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Are the Government's Plans Sufficient In Order to Meet the Legislative Targets for CO_2e Emissions Set Out Within the Climate Change Act 2008?

Abstract

The Climate Change Act 2008 (CCA) has put in place legislation that requires the UK Government to reduce its greenhouse gas (GHG) emissions. The government has produced a number of reports that lay out its plans for meeting its legal obligations under the Act. Those plans are examined, using a quantitative approach. It is argued that the reason the UK is on target to meet it's obligations set out in the CCA is because those targets are unambitious. Furthermore, the methodology used by the government to calculate emissions neglects to take into account the full life cycle of embodied carbon. The implication is that a full life cycle analysis should be an integral part of any GHG methodology, in order to measure emissions properly. It is also shown how deployment of renewable technology presents an alternative that would satisfy the more rigorous criterion suggested.

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Glossary

Terms and Definitions

A gigajoule (GJ)	Equivalent to 1,000,000,000 (10^9) joules.
A gigawatt hour (GWh)	Equivalent to 1,000,000,000 (10^9) watt hours.
A joule (J)	A unit of energy that is equal to passing an electric current of one ampere through a resistance of one ohm for one second.
A kilowatt hour (kWh)	A unit of electrical energy equal to 1,000 (10^3) watt hours.
A megawatt hour (MWh)	Equivalent to 1,000,000 (10^6) watt hours.
A terrawatt hour (TWh)	Equivalent to 1,000,000,000,000 (10^{12}) watt hours.
A watt (W)	A unit of energy, defined as one joule per second.
Bioenergy	Biological materials that are used as an energy resource.
$MtCO_2e$	Metric tons of CO_2 equivalent. A unit of measurement that converts GHG having different potencies into a single CO_2-equivalent unit, convenient for measurement and comparison purposes.
Mtoe	Million of tons of oil equivalent. A unit of measurement of energy, equivalent to burning one tonne of crude oil, which equates to approximately 42 GJ.
Renewables	Technologies powered by natural resources, such as wind, wave and sun.

List of Abbreviations and Acronyms

CCA	2008 Climate Change Act
CCC	Committee on Climate Change
CCGT	Combine Cycle Gas Turbine (power station)
CCS	Carbon Capture and Storage
CERT	Carbon Emission Reduction Target
CESP	Community Energy Saving Programme
CfD	Contracts for Difference
CPDLCF	Carbon Plan: Delivering a Low Carbon Future

CRC EES	Carbon Reduction Commitment Energy Efficiency Scheme.
CSP	Concentrating Solar Powe
DECC	Department of Energy & Climate Change
DEFRA	Department for Environment, Food and Rural Affairs
ECO	Energy Company Obligation
EPC	Energy Performance Certificates.
EPS	Emissions Performance Standard
EU ETS	EU Emissions Trading Scheme
FITs	Feed-in-Tariffs
g CO_2e per kWh	Grams carbon equivalent emitted per unit of energy
GHG	Greenhouse Gases
GIB	Green Investment Bank
GWh	Gigwatt hour
IPCC	The UN's Intergovernmental Panel on Climate Change.
kWh	Kilowatt hour
LCA	Life Cycle Assessment
$MtCO_2e$	Metric tons of CO_2 equivalent
Mtoe	Million of tons of oil equivalent.
MWh	Megawatt hour
NAEI	National Atmospheric Emissions Inventory
PV	Solar photovoltaic
RED	Renewable Energy Directive 2009/28/EC
RHI	Renewable Heat Incentive
RHPP	Renewable Heat Premium Payment
RO	Renewables Obligation
RTFO	Renewable Transport Fuel Obligation
SEWHA	Sustainable Energy: Without the Hot Air

TWh	Terrawatt hour
UKRER	UK Renewable Energy Roadmap
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change

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Introduction

The fifth assessment report of the United Nation's (UN) Intergovernmental Panel for Climate Change (IPCC, 2013) provides a clear view of the current state of independent scientific knowledge of the earth's climate. It attributes to human industrial activity and agricultural expansion, atmospheric concentrations of CO_2e that are unprecedented for 800,000 years or more. CO_2e concentrations have increased by 40% since pre-industrial times alone, due to fossil fuel emissions. This has resulted in the atmosphere warming, which has caused snow and ice levels to fall and in turn, sea levels to rise (Stocker et al., 2013).

The Climate Change Act 2008 (CCA) requires the UK Government to reduce by 80% emissions in all six of the greenhouse gases accounted for by the Kyoto Protocol (Carbon dioxide (CO_2), Methane (CH_4), Nitrous oxide (N_2O), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs), Sulphur hexafluoride (SF_6)), from a 1990 baseline (HM Government, 2008). The act also requires the UK to reduce emissions by 34% by 2020. In addition, Directive 2009/28/EC of the European Parliament requires the UK to meet 15% of its energy demand through renewable technology (European Parliament, 2009).

During a visit to a flooded Kent village on December 27th 2013, the UK Prime Minister, David Cameron, acknowledged that the extreme weather that had caused the floods was happening more often and that his government needed to take action in order to prevent more damage:

> You only have to watch the news over the last few years to know these events are happening more often now. It needs to be a bigger priority for the government and it is.
>
> (The Guardian, 2013)

Table 1 lists many of the actions the government has taken since the CCA.

Table 1: UK GHG reduction measures since CCA. Source (Bowen and Rydge, 2011)

Date	Measure
2008	Climate Change Act. Sets a legally binding target for 2050 of 80% emission reductions from 1990 baseline levels.
2008	Carbon Emission Reduction Target (CERT). Focused on household energy saving measures.
2008	Renewable Transport Fuel Obligation (RTFO). Requires suppliers of transport fuel to ensure that a specified percentage of their supply is from renewable fuels.
2008	Energy Performance Certificates (EPS). These are required whenever a building is built, sold or rented out in the UK. 'A' rated buildings are the

Date	Measure
	most energy efficient, whilst those rated 'G' are the least.
2009	Community Energy Saving Programme (CESP). Established to complement CERT, and address fuel poverty, by requiring energy suppliers to achieve emission savings in the most deprived areas of the UK.
2010	National Renewable Energy Action Plan. The UK published its plan, in accordance with Article 4 of Directive 2009/28/EC, which detailed a roadmap of how it would meet a target of 15% of energy demand to be met by renewable technology by 2020.
2010	Carbon Reduction Commitment Energy Efficiency Scheme (CRC EES). Covers emissions by firms and public bodies not already subject to the EU system or substantially covered by other agreements.
2010	Feed-In Tariffs (FITs). From April 2010 the government has offered money for small-scale low-carbon electricity generation.
2010	Carbon Capture and Storage (CCS) Demonstration Project. The government announced £1 billion of capital funding for the first full-scale CCS demonstration project in the UK.
2011	Carbon Plan. A government-wide carbon reduction plan that sets out a timetable for achieving the United Kingdom's 2020 emission reduction targets.
2012	Green Investment Bank (GIB). A Government backed bank that will try and unlock finance for 'green' projects. The bank is due to begin trading in the Spring of 2014.
2012	Renewable Heat Incentive (RHI). Intended to provide long-term financial support across a wide range of renewable heat installations
2012	The Energy Bill. Included provisions for a 'Green Deal' on energy efficiency, greater security of energy supplies and more low-carbon electricity.
2013	UK Renewable Energy Roadmap. Describes how the UK will meet its 2020 emission targets.
2013	The Energy Act. The Energy Act received Royal Assent on 18 December 2013. It makes for provisions for electricity market reform (EMR), sets out measures for consumer protection and creates a statutary body

Date	Measure
	responsible for the countries nuclear industry; the Office for Nuclear Regulation (ONR).

Table 1 shows that the UK Government has introduced many schemes to address the requirements laid out by the CCA. The government details its current carbon reduction plans in Carbon Plan: Delivering a Low Carbon Future (CPDLCF) (HM Government, 2011) and the UK Renewable Energy Roadmap Update 2013 (UKRER) (HM Government, 2013a). These are considered by Gough (2013) to have 3 main goals, 1) explicit pricing of emissions 2) promoting clean energy, and 3) improving energy efficiency. The independent statutory body established under the CCA, the Committee on Climate Change (CCC) (2013a), describe the plans as addressing the 3 main areas of power, heat, and transport.

Figures from DECC show that from 1990 to 2011, the UK has reduced its carbon emissions.

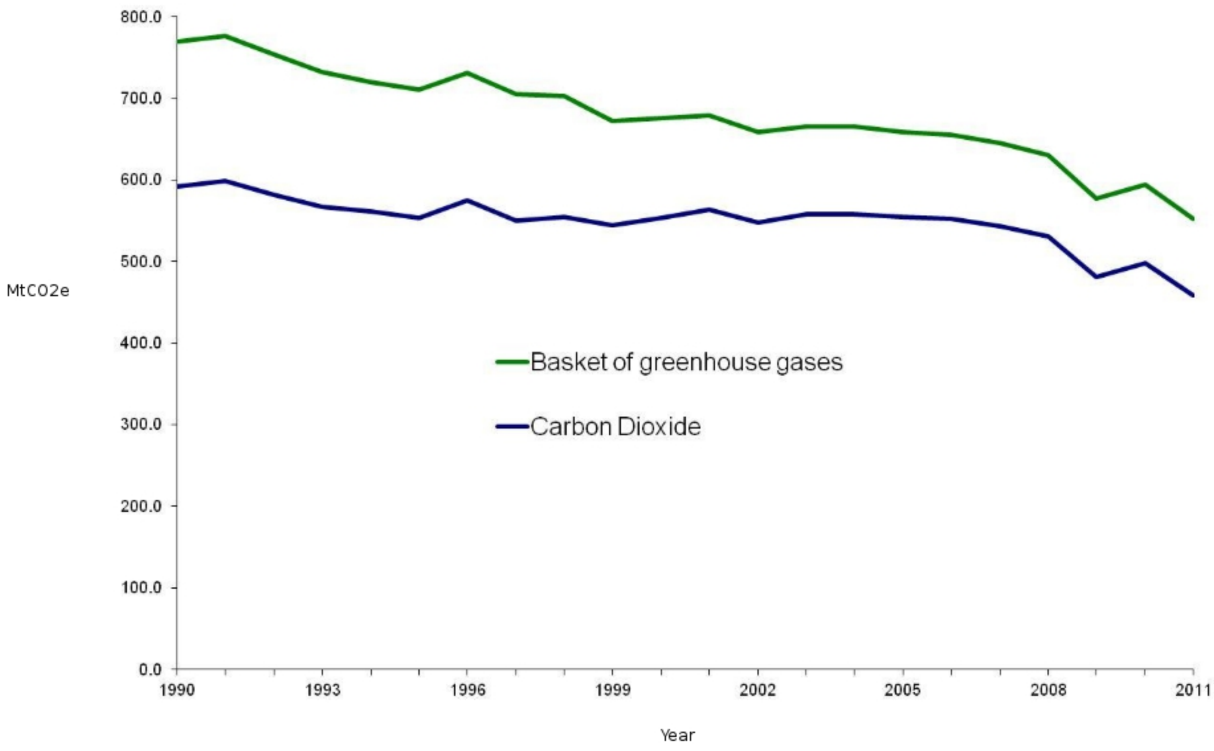


Figure 1: Emissions of greenhouse gases, 1990-2011. Source (DECC, 2013i)

The CCC (2013a) says that although energy efficiency and industrial restructuring have been a factor in some of the recent reductions in emissions, the main driver has been the recession, rather than any explicit UK government policy. At around 7 minutes into a recent interview with Jeremy Paxman, which was broadcast on the BBC's Newsnight in October, 2013, the UK comedian Russel Brand described the UK's climate change measures as, “Indifferent. They will not solve the problem” (BBC newsnight, 2013). Unlike the CCC, Brand may not have formed his opinion based upon extensive research. However, he appears to be broadly in agreement with their findings; that the UK government's policies are not reducing emissions. That claim is examined, by looking at whether the UK Government's current plans are sufficient to reduce the UK's carbon emission in line with their legislative targets for 2020 and 2050.

Literature Review

The background to the topics discussed is the IPCC's fifth assessment report, which makes the case for dramatic reductions in CO_2e emissions caused through human action (Stocker et al., 2013). The context is the CCA (HM Government, 2008) and the Renewable Energy Directive 2009/28/EC (RED) of the European Parliament (2009), both of which put into statute the UK's legal requirement to address climate change and reduce its carbon emissions.

The Plans of the UK Government

Article 4 of RED required all EU member states, including the UK, to publish National Renewable Energy Action Plans (NREAPs). The UK published its own NREAP in 2010. This outlines a roadmap of how the UK intend to have 15% of its energy demand met by renewable technology by 2020 (HM Government, 2010a). The report says that renewable sources would produce around 30% of electricity demand, 12% of heat demand; and 10% of transport demand. There have since been numerous updates to this plan, UKRER being the latest (DECC, 2013a). UKRER, like many of the government publications concerning energy, gives prominence to energy market reform (EMR). Indeed. the recent Energy Act features EMR prominently (DECC, 2013c). It claims that the UK is “the world’s biggest offshore wind market with more capacity deployed than any other country”, and that through EMR, strong private sector investment will result in a predicted 16GW of offshore wind by 2020, and as much as 39GW by 2030. It also promotes schemes such as FITs, RO, RHPP, and RHI, which it says will build new markets that will help reduce carbon emissions. It says that there has been increasing interest in the potential for tidal energy generation, with a 240 MW tidal project planned in Swansea Bay, as well as another across the Severn. Renewable transport policy focusses on sustainable biofuels, with £25 million of capital funding committed from 2015 for demonstration projects. Finally, the report says that Government is keen to decentralise supply through community ownership of local renewable energy generation, with a promise for a community energy strategy in the near future.

Many more of the government's carbon reduction plans are given in CPDLCF (HM Government, 2011). It discusses the deployment of a range of technologies: renewable energy, particularly onshore and offshore wind farms; a new generation of nuclear power stations; and gas and coal-fired power stations fitted with CCS technology. In support of such measures, the government has introduced the Renewables Obligation (RO), which ensures that large energy suppliers source some of their electricity from eligible renewable sources (HM Government, 2013a). The paper says by 2030 they estimate achieving up to 70 GW of new low carbon power, when nuclear capacity will have reached 20 GW, CCS 10 GW, and renewable electricity could deliver anywhere between 35 and 50 GW. This final figure approximately correlates with the predicted 2030 capacity of 39 GW of offshore wind in UKRER outlined above. CPDLCF says that this will mean that, by 2030, emissions from electricity generation could be over 80% lower than 2009 levels. Indeed, by 2050, CPDLCF claims that such technologies will have scaled to the point whereby emissions will be close to zero.

CPDLCF says that UK buildings must be better insulated, use more energy efficient products and that they must be supplied with low carbon energy. The government has introduced a number of initiatives in order to achieve this. Feed-in-tariff's (FITs) are a scheme used to encourage small-scale (less than 5MW) low-carbon electricity generation (HM Government, 2013b). Installation of renewable heating technology, such as air or ground-source heat pumps, will be supported by schemes such as the Renewable Heat Premium Payment (RHPP) (HM Government, 2013c), and the Renewable Heat Incentive (RHI), which claims to be the world's first financial support program for renewable heat (HM Government, 2013d). These schemes mean that the government has made provision for buildings to have achieved a low carbon heat supply of up to 45% by 2030. The report concludes that the majority of homes with cavity walls and lofts will be insulated by 2020. This will be achieved through measures such as the Green Deal; which gives financial help to homeowners wanting to pay for energy saving improvements (HM Government, 2013e), and Energy Company Obligations (ECO), which works alongside the Green Deal and creates a legal obligation on energy suppliers to improve the energy efficiency of low income households (Ofgem, 2013).

CPDLCF addresses transport, which it says will achieve low carbon emissions by encouraging lower carbon travelling, such as walking, cycling or the use of public transport. There will be continued progress on efficiencies of conventional internal combustion engines, as well as the mass roll-out of technologies such as fully electric, plug-in hybrid, and fuel cell powered cars. This will eventually result in 2027 emissions being up to 27% lower than 2009 levels.

There are also plans for reducing emissions from industry, aviation, shipping and agriculture. CPDLCF hopes that emissions from industry will be up to one quarter lower than 2009 levels, and up to 70% lower by 2050, through greater energy efficiency, bioenergy, low carbon electricity, and CCS for industrial processes. Aviation and shipping emissions will be capped by the UK being part of the EU Emissions Trading Scheme (EU ETS). This is a scheme that allow the trading of carbon on a European wide open market (European Commission, 2013). Hence the government believe it will be able to offset any aviation pollution by reductions elsewhere. According to the report, agriculture accounts for nearly 10% of emissions. Though it suggests that emission reduction targets will be met elsewhere, it says the government will seek to encourage better land management and feeding practices, which will reduce emissions here too.

Finally, CPDLCF again promotes EMR, which it says will be an important driver for reducing emissions, since this will provide “financial incentives for investment in all forms of low carbon generation”. The government says that EMR will be in 4 key areas, 1) Contracts for Difference (CfD) that give incentives for companies to invest in low carbon energy generation through stable, long-term, contracts. 2) the establishment of a minimum carbon price for UK electricity generation (a carbon price floor), 3) an Emissions Performance Standard (EPS) which will limit the amount of emissions of new fossil fuel power stations, and 4) A Capacity Market, which the government believes will support investment in generation capacity (DECC, 2013b).

Many of the technologies discussed in UKRER and CPDLCF can be modelled on an online tool the UK government has developed, called the 2050 Pathways calculator (2050PC) (DECC, 2013c). This resource is used to quantify the effects of implementing varying quantities and types of energy supply and demand measures.

Alternative Plans

Mackay (2009) favours a CO_2e emission reduction plan that is based around electrifying transport, solar thermal and heat pumps for heating, with a mix of renewables to provide green electricity. This mix includes wind, solar, wave, tide and hydroelectric, both home produced and imported, as well as clean coal (if carbon capture and storage becomes feasible) and nuclear. Though he agrees that demand reduction is an ideal, this does not feature as part of his plans because he feels the idea is, “a difficult policy to sell”.

Patterson (2007) argues that centralized power distribution is wasteful. Instead, he 'd rather a mix of on-site generation of heat and power, coupled with measures to ensure that our buildings are well insulated and use efficient lighting, heating, ventilation and electronics, “upgrading end-use technologies is the most effective way to deliver better services more reliably at lower cost and with lower impact”.

Boardman et al. (2012) discuss the policy framework necessary to ensure that all buildings in the UK achieve zero carbon emissions by 2050. The idea is that policy should recognise the roles of owners, who are responsible for energy use due to a building's characteristics, and occupants, who affect energy consumption through their behaviour. Boardman argues that owners could be motivated to ensure that their properties use as little energy for space and water heating as possible, by introducing standards that rewards energy efficiency by increasing the value of such buildings. Policy could also help improve the energy efficiency of appliances, which in turn would motivate occupants to reduce demand, because by using such equipment, they would lower their bills. Anaerobic digestion is suggested as a means of decarbonising the gas supply until such time as buildings become so energy efficient, they no longer require space heating.

The National Grid (2009) claim that renewable gas can deliver large-scale renewable heat to the UK. They quantify the possible benefits, based both on a 'Baseline' scenario (where waste is used for gas generation, but where a significant proportion is still wasted by sending it to landfill), and a “'Stretch' scenario (where all waste is directed at renewable gas).

Table 2: Potential for renewable gas production under the National Grid's 'baseline' and 'stretch' scenarios. Source (National Grid, 2009)

	2020 (baseline) million m³	2020 (stretch) million m³
Sewage / waste water	270	629
Manure - dairy and cattle	254	507
Agricultural waste	234	967
Food waste	729	1,333
Biodegradable waste	1,042	8,328
Wood waste	1,253	2,697
Miscanthus	1,845	3,971
Total	**5,625**	**18,432**
As % total UK gas demand (~97bcm)	**5%**	**18%**
As % residential gas demand (~35bcm)	**15%**	**48%**

Table 2 shows that The National Grid believes that, under their stretch scenario, renewable gas could have contributed something like 18% of the 2009 total gas demand of around 97 billion cubic metres. They claim that this would have accounted for as much as 50% of the entire UK's residential gas use.

The CCC (2013a) says that the power sector is key to reducing emissions, because it can be used to decarbonise other sectors too. They recommend an energy mix generated by 40% nuclear, 40% renewable (mainly wind, but with some solar too), 15% CCS and 5% gas (used for load balancing). Of all the low carbon technologies, the CCC believes nuclear and wind have relatively small footprints. They say that CCS should, where possible, use gas and not coal, which they say has relatively high emissions. The CCC includes gas extracted from shale within their CCS scenario. This technology has caused a controversy in the UK recently. Though it does not yet feature prominently in the UK's carbon reduction plans, the government has recently published a consultation paper on a possible improved tax regime for shale, in order to give incentives to develop an industry that they believe, “has the potential to provide the UK with greater energy security, growth and jobs“ (HM Treasury, 2013). However, the CCC says that shale should be limited to load balancing the system, since, “like other forms of gas, [shale gas] cannot be regarded as a low-carbon fuel source”. The CCC prefers electric vehicles over other transport decarbonisation measures. It also promotes the deployment of solid wall insulation and heat pumps, which it believes have significantly lower emissions than gas boilers. Finally, the CCC believes that bioenergy could meet as much as 10% of primary energy demand by 2050 but that it must meet stringent sustainability criteria in order to reduce its life cycle emissions.

The Centre for Alternative Technology (CAT) (2013) plan to reduce UK GHG emissions by investing in a variety of renewable energy generation technologies suited to the UK, by using biomass for liquid fuels required for heating, transport and industrial processes, and by the use of smart metering to manage demand. CAT believes this can all be achieved without relying on promises of future technology, without imports and without relying on nuclear energy.

Though they do not discount the technology, the CCC (2011) raise concerns regarding nuclear, when they say, “full reliance on nuclear would be inappropriate, given uncertainties over costs, site availability, long-term fuel supply and waste disposal, and public acceptability”. However, like CAT, two of the UK's largest environmental charities, Friend's of the Earth (FoE) and the World Wildlife Fund (WWF), envisage a power sector that reduces carbon emissions without requiring nuclear technology. That's because they say that nuclear energy involves spiralling costs, is unacceptably dangerous, and leaves a legacy of radioactive waste. WWF (2011) create 6 non-nuclear low carbon scenarios for 2030, all of which have at least 60% of the UK's electricity demand being met by renewable sources. All of the scenarios include electric vehicles and electric heating, whilst also reducing electricity demand through energy efficiency measures. Their preferred scenario includes boosting UK's renewable capacity via electricity grid interconnections with Europe. Aside from disallowing nuclear, the FoE (2012) also believes that shale gas extraction should not feature in the UK's plans, because it involves unacceptable environmental impacts. They say that by 2030, 75% of the UK's electricity, which they say would amount to 350 TWh, should come from renewables, by which time electricity generation emissions should be less than 50g CO_2e per kWh. Figure 2 shows that the FoE believe the key is a balanced, diverse mix of wave, tide, solar, geothermal hydro and wind, with some gas fitted with CCS technology.

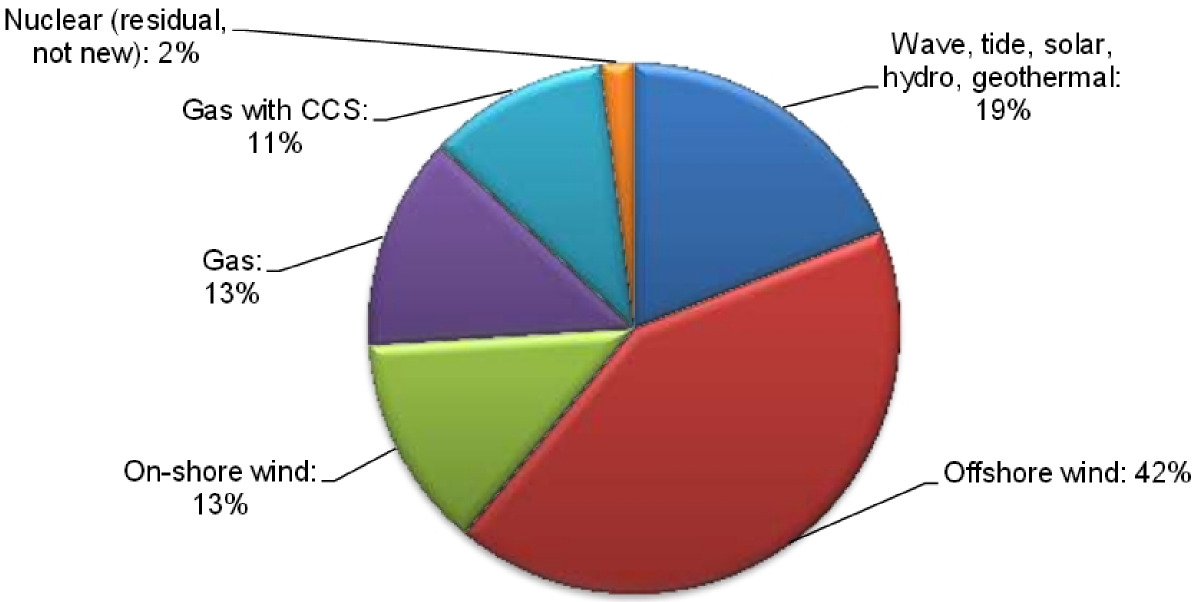


Figure 2: FoE envisaged UK electricity mix for 2030. Source (FoE, 2012)

Like the WWF, the FoE also believes that the UK should increase grid interconnections with Europe. Renewable technologies and intercontinental grid connections are very much the theme of Jacobsen and Deluchi's (2009) plans for reducing CO_2e emissions. They envisage an interconnected world powered by 100% renewable technology, including, “3.8 million large wind turbines, 90,000 solar plants, and numerous geothermal, tidal and rooftop photovoltaic installations”. They argue that such technologies emit very few greenhouse gases over their entire life cycle and that there is plenty of supply of wind, water and solar to power it all. They do though have concerns over the supply of some of the rare earth materials required for such technology. However, they suggest that the biggest obstacle is the political will to, “invest in a robust, long-distance transmission system”, and resist, “lobbying by the entrenched energy industries”.

Methodology

Methods Used

A quantitative approach is taken that measures the amount of CO_2e emissions produced by energy generation technologies. The key metric used will be the amount of CO_2e emitted per unit of energy consumed, expressed in grams per kilowatt hour (g CO_2e per kWh). This is then used to estimate the quantity of emissions, in $MtCO_2e$, based on the predicted total final consumption of energy, given in terawatt hours (TWh). This enables a judgement of the likely success of the UK's CO_2e emission reduction plans.

Methodology Review

According to Cohen, Manion and Morrison (2003), there are many, varied and valuable, tools to choose from in order to conduct research. They come in three broad categories:

1. Natural, interpretive methods.
2. Critical theory.
3. Scientific research.

Natural Methods

When attempting to answer the question posed by this thesis, a qualitative, natural approach, in the form of a questionnaire, was the first method to be considered.

According to figures from DECC (2013d), in 1990 the UK emitted approximately 774 $MtCO_2e$, which means the 2020 CCA target emissions of 34% from baseline equates to 511 $MtCO_2e$. An implicit assumption in UKRER is that final consumption in 2020 will be 1500 TWh. This leads to the following calculation for relative emissions in 2020:

511 $MtCO_2e$ / 1500 TWh = 340.67g CO_2e per kWh.

The UK's 2012 final consumption of energy was 1724 TWh, generating emissions of 572 $MtCO_2e$. That means that relative emissions in 2012 were:

572 $MtCO_2e$ / 1724 TWh = 332g CO_2e per kWh.

Since 332g CO_2e per kWh is less than the target figure of 340g CO_2e per kWh, if the assumption is that the quantity of emissions per unit of energy is not going to rise between now and 2020, then the UK will easily meet 2020 CCA legal obligations, if measures intended to reduce demand are effective.

Current UK Government policy for reducing demand centres around schemes such as the Green Deal and ECO. So the questionnaire would have been in the form, “How likely are you to take out energy improvement measures, using schemes such as The Green Deal and ECO?” The answers could then have been transposed to the UK population as a whole, which would have allowed judgement of the success of UK policy in reducing demand and meeting the CCA target. However, aside from qualitative issues concerning how representative the data would have been of the UK population, the key problem was how many people could have been compelled to complete a questionnaire, and would this have been enough to draw satisfactory conclusions? According to Science Buddies (2014), the likelihood that a confidence level of 95% is achieved is given by the formula $1/\sqrt{N}$, where N is the sample size. So if 100 people had answered the survey, then the margin of error would have been $1/\sqrt{1000} = 0.10$, or 10%. 500 people would have been better, with a margin of error of 4.5%. With a 1000 people, the margin of error would have been just 3%. However how likely is it that 1000 people could be found that were willing to fill out a survey on the Green Deal? According to DECC (2014a), since the scheme began in May 2013, just 662 households have had all Green Deal measures installed. Therefore, that's fewer people than the amount that may have been needed to fill out a survey on the Green Deal. Perhaps such a low uptake speaks for itself, and no survey is required.

Besides, what conclusion to draw even if a satisfactorily sized survey suggested a low take-up of the Green Deal? It would not necessarily have meant that the UK would fail to reduce demand, because as the CCC (2013a) suggests, there are other factors involved that might drive down demand, such as industrial efficiencies or a difficult economic climate. Indeed, the UK Government's 2013 annual digest of energy statistics (DUKES) says that the general trend since 2005 has been for demand to fall (DECC, 2013e).

Critical Theory

Agger (1991) says that critical theory reduces the world to patterns of cause and effect. Cohen et al. (2003) suggest that its aim is not merely to understand behaviour, but to change it. In this context, instead of asking, “How likely are you to take out energy improvement measures, using schemes such as The Green Deal and ECO?”, critical theory thinking would ask, “What would persuade you to install energy improvement measures, using schemes such as The Green Deal and ECO?”. This could be a more interesting question, given the lack of take-up of the Green Deal. Perhaps such a question would help inform government policy, resulting in the introduction of incentives that encouraged a greater take up of the scheme. For instance, one of the companies responsible for implementing the scheme has raised concerns over Green Deal interest rates (The Telegraph, 2013). An obvious question then would be, “If the interest rates of the Green Deal were lowered, would you be more likely to install energy improvement measures?” However, critical theory still suffers from the same problems as the natural approach above; the sample size issue and what conclusions to draw should the answers predict that people are unlikely to install measures.

Scientific Research

Epistemology is a branch of philosophy that concerns itself with the very nature of knowledge, how people acquire knowledge, and seeks an understanding of what people know. Lacey (1996) describes the epistemological tendencies of rationalism as seeing reason as the source of all knowledge. This lends itself to the deductive thinking of scientific methods, and it is this category of research that is used in order to answer the question as to whether the government's plans are sufficient in order to meet its obligations under the CCA.

Cuff (2006) states that the scientific method involves procedures that show a match between a particular idea and demonstrations of what has happened. Kratz (2010) agrees, stating that scientific research involves forming a hypothesis and producing evidence that supports or refutes it. Cohen et al. (2003) define historical research as a particular scientific method that evaluates evidence from the past in order to establish facts that throw light on future trends. That is the approach taken here; government statistics are used that show historical energy consumption and associated emissions, in order to draw conclusions for future emissions, based on the plans for generation technology discussed in the literature review.

First, figures for CCA legal obligations for emissions in 2020 and 2050 are calculated, based on the 1990 baseline level against which they are compared. 1990 emission figures are given by DECC (2013f). UKRER is then used to define the amount of energy that must be generated by 15% renewables in 2020, as required by RED. This also enables an estimate of total final energy consumption in 2020, which in turn enables an estimate of the quantity of energy that is going to be generated from non-renewable sources.

The tools used to estimate emissions are then defined. DECC (2013h) list emission factors in their guidance to companies having to report emissions, and DUKES list emission factors for fossil fuels in Annex A (DECC, 2013e). Various studies are used to find factors according to life cycle assessments (LCA), including the CCC (2013a), the IPCC (Moomaw et al., 2011), Allen (2011), and Sovacool (2008). The average of these figures is then calculated and used in the models using LCA.

Scenarios are then modelled, using energy generation technologies defined in UKRER and CPDLCF. Each technology's estimated contribution to the total final consumption of energy is based on historical figures from DECC (2013f), as well as estimates from 2050PC. Models are then developed for 2020 and 2050, first using emissions factors to estimate each technology's emissions, which in turn allows a prediction of total emissions. Since DECC uses emission factors to estimate UK emissions, these totals are used to answer whether the plans are sufficient to allow the UK Government to meet its CCA legal obligations. The same 2020 and 2050 plans are then modelled using LCA. This allows a comparison of LCA against emission factors in order to judge the suitability of DECC's methods in estimating the UK's emissions.

An energy generation model that draws on many of the technologies listed in the literature review is also developed. The aim of this model is to meet the UK's predicted demand in 2050, whilst generating as few emissions as possible. This model defines a number of requirements for each technology deployed, such as the technology must be proven, have low emissions per unit of energy, whilst being safe and maintaining biodiversity.

CO_2e Emissions Data

Quantifying the UK's CCA Targets

What do the legislative targets of the CCA mean in terms of metric tons of CO_2e ($MtCO_2e$)? The legislation says that “The 1990 baseline” means the aggregate amount of (a) net UK emissions of carbon dioxide for 1990, and (b) net UK emissions of each of the other targeted greenhouse gases (GHG) for the year that is the base year for that gas. That's 1990 for methane, 1990 for nitrous oxide, 1995 for hydrofluorocarbons, 1995 for perfluorocarbon, and 1995 for sulphur hexafluoride (HM Government, 2008). The CCA also requires the UK Government to make an annual statement regarding emissions. The 2011 statement shows that 1990 GHG emissions were 774.3 $MtCO_2e$ (DECC, 2013f). Table 3 details these.

Table 3: UK baseline emissions, in tCO_2e, for each GHG. Source (DECC, 2013f)

Greenhouse gas	Base year	Net base year emissions
Carbon dioxide CO_2	1990	590,522,357
Methane CH_4		98,619,573
Nitrous oxide N_2O		68,164,665
Hydrofluorocarbons HFCs	1995	15,316,751
Perfluorocarbons PFCs		461,669
Sulphur hexafluoride SF_6		1,239,300
	TOTAL[b]	**774,324,315**

Using the figures from table 3, 34% from 1990 baseline levels is taken to mean emissions at or below 511 $MtCO_2e$ by 2020, and 80% is taken to mean emissions should be at or below 155 $MtCO_2e$ by 2050. This is very similar to the 160 $MtCO_2e$ figures quoted for 2050 by the CCC (2013b), and almost identical to the 154 $MtCO_2e$ given in an example pathway from 2050PC (DECC, 2014b), which is said to achieve the 80% target exactly.

Figure 3 shows UK carbon emissions since 1990, both in absolute terms of $MtCO_2e$, and in relative terms, in the form of the amount of emissions per unit of energy (g CO_2e per kWh). It shows that in terms of grams CO_2e per kWh, emissions have remained very stable since 2000; they are currently at 332g CO_2e per kWh.

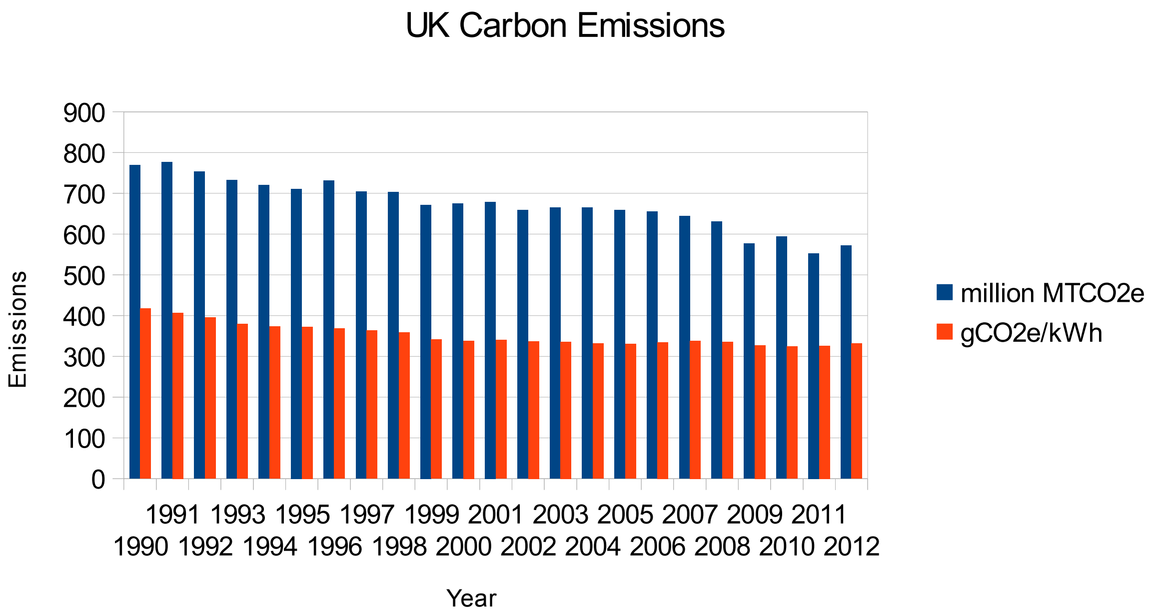


Figure 3: UK carbon emissions since 1990. Source (DECC, 2013d)

Figure 4 shows that the fall in absolute emissions since 1990 has coincided with a switch from coal to gas. DECC (2013g) explain why; coal has a much higher carbon content, which results in one unit of coal emitting more CO_2e than a single unit of gas.

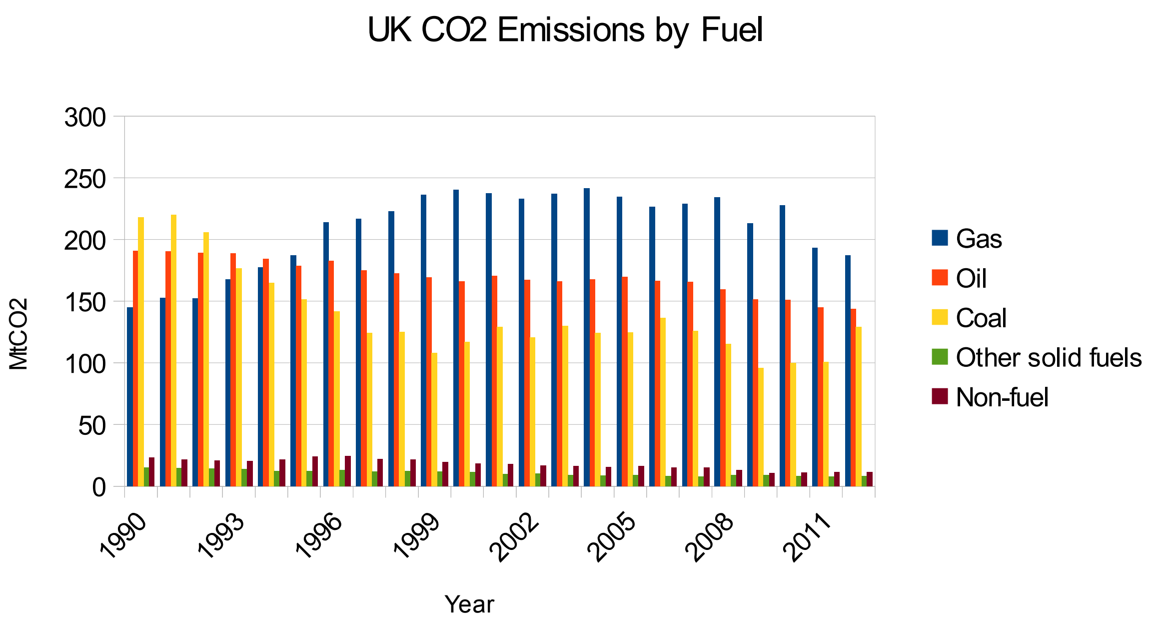


Figure 4: UK emissions by fuel. Source (DECC, 2013d)

The fall in emissions since 2005 is due to demand falling. Bowen and Rydge (2011) put this success down to 'one off factors', such as the recent recession, rather than explicit national policies. They say there has been a slow take up of renewable technology by the power sector. However, this must change since Article 3 of RED states “each Member State shall ensure that the share of energy from renewable sources, calculated in accordance with Articles 5 to 11, in gross final consumption of energy of energy in 2020 is at least its national overall target. UKRER says that the amount of renewable energy required to meet the UK's 15% target, will be 216 to 225 TWh (HM Government, 2013a). This translates to a total final consumption of energy in 2020 of 1500 TWh. The National Grid (2011) predicts very similar figures in their “Gone Green” scenario, in which they estimate total final consumption for 2020 of 1471 TWh, within which renewables contribute 232 TWh. These predictions can be put in historical context, because DECC (2013g) have released figures showing overall energy consumption in the UK since 1970. Figure 5 charts this consumption.

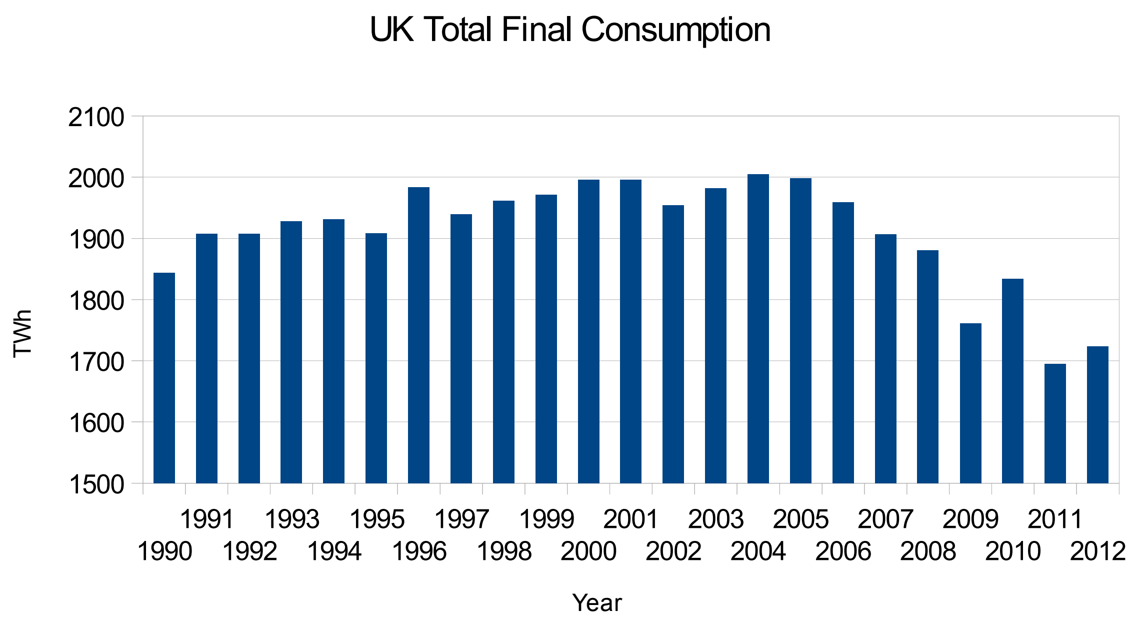


Figure 5: UK total final consumption since 1990. Source (DECC, 2013g)

Figure 5 shows that UK total final consumption for 2012 was approximately 1724 TWh. This was an increase from the year before, which DUKES describes as an anomaly, due to colder weather (DECC, 2013e). This is somewhat higher than the final consumption figure of 1500 TWh that both the government and the National Grid believe will be the UK's final consumption in 2020. However, DUKES says that the general trend since 2005 has been for demand to fall, and the graph above shows that clearly. This suggests that the figure of 1500 TWh for 2020 UK total final energy consumption appears to be a fair approximation. Table 4 details the CCA legislative targets for 2020 and 2050.

Table 4: The CCA legislative targets for 2020 and 2050

Benchmark	Target
2020 final energy consumption to be met by renewables	**225 TWh**
2020 permitted emissions	**511 MtCO_2e**
2050 permitted emissions	**155 MtCO_2e**

Tools Used to Estimate Emissions

There are two methods that are commonly used to estimate emissions; emission factors and life cycle analysis (LCA).

Under the United Nations Framework Convention on Climate Change (UNFCCC), an environmental treaty agreed in Rio de Janeiro in 1992, the UK has to report their annual GHG emissions (UNFCCC, 2014). In 1996, the IPCC published guidelines for the recording of national GHG inventories. These guidelines were revised in 2006 (IPCC, 2006). They are the primary source for emissions factors and form the basis for estimating emissions in the UK, via the following formula:

Emission = Factor x Activity

The activity could be anything ranging from energy production, water consumption, waste disposal, recycling or travel; essentially any activity that occurs within a reporting entities territory. The UK government publish their own set of guidelines that have to use these factors to report their emissions (DEFRA, 2009).

The Covenant of Mayors is an EU organisation that includes many local and regional authorities that are committed to energy efficiency and the use of renewable resources (Covenant of Mayors, 2013). They publish guidance on developing sustainable energy plans (Covenant of Mayors, 2010), in which they describe LCA as including the whole supply train and activities such as mining and extraction. DEFRA (2009) and the Carbon Trust (2013) both list on-site renewable electricity as generating 'zero emissions'. However, LCA also includes the energy used building the power plant that burns the fuel and disposal of any product at end-of-life, and as a result, emissions from renewable generation technologies will not be zero.

Emission Factors

The IPCC guidelines state that any country that was a signatory to the UNFCCC treaty should develop its own set of factors for any major source of emissions. The UK maintains their emissions factors in the National Atmospheric Emissions Inventory (NAEI, UK, 2013). DUKES list some of these factors in Annex A (DECC, 2013e). These are shown in Table 5.

Table 5: 2012 UK Fuel conversion factors used for calculating the carbon emissions of fossil fuels. Source (DECC, 2013e)

	kg CO_2 per tonne	kg CO_2 per kWh	kg CO_2 per litre
Gases			
Natural Gas		0.184	
LPG		0.214	1.491
Liquid fuels			
Gas oil	3190	0.253	2.731
Fuel oil	3220	0.268	
Burning oil	3150	0.244	2.526
Naptha	3131	0.236	
Petrol	3135	0.240	2.302
Diesel	3164	0.249	2.650
Aviation spirit	3128	0.238	2.217
Aviation turbine fuel	3150	0.245	2.516
Solid fuels			
Industrial coal	2295	0.307	
Domestic coal	2485	0.296	
Coking coal	3106	0.349	

All emission factors are based on a Gross Calorific Value basis

Coking coal is listed as having an emissions factor of 0.349kg CO_2e per kWh. DUKES lists UK coal-fired power station as being 36% thermally efficient – this is the efficiency with which they create electrical energy from the heat energy in coal (DECC, 2013e). Using coking coal's emission factor and thermal efficiency figures, it is possible to calculates the emissions per kWh of this fuel:

$0.349 \times (1 / 0.36) = 0.97$kg CO_2e per kWh

If a power station using coking coal produced 2 TWh of energy in 2012, then it would have emitted the following amount of carbon:

0.97×2 TWh = 1.94 MtCO_2e

Since October 2013, all UK companies listed on the London Stock Exchange have been required to report their GHG emissions (HM Government, 2013f). DECC (2013h) publishes guidance for such companies, which lists emissions factors for various technologies, such as energy generation and transport. The guidance describes the emissions factors as covering both direct emissions, and upstream indirect/well-to-tank emissions resulting from activities such as transporting the fuel, as well as refining it and its final distribution. DEFRA (2009) says that biomass would have produced carbon emissions once the crop had died. So they attribute non-zero factors; they list biodiesel as emitting 34.182kg CO_2e per GJ, bioethanol as emitting 38.903kg CO_2e per GJ, and biomethane as emitting 27.106kg CO_2e per GJ. 1 GJ = 277.78 kWh. Table 6 shows the emission factors for biofuels.

Table 6: Emission factors for biofuels. Source ((DEFRA, 2012)

Biofuel	**Emission Factor (g CO_2e per kWh)**
biodiesel	123.4
Bioethanol	140.44
Biomethane	97.85

Life Cycle Analysis

The CCC (2013a) has conducted a 'cradle to grave' LCA of various low carbon technologies. They describe their life cycle analysis of emissions as referring to anything that's emitted either directly or indirectly, from mining the raw material to the product's manufacture, right through to re-use, recycling and final disposal. In order to conduct their analysis, the CCC has drawn data from various literature studies, adjusted for UK specific parameters. Table 7 shows their findings for their current emissions estimates. The final column gives the average, or midpoint, between the 2 figures that the CCC quote. The table is sorted on this average column.

Table 7: CCC estimates of life cycle emissions of various technologies. Source (CCC, 2013a)

Technology	**LCA g CO_2e per kWh**	**LCA Average (g CO_2e per kWh)**
Solid Wall Insulation		Net emission reductions
Onshore Wind	7 to 20	13.5
Offshore Wind	5 to 24	14.5

Technology	**LCA g CO_2e per kWh**	**LCA Average ($g\ CO_2e$ per kWh)**
Nuclear	5 to 55	30
Solar PV	20 to 85	52.5
Air Source Heat Pumps	45 to 235	140
Battery Electric Vehicles	70 – 220	145
Gas CCS	90 to 245	167.5
Ground Source Heat Pumps	60 – 275	167.5
Plug-in Hybrid Vehicles	125 – 230	177.5
Coal CCS	80 to 310	195
Conventional Vehicles	165 to 330	247.5
Gas Boilers	255	255
Gas CCGT	380 - 500	440

The IPCC (Moomaw et al., 2011) has reviewed 2165 LCA studies of energy generation technologies. Following the review, they list greenhouse gas (GHG) emissions distributed statistically in terms of minimum, 25th percentile, 50th percentile, 75th percentile and maximum. Table 8 summarises their findings.

Table 8: IPCC review of studies giving GHG emissions data for electricity generation technologies. Source (Moomaw et al., 2011)

Values	Bio-power	Solar		Geothermal Energy	Hydropower	Ocean Energy	Wind Energy	Nuclear Energy	Natural Gas	Oil	Coal
		PV	CSP								
Minimum	-633	5	7	6	0	2	2	1	290	510	675
25th percentile	360	29	14	20	3	6	8	8	422	722	877
50th percentile	18	46	22	45	4	8	12	16	469	840	1001
75th percentile	37	80	32	57	7	9	20	45	548	907	1130
Maximum	75	217	89	79	43	23	81	220	930	1170	1689
CCS min	-1368								65		98
CCS max	-594								245		396

Allen (2011) looks at the carbon footprints of various generation technologies, via data taken from various international studies. He lists tidal barrages as having net emissions reductions, due to assumed carbon sequestration from upstream silt deposits. Dr Allen remarks that other than CCS, which has yet to be proven at large-scale, all his data is taken from existing processes and technologies. Table 9 shows his results. The final column gives the average of all of Allen's figures, and the table is sorted on that column.

Table 9: Life cycle emissions for various electricity generation technologies, taken from a report for the UK houses of parliament. Source (Allen, 2011)

Technology	LCA g CO_2e per kWh	LCA Average ($g\ CO_2e$ per kWh)
Hydropower	2 to 13	7.5
Offshore Wind	5.2, 9, 13	9.07
Nuclear	5.5, 6.4, 7, 26	11.225
Tidal Barrages	-20 to 50	15
Wave and Tidal	15, 23	19
Bioenergy from gasification (anearobic digestion)	25	25
Geothermal	15 to 53	34
Onshore Wind	38	38
Bioenergy blended with Coal	88 to 97% reductions compared to the coal it displaces	65.55
Solar PV	75 to 116	95.5
Gas with CCS*	56, 140	98
Bioenergy from short-rotation coppice wood chips	60 to 270	165
Coal with CCS*	160 to 280	220

Technology	LCA g CO_2e per kWh	LCA Average (g CO_2e per kWh)
Bioenergy from straw	200 to 550	375
Gas (CCGT)	365, 488	426.5
Coal	786, 846, 990	874

Sovacool (2008) says that, "nuclear energy is in no way 'carbon free' or 'emissions free', even though it emits much less carbon than coal, oil, and natural gas electricity generators. However, it is worse than renewable and small scale distributed generators". Table 10 shows his results.

Table 10: Life cycle emissions taken from a study on nuclear emissions. Source (Sovacool, 2008)

Technology	Capacity/configuration/fuel	Estimate (gCO_2e/kWh)
Wind	2.5 MW, offshore	9
Hydroelectric	3.1 MW, reservoir	10
Wind	1.5 MW, onshore	10
Biogas	Anaerobic digestion	11
Hydroelectric	300 kW, run-of-river	13
Solar thermal	80 MW, parabolic trough	13
Biomass	Forest wood Co-combustion with hard coal	14
Biomass	Forest wood steam turbine	22
Biomass	Short rotation forestry Co-combustion with hard coal	23
Biomass	FOREST WOOD reciprocating engine	27
Biomass	Waste wood steam turbine	31
Solar PV	Polycrystalline silicone	32
Biomass	Short rotation forestry steam turbine	35
Geothermal	80 MW, hot dry rock	38
Biomass	Short rotation forestry reciprocating engine	41
Nuclear	Various reactor types	66
Natural gas	Various combined cycle turbines	443
Fuel cell	Hydrogen from gas reforming	664
Diesel	Various generator and turbine types	778
Heavy oil	Various generator and turbine types	778
Coal	Various generator types with scrubbing	960
Coal	Various generator types without scrubbing	1050

Table 11 collates all of the figures from the studies of life cycle emissions discussed in this section. Figures from the IPCC reflect the 50th percentile. The final column gives a simple average of the 4 studies. The table is sorted on the lowest emitting technology from this final column.

Table 11: Summary of fife cycle assessments of energy technologies from the 4 different LCA studies.

Technology	CCC	IPCC	Allen	Sovacool	LCA Average (g CO_2e per kWh)
Solid Wall Insulation	Net emission reductions				Net emission reductions
Bioenergy with CCS*	-981				-981
Hydropower		4	7.5	11.5	7.67
Offshore Wind	14.5	12	9.07	9	11.14
Solar Thermal				13	13
Wave and Tide		8	19		13.5
Tidal Barrages			15		15
Anaerobic Digestion			25	11	18
Onshore Wind	13.5	12	38	10	18.37
Nuclear	30	16	11.225	66	30.8
Geothermal		45	34	38	39
Bioenergy			65.55	18.5	42.025

Technology	CCC	IPCC	Allen	Sovacool	LCA Average (g CO_2e per kWh)
blended with Coal					
Solar PV	52.5	(46 + 22) / 2 = 34	95.5	32	53.5
Bioenergy		18	270	31.2	106.4
Air Source Heat Pumps	140				140
Gas CCS	167.5	155	98		140.17
Battery Electric Vehicles	145				145
Ground Source Heat Pumps	167.5				167.5
Plug-in Hybrid Vehicles	177.5				177.5
Coal CCS	195	247	220		220.67
Conventional Vehicles	247.5				247.5
Gas	440	469	462.5	443	453.62
Fuel Cell Vehicles				664	664
Petroleum		840		778	809
Coal		1001	874	1005	960

Analysing the UK's Planned Energy Mix

DECC use emission factors to report their GHG emissions under the UNFCCC, and it is against these factors that the CCA will be judged. Hence, the models that use these factors form the basis of the conclusions made. The results from these models will then be compared against that employing LCA.

The 2020 Scenario Using Emission Factors

The UK Government's original renewable energy roadmap lists the technologies that will need to be deployed in order to meet the 15% target required by RED (DECC, 2011). Table 12 details the proposed plans.

Table 12: The UK's proposed 2020 renewable energy deployment. Source (DECC, 2011)

	Central range for 2020 (TWh)
Onshore wind	24-32
Offshore wind	33-58
Biomass electricity	32-50
Marine	1
Biomass heat (non-domestic)	36-50
Air-source and Ground-source heat pumps (non-domestic)	16-22
Renewable transport	Up to 48TWh
Others (including hydro, geothermal, solar and domestic heat)	14
Estimated 15% target	234

Although UKRER revises those figures slightly, down to 225 TWh, table 12 will be used in order to help answer whether the UK Government’s plans are sufficient to meet the targets legislated in CCA.

Table 13 translates the proposed deployment in table 12 into emissions, based on DECC's implementation of the IPCC's emission factors. Only bioenergy will have any impact at all because DECC considers the other technologies to have 'zero emissions'. Assumed is the use of bioethanol for electricity and heat, with emissions at 140.44g CO_2e per kWh. Also assumed is that renewable transport equates to 100% biodiesel, with emissions at 123.4g CO_2e per kWh.

Table 13: Predicted emissions of the 2020 energy generation technologies detailed in UKRER.

Technology	Annual Energy Contribution (TWh)	Emission Factor (g CO_2e per kWh)	Annual Emissions (tCO_2e)
Onshore Wind	24	0	0
Offshore Wind	39	0	0
Biomass Electricity	41	140.44	5,758,040
Marine	1	0	0
Non-domestic Biomass Heat	43	140.44	5,306,200
Air-source Heat Pumps	9.5	0	0
Ground-source Heat Pumps	9.5	0	0
Renewable Transport	44	123.4	5,429,600
Hydropower	3.5	0	0
Geothermal	3.5	0	0
Solar	3.5	0	0
Domestic Biomass Heat	3.5	140.44	491,540
Total	**225**		**16,985,380**

This model predicts emissions at 16.98 $MtCO_2e$ for renewable technologies.

The remaining 1275 TWh of the UK's predicted final consumption in 2020, is likely to come from existing technology, since aside from the plans in UKRER, CPDLCF makes very little provision for any new technology to provide part of the energy mix. Instead, CPDLCF concentrates on how it must prepare for post 2020, with Chris Huhne, the Secretary of State for Energy and Climate Change at the time of CPDLCF, declaring, “the 2020s will require a change of gear. Technologies that are being demonstrated or deployed on a small scale now will need to move towards mass deployment." This includes CCS, with DECC's (2012a) roadmap for the technology stating that, "our aim is to enable industry to take investment decisions to build CCS equipped fossil fuel power stations in the early 2020s". Nuclear is likely to have similar capacity as it does today, despite ageing plant, because the UK government's paper on the future of the nuclear industry states that it will look for further life extensions of its existing fleet of nuclear power stations and continue their safe operation past 2020 (Great Britain et al., 2011). The biggest change to the UK's energy generation mix, pre-2020, is likely to come from coal, because under the EU's Large Combustion Plant Directive (European Commission, 2012), the UK's older, more polluting, coal-fired power stations must be closed by the end of 2015. This will result in approximately 7GW of the UK's 28GW of coal-fired generation capacity closing in 2015 (Mita Kerai, 2013), likely to be replaced by imported gas, in order to fill the void.

Data from DECC (2013f) shows the UK's 2012 energy consumption by fuel. It excludes non-energy use. This is shown in Table 14.

Table 14: The UK's 2012 energy consumption by fuel (MtCO$_2$e). Source (DECC, 2013f)

Coal	Coke and Breeze	Other Solid Fuels	Coke Oven Gas	Natural Gas	Electricity	Bioenergy	Oil	Total
19	5	4	1	547	318	28	700	1635

By translating the figures from table 14 into percentages of total final consumption, they can be used to predict the fuel mix of the remaining 1275 TWh predicted for 2020. Table 15 shows the results of this analysis. It includes a 25% reduction in the amount of energy consumed from the burning of coal, which is assigned to natural gas instead.

Table 15: Predicted UK 2020 energy consumption by fuel (MtCO$_2$e).

Coal	Coke and Breeze	Other Solid Fuels	Coke Oven Gas	Natural Gas	Electricity	Petroleum	Total
11.13	3.78	3.25	0.51	441.53	254.19	560.05	1274.44

DECC (2013f) list the emission factor for electricity consumed, as a whole, as 490.56g CO$_2$e per kWh. It is assumed that this figure is unlikely to change significantly for fossil fuel based electricity generation technologies in 2020. The rest of the required emissions factors can be found via DUKES (shown in table 5). 'Other solid fuel' is modelled as domestic coal and 'coke gas' is assumed to have the same emission factor as LPG. Table 16 shows the emissions based on these assumptions.

Table 16: The predicted carbon emissions for the remaining generation technologies likely to provide energy in 2020.

Technology	Annual Energy Contribution (TWh)	Emission Factor (g CO_2e per kWh)	Annual Emissions (tCO_2e)
Coal	11.13	307	3,416,910
Coke	3.78	349	1,319,220
Other Solid Fuel	3.23	296	956,080
Coke Gas	0.51	214	109,140
Natural Gas	441.53	214	94,487,420
Electricity	254.19	490.56	124,695,446
Petroleum	560.05	240	134,412,000
Total	**1274.44**		**359,396,216**

This estimates non-renewable energy generation will emit 359.4 $MtCO_2e$ in 2020. Adding these to predicted renewable emissions at 16.98 $MtCO_2e$, gives:

359.4 + 16.98 = 376.4 $MtCO_2e$

Agriculture, livestock management and land use cause emissions through factors such as the breakdown of soils enriched by fertilisers. According to CPDLCF, such emissions amounted to 48 $MtCO_2e$ in 2009, and these are predicted to fall to 44 $MtCO_2e$ in 2020, through measures such as 'resource efficiency' and active woodland management. CPDLCF also plans to reduce waste emissions to 10 $MtCO_2e$ through measures such as waste prevention and recycling, as well as landfill tax. This gives additional emissions of:

376.4 + 44 + 10 = 430.4 $MtCO_2e$ total final consumption emissions in 2020.

430.4 $MtCO_2e$ is well within the 2020 target emissions of 511 $MtCO_2e$. Therefore, this model, based on DECC's emission factors, predicts that the government's plans are sufficient in order to meet CCA legal obligations for 2020.

The 2050 Scenario Using Emission Factors

In a UK government report analysing routes to achieving an 80% reduction in carbon emissions by 2050, various pathways are outlined (HM Government, 2010b). Though the analysis says that "none of the pathways that this analysis illustrates is a preferred route", pathway alpha is the closest to the plans in the CPDLCF, because much like CPDLCF, it features an equal balance of demand reduction measures and energy supply coming from renewables, nuclear, fossil fuels, and sustainable bioenergy. The 2050 Pathway Calculator (2050PC) includes a number of examples and the one labelled *Higher renewables, more energy efficient* (HREE) closely models the ideas in the alpha pathway (DECC, 2014b). HREE shall be used as a basis for the model developed in this scenario.

The figures for power supply in HREE are shown on a primary demand basis. They have been translated into equivalent quantities for final consumption, based on the total final consumption of 1122 TWh in HREE. This is a significant saving on final energy consumption of 1500 TWh predicted for 2020, which HREE puts down to some of the measures outlined in CPDLCF; transport efficiencies, and wholesale changes that make homes much more energy efficient and more reliant on electricity.

Some estimates have been made, because some of the figures in HREE are not detailed explicitly. In addition, in order to make supply add up to that shown, it is assumed that all of the bioenergy imports are used in biomass CCS plants. The emission factors for coking coal from table 5 are used for coal. For gas; LPG. For oil; fuel oil. For biomass and bioenergy; bioethanol.

The negative emissions factors listed for biomass, gas and coal CCS technologies in table 17 are derived from HREE's figure for total net reductions in carbon emissions. They reflect the ability of CCS to capture the emissions that would otherwise have been generated. They are calculated by applying the formula:

Annual Emissions / Annual Energy Contribution = Emission Factor

Table 17: Emissions estimates for the proposed 2050 energy generation mix detailed in HREE. The negative figures reflect the ability of CCS to capture the emissions that would have been generated otherwise.

Technology	**Annual Energy Contribution (TWh)**	**Emission Factor (g CO_2e per kWh)**	**Annual Emissions (tCO_2e)**
Nuclear	199	0	0
Gas CCS	114	-371.51	-42,345,064
Coal CCS	7	-371.58	-2,647,065
Biomass CCS	50	-962.57	-48,000,157
Offshore Wind	128	0	0
Onshore Wind	57	0	0
Wave	21	0	0

Tide	7	0	0
Biomass	4	140.44	500,234
Solar PV	28	0	0
Solar Thermal	11	0	0
Hydroelectricity	5	0	0
Bioenergy	121	140.44	17,007,953
Coal	14	349	4,972,419
Gas	72	214	15,397,402
Oil	284	268	75,985,402
Total	**1122**		**20,871,123**

This model details renewable technologies that supply 381.8 TWh of final consumption, or 34% of the total final consumption. Coal and gas CCS supply 170.98 TWh, or 15.24%. Nuclear, at 199.47 TWh, supplies 17.78% of the final consumption. Coal, oil and gas supply nearly one third of the total final consumption, or 32.95%, at 369.73 TWh.

The amount of emissions before CCS reductions total approximately 114 MtCO_2e. HREE gives a very similar figure of 111 MtCO_2e. HREE lists a total figure of 93 MtCO_2e net carbon emission reductions for CCS and this model does the same. Taking all these factors into account, this model predicts 2050 total carbon emissions, via energy generation technologies, to be 20.87 MtCO_2e.

HREE then includes 70 MtCO_2e of emissions for international aviation and shipping. This model does not do the same since such emissions are not included in current UK emissions data. MacKay says that this is because there is no internationally agreed on way of allocating such figures to different countries (MacKay FRS, 2012). Also included in HREE are emissions totalling 7 MtCO_2e due to land use and land use change and 38 MtCO_2e for agriculture.. The 2050 Pathways Analysis (2050PA) give a number of reasons for why such emissions, such as CO_2e being emitted due to soil disturbance and direct from livestock (HM Government, 2010b). Industrial processes are predicted to emit 14 MtCO_2e and waste is predicted to emit 6 MtCO_2e. Taking all these additions into account, this model estimates 2050 emissions at 86 MtCO_2e.

86 MtCO_2e is well within the 80% target for 2050, of 160 MtCO_2e. Even if aviation and shipping were included, emissions would still be inside the 2050 target, at 156 MtCO_2e.

Based on the emission factor model, the government's plans appear sufficient in order for them to meet their CCA legal obligations for 2050.

Evaluating The Emission Factor Based Scenarios

The scenarios developed below will model the exact same plans as above, but predicts emissions based on LCA instead. Klöpffer (1997) suggests that the aim of LCA is to give a complete picture of all the environmental burdens connected with a particular technology, because it considers everything from raw material extraction through to disposal.

By estimating the models emissions using LCA, it is possible to judge the suitability of DECC's emission factors in reporting the UK's actual emissions.

The 2020 Scenario Using Life Cycle Analysis

Table 18 lists emissions for the renewable technologies described in UKRER, based on figures for LCA given in the 'Average' column of table 11. Similar to the emission factor based model, it will assume that renewable transport equates to 100% bioenergy.

Table 18: LCA emissions for the renewable technologies described in UKRER.

Technology	Annual Energy Contribution (TWh)	LCA (g CO_2e per kWh)	Annual Emissions (tCO_2e)
Onshore Wind	24	18.37	440,880
Offshore Wind	39	11.14	434,460
Biomass Electricity	41	106.4	4,362,400
Marine	1	13.5	135,00
Non-domestic Biomass Heat	43	106.4	4,575,200
Air-source Heat Pumps	9.5	140	1,330,000
Ground-source Heat Pumps	9.5	167.5	1,591,250
Renewable Transport	44	106.4	4,681,600
Hydropower	3.5	7.67	26,845
Geothermal	3.5	39	136,500
Solar	3.5	53.5	187,250

Technology	Annual Energy Contribution (TWh)	LCA (g CO_2e per kWh)	Annual Emissions (tCO_2e)
Domestic Biomass Heat	3.5	106.4	372,400
Total	**225**		**18,152,285**

The LCA model predicts emissions at approximately 18.1 $MtCO_2e$ for renewable energy generation technologies. This compares to 16.98 $MtCO_2e$ in the model using DECC's emission factors. This is an increase of 9.4% and reflects the fact that LCA includes factors such as power plant construction.

Table 19 lists LCA emission predictions for the rest of the energy technologies that are likely to feature as part of the UK's energy generation technologies in 2020. The LCA factors again come from the 'Average' column in table 11. For the proportion of energy generated from the fuel 'electricity', it is assumed that it will be equally generated from nuclear, gas and coal. Therefore, a simple average of their LCA figures is calculated:

(453.62 + 960 + 30.8) / 3 = 481.47g CO_2e per kWh

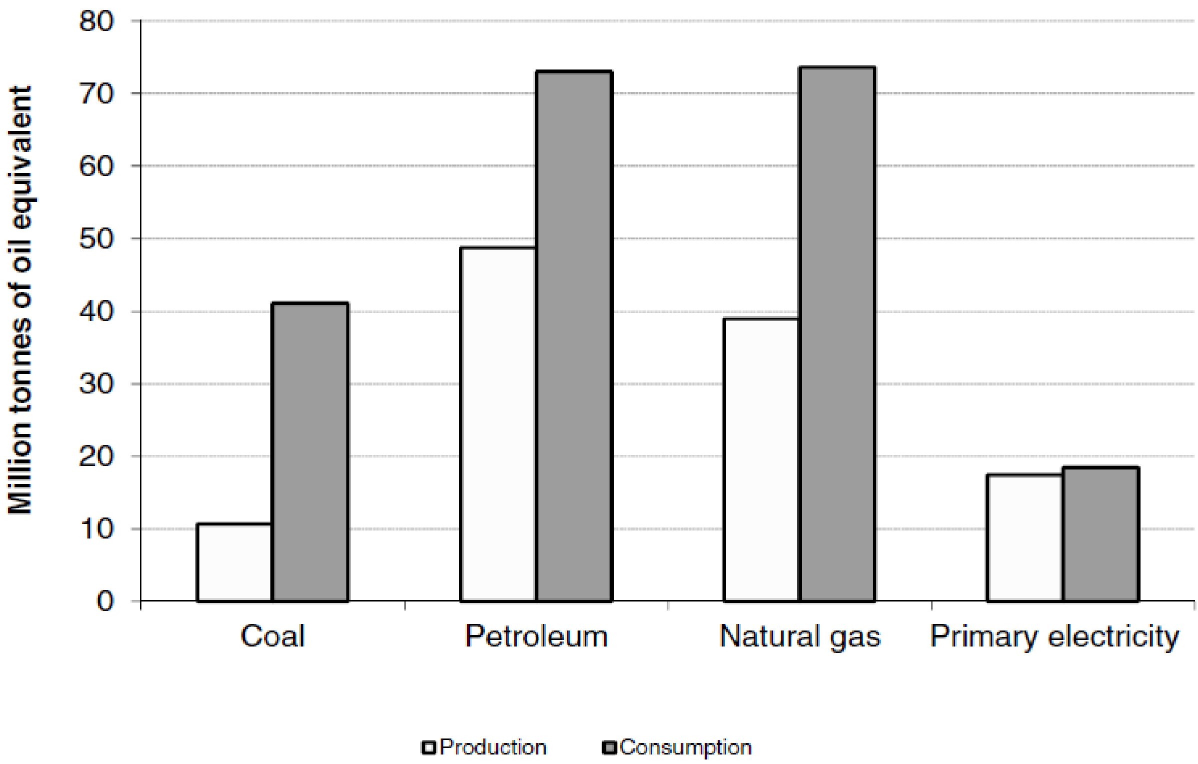
'Other solid fuel' and 'Coke' are both modelled as coal from table 11, and 'coke gas' is assumed to have the same LCA emissions as gas. The model also assigns the 25% reduction in the use of coal to gas, as was done in the emissions model and is likely for 2020.

Table 19: LCA emissions for non-renewable energy generation technologies predicted for 2020.

Technology	Annual Energy Contribution (TWh)	LCA (g CO_2e per kWh)	Annual Emissions (tCO_2e)
Coal	11.13	960	10,684,800
Coke	3.78	960	3,628,800
Other Solid Fuel	3.23	960	3,100,800
Coke Gas	0.51	453.62	231,346
Natural Gas	441.53	453.62	200,286,839
Electricity	254.19	481.47	122,384,859

Technology	Annual Energy Contribution (TWh)	LCA (g CO_2e per kWh)	Annual Emissions (tCO_2e)
Petroleum	560.05	809	453,080,450
Total	**1274.42**		**793,397,894**

The LCA model predicts emissions at approximately 793.4 $MtCO_2e$ for the rest of the 2020 fuel mix, as opposed to 359.4 $MtCO_2e$ from the model using DECC's emission factors. This is a huge increase of 49.3%, mostly accounted for by big increases in estimated emissions from natural gas and petroleum. DUKES says that the UK is a net importer of energy. Indeed, 43% of the total primary supply comes from imported sources. Figure 6 shows this difference between primary demand and UK production.



Note: Includes non-energy use of petroleum and gas. Differences between consumption and production are made up by foreign trade, marine bunkers and stock changes.

Figure 6: 2012 UK production versus UK consumption. Source (DECC, 2013e)

According to the International Energy Agency's (IEA) Energy Technology Systems Analysis Program (IEA ETSAP) (2010), energy losses occur in the exploration of oil and gas because of activities such as gas flaring, venting and fuel combustion due to energy production. Furthermore, only 30-50% of the fuel from an oil field is recoverable, 70-80%

for gas. Emission factors only consider emissions produced within a given territory. Therefore, the differences between emission factors and LCA are accounted for by the scale of imports, coupled with the inefficiencies and emissions in the exploration processes for fossil fuels.

Renewable emissions for 2020 were estimated to be 18.1 $MtCO_2e$ under this model. Adding this to the estimated emissions from non-renewable energy generation technologies from table 19, gives:

793.4 + 18.1 = 811.5 $MtCO_2e$

CPDLCF predicts 54 $MtCO_2e$ of emissions due to agriculture, waste and land use change for 2020. This gives:

811.5 + 54 = 865.5 $MtCO_2e$ total predicted emissions in 2020.

This is more than 350 $MtCO_2e$ above the 2020 target of emissions of 511 $MtCO_2e$. It is also over 400 $MtCO_2e$ above the emission factors model's predicted emissions of 430.4 $MtCO_2e$.

Based on the LCA model, the government's plans are insufficient in order for them to meet their legal obligations for 2020.

The 2050 Scenario Using Life Cycle Analysis

Table 20 applies the LCA emissions for HREE. This model details the same energy mix as the emissions factor model and makes many of the same assumptions. For example, it is assumed that the majority of bioenergy imports are used in biomass CCS plants.

Table 20: Emissions estimates for the proposed 2050 energy generation mix using LCA

Technology	Annual Energy Contribution (TWh)	LCA (g CO_2e per kWh)	Annual Emissions (tCO_2e)
Nuclear	199	30.8	6,129,200
Gas CCS	114	140.17	15,979,380
Coal CCS	7	220.67	1,544,690
Biomass CCS	50	-981	-49,050,000
Offshore Wind	128	11.14	1,425,920
Onshore Wind	57	18.37	1,047,090
Wave	21	13.5	283,500

Tide	7	15	105,000
Biomass	4	106.4	425,600
Solar PV	28	53.5	1,498,000
Solar Thermal	11	13	143,000
Hydroelectricity	5	7.67	38,350
Bioenergy	121	106.4	12,874,400
Coal	14	960	13,440,000
Gas	72	453.62	32,660,640
Oil	284	809	229,756,000
Total	**1122**		**268,300,770**

Total predicted emissions of 229.76 $MtCO_2e$ are well over the target of 160 $MtCO_2e$, even before including the additional emissions that HREE includes, such as those from agriculture, waste, aviation and shipping. Table 21 details these.

Table 21: Sectoral emissions from sectors listed in HREE, using LCA

Sector	Emissions ($MtCO_2e$)
Aviation and shipping	70
Land use	7
Agriculture	38
Industry	14
Waste	6
Total	**135**

Discounting aviation emissions, since they are not included by DECC, this gives total emissions of 229.76 + 65 = 294.76 $MtCO_2e$.

This is 139.76 $MtCO_2e$ above the 2050 target of 155 $MtCO_2e$. It is also over 200 $MtCO_2e$ above the emission factor model's predicted emissions of 86 $MtCO_2e$.

Based on this LCA model, the government's plans are insufficient in order to meet their CCA legal obligations for 2050.

Proposed Energy Generation Model for 2050

An LCA model that aims to meet the CCA 2050 obligations is developed. This is done by deploying many of the technologies discussed in the literature review. These technologies must meet a number of requirements.

The model will not include any technology that is as yet unproven. The IPCC (2005) say that there are no large-scale plants that implement a fully integrated CO_2e capture, transport and storage system. The UK policy website has a page dedicated to CCS (HM Government, 2013g). It admits much the same as the IPCC; that although the processes involved in the technology are not particularly new or unique, there are no projects that use capture, transport and storage altogether, at commercial scale, to decarbonise power plants . So CCS is disallowed under this criterion.

Any technology that could have a direct impact on biodiversity is not considered. Biomass is thought of as carbon neutral, but Bowyer et al. (2012), say that this assumes that emissions from burning organic material are immediately offset by crops grown to replace that which was burnt. They suggest that this is overly simplistic. Furthermore, they raise concerns about the sustainability of biomass and the pressure it puts on land use. DECC (2012b) also raises this concern, when they wonder about the impact biomass has on food production and biodiversity. Because of these factors, biomass has not been considered as a viable energy source for this model.

This model will not employ any technology where there are any concerns over safety. Given Fukishima, Chernobyl, and Three Mile Island, such criteria disallow nuclear.

A report by Carbon Tracker and Grantham Research Institute, LSE (2013) raises concerns about releasing carbon into the atmosphere. Indeed, the IPCC (Stocker et al., 2013) creates alarming scenarios prescribed to carbon emissions. Therefore, any technology that discovers new reserves of fossil fuels that, if burnt, will unlock more carbon, are disallowed. This means that shale gas technologies will not be deployed. However, they would have been disallowed under the following criteria; in order to ensure that the LCA model meets the CCA legal obligations for 2050, any technology that emits significantly more carbon than the target per unit emissions, will not be included. Assuming the same final consumption figure of 1122 TWh in 2050, as per the 2050 models above, this gives:

155 $MtCO_2e$ / 1122 TWh = 138.15g CO_2e per kWh

This criterion disallows the technologies listed in table 22.

Table 22: Energy generation technology disallowed by excessive emissions per unit of energy

Technology	**LCA (g CO_2e per kWh)**
Conventional Vehicles	247.5
Gas	453.62
Fuel Cell Vehicles	664
Petroleum	809
Coal	960

The National Grid (2009) says that there are no major barriers to implementing a renewable gas solution through the use of UK landfill waste. This model will use the National Grid's anaerobic digestion technology (AD), to provide 50% of the UK residential heat requirements and eradicate emissions from UK waste. HREE lists heating and cooling as consuming 258 TWh, so AD will provide 129 TWh for this model. The rest of the heat load will come from electricity generation, thus assuming the electrification of British homes.

This model also assumes a big commitment to renewable technologies such as offshore and onshore wind, solar, wind and wave. This is not an insignificant risk, however. For example, present market conditions in the UK for wind are clearly proving problematic; 2 large-scale offshore wind projects have been cancelled recently; one off the North Devon coast (Renewable Energy World.com, 2013), and the second off the coast of Scotland (BBC, 2013). Both were planning to be capable of producing 1200 MW, or 2.4GW, of renewable electricity. This means that 15% of the planned 2020 capacity has recently been lost.

This model assumes that there is a large scale electrification of the transport sector, both personal and public, similar to the ideas developed by MacKay (2009).

Though the concern is CO_2e emissions, and not issues such as load balancing or energy security, these will be provided by developing intercontinental grid connections with countries such as Sweden and Norway, similar to the ideas proposed by Jacobson and Deluchi (2009). Because these countries already generate much of their power via renewables, this will help this model achieve its primary aim; low CO_2e emissions from energy generation. Similarly, though matching peak demand has not been a concern, it is proposed that the UK also develops its pumped storage capacity in order to cope with those times of high consumption. Pumped Storage is a technology that stores energy by pumping water up to a storage area during low demand, so that it can be released to produce electricity during high demand. Dinorwig, in Snowdonia, Wales, is an example of such a technology (International Power, 2014). The power generation mix in table 23 reflects energy provided by pumped storage, the intercontinental grid., as well as all the other ideas developed in this section.

Table 23: Proposed energy generation model for 2050.

Technology	Annual Energy Contribution (TWh)	LCA (g CO_2e per kWh)	Annual Emissions (tCO_2e)
Offshore Wind	400	11.14	4,456,000
Onshore Wind	200	18.37	3,674,000
Wave	50	13.5	675,000
Tide	30	15	4,500,000
AD	129	18	2,322,000
Solar PV	225	53.5	12,037,500
Solar Thermal	49	13	637,000
Ground Source Heat Pumps	40	167.5	6,700,000
Air Source Heat Pumps	40	140	5,600,000
Hydroelectricity	59	7.67	452,530
Total	**1122**		**37,004,030**

This model estimates total emissions from energy generation of 37 $MtCO_2$e. This compares very favourably to the LCA 2050 model that predicted energy generation emissions of 229.76 $MtCO_2$e. However, the sectoral emissions listed in HREE still need to be considered.

Following the large-scale outsourcing of its manufacturing base, which has continued apace since the 1970's, the UK has extensive imports. According to the CCC (2013a), 'the UK has one of the largest gaps between production and consumption emissions in the world, with our net imports of emissions higher than those of most other countries'. This model assumes that UK government implements policies that begin to reclaim its manufacturing base, thus limiting imports and curtailing emissions from aviation and shipping by 70%. However, some of the savings will be offset by an increase in emissions from industry. It is also assumed that the UK implements progressive mixed use, organic agricultural policy, similar to the ideas promoted by The RSPB (2010). Scialabba and Müller (2010) suggest that such sympathetic grassland and livestock practices encourage carbon sequestration in soil, thus curbing carbon emissions. Using the ideas of the RSPB, a saving of 60% of the agricultural emissions from HREE is predicted. Waste emissions are reduced to zero through AD.

Table 24: 2050 Sectoral emissions of the proposed model.

Sector	**Emissions ($MtCO_2e$)**
Aviation and shipping	21
Land use	4
Agriculture	14
Industry	20
Waste	0
Total	**59**

Total emissions from this model are calculated by adding estimated energy generation emissions to the predicted sectoral emissions:

37 + 59 = 96 $MtCO_2e$.

Therefore, if the government were to implement this model, it predicts that the UK Government would easily meet its CCA legal obligations for 2050, even when considering LCA.

This model predicts emissions that are almost 200 $MtCO_2e$ below the emissions of 294.76 $MtCO_2e$ predicted by the LCA 250 model. It is clear why; looking at final consumption of oil in that model; it is predicted to provide 25% of the energy generation mix. LCA shows that oil generates 809g CO_2e per kWh, whereas the model above predicts average emissions that are almost a tenth of that:

Average emissions for this model = 96 $MtCO_2e$ / 1122 TWh = 85.56g CO_2e per kWh

In fact, figure 7 shows that the UK's use of oil, as a percentage of its final consumption, has remained remarkably stable since 1990, at around 40%. This is also the case for emissions from oil, which have provided approximately one quarter of all emissions since the same date.

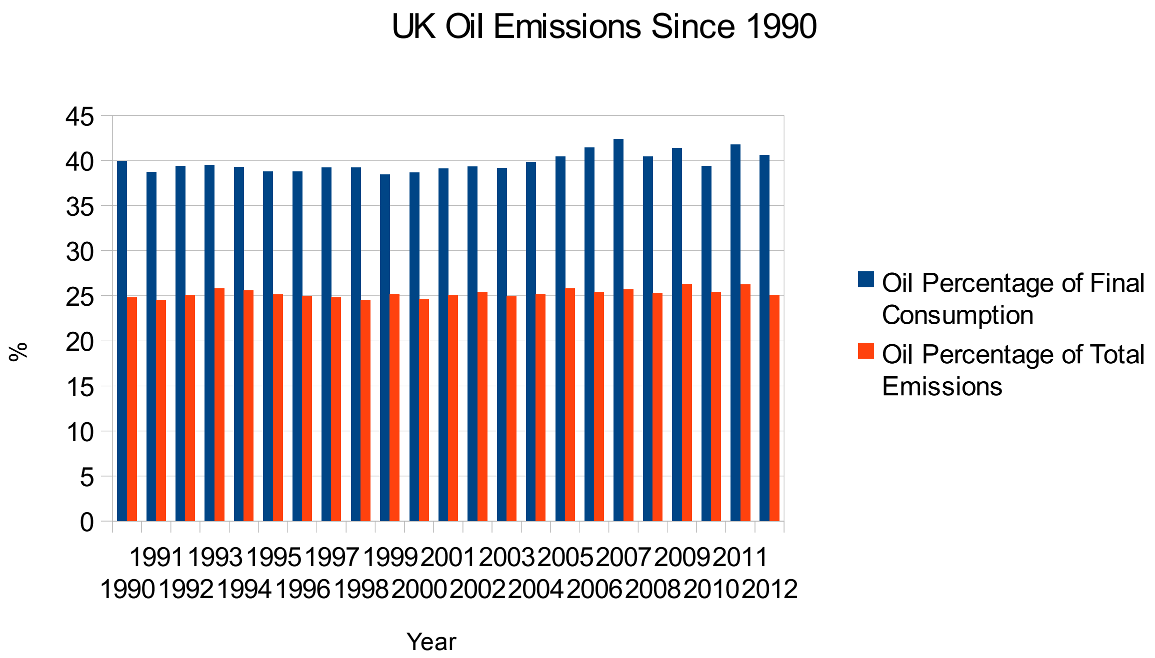


Figure 7: UK final consumption of Oil since 1990. Source (DECC, 2013d)

It is the removal of this heavy dependency on oil, and an investment in renewables instead, that means that the model suggested in this section would result in the UK easily meeting its CCA obligations, even when estimating emissions using LCA.

Conclusion

Using DECC's emission factors to estimate CO_2e emissions for the plans proposed by UKRER and CPDLCF, it would appear that the UK government is on track to meet its CCA legal obligations. Since it is these very same emission factors that the UK government will use to estimate their emissions, when answering the question, "Are the Government's Plans Sufficient In Order to Meet The Legislative Targets for Carbon Emissions Set Out Within the 2008 Climate Change Act?", the answer is yes.

In fact, the figures suggest that emissions are already at the relative level required. The UK's 2012 final consumption of 1724 TWh, which generated emissions of 572 $MtCO_2e$, equates to approximately 332g CO_2e per kWh. The final consumption of 1500 TWh predicted in UKRER, when measured against target emissions of 511 $MtCO_2e$, gives the following figure for per unit emissions required in 2020:

511 $MtCO_2e$ / 1500 TWh = 340.67g CO_2e per kWh.

Since the current relative emissions are under the target, the UK is right to pursue demand reduction measures at this stage, through policies such as the Green Deal and ECO, because if they can reduce demand sufficiently, they will have met their CCA legal obligations. In fact, if the assumption is that per unit emissions will remain stable, as they have done since 2000, then it is possible to calculate exactly to what level final consumption must reach in 2020:

Required demand = (1/332g CO_2e) * 511 $MtCO_2e$ = 1539.15 TWh

However, the conclusion must also be that the CCA 2020 target of 34% emission reductions is unambitious, since it appears to allow the UK to continue with 'business as usual'. In the very first assessment report by the IPCC (1990), 'business as usual' was defined to mean GHG emissions resulting in a per-decade temperature rise of approximately 0.3 degrees Celsius, a degree of warming unprecedented over the past 10,000 years. The main culprit is the UK's dependency on oil. It currently provides 40% of the fuel for the UK's energy, and this level of consumption has remained stable since 1990. Although both the plans for 2020 and 2050 slowly reduce this dependency (to 37% and 25% respectively), when using LCA factors to estimate emissions, it is this dependency on oil that results in a very different conclusion from that above. The plans will not result in the UK's emissions falling to a level where it complies with the CCA legal obligations. LCA predicts emissions for the plans laid out in UKRER and CPDLCF to be at 865.5 $MtCO_2e$ in 2020, more than 350 $MtCO_2e$ above the 2020 target, and 294.76 $MtCO_2e$ in 2050, which is 139.76 $MtCO_2e$ over the 2050 target. This is because LCA considers all emissions associated with any given energy generation technology, no matter where and how that emission occurs. Thus, DECC's use of emission factors does not give a true reflection of the UK's actual emissions. Furthermore, the implication is that this could be a global problem since all signatories to the UNFCCC use emission factors derived from the IPCC, just like the UK.

The model proposed showed that it is to renewables that the UK government should turn if they want to reduce emissions. However, figures from DUKES (DECC, 2013e), shown in table 25, show that the UK still has some way to go in order to achieve the RED 15% target. In 2012, 87% of the UK's energy came from fossil fuels, with 11.9% from what

DUKES term 'low carbon' technologies. Of this, nuclear contributed 7.4% and renewables, just 4.1%.

Table 25: UK fossil fuel and low carbon dependencies 2010 to 2012. Source (DECC, 2013e)

	2010	2011	2012
			Per cent
Fossil fuel	89.7%	87.5%	87.3%
Low-carbon	9.9%	12.0%	11.9%
Other	0.3%	0.5%	0.8%

With just 4.1% of final energy demand currently met by renewable technology, the UK is way down on the EU's member states average, which is approximately 13% of renewables meeting total final consumption (Eurostat, 2012).

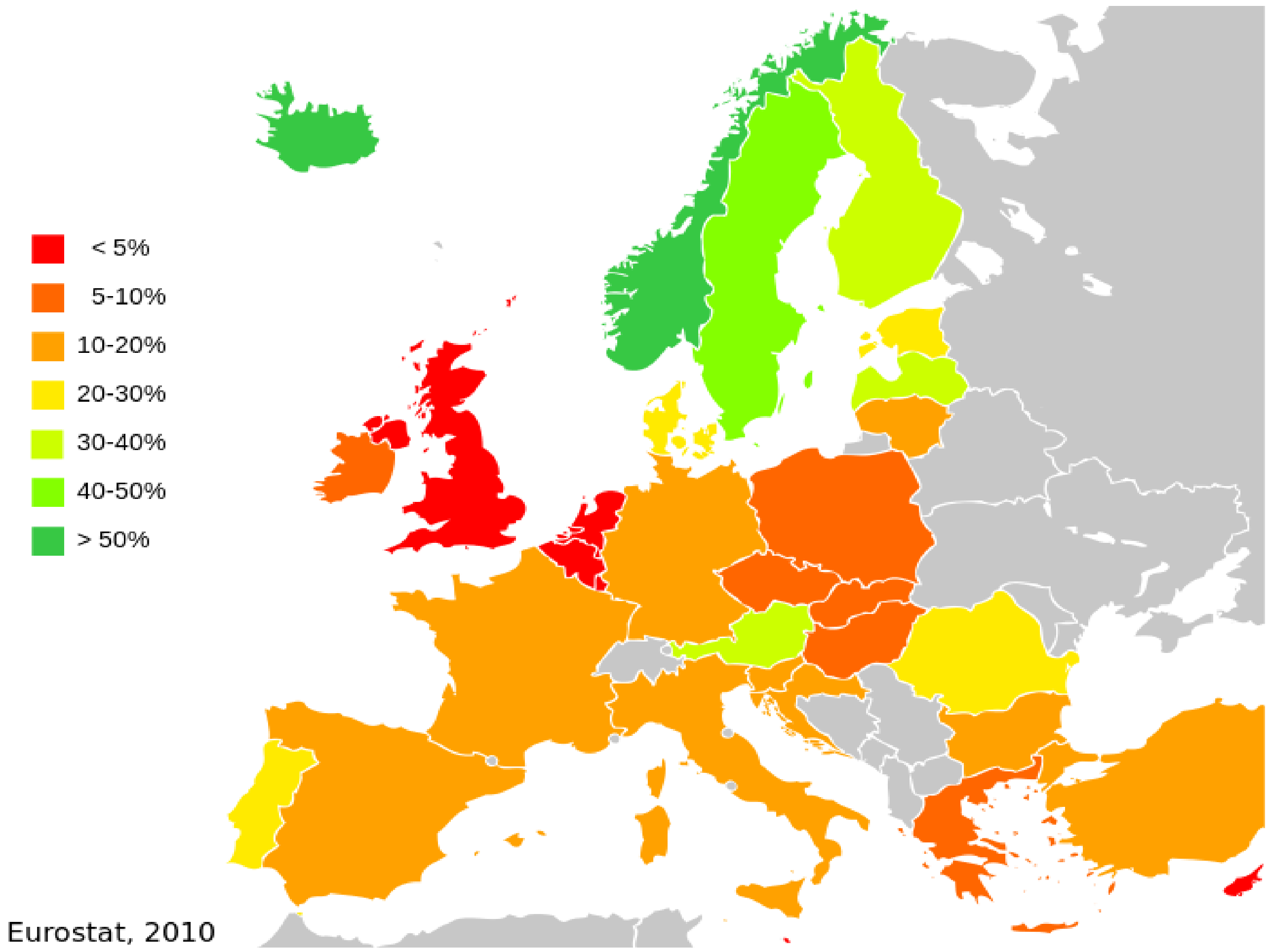


Figure 8: The renewable technology percentage of total final consumption for all 27 EU member states in 2012. Source (Eurostat, 2012)

Figure 8 shows that Norway achieves 61.4% of its energy demand through renewable energy and Sweden 47.9% (EC, 2013). Furthermore, a recent announcement from Spain showed that, due to favourable weather conditions, they met 42% of their final consumption in 2013 through renewables (RED ELÉCTRICA DE ESPAÑA, 2013). In the first quarter of 2013, Portugal achieved 70% of their electricity consumption through renewables (Redes Energéticas Nacionais, 2013). Such results show that it is possible for the UK government to lower its dependency on fossil fuels; they should turn to renewables instead. Indeed the final model proposed, which uses many of the renewable technologies discussed in the literature review, shows exactly how this could be achieved.

Limitations of This Study

Mackay (2009) suggests that the average daily energy use by a UK citizen is 125 kWh per day. The 2011 census put the UK population at 63,182,000, which the Office for National Statistics (ONS) (2012) say was a 7% increase on the data taken from the census in 2001. Assuming that the population will have increased similarly by 2020, it will have reached 67 million. Hence, using Mackay's figures for daily consumption and the population estimate, we have the following estimate for total UK annual consumption in 2020:

67 million x 125 x 365 = ~3057 TWh

The target from RED puts a legally binding target for 2020 of 15% of its total final consumption of fuel to be met through renewable technology. Using figures from UKRER, a figure of 1500 TWh for the total energy demand in 2020 was predicted. 3057 TWh is more than twice the estimate from UKRER. Why the discrepancy? The key is in RED's use of final consumption, rather than primary demand. Referring to DUKES, final consumption is defined as, “net of fuel industry own use and conversion, transmission and distribution losses.”, whereas primary demand includes, “energy used or lost in the conversion of primary fuels to secondary fuels (for example in power stations and oil refineries), energy lost in the distribution of fuels (for example in transmission lines) and energy conversion losses by final users (DECC, 2013e). Hence, the primary demand gives a better measure of total energy use, and it's this measure that MaCkay uses. According to DUKES, in 2012, final energy consumption was 148.2 million tons of oil equivalent (Mtoe), whereas primary energy demand was 214.3 Mtoe. In order to convert to kWh, Mtoe must be multiplied by 11630. This results in the following figure for total primary energy demand in the UK in 2012:

214.3 Mtoe x 11630 = ~2492 TWh

2492 TWh is much closer to MacKay's 3057 TWh. According to RED, their use of final consumption targets ensures efficiencies. It also means that the emission targets are tighter, because 34% of primary demand is a larger figure than 34% of final consumption. However, it is possible that this ignores possible reductions in emissions from primary demand. This could include minimising transmission and conversion losses. For example, DECC (2014c) suggests that the conversion losses at nuclear power stations are as much as two thirds the final energy delivered.

This study, and much of UK climate change policy are based upon a production model of carbon emissions. This model suggests that UK emissions have fallen by a fifth since the early 1990's. Unfortunately, this does not account for goods imported. Consequently, the CCC (2013a) suggests that in the period 1993 to 2010, rather than emissions falling by 21%, it is likely that the UK’s overall ‘carbon footprint’ has increased by around 15% instead. That's because imported carbon emissions having increased by 60%, as figure 9 shows.

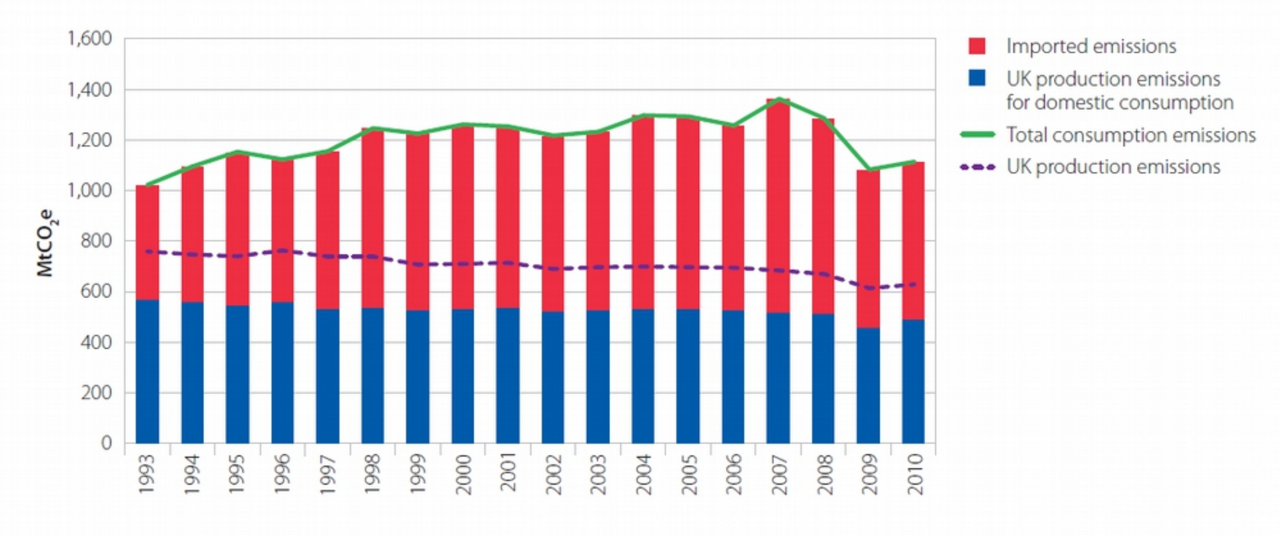


Figure 9: Consumption based model showing total UK imported and domestic emissions from 1993 to 2010. Source (CCC, 2013a)

Therefore, the CCC suggests that the UK government's approach to target setting, which relies on production based emissions, may be inappropriate. They propose that consumption modelling should be used too, so that the UK government can make policy proposals based upon the total carbon footprint of UK society. Hence, the production model used is a limitation. However since territorial emissions form the basis for the agreements made under the Kyoto Protocol, it is also a limitation of all governments signed up to the United Nations Framework Convention on Climate Change, including the UK.

The focus has been carbon emissions based on annual averages of predicted total final energy consumption, and not testing whether the models discussed meet the peaks and troughs of everyday energy demand. However, this is an important issue; supply must meet demand at all times. If the proposed model is to be considered, it needs testing to ensure that it meets this key requirement.

Similarly, consideration of other factors regarding energy supply, namely cost and security were beyond the scope of this thesis. The original proposal was going to consider such things. It asked this question, “Should the UK Government focus more on low-carbon energy supply technologies in order to address the 'trilemma' of cost, security and decarbonisation?” However, the thesis co-ordinator expressed concern as to whether, “it was achievable in the timescale and limited resources sometimes available”. Those concerns were acted upon; the focus became what was considered to be the biggest issue of the three, UK carbon emissions and the plans to reduce them. However, the hope is that a more thorough treatment of the subject has resulted.

Further Research

Areas for further research are two of the issues of the original thesis proposal, namely the cost of any carbon reduction programs, and their contribution to energy security.

The plan outlined in CPDLCF, and modelled by HREE, predicts an oil dependency for UK energy generation of 25% in 2050. Is this feasible? Figures from the IEA (2013) suggest that it may not be. They report that 1,600 oil fields provide 70% of today's global oil supply. These show a decline in oil production of 6.2%, which approximates to a halving in supply from these fields in 10 – 12 years. Oil supply is, therefore, a subject worthy of further research.

The CCC (2013a) draw attention to the limitations on the UK's method of modelling emissions. In particular, that the production based model used by the UK to estimate emissions does not include imported emissions. However, they also suggest that the consumption model, which does include such emissions is also limited because the estimates it uses are subject to a greater degree of error, due to there being no agreed international standard on how different countries record emissions data. Hence, there are inconsistencies with the data. Narrowing such inconsistencies, and investigating steps towards international standardisation of emissions data, is a furtive area for ongoing research, as is combining such a consumption based model with LCA.

In the literature review, Jacobsen and Delucchi (2009) raise concern as to whether there's the political will to invest in an intercontinental renewable energy system; a global energy super-grid. Such technology and politics involved in deploying such a system are worthy of further research. They also fear the lack of availability of some of the materials required for renewable technology systems. Research there would be interesting too.

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