slow Progression scenario also predicts a small decrease in demand of just 3TWh between 2020 and 2030 (335TWh and 332TWh respectively). Though the total annual demand between these two scenarios does not differ hugely, the underlying principles of the Slow Progression scenario represent a more progressive attitude towards improving energy usage which is limited by economic growth as oppose to a reluctance to invest in this sector. It therefore represents a more optimistic view of future conditions, with raised awareness of the need to decarbonise energy sources, but a lack of capital with which to do so.

The final scenario, Consumer Power, is a scenario driven by consumerism and quality of life. In this scenario, the world is relatively wealthy, with high levels of research and development driven by consumers. Whilst this scenario predicts an improvement in technology and the ways in which we use energy, these are not driven by green ambition, but a desire to raise personal standards of living, with energy efficiency improvements recognised as a bi-product and not a main selling point of new technology. Under this scenario, demand is moderate in 2020 (334TWh) and then rises to the relatively high level of 342TWh in 2030.

3.2.2 Original Scenarios Developed for this Study:

Whilst the National Grid scenarios (National Grid, 2015) provide a useful starting point for estimating future energy conditions, three further scenarios were created in an attempt to examine all possible outcomes which may be experienced in the future. Each of these scenarios combined regional electricity consumption (DECC, 2015) and population

data (ONS, 2014) to predict how energy usage per person may affect the regional distribution of energy usage in 2020 and 2030. A full outline of the scenarios and the processes through which they were generated are provided in Table 2 and Figure 3, but a description of each will also be given. In contrast to the national grid scenarios examined previously, these scenarios will not include data for Scotland and Wales as population data for these regions were not available at the time of analysis.

Table 2 – Key parameters associated with each of the future energy scenarios created for use in this study.

Parameter	Scenario		
	Population Based	Electric Vehicle Expansion	Super-Efficient Adoption
Brief Description	A world in which the demand for electricity has not changed dramatically from current day. The amount of energy usage per person remains the same, but population changes regionally according to government lead predications.	A world in which the population is becoming increasingly environmentally focussed and as a result, over 50% of current vehicles in the UK are replaced with electric vehicles. Whilst greatly reducing carbon emissions, electricity demand rises 25% per person, to meet this new aspect of demand.	This is a world in which the population becomes increasingly aware of the need to reduce energy usage alongside developing renewable technology if we are to stop negatively forcing the climate system. This scenario largely represents a change in behaviours, with the additional efficiency developments which may be developed with new technology
Data Input	Consumption (DECC, 2015) Population (ONS 2014)	Consumption (DECC, 2015) Population (ONS, 2014) Electric Vehicle Demand % (IBM, 2010)	Consumption (DECC, 2015) Population (ONS, 2014) Efficiency Increases (Allcott and Greenstone, 2012)
2014 Annual Demand (TWh)	244	244	244
2020 Annual Demand (TWh)	254	286 (+12.5%/person)	222 (-12.5%/person)
2030 Annual Demand (TWh)	273	341 (+25%/person)	205 (-25%/person)

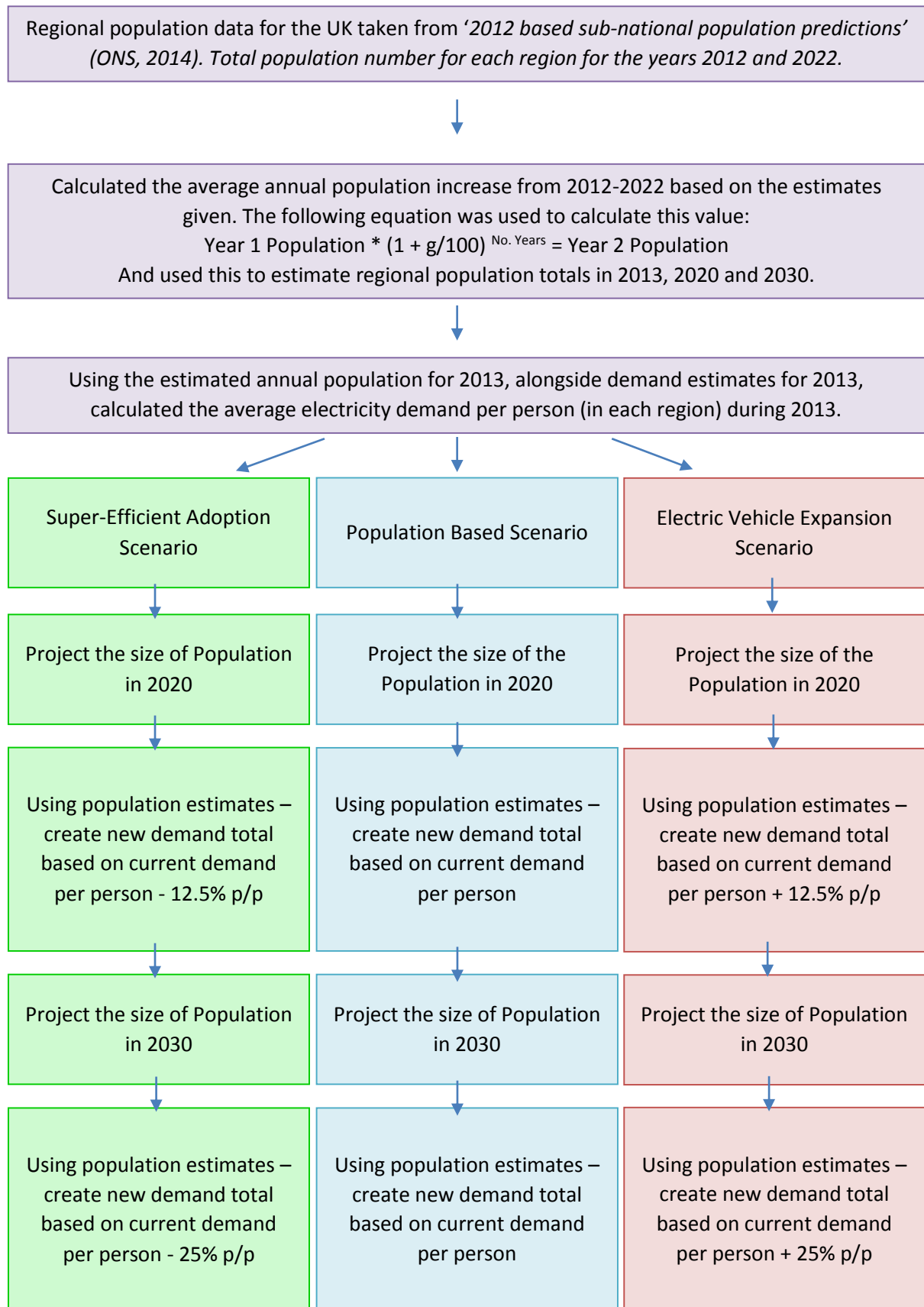


Figure 3 – Key differences between the shaping of each original scenario used in this study.

3.2.2.1 Population Based Scenario:

The population based scenario was the first of the original scenarios created for this study. This scenario represents a world in which current demand per person remains the same throughout the study period, but the population changes based on rates which are in line with estimates made by the office of national statistics (Table 3). Future changes in demand are therefore driven by changes in population as oppose to differing energy usage habits or technological developments. This scenario is helpful as whilst it is difficult to predict the behaviour of people in the future, the rate of population change is easier to quantify and therefore a good indicator of what we can expect demand to do in isolation from the influence of changing behaviours and technology. Total annual demand in this scenario is lower than in all of the national grid scenarios, with values of 255TWh and 273TWh in 2020 and 2030 respectively (Figure 4).

Table 3 – Regional population estimates based on growth rates associated with the predictions made by the Office for National Statistics (ONS, 2014) for 2012 and 2022. For this study it has been assumed that population will continue to rise at the same rate throughout the study period.

Region	Mid-2012	Mid-2022	Annual % Change	Estimate 2014	Estimate 2020	Estimate 2030
London	8,308,400	9,392,100	1.2336	8,514,643	9,164,603	10,359,981
East	5,907,300	6,417,900	0.8325	6,006,062	6,312,366	6,857,978
South East	8,724,700	9,407,400	0.7562	8,857,157	9,266,715	9,991,827
South West	5,339,600	5,707,400	0.6684	5,411,213	5,631,867	6,019,799
East Midlands	4,567,700	4,857,100	0.6162	4,624,167	4,797,789	5,101,767
West Midlands	5,642,600	5,954,600	0.5396	5,703,664	5,890,849	6,216,576
Yorkshire	5,316,700	5,580,800	0.4860	5,368,501	5,526,951	5,801,495
North West	7,084,300	7,342,300	0.3584	7,135,164	7,289,959	7,555,449
North East	2,602,300	2,678,200	0.2879	2,617,306	2,662,845	2,740,511
England	53,493,700	57,337,800	0.6964	54,241,328	56,547,492	60,611,040

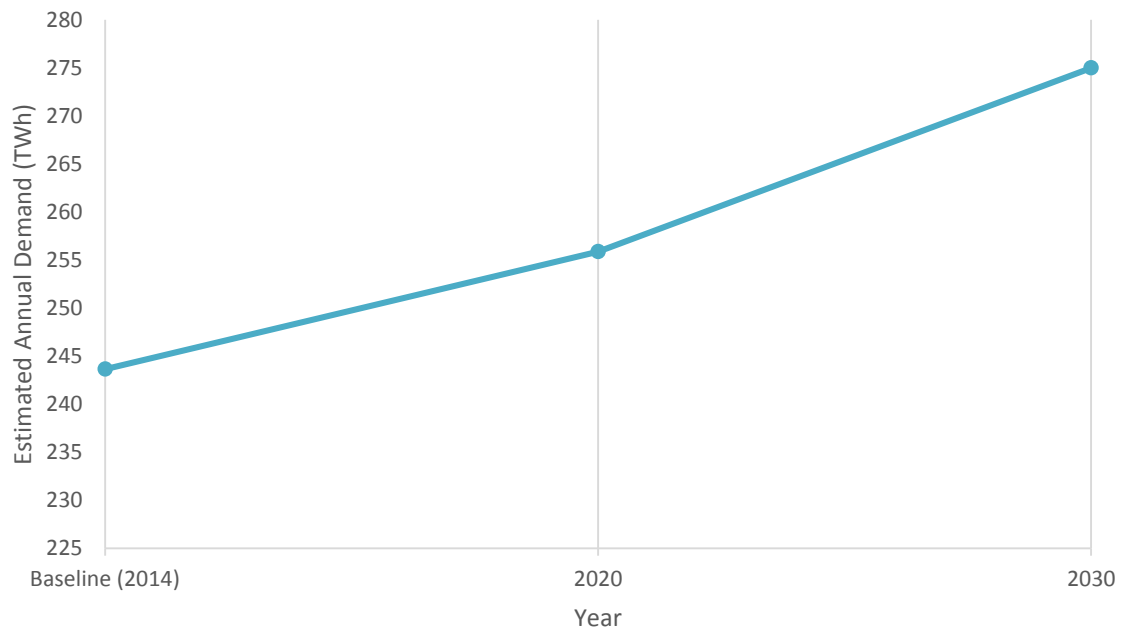


Figure 4 - Total Annual Electricity Demand Estimates (TWh) under the Population Based Scenario

3.2.2.2 Electric Vehicle Expansion Scenario:

The final two scenarios which were created for the study aim to provide a best case and worst case scenario, by examining extreme cases for future electricity demand. The first of these scenarios, termed 'Electric Vehicle Expansion' (EVE) represents a world in which the population is becoming increasingly environmentally focussed and as a result, over 50% of current vehicles in the UK are replaced with electric vehicles by 2030. Whilst greatly reducing carbon emissions, electricity demand rises 25% per person, to meet this new aspect of demand. In this scenario, population trends are extrapolated forwards throughout the study period as stated previously (Table 3). In addition, an increased demand per person is implemented to account for the widespread increase in electric vehicle usage. Within the scenario, this is incorporated into demand projections in two stages, with an increase of 12.5% per person by 2020 before the full 25% increase in demand is realised in 2030 (Figure 5). This increase in demand associated with electric vehicle expansion is in line with demand scale estimates in recent research in the transport sector, though as stated in the research, no-one can be sure how quickly the vehicles themselves will be developed, how readily consumers will buy into the idea and how they will go about using and charging electric vehicles if they do (IBM, 2012). As a result, a linear increase in electricity demand across the study period was deemed an appropriate way to model these projections.

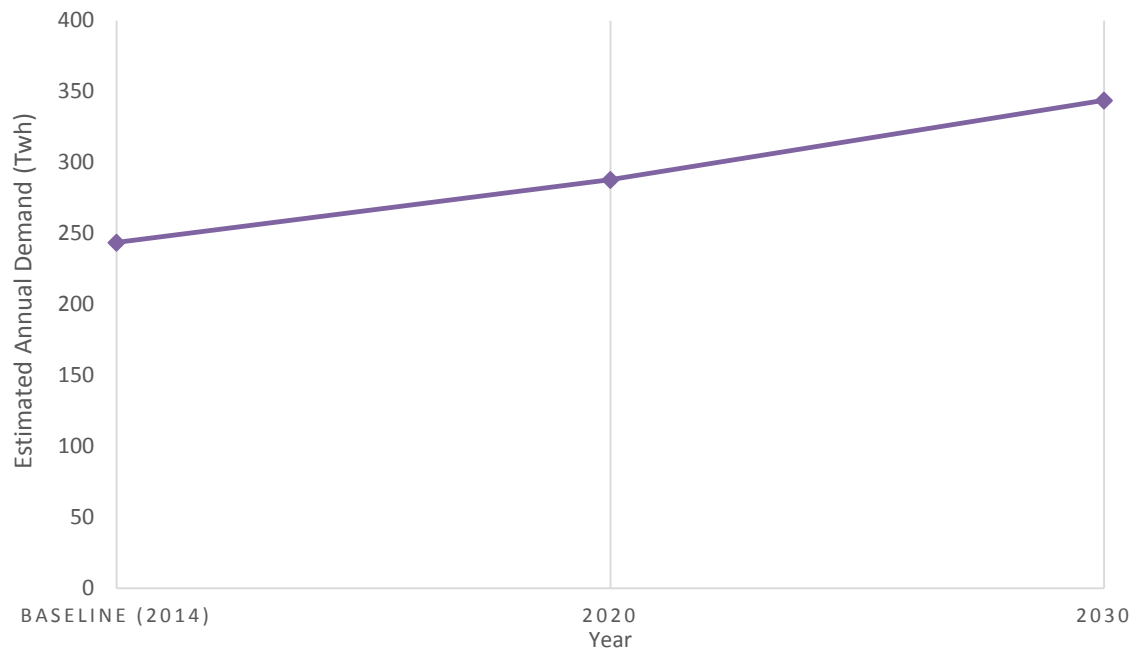


Figure 5 - Total Annual Electricity Demand Estimates (TWh) under the Electric Vehicle Expansion Scenario

3.2.2.3 Super-Efficient Adoption Scenario:

The final scenario created for this study was the 'Super-Efficient Adoption' (SEA) scenario. The population trends used in the previously described original scenarios were also used as the basis for this scenario (Table 3). Super-Efficient Adoption represents a world in which the population becomes increasingly aware of the need to reduce energy usage alongside developing renewable technology, if we are to stop negatively forcing the climate system. This scenario largely represents a change in behaviours, with the additional efficiency developments ingrained in new technology. Through the implementation and widespread acceptance of the energy efficiency strategy outlined by the UK government (DECC, 2012), a reduction in total annual demand of 25% is projected per person, in line with research into energy usage in the domestic sector (Allcott and Greenstone, 2012). Similar to the process used in the EVE scenario, this reduction in demand is introduced in two steps, with a 12.5% decrease in 2020 and a 25% reduction by 2030 (Figure 6).

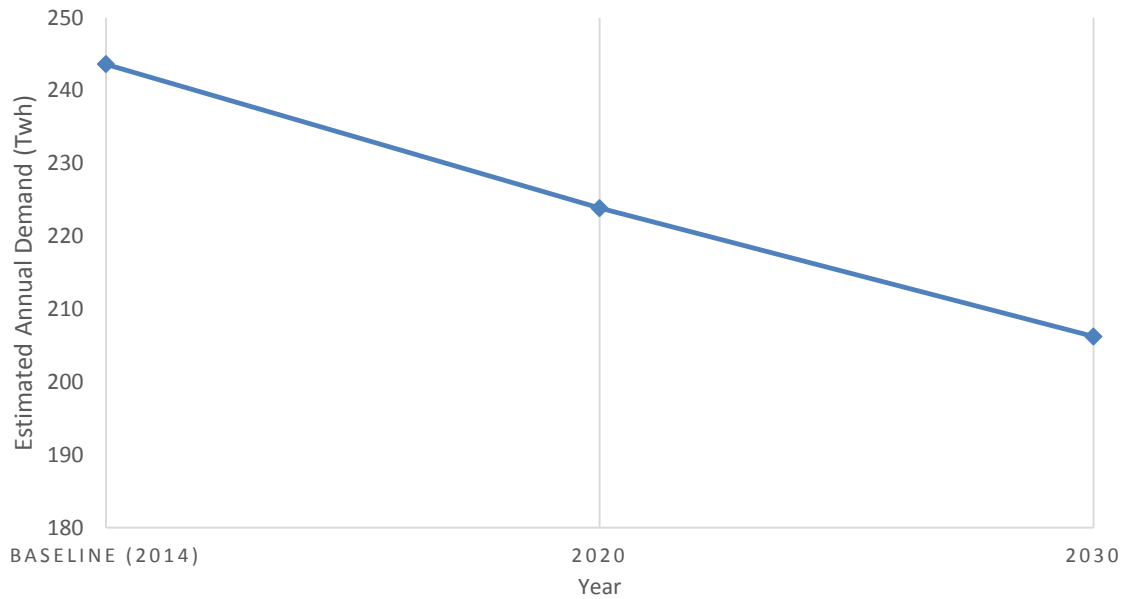


Figure 6 - Total Annual Electricity Demand Estimates (TWh) under the Super-Efficiency Adoption Scenario

Overall, these scenarios outline three possible ways in which energy usage per person may change regionally in the future. To aid comparison of the total annual demand under each scenario (National Grid scenarios inclusive), the total annual electricity demands under each scenario examined in this study have been plotted (Figure 7). From this, it is clear that the EVE and SEA scenarios represent the greatest extremes of electricity demand estimates within the study – projecting a wide range of possible future conditions which encompass the estimates included in each of the national grid scenarios.

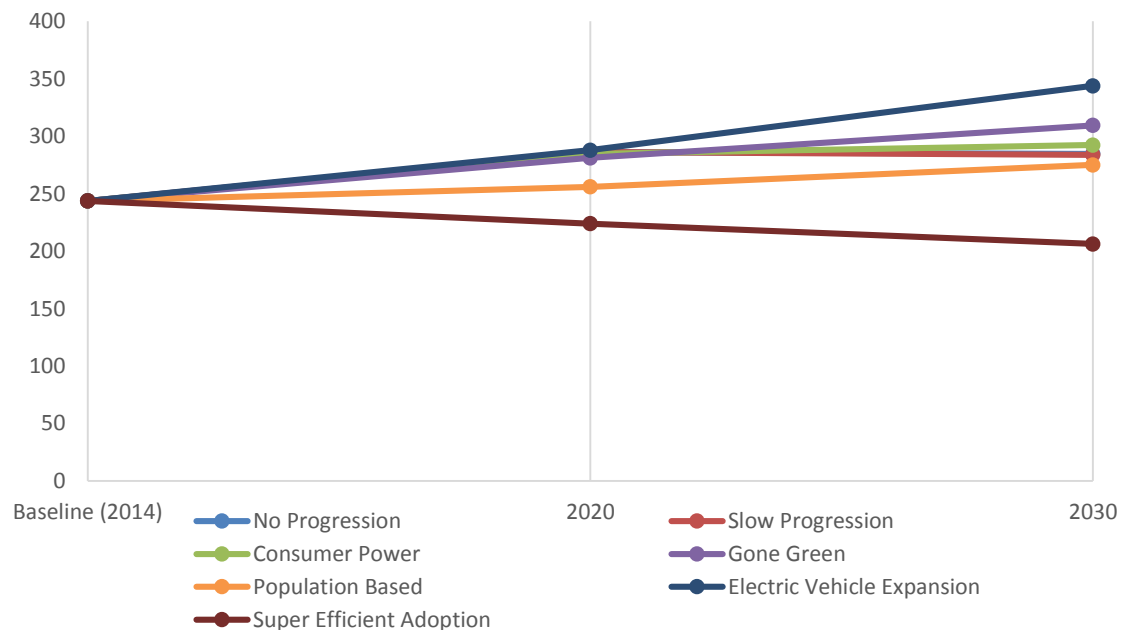


Figure 7 – Total Annual Electricity Demand Estimates (TWh) under all scenarios examined in this study

3.3 Method:

The ‘*Sub-national electricity sales and number of customers 2005-2013*’ (DECC, 2015) dataset was used to collate estimated electricity demands for each region within the UK. Demand is presented here in GWh, on an annual basis, for all regions within the UK. A summary of the most recently predicted demands (2013) is provided in Table 4. This dataset was also used to calculate the percentage of national demand required by each region in order to evaluate the proportional electricity demands across all regions.

Table 4 – A summary of the estimated regional electricity consumption (GWh) in each region throughout the UK in the year 2013. Data from the DECC ‘*Sub-national electricity sales and number of customers 2005-2013*’ (DECC, 2015). A percentage of the national average is also given to ease comparisons between the proportional demands of each region.

Region	Current Consumption (GWh)	% National Total
East England	26756.0	9.4
East Midlands	21113.0	7.4
Greater London	40478.0	14.2
North East	11869.0	4.2
North West	32168.0	11.3
Scotland	25872.9	9.1
South East	38802.5	13.6
South West	24276.5	8.5
Wales	15545.7	5.5
West Midlands	24491.5	8.6
Yorkshire and Humber	23686.0	8.3
TOTAL	285059.1	100.0

To examine the amount of electricity demand that is currently met by renewable electricity generation, the ‘*Renewable Energy Planning Database*’ (DECC and Eunomia, 2015) was used to assemble all currently operational generation projects and their combined total installed capacity (GWh). Due to the intermittent nature of renewable electricity generation it is not realistic to assume that total installed capacity is an accurate prediction of the level of electricity likely to be produced by renewable electricity technology (Twidell and Weir, 2015). For this reason, load factors were applied to the total installed capacity of all existing and planned installations. Load factors describe the efficiency of renewable technologies by comparing the total installed capacity with actual annual generation for individual generation technologies (DECC, 2015d). In this study this method was applied to both currently operational technology and planned energy infrastructure to give a more realistic estimate of current and future generation values. The load factors applied to each technology were based on figures from the ‘Digest of UK Energy Statistics’ (DECC, 2015d) and are provided in Table 5.

Table 5 – Load factors to describe the efficiency of renewable energy based on generation totals compared to total installed capacity. Values here are based on those given in DUKES (DECC, 2015d) and are based on average beginning and end of year capacity. Whilst the amount of energy produced is also dependent on environmental conditions, the annual fluctuation is small and so the most recent figures (2013) were deemed accurate enough for the purpose of the study.

Technology	Average Efficiency (%)
Onshore Wind	28.9
Offshore Wind	38.9
Marine (Tidal and Stream)	9.7
Solar PV	10.2
Hydro (Small)	35.1
Hydro (Large)	31.2
Bioenergy	58
Landfill Gas	56.8
Sewage Sludge Digestion	43.2
Energy from Waste	42.3
Animal Biomass	64.9
Anaerobic Digestion	60.2
Plant Biomass	65.5

The percentage of current electricity demand which could be supplied by renewable generation was then calculated in order to estimate the proportion of current demand which is met by renewable sources within each region. The *Renewable Energy Planning Database* (DECC and Eunomia, 2015) also provided details of the composition of renewable technology types within each region, which allowed an analysis of current and future technological composition in each region. All off-shore wind installations were assigned to the region which the installation was located closest to geographically. Overall, this gave an indication of the amount of renewable generation provided by each generation technology in each region, on both of the study dates.

Further to information about the current amount of renewable generation technology, the *Renewable Energy Planning Database* (DECC and Eunomia, 2015) was then utilised to provide details of future renewable electricity generation within each region. This was achieved through calculating the total installed capacity (GWh) of all projects which were classified as application submitted, awaiting construction and under construction, in addition to the total installed infrastructure which is currently operational. The result was an estimate of regional renewable electricity generation for 2013, 2020 and 2030. Whilst the rate of installation is difficult to predict, it was presumed in the study that all planned infrastructure would be completed by 2020 and remain constant throughout the remainder of the study period. It is likely that during this time, the amount of installed capacity will increase, however as the rate at which this will happen is unknown, the level

of renewable generation was capped at the total of all planned infrastructure which we are currently aware of. It is thus reasonable to assume that the amount of future renewable generation will represent a minimum value. The estimated renewable electricity generation figures for each of the study dates are provided in Table 6.

Table 6 – Estimated renewable electricity generation figures (GWh) for each region on each of the study dates.

Region	2013	2020	2030
East England	6752	18685	18685
East Midlands	3079	9046	9046
Greater London	795	1254	1254
North East	1874	7682	7682
North West	6198	11512	11512
Scotland	15977	51634	51634
South East	5327	9185	9185
South West	1901	8498	8498
Wales	2782	12263	12263
West Midlands	5803	6617	6617
Yorkshire and Humber	9038	45064	45064
TOTAL	59527	181440	181440

The main body of this research then focussed on analysing the amount of regional electricity demand which can be met by regional renewable electricity generation, both under current and future generation levels. The current technology mix within each region was also compared to future technology mix to analyse how the composition of renewable input will change. Both estimates were then used to draw conclusions as to the regional variation in sustainable electricity generation in the UK and the possible opportunities this creates with regards to modernising the existing electricity system and creating a sustainable energy network for future generations.

4.0 Results:

4.1 Regional Electricity Generation:

Regional annual renewable electricity generation (GWh) was investigated throughout the UK under present and future (planned) conditions. Information on the installed capacity, planned future capacity and technology load factors was combined to provide estimates for 2013, 2020 and 2030. As future generation totals were based upon currently planned infrastructure, the level of generation remains the same throughout all future scenarios.

4.1.1 Current Electricity Generation:

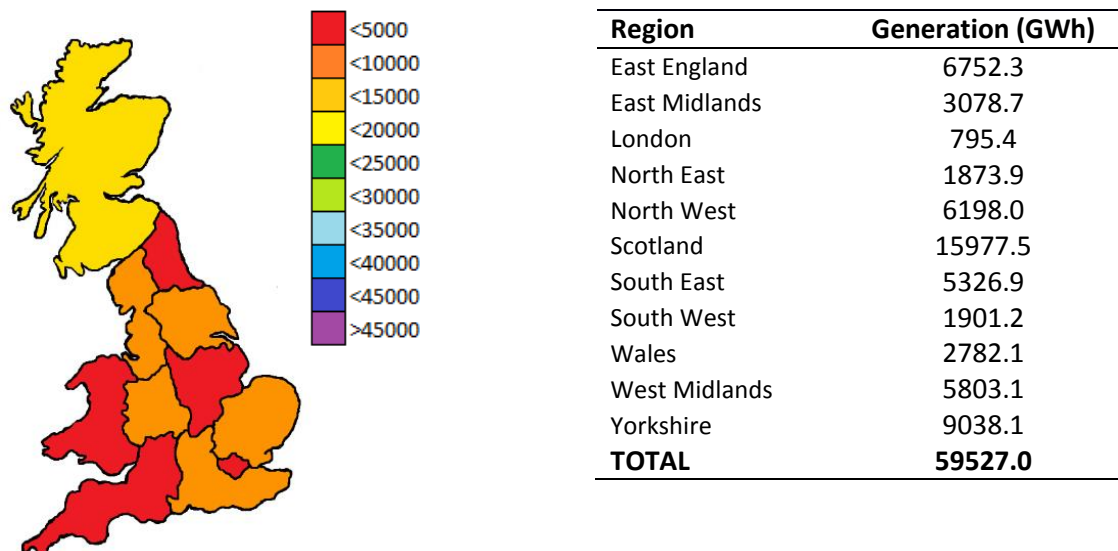


Figure 8 - Regional differences in electricity Generation (GWh) in 2013. Figures derived from 'Renewable Energy Planning Database' (DECC and Eunomia, 2015).

Figure 8 illustrates the current distribution of renewable electricity generation throughout the UK. The region with the highest level of renewable electricity generation is Scotland, which produced an estimated 15,978 GWh of renewable electricity in 2013. Levels of renewable electricity generation across the rest of the UK are consistently low, with no region exceeding 10,000 GWh of renewable electricity generation. The region which produces the lowest amount of renewable electricity is London, which generated just 795 GWh of electricity in 2013.

4.1.2 Future Electricity Generation:

Future regional electricity generation (GWh) was analysed by combining information on the capacity of planned infrastructure and technology load factors. The difference in the level of demand predicted under future scenarios from current generation is illustrated in Figure 9.

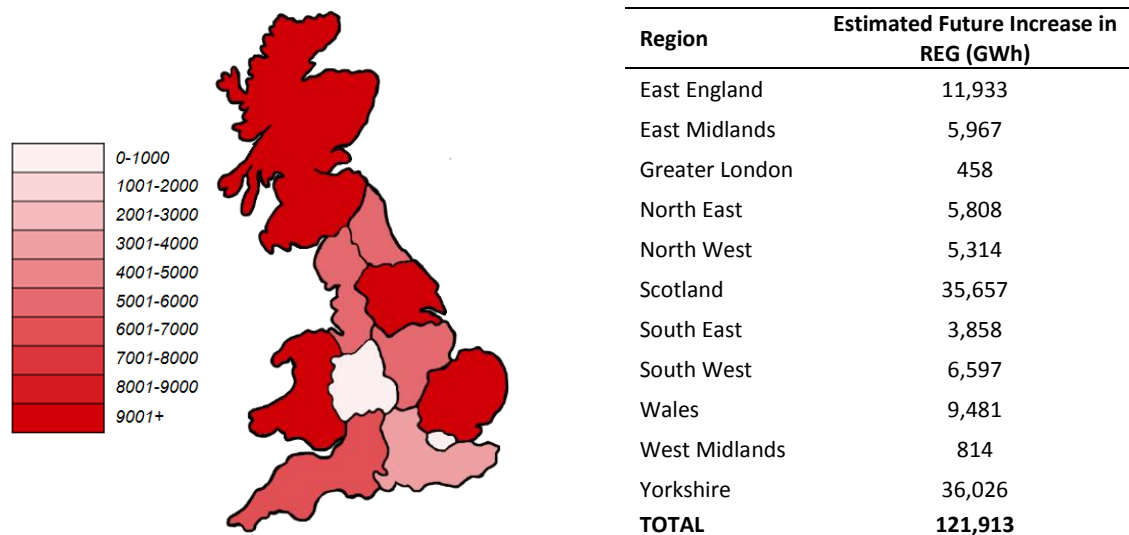


Figure 9 - Regional differences in electricity Generation (GWh) upon completion of all planned renewable energy infrastructure. Figures derived from 'Renewable Energy Planning Database' (DECC and Eunomia, 2015).

Overall, the level of renewable electricity generation is expected to rise by 122 TWh across the whole of the UK, to a total of 181 TWh. The regions which are likely to see the largest rise in renewable electricity generation are Yorkshire, Scotland, Wales and the East of England. All four of these regions are expected to see large increases in renewable electricity generation, the largest of which is seen in Yorkshire, where generation is expected to increase by 36,026 GWh (400% increase). Moderate increases in renewable energy generation are expected across the majority of remaining regions, with the East Midlands, North East, North West and South West regions seeing an increase in annual generation of between 5,314 GWh – 6,597 GWh. The South East region sees a lower increase than the majority of regions, with an expected increase of 3,858 GWh of electricity. Planned infrastructure in the West Midlands and London region is scarce, hence the estimated level of renewable electricity generation in these regions is expected to be small.

4.2 Regional Population Estimates:

For the development of original scenarios used in this investigation, population trends within each region were analysed, in addition to the annual electricity demand per person.

4.2.1 Regional Demand per Person:

The first stages of analysis involved investigating the current electricity usage per person. The total consumption (GWh) from 2013 for each region was divided by the estimated population within each region for this year to provide a crude measure of electricity demand per person. The results of this are displayed in Table 7.

Table 7 – Estimated electricity demand per person (MWh) within each region for the year 2013. Population estimates from (ONS, 2014) and consumption estimates from (DECC, 2015):

Region	Pop. Est. 2013	Current Consumption (GWh)	Current Consumption Per Person (MWh)
East	5,956,476	26,756	4.49
East Midlands	4,595,847	21,113	4.59
London	8,410,890	40,478	4.81
North East	2,609,792	11,869	4.55
North West	7,109,687	32,168	4.52
South East	8,790,679	38,803	4.41
South West	5,375,287	24,277	4.52
West Midlands	5,673,050	24,492	4.32
Yorkshire	5,342,538	23,686	4.43
England	53,864,236	243,641	4.52

When all regional data is combined, the national average consumption per person is 4.52MWh of electricity. The region which displays the highest level of electricity consumption per person (MWh) is the London region, in which the average annual demand is 4.81MWh/person. The East Midlands, North East, North West and South West have consumption estimates which fall closer to the national average, with values between 4.52MWh/person and 4.59MWh/person. The East, Yorkshire and the South East regions form the next band – all with values below the national average, falling between 4.41MWh/person and 4.49MWh/person. The region which displays the lowest consumption per person is the West Midlands region, in which annual demand falls at 4.32MWh/person, significantly below the national average. As the estimated annual electricity demand per person forms a central underlying part to the original scenarios created for this study, these figures will have a profound effect on estimates of total regional demand under future conditions.

4.2.2 Regional Population Trends:

The population predictions generated for these scenarios were based on population estimates given by the ONS for 2012 and 2022 (ONS, 2014). The population figures taken from these estimates were used to estimate population in 2013, 2020 and 2030 in each of the regions, based on an exponential extrapolation of current trends (Table 8).

Table 8 – Population predictions for each of the regions examined in the study based on estimates given in the Office of National Statistics 2012-based Subnational Population Projections for England

Region	Estimate 2013	Estimate 2020	Estimate 2030
East	5,956,476	6,312,366	6,857,978
East Midlands	4,595,847	4,797,789	5,101,767
London	8,410,890	9,164,603	10,359,981
North East	2,609,792	2,662,845	2,740,511
North West	7,109,687	7,289,959	7,555,449
South East	8,790,679	9,266,715	9,991,827
South West	5,375,287	5,631,867	6,019,799
West Midlands	5,673,050	5,890,849	6,216,576
Yorkshire	5,342,538	5,526,951	5,801,495
England	53,866,217	56,547,492	60,611,040

In order to compare the rates of change within each region, the proportional change in total population is provided in Figure 10.

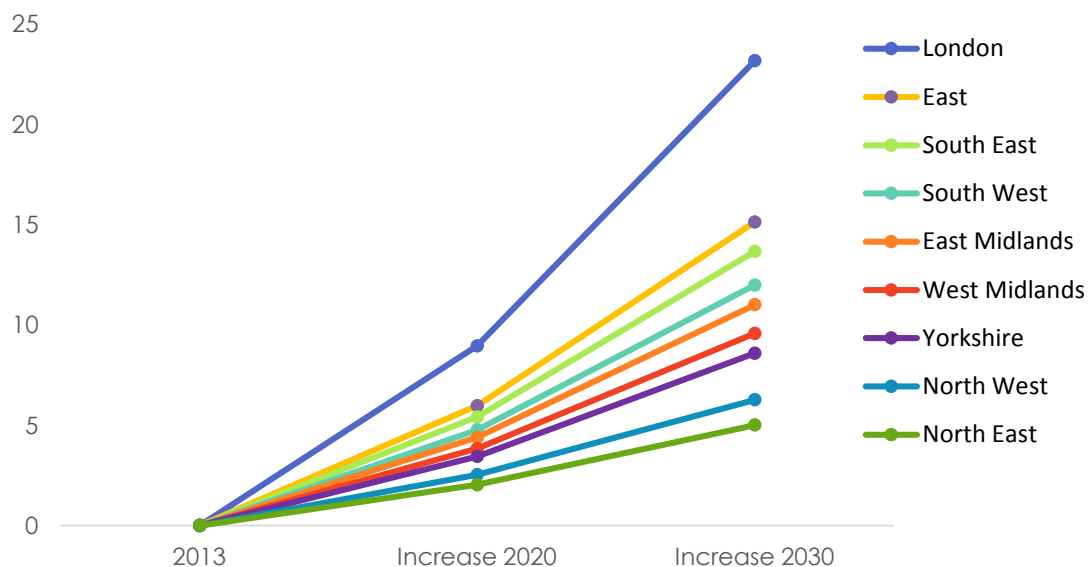


Figure 10 – The proportional change in regional population estimates over each of the future study dates.

Population change is predicted to be highest in the London region, with a total growth in population of 19% by 2030. The remaining 8 regions display less variation in the rate of population change, though a noticeable gradient of relatively high to low population

growth can be seen between the South East and North West of the country. This is reflected in the low population growth predicted in the North East and North West regions, where total population is predicted to increase by just 5.01% and 6.27% respectively by 2030 (Figure 10). As the rate of population change, coupled with the estimated demand per person, is central to each of the original scenarios, it is worth considering these trends when interpreting the results associated with each scenario.

The estimated demand per person for the SEA and EVE scenarios is provided below (Table 9). Under the SEA scenario, demand is estimated to decrease by 12.5% by 2020 and by 25% by 2030. The EVE scenario predicts an increase of 12.5% by 2020 and 25% by 2030. The PBS scenario assumes that the level of demand per person does not change and so the estimates for this scenario are not provided here.

Table 9 – Estimates for the level of demand per person (MWh) under each of the original scenarios created for the study.

Region	2013 (MWh)	SEA		EVE	
		2020 (MWh)	2030 (MWh)	2020 (MWh)	2030 (MWh)
East	4.49	3.93	3.37	5.05	5.61
East Midlands	4.59	4.02	3.44	5.16	5.74
London	4.81	4.21	3.61	5.41	6.01
North East	4.55	3.98	3.41	5.12	5.69
North West	4.52	3.96	3.39	5.09	5.65
South East	4.41	3.86	3.31	4.96	5.51
South West	4.52	3.96	3.39	5.09	5.65
West Midlands	4.32	3.78	3.24	4.86	5.40
Yorkshire	4.43	3.88	3.32	4.98	5.54
AVERAGE	4.52	3.95	3.39	5.08	5.64

4.3 Regional Electricity Demand:

Regional electricity demand (GWh) was investigated throughout the UK under present and future conditions.

4.3.1 Current Electricity Demand:

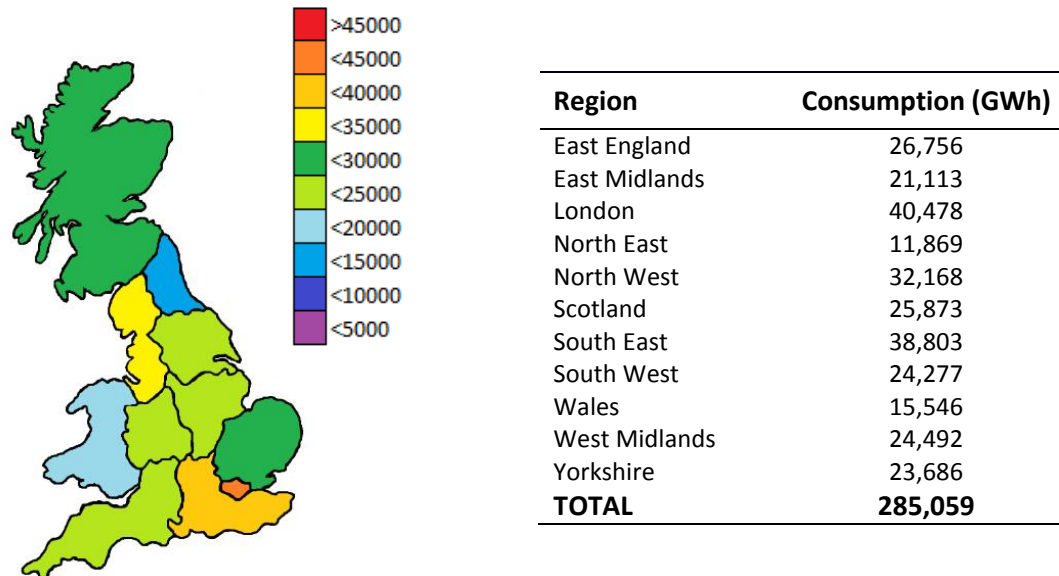


Figure 11 - Regional differences in electricity demand (GWh) in 2013. Figures derived from 'Sub-national electricity sales and number of customers 2005-2013' (DECC, 2015).

Figure 11 displays the regional patterns of demand currently experienced in the UK. The areas which display the highest level of demand are London and the South East, which are also the regions with the highest population estimates (ONS, 2014). Consumption in these two regions is considerably higher than the national average (27,071 GWh), with estimates of 40,478 GWh and 38,802 GWh of electricity demand respectively. The North West also shows a relatively high level of demand (32,168 GWh), which reflects its position as the third most populous region within the UK (ONS, 2014). The regions which have the lowest demand estimates are the North East of England, and Wales. Demand in these two regions is estimated at just 11,869 GWh and 15,545 GWh respectively. A central band of moderate demand is seen across the South West, West and East Midlands and Yorkshire, where annual electricity demand is estimated between 21,113 GWh and 24,492 GWh. When considering all regional demand totals, the estimated total annual electricity demand for the UK in 2013 was 285TWh.

4.3.2 Estimated Future Demand under National Grid Scenarios:

Estimates of demand under each of the National Grid scenarios were used to examine future regional electricity demand (GWh) in 2020 and 2030. The current regional weighting of demand was applied to the estimates of total annual electricity demand (GWh) given by National Grid (National Grid, 2015). As a result, the regional pattern observed is the same as currently observed, however the total electricity demand (GWh) is subject to increases in line with key scenario parameters. The results are presented below.

Table 10 – Estimated regional annual electricity demand (GWh) under each of the National Grid scenarios. Figures are provided for the 2020 and 2030 estimates. Regional weighting is based on current regional weighting of electricity demand.

	Region	NP	SP	CP	GG
2020	East England	31,444	31,444	31,350	30880
	East Midlands	24,812	24,812	24,738	24367
	London	47,570	47,570	47,428	46718
	North East	13,948	13,948	13,907	13699
	North West	37,804	37,804	37,691	37127
	Scotland	30,406	30,406	30,315	29861
	South East	45,600	45,600	45,464	44784
	South West	28,530	28,530	28,444	28019
	Wales	18,269	18,269	18,215	17942
	West Midlands	28,782	28,782	28,696	28267
	Yorkshire and Humber	27,836	27,836	27,753	27337
	TOTAL	335,000	335,000	334,000	329000
2030	East England	31256	31162	32101	33978
	East Midlands	24664	24590	25330	26812
	London	47286	47144	48564	51404
	North East	13865	13823	14240	15073
	North West	37578	37465	38594	40851
	Scotland	30224	30133	31041	32856
	South East	45328	45192	46553	49276
	South West	28359	28274	29126	30829
	Wales	18160	18106	18651	19742
	West Midlands	28610	28525	29384	31102
	Yorkshire and Humber	27669	27586	28417	30079
	TOTAL	333000	332000	342000	362000

As mentioned previously, the pattern of demand remains the same, with relatively high levels of demand in the three most populous regions (London, South East and South West), relatively low demand in the North East and Wales, and a central band of moderate demand, across all four National Grid Scenarios. The difference lies in the total annual electricity demand, which is estimated to be larger than current demand in all four scenarios. Figure 12 illustrates the differing level of regional demand from current demand estimates.

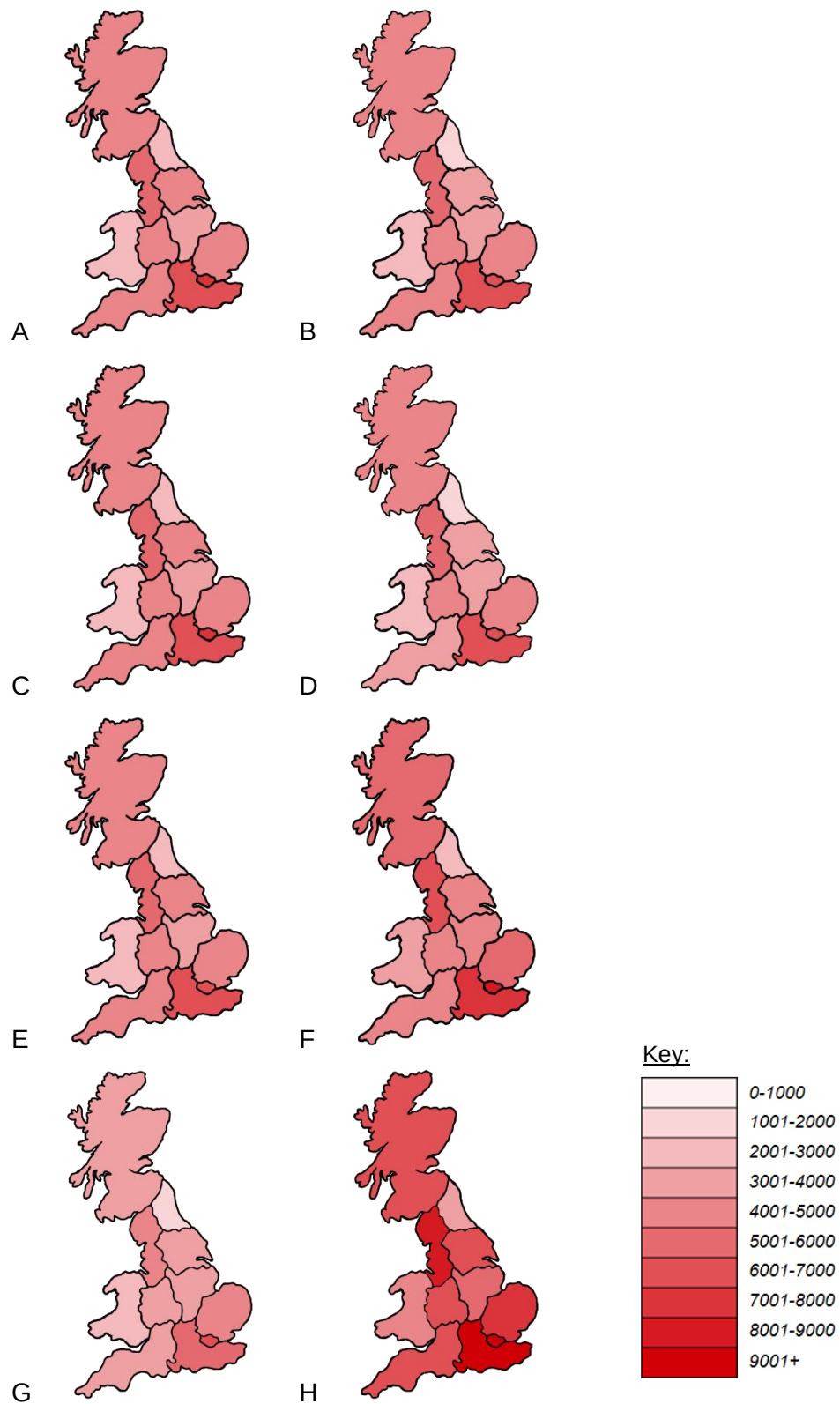


Figure 12 – Estimated increases in regional electricity demand (GWh) across each of the National Grid scenarios; (a) No Progression 2020, (b) No Progression 2030, (c) Slow Progression 2020, (d) Slow Progression 2030, (e) Consumer Power 2020, (f) Consumer Power 2030, (g) Gone Green 2020 and (h) Gone Green 2030.

Due to the weighting similarities, the regions which have the highest level of demand in 2013 are estimated to see the largest rise in demand. Although each scenario has a unique set of underlying properties, the differences in total estimated annual electricity

demand (GWh) in 2020 are small, ranging from 329 TWh – 355 TWh across all four scenarios. As a result there is little discernible difference across the maps. The scenario which represents the most difference to any other is 'Gone Green', under which demand is projected to be the lowest of any of the four scenarios (329 TWh). In this scenario, the level of consumption in the South West and Scotland appear to ease slightly, as total demand dips below 45,000 GWh and 30,000 GWh in each respective region.

The differences in total estimated annual electricity demand (GWh) in 2030 are slightly larger than those predicted in 2020, with estimates ranging from 332 TWh – 362 TWh. The largest total annual electricity demand in 2030 is seen in the Gone Green scenario. Of note is that under this scenario, the level of consumption in the London region is expected to exceed 50,000 GWh – this is equivalent to 14% of total demand under this scenario or, for perspective, 18% of the current total demand across the UK. The scenario which predicts the least growth in annual electricity demand by 2030 is the 'Slow Progression'. Under this scenario the rise in energy demand is less dramatic, with the largest increase in the London region (16%). The North East region has consistently low estimates of annual electricity demand across all four scenarios, representing less than 50% of the national average under each projection.

4.3.3 Estimated Future Demand under Original Scenarios:

Estimates of demand under each of the original scenarios were then used to examine further possibilities of future regional electricity demand (GWh) in 2020 and 2030. In contrast to the National Grid scenarios presented previously, the demand weighting in these scenarios was based upon regional population trends as oppose to current regional weighting of electricity demand. As a result, regional patterns differ slightly from those seen previously, though are similar amongst the three original scenarios. Each of these scenarios applied a differing level of demand per person to estimates of total regional population for each of the study dates. In the PBS scenario demand per person remains the same as current estimates, with the remaining two scenarios, SEA and EVE, predicting a 25% decrease/increase in demand per person in each scenario respectively. These changes in demand were applied in two stages, with a change of 12.5% by 2020 followed by the full 25% change in 2030. This variance in demand per person leads to considerable differences in the estimated level of regional consumption across the three scenarios.

A quantitative breakdown of regional electricity demand is given to facilitate comparisons between the regions across both of the study dates (Table 11).

Table 11 – Estimated regional annual electricity demand (GWh) under each of the Original scenarios. Figures are provided for the 2020 and 2030 estimates. Regional weighting is determined by population trends determined by figures from the ONS (2015) for each region.

	Region	SEA	PBS	EVE
2020	East	24,810	28,355	31,899
	East Midlands	19,286	22,041	24,796
	London	38,592	44,105	49,619
	North East	10,597	12,110	13,624
	North West	28,861	32,984	37,107
	South East	35,791	40,904	46,017
	South West	22,256	25,435	28,615
	West Midlands	22,253	25,432	28,611
	Yorkshire	21,441	24,504	27,567
	Total	223,885	255,869	287,853
2030	East	23,104	30,805	38,507
	East Midlands	17,578	23,437	29,296
	London	37,394	49,858	62,323
	North East	9,348	12,463	15,579
	North West	25,639	34,185	42,731
	South East	33,078	44,104	55,130
	South West	20,390	27,187	33,984
	West Midlands	20,129	26,838	33,548
	Yorkshire	19,291	25,721	32,151
	TOTAL	205,950	274,600	343,250

Overall, despite the differing methods of estimating renewable electricity demand for the original scenarios, the patterns illustrated take a similar form to those previously explored. To analyse the extent to which demand in the original scenarios differs from current estimates of electricity demand, Figure 13 provides a spatial illustration of the estimated change in demand within each region, under the SEA, PBS and EVE scenarios.

Under the original scenarios in 2020, the London and South East regions display the highest levels of demand, with the estimates of electricity demand in the London region reaching its highest of any 2020 scenario under 'EVE' (49,619 GWh). The North West and Eastern regions also display a relatively high level of consumption in each scenario (Table X), despite the North West being previously recognised as a region with a low rate of population growth and moderate demand per person. The North East has consistently low consumption across each of the scenarios with a range of just 10,597-13,624 GWh under SEA and EVE respectively. A central band, consisting of the South West, West Midlands,

East Midlands and Yorkshire region display moderate levels of demand across all three scenarios.

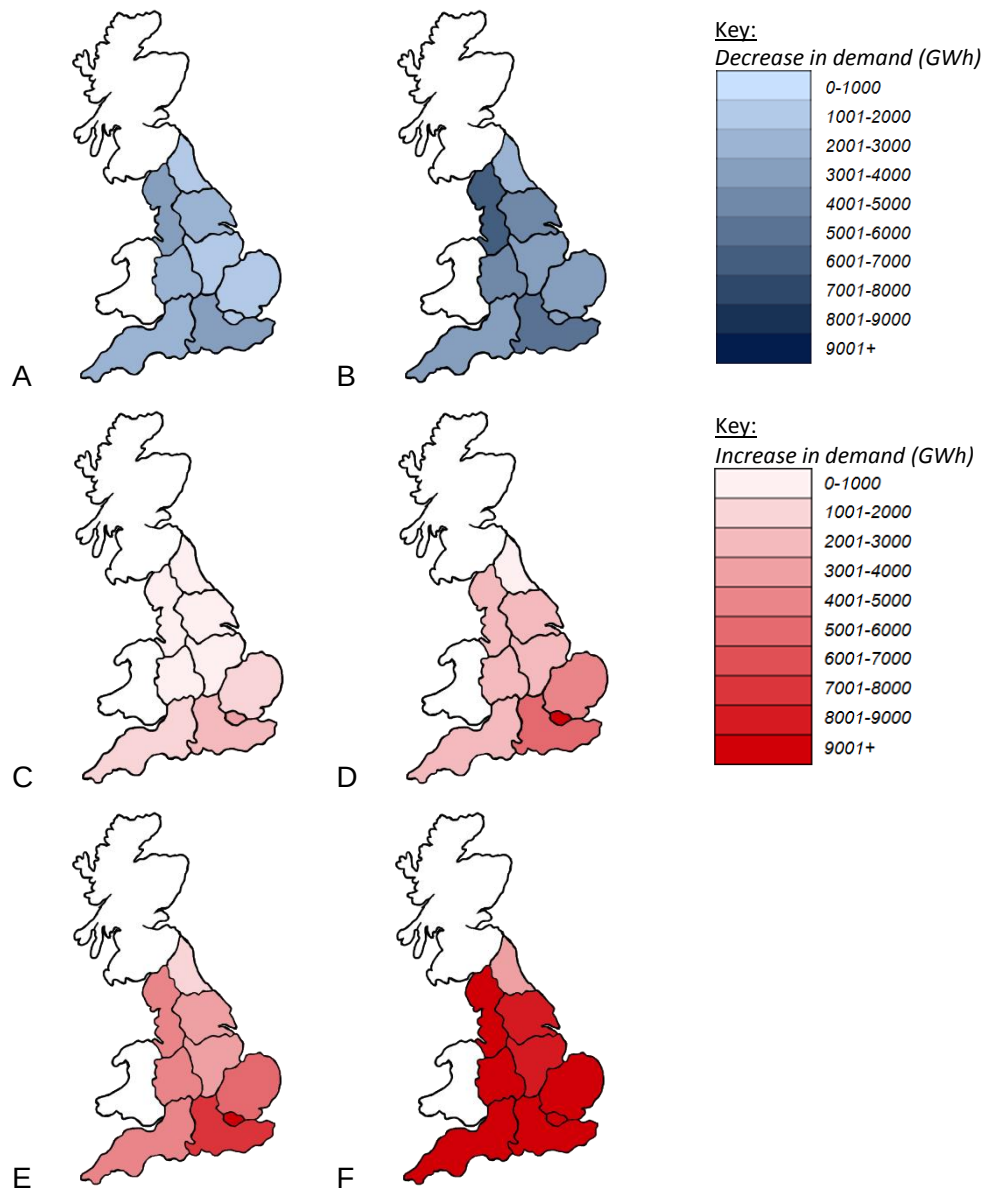


Figure 13 – Estimated changes in regional electricity demand (GWh) across each of the Original Scenarios; (a) SEA 2020, (b) SEA 2030, (c) PBS 2020, (d) PBS 2030, (e) EVE 2020 and (f) EVE 2030.

The regional differences in estimated electricity demand in 2030 across all of the original scenarios created for this study are also illustrated in Figure 13. These maps show the greatest variation across all scenario maps produced as the range of values between the Super-Efficient Adoption and Electric Vehicle Expansion scenarios continues to increase moving forwards through time. Overall consumption under each of these scenarios is 205,950 GWh and 343,250 GWh respectively (Table 11), highlighting that if a more efficient lifestyle is adopted, total annual electricity demand could be reduced by 40%.

The SEA scenario has the lowest estimated annual electricity demand in 2030. As a result, a more positive view of future consumption is presented in Figure 13 (B). A slight gradient of relatively low consumption in the North and high consumption in the South can be seen in this scenario, however overall, demand is lower across all regions than is seen under current conditions. Under the PBS and EVE scenarios, this decreasing trend in demand towards the north of the country is less apparent due to the heightened consumption estimates in the North West region, within which demand exceeds 40,000 GWh under the EVE scenario.

The largest differences in demand estimates under the original scenarios are found in the London and South East regions. Large changes are also estimated for the North West region and to a lesser extent the East region (Table 11). These rates of change help to explain why the gradient in demand from the south to the north of the country becomes less apparent in the more energy intensive scenarios. In line with previous scenarios, the North East region displays a consistently low level of demand and the lowest rate of increase between the three scenarios.

4.4 Level of Demand Met by Renewable Electricity Generation:

The proportion of regional demand which can be met through local renewable energy generation was investigated throughout the UK under current and future energy scenarios.

4.4.1 Current % Electricity Demand Met by Renewable Electricity Generation:

Initially, the proportion of demand which can presently be met within each region was estimated using demand and generation data described previously. The results are presented in Figure 14.

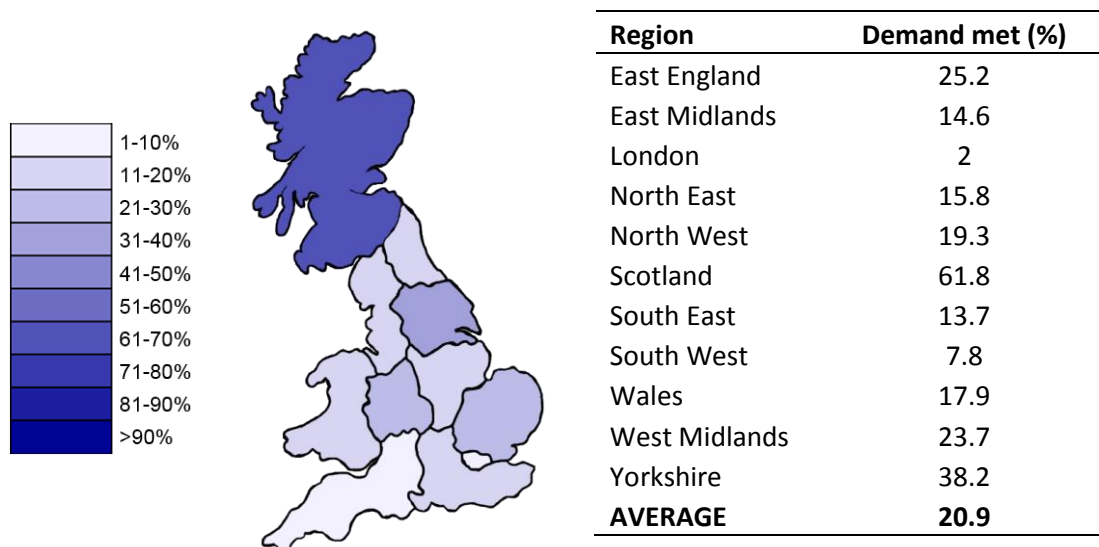


Figure 14 - Regional differences in the amount of regional demand which can be met by renewable generation (%) in 2013.

High generation levels in Scotland, coupled with a relatively low rate of consumption (only the North East and Wales have lower consumption estimates) leads to a large proportion of demand being met by renewable sources in this region (61.8%). Despite having a smaller land surface area and a level of demand which is not dissimilar to that of the Scottish region (25,873 GWh and 23,686 GWh respectively), the Yorkshire region also generates enough renewable electricity to meet 38.2% of current electricity demand – significantly more than any other region in the UK. Due to having a high level of demand alongside the lowest amount of renewable electricity generation across the UK, the London region can only account for 2.0% of current electricity demand through renewable electricity generation. Another region which can account for only a very low proportion of current demand with renewable sources is the South West, which despite having an annual demand that is below the national average (24,277 GWh) accounts for just 7.8% of annual electricity demand through renewable energy sources. Overall in 2013, the UK had a total

estimated annual electricity demand of 285 TWh, 20.9% of which could be accounted for by renewable electricity generation.

4.4.2 Future % Electricity Demand Met by Renewable Electricity Generation – National Grid Scenarios:

The level of demand which can be met by renewable electricity generation under each of the national grid scenarios was investigated in 2020 and 2030. The quantitative results of this are displayed in Table 12. The changing level of demand which is met across the study period (2013-2030) is also presented spatially in Figure 15.

Table 12 – Estimated amount of regional electricity demand which can be met by local renewable electricity generation (%) under each of the national grid scenarios (National Grid, 2015).

	Region	% Demand met by REG			
		NP	SP	CP	GG
2020	East England	59	59	60	61
	East Midlands	36	36	37	37
	London	3	3	3	3
	North East	55	55	55	56
	North West	30	30	31	31
	Scotland	170	170	170	173
	South East	20	20	20	21
	South West	30	30	30	30
	Wales	67	67	67	68
	West Midlands	23	23	23	23
	Yorkshire	162	162	162	165
	National Average	59.6	59.6	59.8	60.7
2030	East England	60	60	58	55
	East Midlands	37	37	36	34
	London	3	3	3	2
	North East	55	56	54	51
	North West	31	31	30	28
	Scotland	171	171	166	157
	South East	20	20	20	19
	South West	30	30	29	28
	Wales	68	68	66	62
	West Midlands	23	23	23	21
	Yorkshire	163	163	159	150
	National Average	60.1	60.2	58.5	55.2

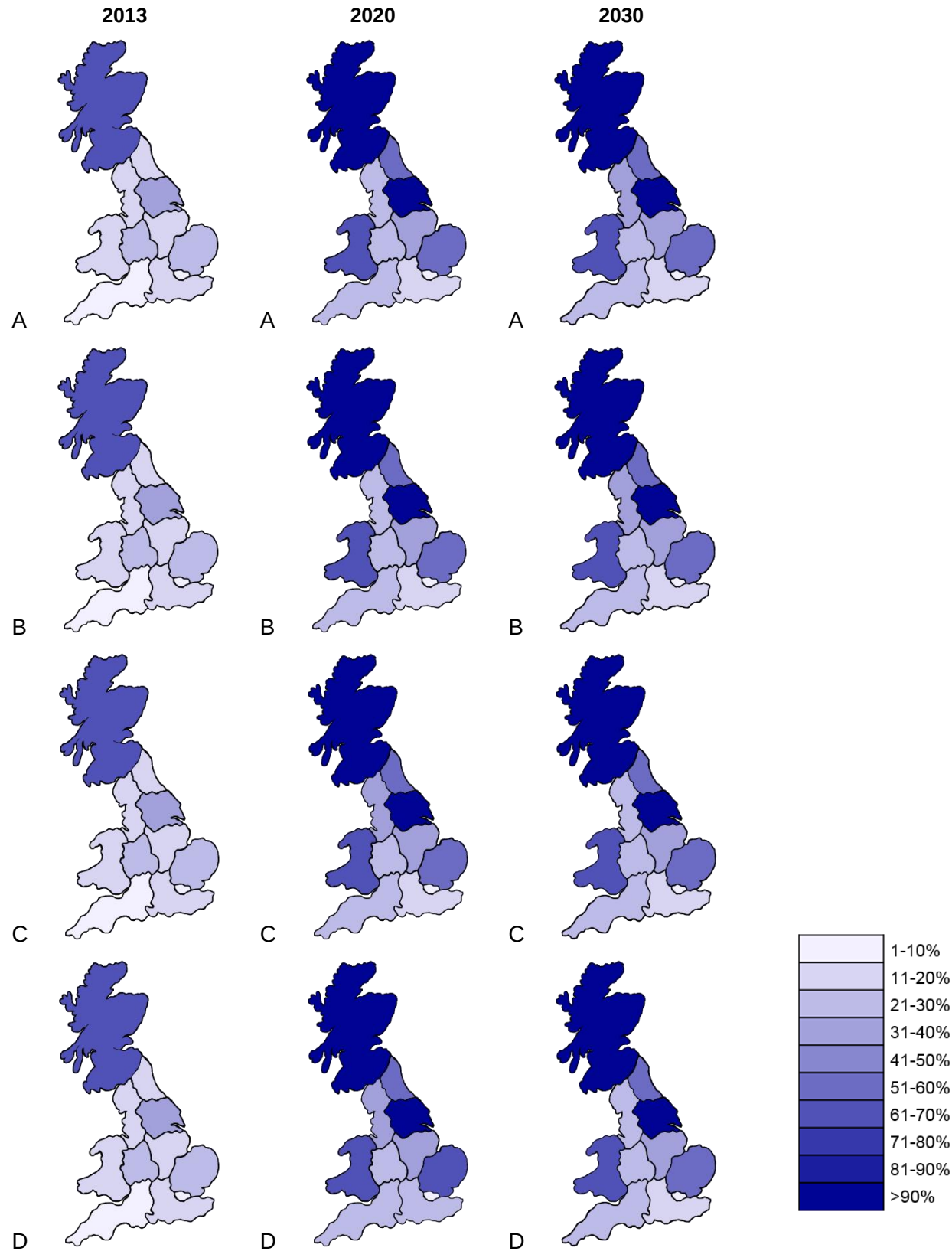


Figure 15 – Regional patterns of the amount of annual electricity demand (%) that can be met through local renewable electricity generation under each of the national grid scenarios. Scenarios are labelled as follows; (A) No Progression, (B) Slow Progression, (C) Consumer Power, (D) Gone Green.

Although each scenario has a unique set of underlying properties, the differences in estimated annual demand (GWh) in 2020 are small, ranging from 329 TWh – 355 TWh across all four scenarios. The weighting of demand also remains the same across each of the national grid scenarios as it is based on current weightings of electricity demand. As a result, there is little discernible difference across the average amount of demand which can be met by renewable resources in 2020 – with a range of just 1.1% across the four scenarios (Table 12). The scenario which represents the biggest variance is the Gone Green scenario, under which 60.7% of annual electricity demand is estimated to be provided by renewable electricity generation. The similarities in the proportion of demand which is met in 2020 is also apparent when examining Figure 15. The maps produced for each of the four scenarios have very few differences, with minor increases in the amount of demand which can be met in the North West and South East regions in the Consumer Power and Gone Green scenarios.

As this study focusses on how much of future demand could be provided by renewable generation, it is more useful to explore how much more demand can be reached under the national grid scenarios than is currently accounted for under present conditions, as oppose to variation between the scenarios. Overall, the amount of demand which can be met by renewable electricity generation is a lot higher under each of the National Grid scenarios in 2020 than is currently seen through existing generation. In 2013, the UK was able to produce enough electricity through renewable sources to account for 20.9% of total demand. Under each of the National grid scenarios this is predicted to increase substantially – to 59.6% under the No and Slow Progression scenarios, 59.8% under the Consumer Power Scenario and 60.7% under the most ambitious scenario, Gone Green. Regionally, the pattern remains the same, with some significant improvements in the level of demand which can be met. This is most noticeable in Scotland and Yorkshire which are predicted to generate greater than 100% of the amount of regional demand. Wales, Eastern England and the North East are also predicted to produce greater than 50% of the amount of regional demand, a significant improvement on current renewable generation totals. The London region continues represent the lowest penetration of renewable generation, with just 3% of regional demand being met under any future scenario. However overall, the view in 2020 is optimistic with all but two of the regions (London and South East) meeting a higher level of demand than the current national average.

Looking to 2030, the amount of demand which can be met by renewable electricity generation is a lot higher under each of the National Grid scenarios than is currently seen through existing generation. However, the rate of increase does not continue beyond 2020 and two of the scenarios (Consumer Power and Gone Green) experience a decline in the

amount of demand which will be met relative to 2020 estimates. The largest of these declines is seen in the Gone Green scenario, under which the increased electricity demand reduces the estimated amount of demand met by 5%.

Regionally, the pattern remains the same across all national grid scenarios in 2030. Scotland and Yorkshire continue to meet greater than 100% of the amount of regional demand across all scenarios. Wales, Eastern England and the North East are also predicted to produce greater than 50% of the amount of regional demand. The London region continues to have low estimates of the proportion of demand which can be met, falling to just 2% under the gone green scenario. Overall, whilst it is promising that all regions (with the exception of London and the South East) are predicted to meet a higher level of demand than the current national average, the results also highlight the need for further development moving forwards to prevent a decline in the level of demand which can be met by renewable electricity generation.

4.4.3 Future % Electricity Demand Met by Renewable Electricity Generation – Original Scenarios:

The level of demand which can be met by renewable electricity generation under each of the original scenarios in 2020 and 2030 was also examined. Table 13 provides a quantitative breakdown of the amount of demand which will be met by renewable electricity generation in 2020 and 2030.

Table 13 – Estimated amount of regional electricity demand which can be met by local renewable electricity generation (%) under each of the original scenarios developed for this study.

		% Demand Met by REG		
	Region	SEA	PBS	EVE
2020	East	75%	66%	59%
	East Midlands	47%	41%	36%
	London	3%	3%	3%
	North East	72%	63%	56%
	North West	40%	35%	31%
	South East	26%	22%	20%
	South West	38%	33%	30%
	West Midlands	30%	26%	23%
	Yorkshire	210%	184%	163%
	National Average	60%	53%	47%
2030	East	81%	61%	49%
	East Midlands	51%	39%	31%
	London	3%	3%	2%
	North East	82%	62%	49%
	North West	45%	34%	27%
	South East	28%	21%	17%
	South West	42%	31%	25%
	West Midlands	33%	25%	20%
	Yorkshire	234%	175%	140%
	National Average	67%	50%	40%

Overall, the average amount of national demand which can be met by renewable electricity generation is much greater across all of the original scenarios. The level of demand which can be met is greatest under the Super Efficient Adoption scenario, which is estimated to meet 60% of demand in 2020 and 67% in 2030. The Population Based and Electric Vehicle Expansion scenarios see a peak in the level of demand being met through renewable generation in 2020, followed by a proportional decrease in 2030. The spatial distribution of renewable generation is explored further in Figure 16.

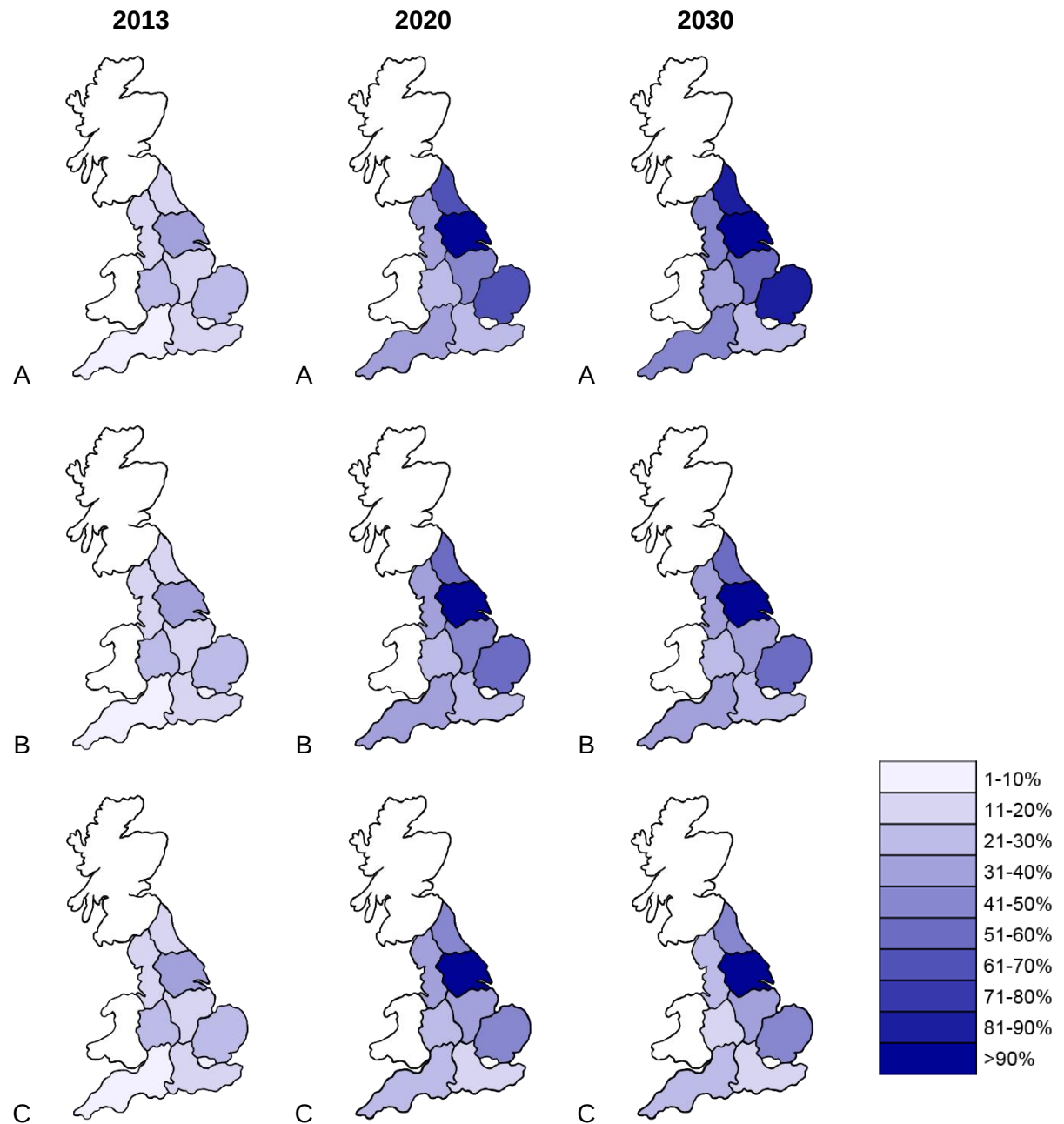


Figure 16 – Regional patterns of the amount of annual electricity demand (%) that can be met through local renewable electricity generation under each of the original scenarios. Scenarios are labelled as follows; (A) Super-Efficient Adoption (B) Population Based, (C) Consumer Power.

4.4.3.1 % Met in 2020:

In line with previous estimates, London consistently represents the region in which the lowest proportion of demand can be met by renewable electricity generation – with just 3% of demand able to be accounted for under all of the scenarios in 2020. The South East region also displays a relatively low proportion of electricity demand which can be met by renewable generation, with a range of 20-26% met. Although this represents twice the

proportion as is currently met, it remains fairly consistent with the current national average and does not represent an optimistic energy future in this region.

Across the remaining regions, an overall trend is visible from East to West, with high levels of demand able to be met in the East and relatively low levels in the West. This is most apparent in the Yorkshire region, in which over 100% of electricity demand is predicted to be catered for in 2020 under all scenarios. The East and North East regions are predicted to generate enough renewable electricity to meet over 50% of demand in all three scenarios and the East Midlands is also predicted to meet a relatively high level of demand with renewable energy generation (36-47%). The South West, West Midlands and North West regions collectively have relatively low estimates of the amount of regional demand which can be met by renewable electricity generation. The most severe of these regions is the West Midland region, which despite having the lowest demand per person (GWh), is predicted to produce enough renewable electricity to cater for just 23-30% of regional demand across all three scenarios.

Overall, the amount of national electricity demand which can be met by renewable electricity generation is predicted to increase substantially under each of the original scenarios created for this study. In 2013 the national average proportion of demand which could be met by renewable electricity generation was 21%. This is predicted to increase to 60% under the SEA scenario, 53% under PBS and 47% under the least optimistic scenario, EVE.

4.4.3.2 % Met in 2030:

In 2030, London continues to represent the region in which the lowest proportion of demand can be met by renewable electricity generation – with just 2-3% of demand able to be accounted for under all of the scenarios. The South East region also displays a relatively low proportion of electricity demand which can be met by renewable generation, with just 17% of demand able to be accounted for by 2030 under the EVE scenario.

Across the remaining regions, an overall trend remains visible from East to West, with high levels of demand able to be met in the East and relatively low levels in the West. This suggests that when population is accounted for, the estimates shift from having a North-South divide to an East-West divide. The Yorkshire region continues to be able to produce over 100% of electricity demand from renewable sources in 2030 regardless of any change in population or the amount of demand per person. The East and North East regions continue to meet a large proportion of demand with renewable electricity – with both regions producing over 80% of regional demand in 2030 under the Super-Efficient Adoption scenario.

The South West, West Midlands and North West regions collectively have relatively low estimates of the amount of regional demand which can be met by renewable electricity generation. The most severe of these regions is the West Midland region, which despite having the lowest demand per person (GWh), is predicted to produce enough renewable electricity to cater for just 20-33% of regional demand across all three scenarios.

Overall, the amount of national electricity demand which can be met by renewable electricity generation is predicted to increase from 2020 estimates under the SEA scenario – from 60% in 2020 to 67% in 2030. Under the remaining two scenarios, the amount of demand which can be met by renewable electricity resources dips slightly, suggesting that a lot more renewable infrastructure will be needed to be put in place if we are to meet the ever increasing demands of future populations. In 2013 the national average proportion of demand which could be met by renewable electricity generation was 21%. By 2030, this is predicted to increase to 67% under the SEA scenario, 50% under PBS and 40% under the least optimistic scenario, EVE.

4.5 Regional Balance of Renewable Generation Technologies:

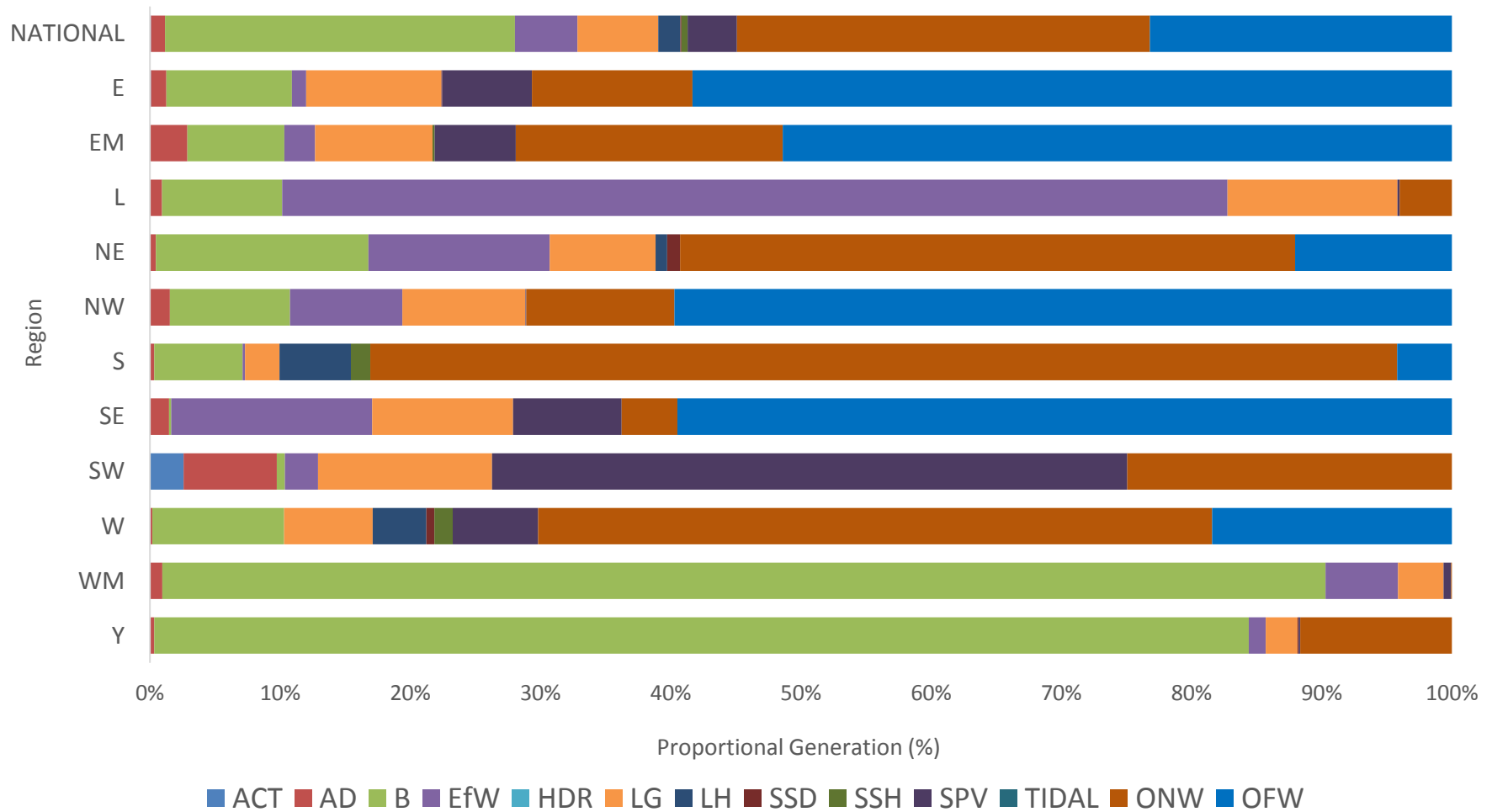


Figure 17 – The proportion of renewable electricity generation (GWh) produced by each technology type on a national and regional scale, in 2013

In addition to the analysis of the level of demand which will be able to be met by renewable energy generation under future scenarios, the technology mix from which this energy will be generated was also investigated.

4.5.1 National and Regional Renewable Technology Composition 2013:

The current composition of renewable electricity generation technologies in the UK is given in Figure 17. The largest proportion of generation is currently provided by onshore wind generation (32%). This is accompanied by large amounts of electricity from biomass generation (27%) and offshore wind generation (23%). Relatively small amounts of electricity sourced from landfill gas (6%), energy from waste (5%), solar photovoltaics (4%), large hydro (2%), and anaerobic digestion (1%) represent the remaining significant contributors to national renewable electricity generation.

At a regional level, three groups are identified which share similar mixes of renewable generation technology. The first of these groups is composed of the East, East Midlands, North West and South East regions. Across each of these regions, the dominant generation technology is offshore wind generation. These regions are also characterised by relatively smaller contributions from onshore wind, solar photovoltaics, landfill gas and (excluding the South East region) biomass generation. This is the regional grouping which most closely represents the national proportion of technology types, though the contribution from offshore wind here is larger than the national average.

The second grouping can be applied to Wales, the North East, and Scottish regions, all of which are characterized by a dominance of onshore wind generation. The largest proportional share of onshore wind generation is seen in Scotland, where 79% of renewable electricity is generated in this way. Smaller contributions in these regions come from offshore wind, biomass, landfill gas and solar photovoltaics – particularly in Wales. The final grouping can be applied to the West Midlands and Yorkshire regions, where there is a profound dominance of generation from biomass. Also contributing in these regions are energy from waste, landfill gas and onshore wind.

The South West and London region both have unique mixes of energy generation technologies which don't fall into any of the aforementioned groups. In the London region, the dominant generation technology is energy from waste generation, which accounts for 73% of generation in this region, with smaller contributions from landfill gas, biomass and onshore wind. In the South West, the dominant energy generation technology is solar photovoltaic generation, with significant contributions from onshore wind and landfill gas technologies.

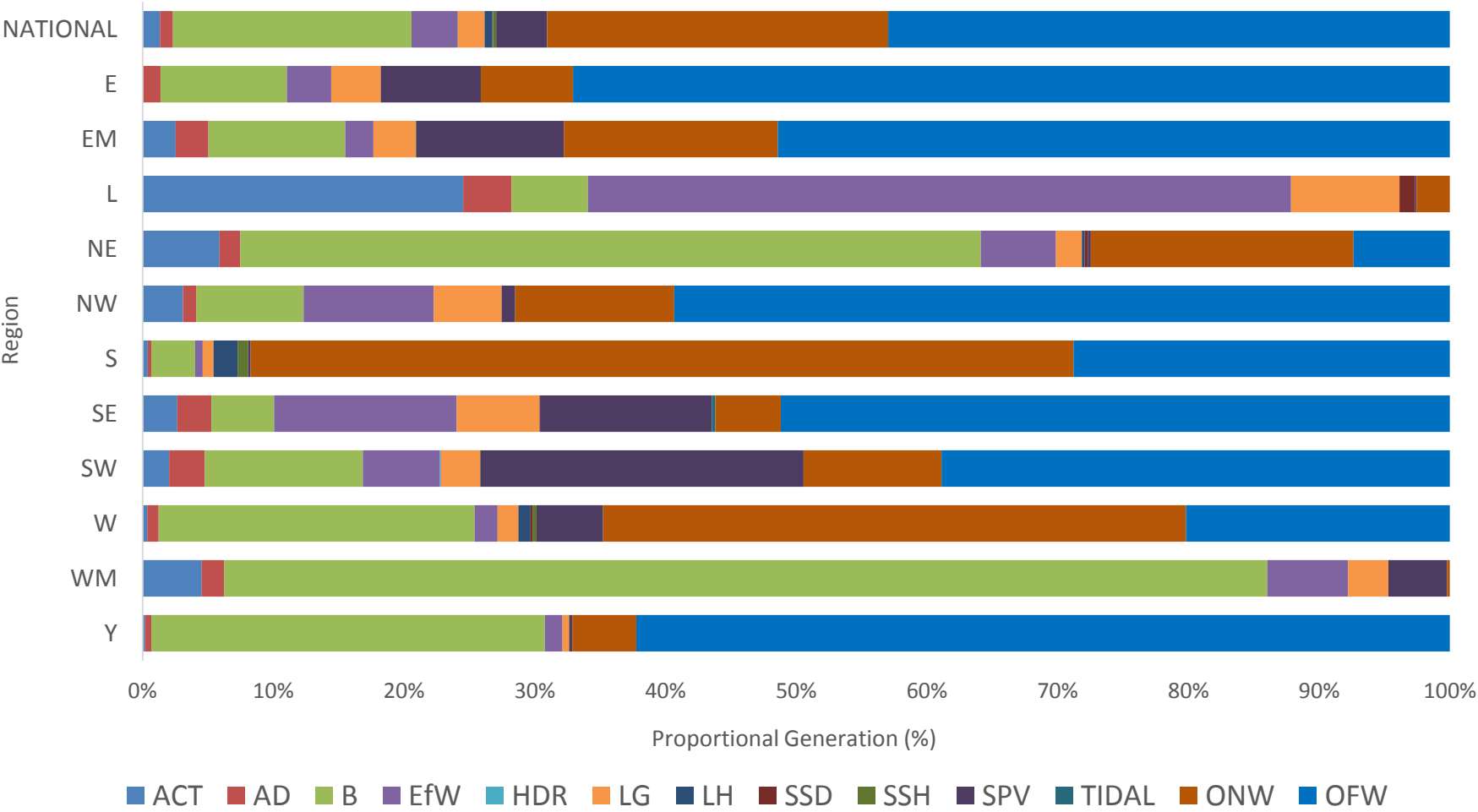


Figure 18 – The proportion of renewable electricity generation (GWh) produced by each technology type on a national and regional scale, upon completion of all planned renewable electricity infrastructure.

Table 14 – Estimated increases in regional renewable electricity generation (GWh) upon completion of all planned renewable infrastructure in the UK. The largest increases in each technology type are highlighted in red to facilitate analysis.

Estimated Increase in Regional Renewable Generation (GWh)												
Technology	E	EM	L	NE	NW	S	SE	SW	W	WM	Y	NATIONAL
ACT	0	229	308	452	356	206	245	124	44	299	91	2353
AD	170	139	39	113	23	89	161	96	101	58	181	1170
B	1155	717	0	4044	373	643	433	1016	2682	95	5975	17131
EfW	561	122	96	182	611	275	459	452	215	87	484	3544
HDR	0	0	0	0	0	0	0	7	0	0	0	7
LG	8	15	0	0	10	0	5	0	6	0	0	44
LH	0	0	0	0	0	72	0	0	0	0	0	72
SSD	0	0	15	0	0	0	4	0	0	0	0	19
SSH	0	0	0	0	0	179	0	4	0	0	0	183
SPV	961	828	0	17	117	95	762	1172	442	265	96	4754
TIDAL	0	0	0	0	0	0	25	0	0	0	0	25
ONW	484	850	0	660	695	19909	232	422	4028	10	1158	28450
OFW	8594	3067	0	340	3128	14189	1532	3305	1963	0	28041	64160
TOTAL	11933	5967	458	5808	5314	35656	3858	6597	9481	814	36026	121914

4.5.2 Future National and Regional Renewable Technology Composition:

Figure 18 displays the proportion of renewable electricity produced by each technology type, upon completion of all planned renewable energy infrastructure in the UK. On a national scale, the balance of renewable energy technologies is likely to be different in future, with a larger share of offshore wind generation making this technology the dominant form of renewable generation, providing 43% of all renewable electricity produced in the UK. The majority of the remaining electricity generation continues to be provided by onshore wind and biomass generation, with each technology producing 26% and 18% of total renewable electricity generation respectively. The remaining 13% of generation is derived from energy from waste (4%), solar photovoltaics (4%), landfill gas (2%), active conversion technologies (1%), anaerobic digestion (1%) and large hydro (1%). Whilst the figures generated here were accurate as of January 2015 (DECC, 2015), planned infrastructure is an area subject to rapid change and this should be considered when analysing results of this nature.

The three regional groupings identified under current generation figures remain visible under future generation, albeit with a few key differences. Firstly, the number of regions which will experience the greatest proportion of renewable electricity generation from offshore wind technology will increase, to incorporate the East, East Midlands, North West, South East, South West and Yorkshire regions. The largest change in the amount of offshore wind generation is seen in the Yorkshire region (Table 14), which despite having no currently operational offshore wind generation, will generate 63% of renewable electricity in this way under future conditions. The lowest proportion of offshore wind generation in this group is seen in the South West region, where offshore wind represents just 39% of overall renewable energy generation, due to simultaneous large increases in solar photovoltaics in this region (Table 14).

The national proportion of onshore wind generation is predicted to fall under future generation estimates due to the increased injection of offshore wind generation. However, Scotland and Wales continue to see the largest of proportion of renewable electricity generation from this technology, with onshore wind predicted to provide 63% and 45% of each regions total renewable electricity generation upon completion of all planed infrastructure.

The third group, characterized by a dominance of biomass generation, is still discernible, materialising itself in the West Midlands and North East regions. The greatest proportion of biomass generation remains within the West Midlands, within which, biomass generation is predicted to provide 80% of all generated renewable electricity. Table 14

highlights that this is perhaps more of a reflection of an overall lack of increase in renewable infrastructure in this region, with a relatively low total planned capacity increase of just 814 GWh. In contrast, the amount of biomass generation is expected to increase significantly more in the North East, with an estimated increase in generation from biomass of 4044 GWh. Interestingly, this is not the largest increase in biomass generation, however large increases in generation from this technology in Yorkshire are overshadowed by even greater increases in offshore wind generation (Table 14).

Finally, the technology mix in London continues to be unique in its constitution under current and future energy infrastructure. Upon completion of all planned projects, the dominant form of generation in the London region is expected to continue to originate from energy from waste generation (54%), however this will also be accompanied by a greater level of energy from advanced conversion techniques (25%). Also noteworthy is that the level of generation in London remains low under estimated future conditions, with an increased generation capacity of just 458 GWh in comparison to a national average increase of 11,083 GWh.

5.0 Discussion:

5.1 National Outlook:

This study aimed to investigate the regional distribution of renewable energy generation in an attempt to see whether the notion of a 100% sustainable energy system is a realistic target for UK energy policy. It is useful to firstly examine the results at a national scale, in order to analyse the full extent of differences between each of the scenarios utilised in this investigation.

5.1.1 The Need for a Sustainable Energy System:

The growing challenges of an energy system based on a dominance of fossil fuel generation creates the need for a transition to a clean energy system, not just in the UK, but on a global scale. Increasing the amount of renewable energy generation in the UK will have a number of benefits, including but not limited to; lessening the UK contribution of greenhouse gases and hence reducing the effects of global climate change (IPCC, 2014), increasing the capacity for sustainable economic development (Wolfram et al. 2012), and ensuring a reliable supply of energy despite dwindling fossil fuel reserves and increased international security issues (Hook and Xu, 2013; Johansson, 2013). In addition to the benefits associated with a move to renewable generation, the UK also has a legal obligation to increase renewable energy generation in line with EU policy. The Renewable Energy Directive (European Commission, 2009) establishes an overall policy for the production of energy from renewable sources and requires the EU to fulfil at least 20% of its total energy demand through renewable generation by 2020. This is accompanied by further targets, to achieve 27% of EU demand through renewables by the year 2030. There is clearly an established move towards renewable generation intertwined with European development strategies, which the UK will be legally bound (assuming a continued membership) to employ. The UK is in a strong position to meet these targets and, as the existing power system is in need of replacement (Strbac, 2008; Alderson et al. 2012), has a great opportunity to become a leader of renewable generation in Europe.

5.1.1 National Outlook under National Grid Scenarios:

The first four scenarios investigated in this study were those presented by the National Grid in 'Future Energy Scenarios' (National Grid, 2015). The National Grid is responsible for coordinating and directing power flows across the transmission system in accordance with strict security standards set by Ofgem, the system regulator (House of Lords, 2015). As a result, the National Grid is considered to be an industry expert and the scenarios provided in their future energy scenarios represents a useful starting point.

The first of the National Grid scenarios investigated here was the No Progression scenario. Under this scenario, the primary concern in the UK lies in achieving the greatest security of supply at the lowest possible cost. This incorporates a continued reliance on traditional sources of energy, with little innovation or improvement in the way in which we use energy. As a result, whilst the study predicts an increasing amount of demand which will be met by renewable electricity generation in the future (59.6% in 2020 and 60.1% in 2030), this is not necessarily implicit of a move towards a more sustainable future of energy production in the UK. The underlying scenario principles state that there is unlikely to be an improvement in the level of research and implementation of renewable technologies. Therefore, whilst the amount of renewable generation is likely to increase in line with completion of projects which have already been given planning permission, it is likely that the planned renewable infrastructure in this scenario represents the maximum likely increase in renewable generation. This is worrying as the level of demand predicted to be met is therefore not likely to increase past the 2030 estimate of 60.1% and may decrease as population continues to grow. Therefore, whilst an increase of renewable electricity penetration to 60% of the total national demand may be seen as a positive improvement, the behavioural attachment associated with actions in this scenario mean that future development will be limited within these bounds, due to a reluctance to continue improving knowledge and utilisation of clean energy sources.

The Slow Progression scenario yields similar results to the No Progression scenario in this investigation, with an estimated 59.6% and 60.2% of demand estimated to be met under this scenario in 2020 and 2030 respectively. Though the proportion of demand which is met does not differ hugely between these two scenarios, the Slow Progression scenario represents a more progressive attitude towards improving energy usage, with limitations imposed by economic growth as oppose to a reluctance to change. As a result, the estimates of demand met under this scenario are likely to represent a stepping stone in a long term move towards sustainable energy usage, and are therefore illustrative of a more optimistic future than that depicted by the No Progression scenario.

The third National Grid scenario investigated in this study was the Consumer Power scenario. Consumer Power, represents a world in which policy is driven by consumerism and quality of life. Within this scenario a high level of wealth is assumed within the UK, with an increase in research and development into renewable energy technologies. Improvements in technology and the ways in which we use energy are expected, but these are driven predominantly by a desire to raise personal standards of living, with energy efficiency recognised as a bi-product and not a main selling point of new technology. Under

this scenario, this investigation predicts that in future 59.8% and 58.5% of electricity demand will be met by renewable energy generation in 2020 and 2030 respectively. The estimates of demand met under Consumer Power by 2030 are less than that of the previous two scenarios. Whilst this may seem to suggest that this future for the UK is less optimistic, the results of this scenario are arguably more optimistic than those given in the No Progression scenario, due to the improvements in technology which occur as a bi-product of the quest to improve standards of living. Combining the wealth of the Consumer Power scenario with the improved mind-set associated with the Slow Progression scenario could see an improved proportion of demand which can be met by renewable energy generation, though would require serious planning and implementation of policies which maximise economic growth whilst facilitating a transition to renewable energy sources. Research has shown that on a national scale, there is strong support for renewable technologies as a replacement for fossil fuels, and that a significant change is needed to the existing energy structure in the UK (Devine-Wright, 2007; Demski et al. 2014; Stigka et al. 2014). As a result, increasing the investment in renewable energy technologies in the UK to the maximum possible level could enable a future which may combine the strengths of these two scenarios.

The final National Grid scenario investigated in this study was the Gone Green scenario – arguably the most environmentally optimistic of all National Grid scenarios. Under Gone Green, there are estimated to be high levels of prosperity, many technological developments and increasing green ambition throughout society. This public ambition is accompanied by a political vision, with high levels of capital to support investment and development in this area. This investigation estimates that under the Gone Green scenario parameters 60.7% and 55.2% of electricity demand will be met by renewable energy in 2020 and 2030 respectively. The higher proportion of demand met in 2020 is a reflection of the shift in behaviours to be more environmentally conscious about energy usage. However, this behavioural shift is accompanied by an increased view of the necessity to de-carbonise the transport industry in addition to energy markets. As a result, the proportion of demand met under the 2030 scenario parameters is the lowest of all National Grid scenario estimates. Whilst this appears as an unfavourable future for the UK energy system, this may be due to the fact that infrastructural increase was limited across all four scenarios to the infrastructure which is currently planned. Under increased wealth and behavioural change, it is likely that through time there will be a greater investment in renewable energy technologies and a greater amount of planned infrastructure. This may be increasingly true as the market for electricity increases through the development of electric vehicle technology. Consequently, whilst the proportion of demand met by renewable generation is

the lowest in this scenario, Gone Green may represent the most optimistic future scenario on a national scale. Further investigation into technology development and economic influences may help to estimate the likely consequences of transcending this path on the way to a sustainable energy future in the UK.

5.1.2 National Outlook under Original Scenarios:

Further to the National Grid scenarios, three scenarios were created to increase the range of possible future conditions examined in this investigation. The scenarios were based fundamentally on demand per person and population change. As a result, these scenarios add an extra dimension when examining regional proportions of demand met under future conditions, as they take into account the likely changes in population totals in each region. As with the National Grid scenarios, it is useful to start with a national perspective of the full extent of scenario changes, to examine the overall likely future of the UK energy system under each possible set of future conditions.

The Population Based scenario presents a future in which current demand per person remains the same throughout the study period, but the population increases in line with most recent estimates (ONS, 2014). Future changes in total annual demand are therefore driven by changes in population as oppose to differing energy usage habits or technological developments. Under this scenario, it is estimated that 53% and 50% of total electricity demand could be met by renewable energy generation in 2020 and 2030 respectively. Whilst these estimates are lower than all estimates presented in the National Grid scenarios, they demonstrate that by continuing to use energy in the same manner as present and by only developing the infrastructure which has already been planned, the UK will be able to produce enough renewable electricity to meet 50% of national electricity demand in 2030. Though this may be received positively by those concerned about having to reduce energy usage to accommodate increased renewable penetration, much of the UK population (65%) state that they would be willing to greatly reduce their energy usage to help tackle climate change, and the majority (52%) would also be willing to increase their energy bill by £10 a month to ensure increased renewable generation (Spence et al. 2010). From this perspective, this scenario should represent the minimum amount of demand which will be met under future conditions in the UK. The ability to meet 50% of demand with no changes to the way in which energy is used or to the behaviour of consumers should highlight the opportunity for the UK to develop a system which is highly dependent on renewable and sustainable energy sources in the future.

In contrast to the Population Based scenario, the Super-Efficient Adoption scenario depicts a 'best-case' set of future conditions based on the planned energy infrastructure within the UK. This scenario presents a world in which the population becomes increasingly aware of the need to reduce energy usage, alongside the need to develop new renewable technology. These changes are estimated to result from a change in behaviours, in addition to further efficiency developments as a result of new technologies. The estimated proportion of demand which can be met by renewable energy generation under this scenario is 60% and 67% in 2020 and 2030 respectively. Perhaps unsurprisingly, the proportion met in 2030 is greater in this scenario than in any other scenario examined in this study, due to the large decrease in demand per person (-25%). Whilst this value is supported in the literature (Allcott and Greenstone, 2012), it is extremely difficult to estimate how much energy could be saved through increases in awareness and efficiency, and so the 25% reduction in energy use should be seen neither as a maximum or minimum change in energy usage. It should therefore be seen as an indicator of how a decrease in energy use per person could aid the transition to a sustainable energy system. Equally, as only 67% of national demand can be met under this scenario, it also serves to illustrate that further investment into renewable technologies will be necessary if the UK is to realise a 100% renewable energy system in the future.

The final scenario investigated in this study served to illustrate a 'worst-case' demand scenario for the planned energy infrastructure within the UK. The Electric Vehicle Expansion scenario represents a future in which the UK population is becoming increasingly environmentally focussed and as a result, over 50% of current vehicles in the UK are replaced with electric vehicles by 2030. In line with the Super-Efficient scenario explored previously, the amount of demand per person is estimated to change 25% by 2030, albeit this time realised through an increase in total electricity demand. Whilst this scenario represents a future in which society actively seeks to mitigate environmental challenges created by the previous energy system, the accompanied replacement of transport fuels with electricity produces a challenging level of demand which will require further infrastructural developments. Under this scenario, the UK is expected to meet 47% and 40% of total electricity demand through renewable sources in 2020 and 2030 respectively. Thus, this scenario represents the least optimistic future of any of the scenarios investigated in this study in terms of realising a 100% renewable energy system in the future. However, when one considers the underlying properties of this scenario, it is likely that over time, more plans will be developed to increase the level of renewable electricity generation, to meet growing societal needs. As oppose to the National Grid and Population Based scenarios, under this scenario the public are aware and willing to actively mitigate climatic

effects of the extensive use of fossil fuels. This represents a positive platform from which to develop a 100% renewable energy system, and whilst low levels of demand are met in 2030, the overall benefits of moving to an electrified transport system will in effect buy time, in which we can develop the energy infrastructure further in a sustainable and environmentally friendly manner. The Electric Vehicle Expansion scenario therefore represents a positive future for the energy system in the UK, but further infrastructural developments will be required to ensure this is a truly sustainable system.

5.1.3 National Outlook – Summary:

This aim of this study was to investigate whether the notion of a 100% sustainable energy system is a realistic target for UK energy policy. Overall, amongst all of the scenarios examined, the range of future demand which will be able to be met by renewable energy generation falls between 40-67%. Therefore, it is clear that under current planned infrastructure, despite a range of demand values being investigated, it will not be possible to meet 100% of electricity demand through renewable energy generation alone. However, the relatively short timescale over which the study falls should be taken into consideration, as the expectation for a complete energy system reform over the next 15 years would be highly improbable. The outcome of this investigation suggests that on completion of all planned infrastructure and with no changes to the way in which energy is used, 50% of demand could be met in 2030. Policy makers should see this as a huge opportunity to develop further infrastructural plans which realise a 100% renewable energy system in the near future. By improving the way in which we use energy, in addition to the amount of renewable energy that is generated, this could become an achievable target for UK energy policy in coming decades. To achieve this, further studies of this nature will be essential to determine the level of infrastructure that will be required and the most effective way in which this technology can be installed, both spatially and temporally.

5.2 Regional Outlook:

Whilst it is useful to examine the scenario impacts on a national scale, the focus of this investigation was on regional differences in the level of generation, and the likely implications these are to have on the future energy system in the UK. Each of the regions will now be discussed in turn.

5.2.1 Scotland:

Scotland was included in initial analysis of current energy system parameters and in line with National grid scenarios in 2020 and 2030, but was not included in the original scenario examination as sufficient data was not available at the time of analysis. Current renewable electricity generation in Scotland is greater than any other region in the UK, with a total annual renewable electricity generation total of 15,978 GWh in 2013. This represents 27% of the total annual renewable generation within the UK. Demand in this region does not reflect the high level of renewable generation, with an estimated annual demand of 25,873 GWh, a moderate amount when compared to the rest of the UK. As a result, the current amount of demand which can be met by renewable generation in this region is significantly higher than all other regions examined in the study, with enough renewable energy produced to meet 61.8% of annual electricity demand.

Upon completion of all planned infrastructure, the amount of renewable electricity generation in this region is estimated to reach 51,634 GWh, with the majority of generation increase resulting from an increase in onshore and offshore wind generation (19,909 GWh and 14,189 GWh respectively). As a result, the level of demand which can be met by renewable generation under each of the national grid scenarios is high, with estimates of greater than 170% of demand being met across all scenarios in 2020, and a range of 157-171% of demand being met across the scenarios in 2030. Though the range of values expected to be met in 2030 are subject to relatively large differences depending on the scenario in question, it is clear from the results that Scotland has enough planned renewable infrastructure available to create enough energy to meet 100% of total annual electricity demand in this region, under a variety of future scenarios. Furthermore, the surplus of energy generation will be useful when considering the variable nature of renewable sources of electricity and may help to address issues of a mismatch between supply and demand, which is often considered to be a major drawback of the use of these sources of energy generation (Freris and Infield, 2008; Pereira et al. 2014).

The Scottish Government has a target for renewable energy in Scotland to generate the equivalent of 100% of annual electricity demand by 2020 (Scottish Government, 2016). The results of this investigation suggest that this is an achievable goal under a variety of

different future scenarios. This should demonstrate to other regions in the UK that given strong policy and target setting, it is possible to generate a high level of demand through renewable electricity sources, and that a future in which nations can rely on 100% renewable energy sources is upon us. In order for the UK to maintain its position of a powerful economic player in the future, other regions should strive to achieve a similar level of renewable energy generation from a mix of technologies best suited to their regional needs.

5.2.2 Wales:

In addition to the Scottish region, Wales was included in initial analysis of current energy system parameters and in line with National grid scenarios in 2020 and 2030, but was not included in the original scenario examination due to insufficient data at the time of analysis. Unlike the Scottish region, the current level of renewable energy generation in Wales is relatively low, representing just 5% of annual renewable electricity generation in the UK. The low level of generation seen in this region is a likely to be a reflection of the complex planning issues associated with renewable energy infrastructure in this region. This can be illustrated with the nature of onshore wind planning policy in Wales throughout recent history. Since the devolution of energy powers in 1998, the Welsh Assembly Government (WAG) has been responsible for the planning of renewable infrastructure in its own territory. During this time a structured plan of how to increase the onshore wind technology to meet EU targets has been developed, but not without difficulties arising from a variety of sources. The majority of these barriers lie within the natural heritage of the Welsh landscape, with opposition rising due to the need to protect areas which possess national and international status for environmental features (e.g. National parks, Sites of Specific Scientific Interest, Wildlife Protection Sites etc. which cover 24% of the land area in this region), with additional barriers surrounding local reluctance to industrialisation – particularly in areas subject to heavy energy development in the past e.g. the South Wales Valleys (Cowell, 2009). As a result of these localised objections, onshore wind development has been limited to specific locations within this region, albeit at high concentrations.

Fortunately, whilst the level of generation is relatively low in this region, it is accompanied by a low level of demand. Consequently, the level of demand which can currently be met by renewable energy generation in this region amounts to 17.9%, a moderate level of demand when considering the low level of renewable generation currently seen in this region. Under future estimates, the level of renewable energy generation is estimated to increase substantially, the majority of which will be realised through onshore wind and biomass infrastructure, the capacity of which is likely to increase by 4,028 GWh and 2,682 GWh for each generation technology respectively. The result of this injection of

renewable generating capacity means, under each of the National Grid scenarios, Wales is estimated to produce enough renewable electricity to meet greater than 60% of total annual demand. The greatest variation in scenario estimates occurs under the 2030 study date, with the highest proportion of demand met under the No and Slow Progression scenarios (68%) and the lowest proportion met under the Gone Green scenario. As discussed on a national scale, whilst the ability to meet almost 70% of demand under the No and Slow Progression scenarios appears favourable, the 62% of generation met under Gone Green should perhaps be seen as the most optimistic energy future due to underlying scenario properties. Overall, the ability to meet greater than 60% of energy demand through renewable sources, despite varying levels of estimated growth in demand, should be seen as a positive move towards a more sustainable energy future in Wales.

The generation technology analysis in this region reveals the high proportional dependence on onshore wind generation, which will account for 45% of all renewable electricity produced in this region. Wind energy is often posited as one of the greatest energy assets of the UK, with the nation boasting the largest potential wind resource of any European country (DECC, 2011r). However, the nature of the WAG planning structure favours the concentrated development of wind infrastructure through condoning windfarm landscapes as oppose to disperse wind turbines across its territory (Cowell, 2009). This could potentially be problematic when considering the high level of penetration of renewable sources which will be necessary in the future, due to the inherent characteristics of renewable generation. Wind energy is subject to variation on a number of time scales – from seconds to years – and over small distances, especially in hilly terrain (Twidell and Weir, 2015). As a result, concentrating wind generation in small geographical areas removes any aggregation effect of spreading wind generation over a larger geographical area, and may lead to increased problems of matching supply with demand. This highlights the challenge posed to the existing way in which we use energy when incorporating renewable sources. Whilst some of this may be tackled by increased intelligence surrounding the use of energy and the utilisation of a number of different renewable technologies, creating a supply of electricity that is readily available at all times of day will be vital if we are to see continued economic growth, not just in Wales but across the nation as a whole.

5.2.3 North East:

The North East region is currently characterized by a relatively low level of renewable energy generation, representing the second lowest regional producer of renewable electricity in the UK. Demand per person exceeds the national average at 4.55 MWh/person (national average 4.52 MWh/person). However, due to a relatively low

population in this region the North East also presents the lowest level of total electricity demand in 2013. As a result, whilst the level of demand which is currently met by renewable generation falls below the national average, it represents a higher proportion than other regions which produce more renewable electricity but have a higher level of regional demand to compensate for.

Under future scenarios, the energy situation in the North East appears more optimistic, with the level of demand predicted to be met by renewable energy generation estimated at greater than 50% across all scenarios (with the exception of the most energy intense scenario - EVE in 2030). This is in part due to the increased energy generation through planned biomass infrastructure in this region, and also due to the low rates of estimated population increase in the North East. The most optimistic energy future for the North East is predicted under the SEA scenario, under which 72% and 82% of regional demand is estimated to be met by renewable electricity generation in 2020 and 2030 respectively. The PBS scenario also illustrates an optimistic future, whereby 63% and 62% of demand can be met in each of the study dates respectively. The EVE and National Grid scenarios yield similar results, with the amount of demand which can be met remaining fairly stable across all four National Grid scenarios (51% - 56%) across the whole study period. Under EVE in 2020 56% of demand is estimated to be met but due to the rise in demand by 2030, the proportion which can be met falls to the lowest regional estimate of 49%.

Overall, all of the scenarios investigated in this study predict that a significant proportion of electricity demand will be met through renewable generation in future in the North East. The technology mix in this region suggests that the majority of this increase in renewable energy generation will come from planned biomass infrastructure. Due to the controversy surrounding the use of biomass generation (Evans et al. 2010) and the related uncertainty in government support for such technologies (McGarrity, 2013) it would be wise for the North East region to examine the possibility of developing other sources of renewable generation to facilitate the complete integration of renewable forms of energy, and to mitigate against any shortfall which may occur due to government legislation regarding the development of biomass technology.

The low level of demand in the North East region, coupled with the low rates of population increase, should highlight the opportunity for this region to gain a sense of independence by investing further in renewable technologies. Consideration should also be given to the economic and employment benefits of renewable technologies (Mathiesen et al. 2010) which could help to boost the regional economy and help the North East to be able to compete with the Southern Counties which have historically experienced the majority of

economic growth in the UK (Pike and Tomaney, 2009). Developing a network of power which allows regions to be responsible for their own renewable generation could therefore have benefits which extend beyond the power system itself and enable a decentralization of growth, leading to a more positive socio-economic future for the nation as a whole.

5.2.4 North West:

In contrast to the North East, the North West region currently produces the 4th largest amount of renewable electricity of any region in the UK. Demand in this region is surprisingly high, with demand per person equalling the national average of 4.52 MWh/person but large population centres such as Manchester and Liverpool driving total demand to 32,168 GWh. This represents the third highest regional demand in the UK, or 9% of total UK annual electricity demand. The relatively high level of regional electricity demand results in the total amount of demand which could be met by current renewable generation falling below the national average. However, it should be noted that the amount of demand met by renewable generation is still higher than would be expected of a region with such high levels of demand due to the relatively high level of renewable infrastructure already operational within this region.

Upon completion of all planned infrastructure in this region, the level of renewable electricity generation is expected to increase to 11,512 GWh. When accompanied by population growth estimates, which are relatively low in the region, the percentage of demand which can be met under future energy conditions is expected to increase across all scenarios. The level of demand estimated to be met in this region under each of the National Grid scenarios falls considerably below the national average, with a range of 30-31% of demand able to be met across all four scenarios in 2020. Despite further predicted changes in consumption, the likely amount of demand to be met in 2030 does not show an improvement. Overall, under each of the National Grid scenarios, the level of renewable generation is not likely to meet a large proportion of demand in this region.

When considering the original scenarios, SEA offers a slightly more optimistic outlook of the amount of demand which could be met by renewable generation, with 40% and 45% of demand able to be met in 2020 and 2030 respectively in this region. The PBS scenario also estimates a higher level of demand that will be able to be met by renewable generation, with 35% and 34% predicted on each of the study dates respectively, with the EVE scenario generating the lowest predictions of all three original scenarios, with estimates of 31% in 2020 and 27% in 2030. Arguably, the outlook across all three of the original scenarios represents a more positive future for the North West region than those predicted under National Grid scenarios. This is clear in the SEA, whereby increases in

efficiency paired with a low rate of population increase give rise to the highest proportion of demand able to be met by renewable generation. The small decrease in demand which can be met by renewable generation under EVE, despite large increases in demand per person, is also reflective of low rates of population growth in this region. This is a positive for the North West region, as it means that total demand is not likely to increase as dramatically as it will in other areas of the country. As a result, EVE represents a fairly positive energy outlook as it is representative of a society which understands the need to decarbonise, which is also a society likely to invest in further generation technology, helping to increase the proportions beyond estimates given here. The least optimistic of the three original scenarios is PBS, despite this being the scenario in which the second highest proportion of demand is estimated to be met. This is due to the lack of behavioural change inherent in the scenario parameters, with renewables seen as a solution to shortages as oppose to an opportunity for growth. The increased proportion should however serve to highlight the potential to further reduce demand if behavioural changes can be put in place, whilst removing the need for further infrastructural development.

5.2.5 Yorkshire:

The Yorkshire region offers optimistic levels of renewable generation both under currently operational renewable technology and planned future infrastructure. In 2013, the Yorkshire region generated sufficient electricity from renewable energy sources to meet 38.2% of total annual demand. Total electricity demand in this region falls just below the national average, explaining further the relatively high level of demand which could be met by renewable energy generation.

The Yorkshire region also displays the greatest increase in generating capacity of any region analysed in the study, bringing the estimated future total to 45,064 GWh (25% of total renewable generation in the UK). The majority of this increase (28,041 GWh) is expected to be realised through the development of large offshore wind projects located on Dogger Bank (Forewind 2016). As a result, similar precautions should be taken as suggested in the analysis of technology mix in Wales, due to the problems associated with relying on large volumes of generation from a naturally dispersed energy source, across a small and highly concentrated area of generation (Twidell and Weir, 2015). Notwithstanding, the level of renewable generation which is predicted under future infrastructural conditions is estimated to provide enough electricity to meet greater than 100% of demand within this region under all future scenarios. The National Grid scenarios see values of 162-165% across all scenarios in 2020 and 150-163% in 2030, with the lowest estimates under the gone green scenario and 163% across the No and Slow Progression scenarios. The estimate of 150% of demand being met under the gone green scenario is particularly

reassuring as it suggests that despite a higher level of demand due to an increased awareness of the need to switch to low carbon technologies, all demand could be met by renewable generation, with an excess to cover discrepancies in patterns of supply and demand.

Under the original scenarios, the SEA and PBS scenarios both estimate that a greater proportion of demand will be attainable through renewable generation, with estimates of 210% and 234% under SEA, and 184% and 175% under PBS, in 2020 and 2030 respectively. The EVE yields relatively lower estimates of the proportion of demand which will be met sustainably, with estimates of 163% in 2020 and 140% in 2030. Despite the decreased estimate of the amount of demand which can be met in this region in 2030, Yorkshire would be in a position whereby it is able to sustain both a renewable energy system in addition to a transport sector reliant on renewable technologies. As a result, Yorkshire could represent a fully sustainable region in future where growth is not limited by a lack of energy generation, and all demand is catered for in a sustainable and environmentally friendly manner.

5.2.6 West Midlands:

Moving towards the south of the Country, the energy outlook looks less optimistic than in more northerly regions due to a lower level of renewable generation both presently and in the future, in addition to high population densities and the associated high levels of demand. In the West Midlands, the current level of renewable generation is moderate, representing 10% of the national total. Upon completion of all renewable energy infrastructure in this region, the estimated increase in generating capacity is low, resulting in this region being the second lowest producer of renewable electricity in the UK under future conditions. Whilst this small increase in renewable generation is likely to be detrimental to this region in the future, the small increase in generating capacity is accompanied by a relatively low rate of population increase between now and 2030 (9%), and the lowest amount of demand per person (4.32 MWh). This serves to offset some of the implications of a small increase in generating capacity, however overall, the West Midlands shows the smallest improvement in the level of demand which can be met by renewable generation under future conditions of any region examined in the study.

Under current conditions, it is estimated that 23.7% of demand could be met with renewable energy generation, the 4th largest proportion of any region in the UK. Due to the low level of infrastructural development, this is not likely to increase by a substantial amount under future conditions, and is predicted to decrease under certain scenarios. Over all four of the National Grid scenarios in 2020, the level of demand which can be met by renewable

generation remains at 23%, with 2030 yielding similar results albeit a decrease in estimated proportion under the Gone Green scenario (21%). The original scenarios, which account for low levels of demand per person and low population increases, produce a more optimistic energy future in 2020, with 30%, 26% and 23% under the SEA, PBS and EVE scenarios respectively. The SEA and PBS scenarios continue to provide a more optimistic outlook in 2030, with 33% and 25% of demand likely to be met. The EVE scenario predicts the lowest estimate of the proportion of demand which could be met in 2030, suggesting just 20% of demand will be able to be fulfilled by renewably sourced electricity. Overall, the two scenarios with the lowest estimates of the amount of demand which can be met through renewable generation (Gone Green and Electric Vehicle Expansion) will provide the most hopeful energy scenarios due to the trade-offs between a shift in behavioural energy use and immediate reductions in demand. However, the study highlights that the West Midlands region needs to further develop its renewable infrastructure if it is to experience an increase in the amount of demand which can be met through renewable energy generation in the future.

5.2.7 East Midlands:

Total annual electricity demand in the East Midlands is currently estimated to total 7% of total national demand, and falls 2% below average regional demand. The current level of renewable energy generation in this region fails to match that of its western counterpart however, with just 3,078 GWh produced in 2013. Nonetheless, planned infrastructure in this region will lead to a greater increase in generating capacity in this region under future energy scenarios, with estimates of future renewable generation reaching 9,046 GWh, 5% of the national generation total.

As a consequence of the low level of renewable generation in this region, the current level of demand which is able to be met through renewable energy generation is 14.6%, the fourth lowest proportion of all regions under current energy conditions. However, due to the relatively large increase in generation capacity, driven by a considerable increase in offshore wind generation (3,067 GWh), the amount of demand which can be met by renewable energy sources in the future is estimated to increase substantially. Under the National Grid scenarios, the proportion of demand met in 2020 ranges from 36-37% across all four scenarios. This range increases slightly under the 2030 estimates, with the Gone Green scenario providing the lowest estimate of 34%, and a range of 36-37% across the remaining three scenarios. Under the original scenarios, the estimates cover a larger range of estimates across the three scenarios. The SEA and PBS scenarios predict a more optimistic energy future across both study dates, with estimates of 47% and 51% under SEA, and 41% and 39% under PBS, in 2020 and 2030 respectively. EVE provides an

estimate of future proportions that is more in line with those predicted under the National Grid scenarios, with an estimate of 36% in 2020 and 31% in 2030.

Overall the results suggest that given appropriate behavioural changes in the East Midlands there is enough renewable infrastructure planned in this region to meet almost 50% of total demand in the future. Though there is an opportunity here, it is important that policy is put into place to aid a transition to the smarter use of energy. The study also highlights the need for a greater level of planned infrastructure in this region if a truly sustainable system is to be created in the future.

5.2.8 East:

Contrary to the trend of decreasing proportions of demand able to be met under future energy conditions towards the south of the UK, the Eastern region displays a relatively high level of demand that is able to be met by renewable energy generation both under current and future energy scenarios. Current renewable generation in this region is estimated at 6,752 GWh, equivalent to 11% of the national average and representative of the third highest producing region in the UK. In addition, whilst the population growth in this region is estimated to be the second highest of any region in the UK, the demand per person remains below the national average, facilitating a lower total demand in this region. As a result, the level of renewable energy which could be met by renewable generation under current generation falls above the national average, with 25.2% of generation able to be met through clean energy.

In line with its East Midland neighbour, the planned infrastructure in this region is likely to increase renewable generation capacity by a substantial amount. As seen in many regions, the majority of this will be delivered through offshore wind, however, a substantial increase in Biomass generation is also expected. As a result of these increases, the proportion of demand which could be met by renewable generation in the future increases considerably. Under the National Grid scenarios in 2020, a range of 59%-61% of demand is estimated to be met across all four scenarios. In 2030 this range increases slightly, with 55% in the Gone Green scenario and 60% in the No and Slow Progression scenarios (58% Consumer Power). Reassuringly, the Eastern region is expected to meet greater than 50% of demand with renewable generation across a range of future demand scenarios. This represents an optimistic starting point on the road to a 100% sustainable energy future, providing further infrastructure is planned on completion of existing projects.

Under the original scenarios the range of proportional demand which is met increases further. The lowest estimates are given in EVE, under which 59% and 49% are predicted to be met in 2020 and 2030 respectively. Given the benefits in the travel sector

and behavioural changes associated with this scenario, the ability to meet 50% of total demand could have many environmental and social benefits. Under the PBS scenario, energy usage remains the same as is presently experienced meaning that no change is forced upon the consumer. This scenario predicts that despite continuing to use energy in the same manner, over 60% of demand could be met by renewable generation in the future. This may suggest that in future simply increasing generation and not reducing energy use per person could still result in a 100% sustainable system. However, 40% of demand will still need to be provided for on top of all planned infrastructure, so reducing energy footprint would be more advisable and also more economically beneficial (Mathiesen et al. 2010). Finally, the SEA scenario illustrates the full potential of what could be achieved in the Eastern region, with a planned proportion of demand which can be met of 75% in 2020 and 81% in 2030. This paints a very positive energy future for this region, with a combination of all planned infrastructure and increased efficiency of energy use leading to much higher proportions of demand which can be met through renewable generation. Given that this is estimated to be achievable over the next 15 years, there is an opportunity for this region to become self-sufficient in energy terms in the near future. Overall, if the energy behaviours of the SEA scenario were to be adopted throughout this region, a 100% renewable system could be realised with an additional input of generation capacity of less than 5,000 GWh. The total planned increase between 2015 and 2030 is 11,933 GWh, therefore it could be inferred that if the correct plans are put in place, a 100% system could be developed prior to 2040, assuming a consistent rate of infrastructural development.

5.2.9 South West:

The South West region is illustrative of the declined proportion of demand which can be met by renewable generation in the southernmost regions of the UK, with just 1,902 GWh of renewable generation estimated to have been produced in 2013. In addition to the low rates of generation experienced in this region, demand per person equates to the national average (4.52 MWh/person) and population is predicted to increase 11% by 2030, the fourth highest rate of regional population increase within the UK. Consequently, the level of demand which can be met by renewable generation in this region is the second lowest of all regions examined in the study, with an estimated 7.8% met under current generation conditions.

Upon completion of all planned infrastructure, the generation capacity in this region is expected to reach 8,498 GWh. The majority of this increase will be delivered through offshore wind generation (3,305 GWh). However, more distinctive to this region is the planned increase in solar photovoltaics, estimated to draw in a further 1,172 GWh of renewable generation in the future. This planned increase is the largest increase in solar

technology of any of the regions examined in the study. This is perhaps a reflection of the local climate in the South West, with this region seeing a greater number of solar hours both presently and under estimated future conditions than other areas of the UK (Burnett et al. 2014). This represents a good example of matching renewable technologies to the available resource in each region. The low load factors associated with current solar photovoltaics technologies (DECC, 2015d) mean that despite a large planned increase, total renewable region in this region remains relatively low. However, as this region is likely to see an increase in solar radiation in the future (Burnett et al. 2014), and improvements in generation efficiency are likely to emerge as the technology becomes increasingly widespread, investing in solar photovoltaics in the South West may lead to a significant increase in renewable generation in this region in the future.

Under the scenarios considered in this study, the level of demand which can be met by renewable generation is likely to increase in the future. When considering the National grid scenarios, the proportion of demand which can be met in 2020 was estimated to be 30% across all four scenarios. The Consumer Power and Gone Green scenarios saw a slight decrease in the amount which could be met in 2030, with predicted proportions of 29% and 28% respectively. The No and Slow Progression scenarios continued to predict that 30% of demand would be able to be met in 2030. Overall there is very little variation between the differing scenarios as to how much demand will be met under future energy conditions, with estimates suggesting less than a third of total demand will be met through sustainable generation in this region. Under the original scenarios, the estimates of the level of demand which could be met by clean energy generation are more optimistic under the SEA and PBS scenarios, under which 38% and 42%, and 33% and 31%, of demand will be met in 2020 and 2030 in each scenario respectively. The EVE scenario demonstrates a lower estimate of the amount of demand which can be met, with estimates of 30% in 2020, but a decline in proportion to just 25% in 2030.

Overall, the South West region has a considerable amount of planned infrastructure which will serve to increase the level of renewable generation in the region in the future. However, upon completion of these developments the level of renewable energy remains sufficient to meet under a third of regional demand. Given the huge solar resource in this region and the estimated increases in this resource due to climate change (Burnett et al. 2014), further investment in solar technology could help to secure a higher proportion of renewable generation in the future, leading to a more sustainable energy system in the South West.

5.2.10 South East:

Current renewable generation in the South East is estimated to total 5,327 GWh. Surprisingly, given the geographical location of this region, the level of renewable generation currently experienced is very close to the national average, representing 9% of the national total. Though generation is representative of the national average, demand in this region is relatively high, likely as a result of this region currently housing the greatest population of any region in the UK (ONS, 2014). The current proportion of demand which could be met through these energy sources is 13.7%, 7.2% below the national average.

Upon completion of all planned renewable energy infrastructure in this region, the level of generation is expected to increase, however, estimated future generation represents just 5% of national generation. Simultaneously, population increase is expected to be large, with an estimated increase in regional population of 12% by 2030. As a consequence, the proportion of demand which can be met through renewable generation under future conditions is not indicative of a sustainable energy future in the South East. The National Grid scenarios in 2020 result in estimates of 20% of demand able to be met across the No Progression, Slow Progression and Consumer Power scenarios, with the Gone Green scenario providing estimates of just 1% more. In 2030, these scenarios estimated the same level of demand will be met, with the exception of the Gone Green scenario, under which the proportion drops to 19%. The original scenarios yield similar estimates, with results in 2020 ranging from estimates of 26% able to be met under SEA, 22% under PBS and 20% under EVE. In 2030 this range is estimated to increase slightly, with 28%, 21% and 17%, estimated to be met under the SEA, PBS and EVE scenarios respectively. The overall illustration here is that under the best case demand scenarios for the future, the South East region will meet a maximum of 26% of demand through renewable energy sources. As a result, further investment in renewable energy should be considered in this region so that it is not left behind, or worse threatens to hold back, energy systems across the remainder of the UK.

A promising development in this region can be seen in the development of a tidal energy centre, the Perpetuus Tidal Energy Centre (PTEC). PTEC claim that their development will be;

“The World’s leading multi-technology tidal array demonstration facility... [That will] provide sufficient energy to power 15,000 homes.” (Perpetuus, 2016)

Whilst the contribution from this tidal facility will be fairly small in terms of the proportion of total regional demand which it will be able to meet, it represents an exciting step forwards in terms of generation technology research and development. The planned

infrastructure not escaped without opposition from local bodies however, with local fisherman and businesses claiming the developments may damage local shell fish beds (BBC, 2015). However, the benefits of developing a successful tidal energy scheme in the UK should not be underestimated, and whilst the technology is in its infancy and the full implications of such schemes uncertain, there are many more pressing anthropogenic threats to natural ecosystems which could be addressed through an advance in these technologies than are likely to be caused by such a development.

5.2.11 London:

Unsurprisingly, of all regions examined in this study, the London region provides the least optimistic estimates of the amount of annual electricity demand which will be able to be met through renewable electricity generation in the future. This is undoubtedly a consequence of the high concentration of people within this region, with London representing the smallest geographical region, whilst simultaneously supporting the 2nd largest regional population in the UK. In addition to this high concentration of people, the demand per person within this region is the highest of any region, with an average annual demand of 4.81 MWh/person. Renewable energy generation in London also represents an extreme, with the lowest generation of any region. Consequently, demand in this region is the greatest of any region examined in the study, and as a result it is estimated that just 2% of current regional demand could be met through renewable generation.

Under future energy conditions, the outlook for London does not look positive, with the lowest increase in the proportion of demand which can be met, of any region, under any set of scenario parameters. The underlying driver arguably remains the high population density, with population growth in this region representing the highest rate of increase, with total population estimated to grow by 19% by 2030 to represent the largest regional population in the UK. Compounding this, currently planned infrastructure is estimated to add just 458 GWh of additional renewable generation to the energy mix, resulting in total future renewable energy generation of just 1,254 GWh. As a result, all National Grid and original scenarios examined in this study, in 2020 and 2030, estimate that just 3% of total demand in this region will be able to be met by renewable generation in the future (with the exception of EVE and Gone Green scenarios which see a dip to 2% in the 2030 scenario). The lack of planned infrastructure in this region suggests that there are other developmental goals within this region which are given a stronger priority. Whilst there is an inherent difficulty in attempting to capture energy from geographically dispersed sources in a small area, the highest consuming area of the UK seems to be making little effort to attempt to generate this energy in a clean and sustainable way. The EVE and Gone Green scenarios may deliver some benefits due to the high volume of vehicles in the London

region, however, more needs to be done to meet the growing electricity needs of a rapidly expanding population.

The notion of designing a technology mix which is suited to the regional climatic conditions is inherently difficult in a region of such a small size, when considering the dispersed nature of renewable energy flows (Freris and Infield, 2008). One solution which may be of benefit in this region is the development of an extensive solar network. Studies have shown that big cities could receive substantial benefits of solar gain, with cities in southern climates likely to be able to achieve energy independence based solely on solar energy (Monette and Beckers, 2012). Whilst London does not represent one of these southern cities, it could still gain significant power from solar installations, and as technology progresses the yield of these installations is likely to improve, further boosting renewable generation. The solar resource in the UK is concentrated in the southernmost regions and is likely to grow stronger here in the future (Burnett et al. 2014). Therefore solar energy could represent a huge benefit for the London region and comprehensive plans should be developed as soon as possible, to mitigate the effects of a rapidly growing population on energy systems. The rest of the UK is moving forwards with renewable energy generation and it is time that London stepped up to keep pace with other regions, rather than falling further behind and continuing to represent a prospective environmental catastrophe driven by a constant want of expansion and growth, with little consideration of the wider implications of doing so.

5.2.12 Regional Summary:

Overall, the proportion of demand which can be met by renewable energy generation under future conditions varies greatly between regions. Two of the regions examined in this study are estimated to have enough planned infrastructure in place to meet greater than 100% of demand in the future, Scotland and Yorkshire. Though the planned increases in these regions originate from different generation technologies, it is clear that each region has realised the potential of local natural resources and as a result offers an optimistic and secure energy future for its inhabitants. Other regions which are estimated to generate a significant level of electricity from renewable generation in the future are Wales, the North East and the Eastern region. Interestingly, these regions do not share the same dominant technology either, with biomass generation dominant in the North East, offshore wind generation in the East, and onshore wind generation in Wales. This suggests that the regions which have the highest proportion of demand able to be met through renewable generation are those who have moved away from conventional plans for generation (RenewableUK, 2015) to plans which benefit from the local geography, strengthening the

notion for moving towards a regional grid system in which regions will be able to become increasingly self-sufficient.

The remaining regions examined in the study can be largely defined by two groups. The North West, East Midlands and South West regions are estimated to reach moderate amounts of demand with renewable energy generation, with the most optimistic scenarios providing around 50% of demand in this way. In these regions, whilst a clear improvement in the level of renewable generation is visible, further infrastructure will need to be planned to meet the growing energy needs of future generations. The most optimistic region in this group is the South West, which has recognised the potential of its solar resource (Burnett et al. 2014) and has planned infrastructure in place to reach this. Regions should not be afraid to move away from conventional models of generation (e.g. offshore wind) in favour of technologies better suited to their natural environment. The South East, West Midlands and London region are the regions with the least optimistic estimates of the proportion of demand which can be met by renewable generation in the future. Though neither the South East nor West Midlands estimates compare in scale to the small proportions estimated in the London region, the lack of planned infrastructure across these regions highlights a complacency towards the need to develop renewable infrastructure, which could have equally damaging implications in the future.

Nationally, the regional estimates of future energy conditions suggest that a gradient exists in the amount of demand which can be met by renewable generation, from the West to the East of the country (though Wales serves as an exception to the rule). If the level of planned infrastructure in the Scottish, North Eastern, Yorkshire, East Midlands and Eastern regions could be reflected in the western regions, the notion of a 100% sustainable energy system in the UK would be within grasping distance. Whilst there may be some inherent design issues limiting the development of similar scaled industries in the West, no region within the UK can say that they are tapping into the full potential of natural resources in their region, and until we can say that universally, we cannot justify stating that we are doing all we can to tackle the issues associated with the current energy system. Encouraging regions to become self-sufficient will encourage economic competition between regions, boosting the development of successful local networks of power generation.

5.3 Implications and Suggestions for Future Grid Systems:

5.3.1 Impact of Renewable Infrastructure Development on the Existing Grid System:

As previously discussed, the current electricity system in the UK was designed and built over 50 years ago, to accommodate centralised power from the rapidly expanding coal industry (Crispim et al. 2014). The design lifetime of the existing network now draws to an end (Strbac, 2008; Alderson et al. 2012), providing an opportunity to develop new networks, capable of integrating modern technologies in a reliable and efficient way. This study analysed the extent to which realising a future system based 100% on renewable electricity would be possible, upon completion of all planned infrastructure in the UK. The analysis found that upon completion of this infrastructure, the UK would be able to meet an average of 60% of total demand across all 2020 scenarios and 59% across the 2030 scenarios. The above values are given for the National Grid scenarios to be inclusive of estimates for Scotland and Wales. Though 100% of demand is not able to be met upon completion of all planned infrastructure, the need to integrate renewable technologies into the existing grid will be essential if all 121,913 GWh of planned renewable capacity is to be utilised effectively in the future.

The main challenge facing the widespread inclusion of renewable sources into existing grid structure is the difference in the nature of renewable sources of power. The addition of renewable sources of generation is fundamentally and technically not too dissimilar from that of connecting conventional fossil fuel generators to the grid (Freris and Infield, 2008; Twidell and Weir, 2015). However, two key characteristics of renewable sources of generation – a geographically dispersed nature and a variable output which cannot be controlled by the operator - present difficulties not experienced with conventional generators. As the existing electricity system in the UK is built around an idea of a limited number of large plants providing the bulk of generation in a centralised and controllable system (Alderson et al. 2012), the addition of renewable resources will clearly initiate a change to the way in which the existing network is operated.

Boyle (2007) highlighted that the difficulties of incorporating renewable technologies also depends to some extent on the technology being installed. Renewable sources of generation can be generally split into two groups; dispatchable sources such as biomass and hydroelectricity, and non-dispatchable sources such as wind, tidal and solar. This second group of renewables rely on natural flows of energy to determine electrical output and as a result the level of generation from these sources will be subject to greater variation (Denholm and Hand, 2011). For regions in which dispatchable sources of renewable energy represent the dominant technology type, for example the West Midlands and the North East

regions which are likely to have a high penetration of biomass generation, this may facilitate the incorporation of renewable sources into the existing grid structure due to the similarities between the operation of these technologies and conventional methods. The remaining regions, which are dominated by non-dispatchable sources of generation, may face greater difficulty when incorporating renewable sources into the existing grid structure, due to the increased variability in electricity output. Given that the majority of regions are likely to experience these difficulties, with high levels of generation across many of the given regions, an arguably more efficient approach would be to alter our approach to distribution to match the variable nature of supply, as oppose to struggling to make new technologies fit into our outdated network.

As a result of the challenges of variability in supply, many scientists propose that the successful high level implementation of renewable sources of electricity generation will require an aggregated approach which makes use of the complementarity of a mixture of different sources of generation, to reduce variability and smooth power output (e.g. Boyle, 2007; Ribeiro et al. 2014). This will be essential when planning further expansion of the renewable network over coming decades, as regions need to consider not only which renewable technologies are most appropriate for use within their region, but also the balance of technologies that will facilitate a constant and reliable source of electricity that can meet the growing needs of society.

5.3.2 Political and Economic Implications of Renewable Infrastructure Development:

The current electricity system, designed to facilitate the mass production of power from a few, highly centralised sources, has facilitated the dominance of the power market by just a few major energy producers. Consequently, incorporating renewable sources of generation into the existing grid system also has political consequences. The removal of conventional plants and replacement with renewable generators creates a loss of income for the major power producers. In addition, renewable systems have a completely different set of requirements to the existing system – from techniques, applications and locations, through to industrial priorities, company structures and political frameworks. As a result, any move towards renewable energy generation is damaging to the existing system and the major players within it (Scheer, 2012). This presents a big challenge for future power systems as there is an increasing need to alter the way in which power networks operate as a whole, whilst overcoming the dominance of the power system by a group of major producers who are economically motivated to slow down the transition to a sustainable system. This will involve huge levels of investment and face the inherent opposition of hugely powerful global energy firms. However, in the face of global resource shortages (Peduzzi and Harding Rohr Reis, 2013), increasing international insecurity and harmful

rates of climate change (IPCC, 2014), a move to a sustainable system is no longer a choice, but a reality which we will have to face in the near future. The decisions we make today will either prepare us for such an eventuality, or leave us off guard when the reality of the unsustainable nature of our current system finally comes to the forefront of the political agenda.

Arguably, the results of the study suggest that devolving energy powers to a regional level could help to overcome some of the political barriers to the implementation of renewable electricity generation. The results for the Scottish and Welsh regions in this investigation highlight that a large proportion of future demand will be attainable through renewable sources of generation under future conditions, with average estimates of 166% and 66% of demand estimated to be met in each region respectively. The success of these regions is reflected in Ellis et al. (2013) analysis of planning, energy and devolution in the UK. In this paper, Ellis et al. state;

“Under devolution, the scope for the autonomy of planning clashes with powerful centralised systemic connections between the countries of the UK and Ireland in terms of grid systems and energy markets. These tensions may ultimately call into question the fitness of current arrangements for responding to the challenges of a post-carbon world.” (Ellis et al. 2013)

Though this investigation provides only a crude indication of the amount of future energy demand which will be met through renewable generation, the study highlights that under devolved energy powers, Scotland has paved the way to become an entirely self-sufficient energy nation in future, with the Welsh region following close behind, albeit with a need for more planned infrastructure in this region. Whilst not all regions examined in the study have the potential to become entirely self-sufficient in coming decades, a number of other regions examined have sufficient planned infrastructure to meet a significant level of regional demand by 2030, including Yorkshire (which in line with Scotland has enough planned infrastructure to become self-sufficient by 2030), the North East, the East Midlands and the Eastern region. Within these regions, it is a realistic proposition that with an attainable increase in the overall planned infrastructure, these regions could become entirely self-sufficient in the near future. If energy powers were to be devolved to a regional level, local authorities could exploit the high level of generation within their region, and would be more likely to realise the benefits of investing in further infrastructure of this nature. It is likely that this would prompt regions with a low level of planned infrastructure to strive to invest in new technologies, to avoid being outcompeted economically by other areas of the UK.

Results from the northern regions in the study, particularly the North East and Yorkshire regions demand further consideration to the economic and employment benefits of renewable technologies (Mathiesen et al. 2010). Development in these regions could help to boost the regional economy and assist the northern regions in competing with the southern counties, which have historically experienced the majority of economic growth in the UK (Pike and Tomaney, 2009). Encouraging regions to be responsible for their own energy supply and demand will allow regions which are forward thinking and responsible to continue a move towards a sustainable energy network, without the reluctance of centres of economic power holding them back. The difference in the level of renewable generation currently experienced between the north and south of the UK serves to demonstrate the difference in economic opportunity between these regions. Whilst the traditional centres of economic growth in the South East (Pike and Tomaney, 2009) continue to follow the traditional model of continual growth in the search for prosperity (Jackson, 2009), peripheral regions of the UK have an opportunity to develop a prosperous system which is free from the conventional brute force, mass expansion approach (Enriquez, 2007), which stands to benefit the nation as a whole. Arguably, the highly concentrated population in London prevents this region from the immediate development of a self-sufficient 100% renewable energy system, as geographical area is low, space is rare and the demand is extortionate. However, if the government were to devolve energy powers to local authorities, the likely growth in renewable infrastructure that would result, would likely ensure that enough clean energy is produced to sustain the demands of London in the future. In addition, it would draw people away from the capital as industry in other areas flourishes, helping to resolve current issues developing in London through continued population increase.

Many of the traditional arguments against the widespread implementation of renewable sources of generation centre on the issue of the current network not being suitable to accommodate renewable energy technology. As oppose to seeing this as a barrier, we are now in a position to argue that the current energy system is unsustainable, based on the notion that planetary conditions are not suitable to accommodate carbon dominated sources of generation. There is an opportunity to restructure the grid to become a fully sustainable system, and devolving from a nationally controlled energy system to one which operates on a regional basis may be an effective way of achieving this.

5.4 Study Considerations and Ideas for Future Research:

5.4.1 Key Considerations of an Investigation of this Nature:

Given the nature and scale of this study, a number of considerations must be made when interpreting these results. Firstly, though an extremely useful tool for examining possible future conditions, the use of future scenarios of any nature holds an inherent set of assumptions about future conditions, which one is not able to test, as the events have not yet occurred. In order to reduce any uncertainties which this may induce, the scenarios used in this investigation were carefully selected from trusted authorities (National Grid, 2015), or were developed using reliable research into future demand likelihoods (IBM, 2010; Allcott and Greenstone, 2012). The full details of scenario parameters are provided in the methods section of this investigation. Though the scenarios chosen can limit the range of possible futures examined, the scenarios chosen for analysis in this study were deliberately designed to cover a wide range of future demand characteristics, in an attempt to capture as many elements of future reality as possible.

In addition, whilst useful to examine the likely future conditions on two study dates, it is difficult to ascertain the ongoing properties of a dynamic system such as the UK energy system, at a static point in time. The energy domain has a number of variables which are not captured in a study of this nature. Primarily, renewable generation technologies are a relatively young set of technologies, with development still largely in infancy. As a result, many technology developments have occurred over the past few decades (RenewableUK, 2015), and will continue to do so as interest in the field develops. This will lead to improvements in both technological ability and efficiency which will lead to increases in generation capacity from a range of technologies in the future. Whilst this is taken into consideration in this study, the likelihood is that these effects will serve to increase generation in the future, and hence our estimates can be considered as a baseline for generation capacity in future, subject to improvements from advances in efficiency linked to technology development.

The variable nature of generation is something which has appeared central to most of the discussion given here, and could be seen as a limitation to the study technique, when considering the change in renewable output on an annual basis. Given that renewable techniques rely on the natural flow of energy (Freris and Infield, 2008), the level of generation is subject to change. With ongoing changes to our climate system driven by anthropogenic actions, it is increasingly difficult to estimate the level of renewable generation which will be realised in the future. Hence, the load values ascertained from current renewable generation data (DECC, 2015d), in addition to the total generation

capacity, may vary under future conditions. The study uses current energy conditions as a tool to estimate what conditions will be like in the future. Due to the relatively short timescale, this is likely to have minimal implications on the results of the investigation, however investigations of this nature should continuously update climatic and efficiency values to give the best possible estimates of future conditions.

Finally, due to the political links associated with the development of national energy systems, it is worth considering the variable nature of government policy. Despite a widespread agreement that renewable electricity infrastructure is an essential development on a global scale, the currently challenging economic climate has seen developments of this nature put on hold. The UK has seen this recently, with large government cuts to the renewable sector (Carrington, 2015) in an attempt to manifest short term economic gain. Whilst the implications of such a politically volatile sector mean that it is difficult to estimate the number of projects which will be completed in the future, it is useful to examine those that have already made it through the planning stages of development to provide an estimate of the levels of renewable generation which could be seen in future as this creates an indication of performance which can be improved upon to meet long term energy sector goals.

5.4.2 Ideas for Future Research:

As a continually evolving and dynamic field, monitoring the changes in renewable infrastructure plans over time will give more accurate representations of what to expect of future energy systems. Further to the infrastructural aspects of future research, the benefits of investigating the likely economic impacts of developing 100% renewable energy systems, in high levels of detail, would be hugely influential on planning agencies and stakeholders interested in investing in the renewable sector. Investigations into the implications of doing this on a regional basis, would also aid decisions of the most economically effective way of structuring future networks in the UK.

Behavioural studies into societal attitudes towards energy usage and how best to influence this on a national scale are also recommended areas of future research, as this is a dimension fundamental to all future energy scenarios. Finally, the continued research and development of technologies designed to harness the wealth of natural resources which are available to us are essential if we are to create successful and sustainable systems of energy generation in the future.

6.0 Concluding Remarks:

The results of this study suggest that upon completion of all planned infrastructure in the UK, renewable electricity generation will be able to account for just 60% of national electricity demand. Two regions, Scotland and Yorkshire, demonstrate sufficient levels of planned renewable electricity generation to meet greater than 100% of local demand, and could achieve a state of self-sufficiency by 2030. However, throughout the remaining regions, the variation in the proportion of demand which could be met through renewable generation is large, with some regions producing results close to the national average (Wales, North East, and Eastern Regions), and others yielding proportions of just 3% (London). Overall, the level of planned infrastructure in the UK represents a positive step forwards, though further renewable infrastructure will be necessary to ensure the transition to a system which relies solely on renewable sources of electricity generation.

The challenges which accompany incorporating this level of renewable energy into the existing UK electricity system have been discussed at length, with key focuses on the variability of generation (Freris and Infield, 2008; Twidell and Weir, 2015), the dispersed nature of renewable generation in contrast to the centralized nature of fossil fuel generation (Strbac, 2008; Alderson et al. 2012; Crispim et al. 2014), the behavioural challenges of consumers (Spence et al. 2010) and the political difficulties preventing a swift change to renewable sources of generation (Scheer, 2012). In response to these challenges, it is proposed that a move towards a regional system of electricity generation in the UK could have a number of benefits, in addition to overcoming issues associated with current methods of generation and facilitating a move to the full integration of renewable energy technologies on a national scale. These benefits are posited to include those directly related to the reduction of fossil fuel usage, for example environmental benefits and reaching EU targets, and those which extend into the socio-economic and political spheres, including the creation of jobs, injections into the local economy, de-centralisation of energy controls, re-distributed wealth and increased security of supply across the UK. A regional distribution network could potentially create a system of energy which, far from being divisive, offers the chance for each and every region in the UK to make the most of the resources they have and to ensure continued, reliable electricity distribution to the entire population.

As stated in the justification of this study, it is increasingly clear that we are reaching a turning point whereby the age of cheap, seemingly endless supply of fossil fuels is coming to an end (Safian, 2014). The UK has a unique opportunity, as its existing grid system comes to the end of its intended life, to develop an innovative, sustainable system, to secure its

position as a world leader in the field. Though this study presents the idea of moving to a regional distribution network, there are a number of possible developments which could aid the transition to a renewable energy system, each of which should be considered seriously before creating a plan for development. However, as the effects of climate change become increasingly clear, international conflict leads to further questions of the security of supply, and the available resources of conventional fuels continues to dwindle, it becomes increasingly clear that time is of the essence. In light of this, and in the UK context of a government willing to make huge financial cuts to this sector, it is worth leaving this discussion with the words of the 26th president of the United States and passionate environmentalist, Theodore Roosevelt.

"In any moment of decision, the best thing you can do is the right thing, the next best thing is the wrong thing, and the worst thing you can do is nothing."

(Theodore Roosevelt, 1858-1919)

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