The Power of Scotland Renewed

July 2009

Based on research conducted by Paul Gardner of Garrad Hassan
Written by Ben Murray

Supported by:

Contents

Introduction

Climate change has been identified as the greatest threat facing humanity during the twenty-first century; the IPCC's most recent report[1] advises that to limit temperature increases to 2.0 – 2.4°C above pre-industrial levels, the atmospheric concentration of CO_2-equivalent must be stabilised at between 445 and 490 ppm[2], with emissions peaking no later than 2015. This in turn requires that annual global emissions be cut by up to 85% by 2050 compared to a 1990 baseline.

The Climate Change (Scotland) Bill[3] expected to receive Royal Assent in July 2009 commits Scotland to cutting its overall greenhouse gas emissions by at least 80% by 2050. The legislation also includes interim emissions reductions targets of at least 42% by 2020[4]. Given that the power generation sector is the largest single cause of the greenhouse gases that are causing climate change,[5] it is vital that Scotland's electricity generating capacity is almost completely decarbonised over the coming decades.

This report seeks to:

1. Develop likely and practical scenarios for the supply of Scotland's electricity needs up to 2030
2. Assess the likely need for large-scale conventional nuclear or Carbon Capture and Storage (CCS)-equipped fossil fired thermal plant to deliver security of supply in such scenarios
3. Identify and assess alternative means of delivering security of supply by 2030 without reliance on nuclear or fossil-fired thermal plant.

Summary of findings

1. In the "business as usual" scenario (Case 1), we see considerable and rapid expansion of onshore wind capacity to 2020, passing the 2020 target for 50% of electricity consumption from renewables. Cockenzie, Hunterston B and Torness close under this scenario, while Longannet and Peterhead (or equivalent replacements) continue to 2030. Within this scenario, Scotland remains a net exporter of electricity, though exports fall significantly.

2. In Case 1, replacements for Cockenzie and the two nuclear plants are not essential. Security of supply becomes an issue following the closure of Torness, but could be maintained by improved system management, greater use of deferrable demand (facilitated by the planned roll-out of smart metering), increased generator and hydraulic capacity in existing hydro-power facilities and additional interconnector, storage or peaking capacity.

3. Case 1 does not involve any new fossil or nuclear capacity (other than 100% CCS replacement for Peterhead or Longannet). However, it does not deliver the required degree of decarbonisation without the deployment of CCS.

4. Under Case 2, there is continued growth in renewables capacity during the 2020s, primarily in the offshore wave and tidal sector taking Scotland towards an implied target of 90% renewable (as a proportion of consumption) by 2030. In Case 2, net exports are maintained and two large fossil-fired generating stations remain on the system, as in Case 1. To achieve high levels of decarbonisation requires either closure of these stations or the implementation of CCS. Analysis suggests that in this Case, closure would be technically feasible.

5. Security of supply is maintained in Case 2 primarily through investment in interconnector capacity (to England and other European neighbours), storage or peaking capacity of up to 6000MW (roughly twice the 2015 level of interconnector capacity). Since the large thermal stations only run for export or for peak supply, there is a risk that the operators will close them early on economic grounds. Such closure would not undermine the meeting of targets or security of supply in this Case.

6. If the rest of the UK is making equally rapid progress towards decarbonisation of electricity supplies (Case 3), it seems unlikely that this will be primarily based upon renewables. Even so, Scotland would need additional measures to maintain security of supply in comparison with Case 2. For example it could invest more heavily in renewables which are despatchable (such as biomass) or which incorporate storage, such as reservoir hydro or barrage tidal) and in additional deployment of storage or deferrable demand.

7. While Cases 1 and 2 assumed steady growth in Scotland's annual electricity consumption, requiring the continued operation of large-scale thermal generating plant, Case 4 develops two scenarios under which Scotland's annual energy demand falls significantly. These reductions, when combined with the additional offshore generating capacity of Case 2, enables renewable sources to generate up to 143% of its annual electricity demand. Scotland would export significant amounts of clean energy each year, though during periods of high demand and low renewables output, enough interconnector capacity would exist for power to be imported from neighbouring systems.

8. Case 5 sees the electrification of a proportion of Scotland's heat and transport demands. Electrifying 2.5 TWh/y of heat demand and 1 TWh/y of transport demand would add a notable amount to Scotland's annual electricity demand. However, the storable and deferrable nature of such loads, combined with the fact that periods of high heat demand tend to coincide with high renewables output, mean that security of supply is unlikely to be compromised and may well be enhanced.

9. Under Cases 4 and 5, Scotland's renewable output comfortably exceeds our annual electricity demand. While some thermal plant may be retained as peaking capacity, it is entirely plausible that no large-scale fossil fired generating capacity would remain online by 2030.

Decarbonising our power supply

Cases 1 and 2 developed by Garrad Hassan foresee the continued operation to 2030 of two of Scotland's current conventional power stations, Longannet and Peterhead, or equivalent replacements. Peterhead is gas-fired, while Longannet is powered by coal.

To achieve the goal suggested by the UK Government's advisory Committee on Climate Change as essential to meet long terms climate targets – that of largely decarbonising electricity production by 2030 – any remaining fossil-fuelled thermal plant must be fitted with carbon capture and storage technology, at a minimum in line with the timetable proposed by the Committee – for full coverage of CCS by 2025. If CCS technology can be applied sooner, it raises the prospect that Scotland could develop an export market in this technology, rather than importing it from elsewhere. The analysis set out here would suggest that to play a role in such a market, Scotland should seek to ensure rapid and full deployment of CCS at Longannet as part of any refurbishment, and only permit refurbishment or replacement thermal capacity at Longannet or elsewhere on the basis that it incorporates full CCS.

However, the scenarios described below demonstrate that renewable energy sources (on and offshore wind, hydro, wave and tidal, biomass and energy from waste) can supply very high proportions of Scotland's domestic electricity demand. This is also the case taking into account environmental safeguards for sensitive sites and habitats[6]. The scenarios suggest that by 2030 there will be significantly less – if any – need for thermal capacity in Scotland.

Chapter 2: The policy context for Scotland's energy future

The decisions that will influence the direction of Scotland's energy future are influenced by a range of factors, including Scottish, UK and European energy policies on climate change targets, renewable energy potential and energy efficiency. This section of the report will examine each in turn.

The Scottish policy context

Climate Bill

Perhaps the single most important political factor is the target set out in the government's Climate Change (Scotland) Bill[7]. Acknowledging that "climate change is one of the most serious threats facing Scotland and the world" it now commits Scotland to cutting its emission of greenhouse gases by at least 42% by 2020 and 80% by 2050 – in comparison with 1990 levels[8].

In addition to establishing targets for 2020 and 2050, the Bill requires Scottish Ministers to set – under secondary legislation – annual targets between 2010 and 2050.

Renewable electricity targets

For some years, successive Scottish administrations have been increasing the proportion of electricity supplied from renewable resources. The previous Labour/Liberal Democrat administration established a target of 40% of renewable electricity by 2020 with an interim target of 18% by 2010[9], and the current Scottish Government has increased the 2020 renewable electricity target to 50% with an interim target of 31% by 2011.[10] In September 2008, the government announced that it was on track to achieve the 2011 milestone target.[11]

The main driver encouraging increases in Scottish renewables capacity is the Renewables Obligation (Scotland), or ROS. This mechanism is designed to incentivise the roll-out of renewable energy technologies by placing an obligation on licensed electricity suppliers to source an increasing proportion of electricity from renewable sources. The ROS, introduced in 2002 and set to remain in place until at least 2027, only applies to renewable power installed since 1990 – large-scale hydro schemes built before that time do not qualify, for instance.

The ROS operates in conjunction with similar obligations covering other parts of the UK. Renewables Obligation Certificates (ROCs) are issued to eligible generators for each MWh of capacity, and either sold along with a MWh generated or traded separately, with the price determined by the level of supply in the market. Should a supplier not have enough ROCs to meet their obligation, they must pay the appropriate buy-out price for the remainder.

Originally deemed to be "technology neutral", the ROS did not discriminate between different sources of renewable energy. This led to the installed capacity of onshore wind, the most mature of the new renewable technologies, increasing much more quickly than – and arguably at the expense of – emerging technologies such as wave and tidal power. Scottish Ministers, in agreement with the UK Government, moved away from this technology neutral stance towards a banded system that provided additional support to emerging marine technologies.

In another move that indicated that Ministers would like to see increased focus on the offshore renewable sector, the Scottish Government announced in April 2008 the establishment of the Saltire Prize[12], a £10million award for the first team to develop a successful wave or tidal energy device capable of producing 100GWh during a continuous two year period between 2010 and 2014.[13]

It is important to note that renewables capacity is substantial even taking into account environmental safeguards for sensitive sites and habitats. The Scottish Executive commissioned a study in 2001[14] that considered areas of Scotland where wind speeds were high enough to make wind generation economically viable and then identified constraints such as sensitive wildlife and landscape areas and MOD low fly zones. Environmental and MOD constraints together covered 70% of the Scottish land area. Even with these constraints, onshore wind alone was estimated to be capable of providing around 45TWh, which is equivalent to Scotland's entire projected electricity consumption in 2020. Onshore wind in theory could therefore meet the 2020 renewables target of around 17TWh and the additional 20TWh energy gap created by planned conventional plant closures.

Renewable heat policy
The renewable targets discussed above only apply to electricity demand, not to overall energy demand. Since electricity constitutes only around 18%[15] of final energy demand[*], there is clearly a great deal of scope for non-electrical renewable energy generation. The European Union has set a 2020 target for 20% of final consumption of energy to come from renewable sources (see below).

The Scottish Government consulted during late 2008 on a framework for the development and deployment of renewable energy in Scotland[16], and sought views on meeting its EU 20% target by 2020. Respondents recommended that Scotland will need to produce at least 11% of heat from renewable sources in order to meet the overall target of 20%. The Climate Change (Scotland) Bill requires Scottish Ministers to promote the use of heat from renewable sources. Policies which incentivise the recovery and use of waste heat might encourage the deployment of decentralised CHP installations (particularly using biomass, biogas or segregated biomass waste) at levels significantly greater than in the scenarios described.

[*] Based on final energy use at a UK level

Energy efficiency strategy

The renewable electricity and energy targets discussed above deal with the supply side of the energy equation. An energy efficiency strategy or action plan would address the demand side and ensure that demand is reduced and energy used as efficiently as possible. An energy efficiency and microgeneration strategy is still not in place despite repeated commitments and consultations since 2004.[17] However, the Scottish Government is supporting the following energy efficiency initiatives:

- improvements in building standards, underpinned by the findings of an expert panel;[18]
- a Home Help Service, designed to provide households with advice on energy efficiency and microgeneration installations;[19]
- funding for a network of energy advice centres, offering households and small businesses advice on sustainable energy issues;[20]
- an Energy Assistance Package aimed at helping the one million Scots living in fuel poverty;[21]
- an annual £1million prize fund to encourage innovation in developing low-carbon housing.[22]
- the Home Insulation Scheme that seeks to improve the energy efficiency of houses through an intensive area-based approach to promoting and installing insulation and other energy saving measures.[23]

The Climate Change Bill now makes an Energy Efficiency Action Plan a statutory requirement, and one is expected before the end of 2009. Improving the efficiency of energy use within Scotland is not only a key part of measures to tackle climate change and improve security of supply, it can also help to tackle fuel poverty in the domestic sector.

The present Scottish Government's stance on nuclear power

While energy policy – including the construction of generating capacity – is a reserved issued under the 1998 Scotland Act,[24] under section 36 of the Electricity Act 1989, a consent is required from the Scottish Ministers for the construction, extension or operation of a generating station of over 50MW in capacity.[25] This, in effect, gives Scottish Ministers a veto over the construction of any new large-scale electricity generating capacity, be it nuclear, fossil-fuelled or renewable.

The manifesto on which the SNP were elected to power in May 2007 reiterated opposition to the construction of new nuclear power stations: *"An SNP government will make clear that Scotland does not require a new nuclear power station."*[26]

The EU/UK policy perspective

Scotland's energy relationship with the United Kingdom

Schedule 5 of the Scotland Act 1998[27] specifies which powers are reserved to the UK Government, and devolves the remainder to Scottish Ministers. The following is a partial list of the energy powers reserved and devolved under the Act.

Reserved powers (UK)

- Generation, transmission, distribution and supply of electricity;
- The ownership of, exploration for and exploitation of deposits of oil and natural gas, and offshore installations and pipelines;
- Coal, including its ownership and exploitation, deep and opencast coal mining and coal mining subsidence;
- Nuclear energy and nuclear installations, including nuclear safety, security, safeguards, and liability for nuclear occurrences;
- Energy conservation by prohibition or regulation.

Devolved powers (Scotland)

- Environmental protection and pollution under the provisions of the Environmental Protection Act 1990 in relation to coal, nuclear, and oil and gas;
- Planning approval of the development of energy infrastructure under the various Town and Country Planning (Scotland) Acts and relevant sections of the amended Electricity Act;
- Emergency planning at civil nuclear power stations;
- Environmental regulation;
- Encouragement of energy efficiency.

The UK's attitude towards nuclear power

The UK Government produced an energy white paper in 2007[28] which emphasised the need for low-carbon energy technologies, including renewables and coal with CCS. However it also supported nuclear power, placing the UK Government on a potential collision course with the then Scottish Executive, which had committed to not support new nuclear power stations without a resolution of the waste management issue. As noted above, the present Scottish Government has made clear its opposition to any new nuclear power stations being built north of the border.

In April 2009, the UK Government published a list of potential sites for new nuclear power stations; none were in Scotland.[29]

The UK Government's stance on Carbon Capture and Storage

The UK Government recently announced that they would consult on a requirement for any new coal-fired power stations within England and Wales to demonstrate the ability to capture and store the carbon emissions on a portion of the plant's output, and that all new coal-fired stations will have to commit to retrofitting CCS on the plant's entire output by 2025, subject to the technology being ready.[30]

UK Government's energy efficiency objectives

The UK Government's 2007 energy white paper acknowledged that using energy more efficiently was the fastest and most cost-effective way of cutting

CO_2 emissions, in addition to helping to improve productivity and security of supply. The updated National Energy Efficiency Action Plan[31] that was produced in 2007 includes targets for an 18% reduction in delivered energy by 2030.

The Office of Gas and Electricity Markets (OFGEM)
OFGEM is the UK Government's energy regulator for electricity and downstream natural gas markets. Its role in approving transmission and interconnector capacity affects the expansion of Scotland's renewable industry and the ability for Scotland to export or import electricity from other parts of the UK. OFGEM are also trialling the use of smart metering in 18,000 homes to establish the impact of such meters on household use of gas and electricity as part of plans for a roll-out of such meters across the building stock over the coming decade.[32]

Scotland's energy relationship with the European Union
As well as the reserved energy functions that impact upon Scotland, the European Union has developed an energy policy for the entire community of member states. The policy was agreed by the European Council in March 2007, and seeks to achieve the threefold energy objectives of sustainability, competitiveness and security of supply. To this end, the EU has adopted the so-called "20-20-20" initiative, consisting of:

- Reducing GHG emissions by 20%;
- Increasing the share of renewables in energy consumed to 20%;
- Improving overall energy efficiency by 20%;
- Each of these to be achieved by 2020.[33]

It is notable that the renewables target of 20% refers to energy consumption, not electricity. Given that electricity itself only makes up a small proportion of energy consumption, this is a challenging target. The 20% target applies to the entire European Union; different member states have been allocated different renewables targets to achieve. The UK has been told that its renewable energy target is 15%; Scotland has adopted a renewable energy target of 20% by 2020 (see above).

Other EU energy policies include establishing 12 demonstration sustainable fossil fuel plants across Europe and a target for 10% of road transport fuel to be derived from biofuels. However, there is concern that increased bioenergy crop production should not be at the cost of sensitive habitats both in UK and internationally. The EU policy also asks all member states to work towards having CCS technology deployed in all new fossil fuelled power plants by 2020.[34]

In addition to this Europe-wide energy policy, the EU has introduced a number of directives that have a direct impact on Scottish energy policy. A prime example is the Large Combustion Plant Directive (LCPD)[35] that was adopted by the European Parliament in 2001. This directive places constraints on the operation of thermal power plants larger than 50 MW, and requires plants "opting in" to the directive to meet specified emission standards.

Scottish Power has already announced that its plant at Longannet will opt in to the directive, requiring flue gas desulphurisation equipment to be fitted, while the smaller Cockenzie plant will opt out, limiting its running hours and forcing its eventual closure by 2015.

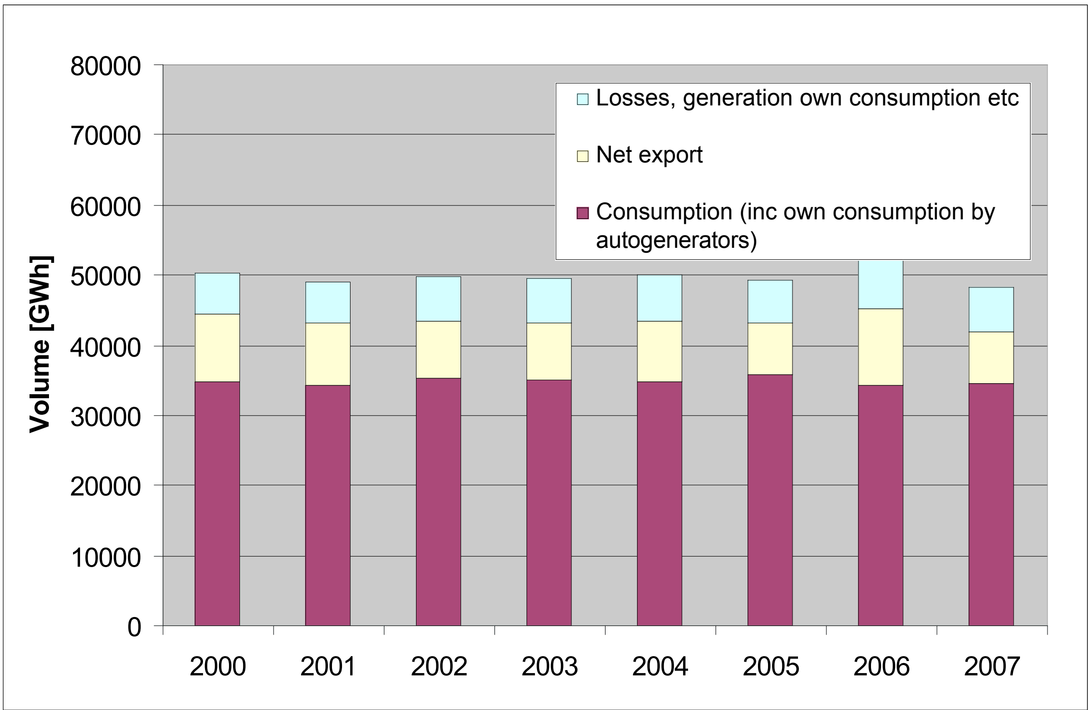
The LCPD itself, along with a number of other European directives, is set to be recast as the Industrial Emissions Directive that will have an impact on the operation of all but the smallest combustion plants. The directive will set emissions standards for a range of pollutants including oxides of sulphur and nitrogen, dust and carbon monoxide. Earlier this year, MEPs were blocked in an attempt to amend the directive to include a binding CO_2 emissions performance standard that would have capped carbon dioxide emissions per unit of power output.

Another key European Union initiative that may have a significant potential impact on Scottish energy policy is the EU Emissions Trading Scheme (EU ETS). This cap and trade scheme relies on EU member states allocating national emissions caps for a number of high carbon emitters. Those installations able to operate within their cap can sell excess emissions allocations to installations needing to exceed their limits. Early phases of the EU ETS were largely ineffective in reducing overall carbon emissions due to overallocation of emissions permits.

Phase III of the ETS covers the period from 2013 to 2020, and the rules governing this phase were approved by the European Parliament in December 2008. They require electricity generators in all but a small number of member states to buy all their emissions permits at auction; this is in contrast to Phases I and II, when permits were allocated for free. The supply of permits during Phase III should stimulate the development of low-carbon electricity generation – including the use of CCS – to remain within the cap.

Chapter 3: The present situation

Electricity Generation and Consumption
The most recent comprehensive information is available on the Scottish Government website[36], and is reproduced here in Figure 1.1 (see also Table 1.1, in modified form in Appendix I). These figures generally agree with those in the recent report by energy consultants Wood MacKenzie[37], but include 2007.



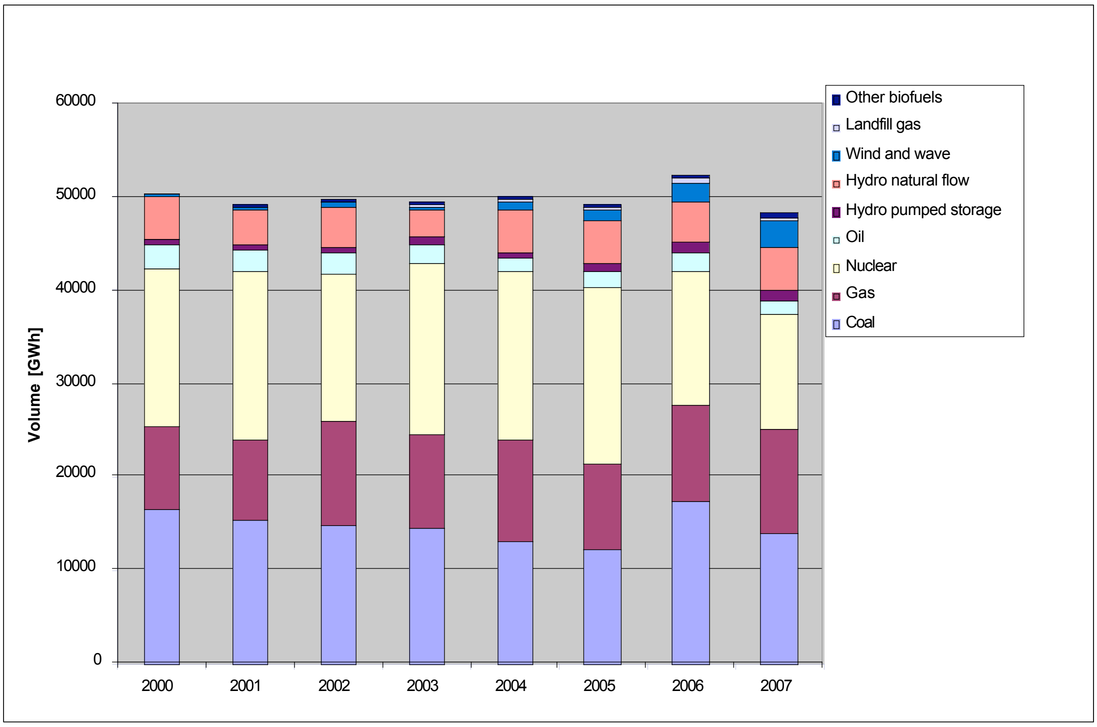
Note 1: Consumption of electricity by the generating plant is shown as 'generation own consumption' and is included within 'losses'.
Note 2: Electricity consumption within industrial plants which generate some of their own electricity ('autogenerators') is included within 'consumption'.

Figure 1.1 Electricity generation, export and consumption in Scotland, 2000-2007

On average over the period 2000-2007, Scotland has used approximately 70% of the electricity generated within its boundaries, exported 17%, and the remaining 13% has been consumed within the major generating plant or within the transmission and distribution systems before reaching customers.

Electricity Generation by Source

Figures from the Scottish Government website[38] are produced here in Figure 1.2 (see also Table 1.2, in Appendix I in modified form). Again, these generally agree with the Wood McKenzie data.



Note 1: 'Wind and wave' is virtually entirely wind generation.

Fig 1.2 Electricity generation in Scotland subdivided by source, 2000-2007

Electricity Generating Capacity

The latest information on electricity generating capacity in Scotland is listed in Table 1.3 (overleaf)[39 40]. There are some minor discrepancies between sources, due principally to differences between actual capacity, design capacity, and contracted transmission entry capacity. Table 1.3 attempts to reconcile these, though the differences are not significant in the context of this report. Table 1.3 also omits relatively small thermal generators (classed as oil and gas turbines in some sources) which are expected to contribute little to annual electricity production, but are locally significant in certain island locations.

Generation type	**Capacity [MW]**
Conventional thermal and CCGT	**5,100**
Longannet	2,400
Cockenzie	1,200
Peterhead	1,500
Nuclear	**2,410**
Hunterston B	1,210
Torness	1,200
Pumped storage	**740**
Renewables (excluding pumped storage)	**2,980**
Hydro (excluding pumped storage)	1,383
Wind onshore	1,408
Wind offshore	10
Biomass	79
Energy from Waste	100
Wave	<1
Total	**11,230**

Table 1.3 Electricity generating capacity in Scotland

Chapter 4: Meeting current targets (Case 1)

Introduction
This section sets out the likely course of events under 'business as usual' assumptions, aimed at meeting current targets or aspirations in EU, UK and Scottish policies. It is assumed in this section that there is no significant increase in the use of electricity for heating or for transport. These issues are discussed in subsequent sections.

It is also assumed here, for simplicity, that any significant increase in the use of Combined Heat and Power (CHP) projects can be included within the assumptions[41] about the general category of conventional thermal generation. Benefits for climate mitigation of such projects arise from displacement of fossil fuels – notably gas – for heating, rather than within the electricity system.

Electricity Demand
From Table 2.1, electricity demand within Scotland is relatively flat. The total for 2007 (34,463 GWh) is very close to the mean for 2000-2007 (34,863 GWh), and no significant long-term trend can be discerned.

In their recent report, energy consultants Wood Mackenzie[42] forecasts that Scottish gross electricity consumption, i.e. including losses etc but excluding exports, will have increased by 9% from 2008 to 2020 (from 42 to 45.9 TWh). This is based on assumptions about demand growth within sectors of the economy, rather than projections of recent demand growth. This is a reasonable estimate for the 'business as usual' case (but see comments on the effect of the current recession, below). However this would not meet UK or EU targets for energy efficiency and demand reduction, which imply a reduction in gross consumption of around 18% by 2030. The effect of sustained demand reduction can be considerable, and is investigated in Section 5 (Case 4).

Wood Mackenzie assumes that electricity demand growth slows towards 2020, to 0.5% per year, which if continued would imply a further growth of 5.1% by 2030, to 48.2 TWh. Again, this is a reasonable 'business as usual' case.

Indications are that the current recession has had a significant impact on electricity consumption in the UK. However, it is too early to tell what the sustained effect in future years will be. Here, it has been assumed that the net effect is zero net demand growth for Scotland in 2009 (in place of 0.9% assumed in the Wood McKenzie report), followed by return to the growth pattern assumed in that report. The net result is that Scottish gross consumption of 42 TWh in 2008 increases to 45.4 TWh in 2020 and 47.7 TWh in 2030.

Sustained efforts to electrify transport or heat provision would of course produce significant changes in these figures by 2020 and 2030: this is considered further in Section 5 (Case 5).

As well as annual energy consumption, it is also important to consider peak demand. Currently this is around 6100 MW[43]. In this study it is assumed that this does *not* increase significantly in future, because of increased use of deferrable loads and 'smart metering'. As it is reasonable to assume in a 'business as usual' case that peak demand grows in proportion to annual demand, which would imply a peak demand of around 6900 MW in 2030. Therefore the assumption used here of no change in peak demand effectively assumes around 800 MW of deferrable demand available at peak periods, or similar measures.

Conventional and Nuclear Generation

The expected future developments of conventional generation are as follows.

Cockenzie has 'opted out' of the Large Combustion Plants Directive (LCPD) and therefore must close by the end of 2015 at the latest, or after 20,000 hours of operation from 1 January 2008 (i.e. roughly equivalent to two years' continuous operation). It is assumed here that it closes at the end of 2015.

The Industrial Emissions Directive is currently under negotiation[44], and in principle could affect decisions on closure dates for Longannet and Peterhead around 2016. This is speculative, and is not included here as a specific assumption. The 'base case' assumption here is that those plants, or replacements of similar size, continue through to 2030. Such replacements could be coal, or combined-cycle gas turbines (CCGT). For the purposes of this study, it is not necessary to distinguish, as either would have at least the technical capabilities of the existing stations.

National Grid assumptions[45], based on known interest from project developers, include an additional 250 MW of thermal generation and 250 MW of CHP in the Scottish Power area from 2019. There is no indication of what form these projects might take. In the context of this study and the uncertainty of other factors in 2019, these possible projects will not have a significant effect on the conclusions of this study, but are included for consistency.

Hunterston B is assumed to close in 2016, and Torness in 2023[46].

Renewables

The existing hydro generation is assumed to continue operating to 2030. In practice, some will no doubt be extensively refurbished within this period, but there is no basis on which to assume any significant reduction in this capacity. In fact refurbishment would be likely to result in a small increase in capacity at some stations.

It is possible that some existing large reservoir hydro stations could be modified to increase their nominal output power. This would allow them to produce more power when needed, which would provide additional 'peaking' capacity. As reservoir size would be unchanged, their annual production would be unchanged. This possibility has not been included in the analysis.

National Grid, on the basis of known interest from project developers, assumes a modest increase in hydro generation of 49 MW in 2009, up to 62 MW in 2019[47]. This is adopted in this report. A recent Scottish Government study [48] identified a further economically-viable resource of 657 MW, and so Garrad Hassan has concluded that the National Grid figures underestimate the future hydro contribution and need modification. The energy price assumed as the base case in the Scottish Government study appears lower than could be expected in future years, and sensitivity studies indicate that for an energy price of around £100/MWh (including ROCs), the new hydro resource is around 1000 MW. Therefore Garrad Hassan has assumed a further 750 MW is added between 2015 and 2030 (i.e. 50 MW per year), as rising energy prices make remaining sites economic.

Pumped storage capacity is assumed to remain constant in this analysis, though it is known that Scottish and Southern Energy have plans to convert the Sloy station to pumped storage operation.

National Grid predicts major increases in onshore wind, based on known interest from project developers. The additional capacity reaches 7605 MW in 2019[49]. Garrad Hassan believes this may be an overestimate, and therefore has adopted a more conservative assumption of an additional 6000 MW by 2018, remaining constant thereafter (total 7400 MW).

National Grid also assumes that 1000 MW of offshore wind is added in 2019. Garrad Hassan believes this figure is reasonable in size and timescale, so it is adopted in this report.

Similarly, National Grid assumptions[50] are adopted here for:

- biomass (a further 52 MW expected in the near future, but no further expansion of this category to 2030)
- energy from waste (no expansion, though new plant could be included within the 500 MW of unspecified additional thermal and CHP plant assumed elsewhere in Case 1).

Wave and tidal capacities in future are extremely difficult to estimate. Based on developers' plans, National Grid[51] assume only a further 23 MW of wave generation in 2019. This figure is adopted here, but the issue is discussed further below.

Note that wave and tidal are lumped together in this document. This is because their characteristics relevant to this study are very similar (large projects, similar types of location, similar stage of development), and given the uncertainties about their rate of deployment it seems unjustified at present to attempt to distinguish between them.

For comparison, the total renewable energy generating capacity assumed by Wood Mackenzie for their base case is 9 GW by 2020, the majority of which is onshore wind. This report assumes 10.3 GW by the same date.

It must be understood that predicting new renewable generation capacity between 2020 and 2030 will be extremely inaccurate, particularly for the technologies that are currently at demonstration stage. This could only be addressed by considering a wide range of alternative scenarios. However, in mitigation it can be pointed out that many of the less certain renewable technologies share the same characteristics as onshore wind (low load factor, variable on timescales of hours, no inherent storage capacity). Therefore, in the context of this study, the total volume of the variable renewables (onshore wind, offshore wind, wave and tidal) is more important than the way in which the total is split between each technology.

Net Result: Generating capacity and security of supply

Generating capacity

The net result is shown in Figure 2.1 and Table 2.1 (see Appendix II). The figure is dominated by the increase in wind capacity, onshore and offshore, and by the closing of Cockenzie, Hunterston and Torness.

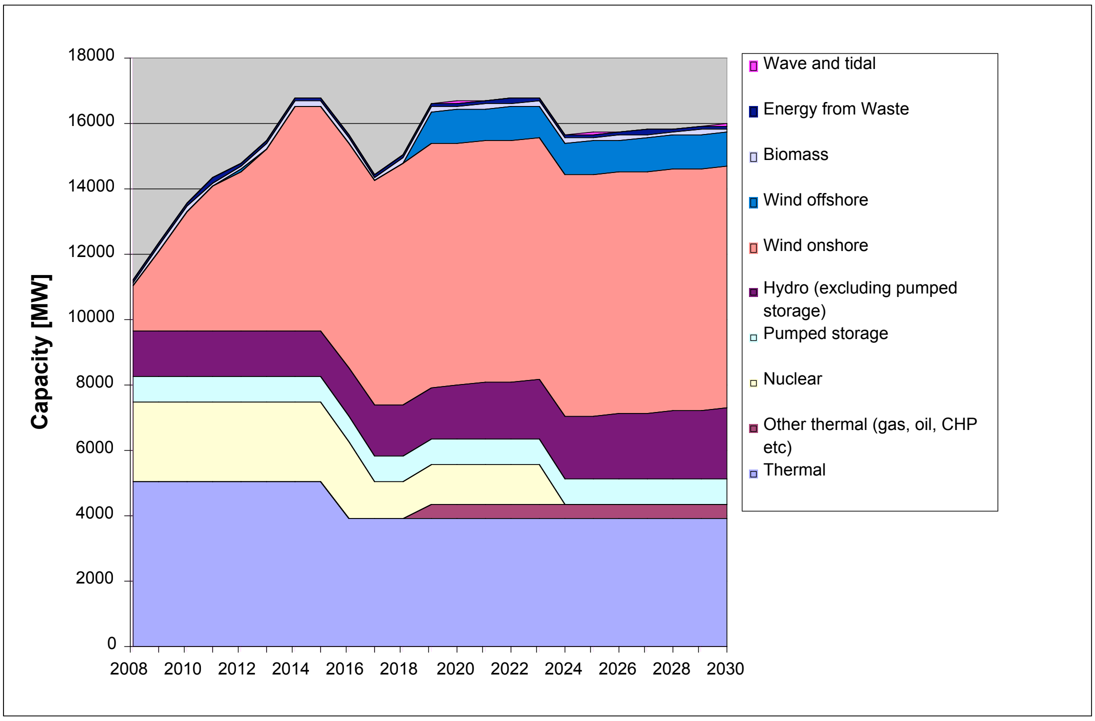


Figure 2.1 Generation capacity to 2030, Case 1

The picture of course depends on the continued use of Longannet and Peterhead to 2030, or their replacement by similar plant.

In simple capacity terms, the total generating capacity to 2030 is significantly greater than at present, and greater than the expected increase in demand. However this is misleading: a large part of this is 'non-despatchable' wind generation.

Security of supply: available capacity

This report provides a basic analysis of security of supply. We acknowledge that anything more sophisticated could require a major probabilistic study beyond the scope of this work. Indeed the methodologies to do this in the presence of large amounts of renewables generation are still under development. A method adopted by the UK Department for Energy and Climate Change (DECC) for the whole of the British system[52] allocates a 'de-rated capacity' to each type of generation, based on 'historically experienced average forced outage rates during peak periods' (70% for existing nuclear, 90% for other conventional generation), and estimated capacity credit values[53] for each of the renewables. The results presented in the DECC analysis are in insufficient detail to allow a simple conclusion to be drawn for the Scottish system alone, though it is relevant to note that no significant reduction in security of supply is anticipated under most scenarios.

A simple and highly conservative analysis for Scotland, based on Figure 2.1 and assuming that onshore wind, offshore wind, wave and tidal and half the hydro capacity could all be at zero output at times of high electricity demand, shows that the remaining generating capacity drops to approximately 6800 MW in 2017 and 6300 MW in 2024. This is significantly less than at present, and similar to the assumed peak demand of 6100 MW.

The capacity of the connections to England currently totals 2200 MW, to be increased to 2800 MW in 2010, 3300 MW in 2012, and with further increases likely in 2015[54], and the interconnector to Northern Ireland is effectively around 450 MW. Therefore at times of high electricity demand and low renewables production, available Scottish generation capacity will roughly match Scottish demand, without significant import, and the Scottish system will have sufficient interconnection capacity to guard against the planned or unplanned loss of a single interconnector circuit (up to 2200 MW), or the largest generator (Longannet, 2400 MW in total). Security of supply will therefore be adequate in normal circumstances, despite the variability of the renewables.

However the concurrent loss of two elements of the power system (for example, two large generators at one time, or the loss of a large generator coupled with the loss of an interconnection circuit) may be an unacceptable risk by 2017 (i.e. on closure of Cockenzie and Hunterston), and almost certainly by 2024 (on closure of Torness).

This does not necessarily mean that additional conventional or nuclear capacity is needed within Scotland by 2017 or 2024: other means may be more appropriate. In such an incident there may be a need to temporarily replace 1000 to 2000 MW of supply to maintain security. Possible alternatives which could contribute to, or deliver this can be split into those which are primarily limited by resource or availability, and those which are limited only by cost.

Those limited by availability are principally:

- greater reliance on variable renewables (detailed probabilistic analysis, including the increasing operational experience with renewables, is likely to allow significantly more reliance to be placed upon renewables than with the very simple and conservative analysis above).
- significantly increased use of deferrable demand, especially at domestic and commercial level via remote short-term control of heating and cooling loads;
- increasing short-term output of reservoir hydro by increasing generator and hydraulic capacity, without increasing reservoir size (i.e. increasing power without increasing energy);
- additional pumped storage hydro.

Note in particular that many studies on the ‘capacity credit’ (or other similar measure of reliability) of wind generation spread over a large area indicate that wind does provide a significant contribution to system security at times of peak demand. A review of several studies indicates a figure of around 30% of wind capacity, dropping to 10 - 15% at very high wind penetrations[55]. Even assuming a contribution of only 10% of installed wind capacity would improve the situation by 700 MW in 2017 and 800 MW in 2024. The greater the mix of different renewables, the greater the contribution to system security.

Similarly, at the periods of concern (i.e. high demand, generally on winter afternoons and early evenings), a substantial part of the demand will be heating. A conservative assumption that 5% of demand at these times could be made deferrable would provide around 300 MW.

Currently there is no estimate available of the possible contributions from increased hydro output or new pumped storage.

Those limited by cost only are principally:

- increased interconnector capacity;
- more ‘peaking’ plant such as open-cycle gas turbines;
- adding storage capacity, such as compressed air or battery storage.

Current thinking on increasing interconnector capacity within the transmission system owners[56] indicates a sub-sea HVDC connection of 1800 MW on the west coast by around 2015, and a similar link on the east coast by around 2018, if required.

It is not possible to estimate the costs of additional peaking plant without detailed calculations of the possible operating regime. Similarly, the economics of available storage technologies in this context cannot be estimated with any accuracy.

Given the timescales for new generation and transmission capacity, these alternatives need addressing now, but this issue should not be considered a 'show-stopper' for current policies.

Security of supply: sudden loss of renewables production

There are other separate concerns which are often expressed about security of supply with high renewables penetration. The first is the 'sudden loss' issue, i.e. where a large part of the renewable generation is suddenly lost due to a common cause. This can be discounted as a problem, as renewable generation consists of relatively small generators of differing types, spatially distributed. The most severe event could be the sudden loss of a 1000 MW offshore wind farm, for example, due to failure of the connection to shore, but this is less severe than the worst-case event for which the power system is currently designed.

Security of supply: ramp rate

The second concern is 'ramp rate', i.e. the sustained increase or decrease in renewables production, typically over an hour or more, at a rate which is greater than the conventional generation can compensate for. Increases should not be a problem, as the system operator can instruct the renewable generation to limit ('constrain') the rate of increase of output. It is assumed here that the system operator will have this ability, and also has visibility of the output of a large fraction of the renewables generation in near to real time.

A decrease is harder to handle. The worst case is generally assumed to be where wind speeds become so high that a large number of wind turbines shut down from full output. However, experience so far with storm events indicates significant spatial 'smoothing' of the effect. More importantly, wind forecasting is now sufficiently accurate that such events can be seen approaching, and the output of the wind farms can be reduced gradually in advance.

Constraining the output of renewable generation is of course not to be done lightly: there will be a significant economic cost, which may introduce uncertainty into decisions about investment in renewable generation, and in any case is eventually borne by electricity consumers.

Annual electricity production

The annual electrical energy produced by each category of generation is shown in Figure 2.2 (and in Table 2.2. in Appendix II)

These figures are produced by multiplying the generation capacity for a given year by an assumed capacity factor. A capacity factor of 1.0 would correspond to the plant producing at full output for the entire year. Particularly for the thermal and nuclear generation, the capacity factor for any one year can be significantly different, due to forced or scheduled outages. The capacity factors for renewables will also vary from year to year.

The figures assumed here are as follows:

- Conventional thermal generation: 0.55 (historic average 2000-2007 for Cockenzie, Longannet and Peterhead)
- New conventional thermal generation: also 0.55 (in reality, new thermal generation is expected to achieve a significantly higher capacity factor, but in the absence of detailed economic modelling of generator costs it is reasonable to assume that higher capacity factors for new generation will be accompanied by lower capacity factors for the existing thermal generation)
- Nuclear generation: 0.78 (historic average 2000-2007 for Hunterston and Torness)
- Pumped storage: 0.12 (historic average 2000-2007)
- Hydro: 0.36 until 2020 (the historic average 2000-2007), increasing gradually from 2020 to reach 0.41 in 2030 (the average figure for potential new schemes identified by FREDS for the Scottish Government[57] is 0.48)
- Onshore wind: 0.35 in 2008, decreasing to 0.27 by 2019 as capacity increases (Garrad Hassan estimate, intended to reflect the fact that the best sites can be expected to be used first)
- Offshore wind: 0.40 (Garrad Hassan estimate, based on experience elsewhere)
- Biomass: 0.7 (Garrad Hassan estimate, assuming plant run effectively as baseload, with allowance for outages and variability of fuel supply)
- Energy from waste: 0.7 (Garrad Hassan estimate, assuming plant run effectively as baseload, with allowance for outages and variability of fuel supply)
- Wave and tidal: 0.35 (Garrad Hassan estimate for mature technology)

The assumed capacity factors for biomass and waste could be markedly different, depending on the operating regime, but due to the small capacities considered here, detailed investigation is not justified.

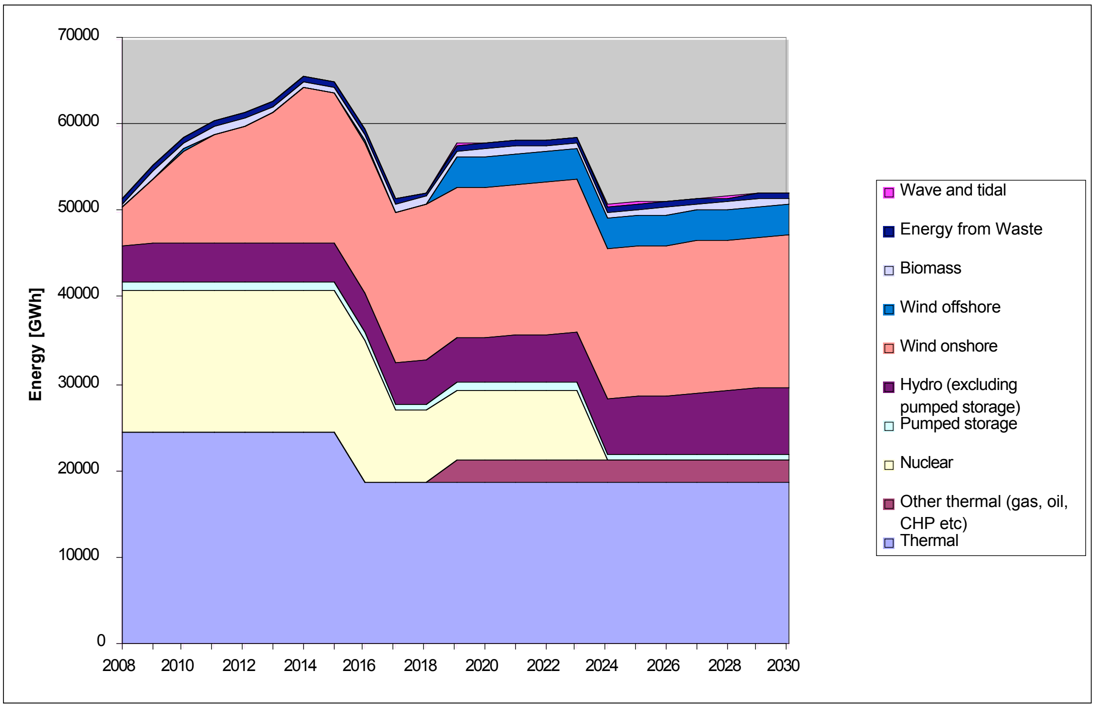


Figure 2.2 Electricity production to 2030, Case 1

Annual electricity production compared to electricity consumption and exports

In Table 2.3, the annual electricity production estimates of Table 2.2 (Appendix II) are compared to consumption projections from Section 2.2 for key years.

Year (description)	2008	2014 (peak)	2017 (After closure of Cockenzie & Hunterston)	2020 (New thermal plant & offshore wind)	2024 (After closure of Torness)	2030
Annual electricity production [TWh]	51.6	65.8	51.5	58.0	50.8	52.3
Gross consumption [TWh]	42.0	43.9	44.7	45.4	46.3	47.7
Resulting net export [TWh]	9.6	21.9	6.8	12.6	4.5	4.6

Table 2.3 Future Scottish electricity production, consumption and export, Case 1

'Gross consumption' is the consumption by consumers within Scotland, plus the energy consumed by the major generating plant in operation, and losses within the transmission and distribution systems.

The 'resulting net export' is defined as the forecast production minus the forecast gross consumption within Scotland. This implicitly assumes a ready market for the surplus electricity within the rest of the UK (and potentially also the Republic of Ireland), and also assumes no constraints imposed by transmission capacity.

It can be seen that the volume of net energy export to the rest of the UK varies significantly. At its peak (2014) it is more than twice the current export volume, which indicates that if the transmission capacity out of Scotland is not reinforced in time, generation is likely to be constrained. The conventional thermal generation and reservoir hydro would be most constrained. The next major reinforcement currently under discussion (sub-sea cable on the West Coast) is considered feasible for completion around 2015[58].

By the end of the period, export volume has reduced very significantly, so that net exports shrink from around 19% of generation to around 9%. In reality, this will mean that after closure of Torness, Scotland will in some circumstances be exporting large amounts of electricity (principally from wind generation). In other circumstances, mainly when wind production is low and demand is high, Scotland will import large amounts of electricity from England, Wales, Ireland, and potentially from continental Europe.

The situation in reality will perhaps not be as extreme as is shown in Table 2.3, because it is possible that economics will favour increased output from the remaining conventional generators, or construction of additional coal or gas generation within Scotland to replace at least some of the closed stations.

Annual electricity production compared to targets

The relevant targets for this study are as follows[59]:

- 2011: renewable electricity to match 31% of Scottish demand
- 2020: renewable electricity to match 50% of Scottish demand

Achieving these targets is likely to mean that Scotland will have contributed its share of meeting UK and EU targets.‘Demand’ is defined in these targets as gross consumption.

There are related targets which are also relevant:

- 2020: energy efficiency to have improved at least 20%
- 2030: final demand to have been reduced by 18%

There is currently no firm target for renewable electricity for 2030. The UK Government has an aim to reduce UK greenhouse gas emissions to 20% of 1990 levels by 2050. The Scottish Government has committed to the same in the recently approved Climate Change Bill[60] as well as an ambitious interim target of 42% greenhouse gas emissions reduction by 2020. It is not clear what role renewable electricity should play in achieving this 2030 interim target. However, an indication can be gained from the First Report of the UK Committee on Climate Change[61], which indicates that the least-cost path to meeting the UK 2050 target includes ‘the radical decarbonisation of power generation by 2030', also stated as 'the almost full decarbonisation of the power sector required by 2030'. On this basis, this report assumes that the renewable electricity target for Scotland for 2030 will be 90% of gross consumption.

Of course, substantial decarbonisation of electricity production could also be supported by including some new nuclear generation, or carbon capture and storage with fossil plant.

From Table 2.2[62], it can be seen that the 2011 and 2020 targets are expected to be achieved early: the 2020 target could be met by 2014.

The 2030 target has not been reached: indeed renewable electricity production, as a fraction of Scottish gross consumption, reaches only 63% by 2030. This is because of the conservative assumption in Case 1 of only a very slight increase in renewable generation capacity from 2019 onwards. The conclusion is therefore that renewable capacity (or other low-carbon generation) must continue to increase in the period after 2020. This is considered in more detail in Case 2 (in Chapter 5).

Summary for Case 1

This report has developed a set of assumptions for growth in renewable electricity generation in Scotland to 2030, assuming continuation of current policies. This is entitled 'Case 1'.

Uncertainty increases significantly in later years, especially post 2020. The major uncertainty is the assumed programme for closure of major generating stations: Cockenzie, Hunterston and Torness, and possible replacements for these stations. In practice, it is useful to consider the situation rather than the date, i.e. 'after Hunterston and Cockenzie close' rather than 'after 2016'.

There is also uncertainty about the mix of renewable generating capacity. This study assumes the majority of new renewable generation capacity is wind, with very small contributions from other renewables. The reasons for this assumption are:

- It is not possible to predict the growth of, for example, wave and tidal generation in the period to 2030 with any accuracy. Any set of predictions will be open to challenge.
- And in practice, it does not matter. The variable renewables (onshore and offshore wind, wave, and tidal), which are the technologies that raise the most technical issues for electricity system operation due to their variability and low capacity factor, share many characteristics, so that from the point of view of this study the mix of these technologies matters much less than the total volume. Therefore, if in 2030 the renewable generation capacity in Scotland turns out to be dominated by wave rather than wind, the conclusions of this study will not be invalidated. In fact, assuming a mix dominated by one technology

makes a more challenging case than one in which there is a broad mix of renewables, as the benefits of averaging effects are lost.

Security of supply with high renewables penetration cannot be accurately quantified within the scope of this study, and indeed the tools for doing this are still under development. However, it is concluded that under current conditions, security of supply may become an issue on closure of both Cockenzie and Hunterston, and is likely to be an issue on closure of Torness. This does not mean that present policies are infeasible: it means that these issues need to be considered now, and some combination of the many possible mitigating options can be chosen.

The volume of net electricity exports from Scotland varies widely over the period to 2030. Further reinforcement of the transmission connections to England, Wales and Northern Ireland appears necessary before either Hunterston or Cockenzie close (around 2015), if generation in Scotland is not to be constrained. After that date, net exports drop considerably, and it is likely that there will periods when high renewable production is exported, compensated by high imports when renewable production is low. Alternatively, new conventional generation may be built in Scotland to replace some of the closed stations. These could be gas-fired, or coal with Carbon Capture and Storage (CCS).

It is assumed here that the export and import flows to and from England & Wales, and possibly also Northern Ireland, are not sufficient to cause any major problems to those systems. This will not be the case for higher renewable production, and is considered in Case 3.

The Scottish Government targets for 2011 and 2020 are expected to be reached early. However, it is assumed in Case 1 that very little further renewable capacity is built after 2020, and this results in Scotland failing to keep pace with the growth in renewable electricity production necessary to meet likely targets for 2030. Note that Case 1 assumes continued growth in demand, and a failure to meet efficiency and demand reduction targets. Demand reduction will have a significant effect on targets for 2030, and this is examined in Case 4.

Chapter 5: Alternative scenarios

Introduction

The aim of this chapter is to consider scenarios other than the 'Case 1' considered in Chapter 4.

Case 2: Meeting the Renewables Target for 2030 for Scotland

Renewable generation capacity

As noted previously, the base case assumption in this study is that renewable generation capacity does not increase significantly beyond 2020. The assumed target for 2030 is that renewable electricity production in Scotland meets 90% of gross consumption, which equates to 43 TWh if demand continues to grow as assumed in Case 1. This requires an increase of 12.6 TWh over the Case 1 assumptions.

If this additional energy is to come from technologies such as onshore wind, offshore wind, wave and tidal, which have capacity factors in the range 0.3 to 0.4, then additional renewable capacity of the order of 4.1 GW is required. This brings the total renewable capacity in 2030 from 10.8 GW to 14.9 GW.

This volume of renewable capacity is high (more than twice current Scottish maximum demand), but well within Scotland's identified renewable resources. There are environmental constraints and designated sites and sensitive environmental areas should be avoided in order to ensure renewables energy development is truly sustainable. Within these parameters, the possible limits on the resource are therefore:

- cost, especially for offshore wind and wave resources far from shore;
- public acceptance, especially for onshore wind.

For the purposes of this study, it is assumed that political will is sufficient to overcome both these potential limiting factors.

The build rate in the period 2020-30 would be 460 MW per year, which compares with approximately 500 MW per year necessary in Case 1 for the period 2010-2020, and is therefore achievable.

The effect on generating capacity and energy production is shown in Figures 4.1 and 4.2. In these figures, it is assumed that this additional capacity is made up of wave and tidal generation: this is not essential for the analysis, but is a realistic case. The capacity factor assumed for wave and tidal is 0.35.

It is possible that in these timescales, microgeneration could make a significant impact: a contribution of around 10% of electricity production from various technologies can be estimated[63], though this is subject to considerable uncertainty. It should not be concluded from this study that wave or tidal <u>will</u> be the preferred options post 2020.

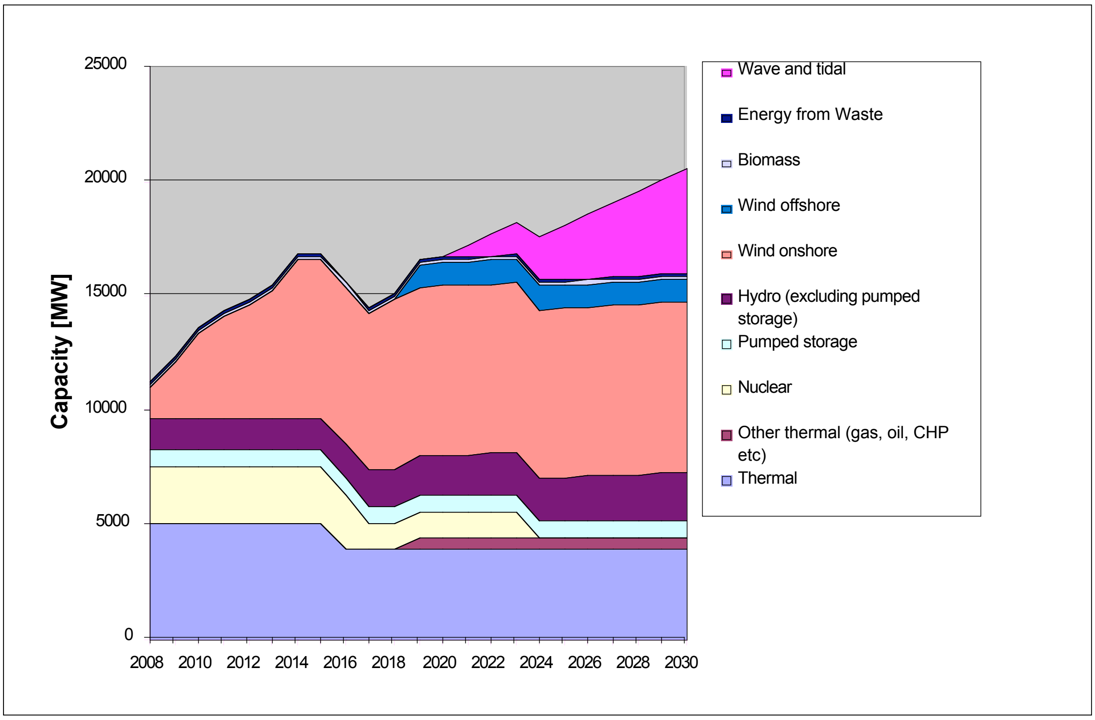


Figure 3.1 Generation capacity to 2030, Case 2

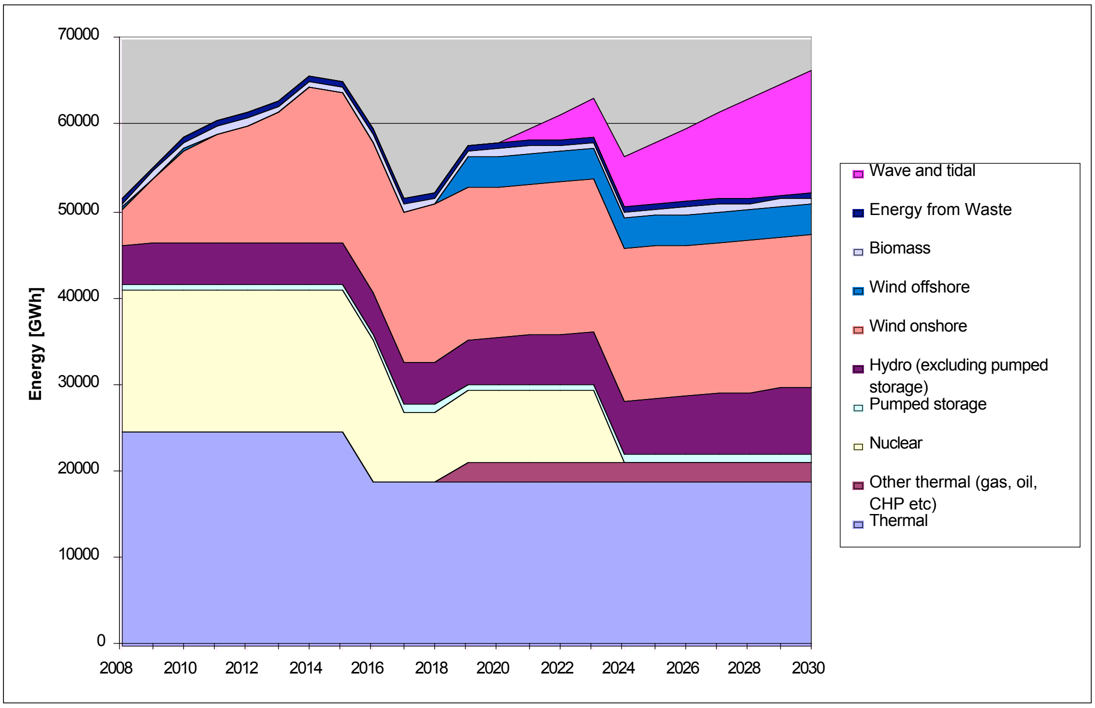


Figure 3.2 Electricity production to 2030, Case 2

Figure 3.2 is useful in understanding the fundamental points of Case 2. Comparing 2014 and 2030, it can be seen that total Scottish electricity production is very similar, but nuclear and some thermal production (Cockenzie) has been replaced by a mix of renewables.

Figure 3.2 also makes it clear that Case 2 assumes that thermal generation output remains unchanged from 2019 onwards. In effect, as renewables meet 90% of Scottish gross consumption by 2030, it is assumed that virtually all this thermal generation output will be exported. In reality, it is likely that the thermal generation output will be reduced to some extent. It is possible that some of the thermal generation would close. This would not affect achievement of the 2030 target.

Effect on exports and imports

Compared to Case 1, renewable electricity generation in 2030 reaches 44.5 TWh, or 93.2% of Scottish gross consumption, thereby achieving the assumed 2030 target.

Table 3.1 shows the same information for Case 2 as is shown in Table 2.3 for Case 1. It is seen that the annual net export in 2030 is around twice the current value, but does not exceed the net export previously achieved in 2014.

Almost certainly, further transmission system reinforcement would be needed to England and Wales, to Northern Ireland, or possibly to Norway, the Netherlands or Germany, perhaps as part of an 'offshore grid'. The amount of reinforcement will depend on the generation mix in the connected systems (principally England and Wales) and other factors, and cannot realistically be assessed at this stage. However, this is far enough in the future that normal planning and construction timetables should be satisfactory.

Year (description)	**2008**	**2014 (peak)**	**2017 (After closure of Cockenzie & Hunterston)**	**2020 (New thermal plant & offshore wind)**	**2024 (After closure of Torness)**	**2030**
Annual electricity production	51.6	65.8	51.5	58.0	56.4	66.5
Gross consumption.	42.0	43.9	44.7	45.4	46.3	47.7
Resulting net export	9.6	21.9	6.8	12.6	10.1	18.8

Table 3.1 Future Scottish electricity production, consumption and export [TWh] for Case 2

It is useful to ask what Case 2 means for imports and exports. Case 2 assumes that significant thermal generation (4,400 MW) continues to exist in Scotland, that it continues to operate at 0.55 capacity factor, and (as noted above) over a year its output is very close to the total volume of exports.

Under current market arrangements, the production from this thermal generation will depend on the electricity market, and this will to a large extent drive the volume of imports and exports.

However, if all this thermal generation closed by 2030 (an extreme case), there would still be substantial volumes of import and export, as Scottish demand and renewable electricity production fluctuated. The worst conceivable cases might be virtually no renewable production during high electricity demand (say 6GW import), and high renewables production during low electricity demand (say 15 GW of renewables production and 3 GW of Scottish demand, i.e. 12 GW export). Provided sufficient transmission capacity exists, to connect to an electricity system or systems able to match these net fluctuations, there is no fundamental technical difficulty with this. This is discussed further in Case 3.

Security of supply

If the thermal generation capacity in Scotland is unchanged, then the security of supply issues are as for Case 1, i.e. there is no particular difficulty. In fact, the increased renewables capacity after 2020 in Case 2 is likely to improve the situation compared to Case 1. However, if the thermal generation in Scotland closes, because it runs so infrequently that it becomes uneconomic, or for other reasons, then additional interconnection capacity would be needed to retain a secure system. In the limit, the need would be for sufficient interconnection to meet all Scottish demand, say 6GW, concurrently with the loss of the largest (and possibly also the second-largest) interconnection circuit. Alternatively significant volumes of pumped-storage plant and 'peaking' plant could be built in Scotland.

Summary

Case 2 shows that even if electricity demand continues to grow as assumed in Case 1, it is possible to meet the assumed 2030 target, provided the Scottish electricity system retains significant thermal generation, or alternatively if there is sufficient interconnection capacity to other electricity systems capable of meeting Scottish demand.

Case 3: Meeting the 2030 target with high renewables penetration in neighbouring systems

This case is included here to illustrate briefly an important point. Case 2 effectively assumed that there would always be a bigger electricity system or systems to absorb surplus renewable generation from Scotland, and supply Scotland at times of low renewable production. If the rest of the UK (or other interconnected system) follows a similar energy strategy, this assumption no longer holds. As noted above, the UK targets for 2030 will include major decarbonisation of electricity supply, assumed here to be in the region of 90%. Although the nuclear and 'cleaner' coal contributions are likely to be larger in England and Wales than in Scotland, there will still be a high penetration of variable renewables such as wind, wave and tidal. This can only work with some combination of the following:

- ‘despatchable’ renewables;
- gas-fired ‘peaking’ stations;
- renewables which incorporate storage, such as reservoir hydro or tidal barrages;
- very high interconnection capacity to other systems such as France and the Netherlands (though if those other systems also use variable renewables, this will not be a complete solution);
- connection to an electricity system with large amounts of storage (e.g. the Scandinavian hydro systems);
- constraining the output of the renewable generation occasionally;
- expanded use of deferrable demand, district heating, electric storage heating and cooling, electric vehicle charging;
- electricity storage of some form, such as pumped storage;
- non-renewable low-carbon generation such as coal with carbon capture, or nuclear, though current nuclear plant designs are probably insufficiently flexible in operation.

It is not possible at this stage to identify which mix of the above options would be optimal, or the feasible contributions of each.

The point of Case 3 is to illustrate that though Scotland in principle can meet the assumed 2030 target, with some ease in Case 2, in practice the systems it is connected to are likely to be following a similar path in some respects. The technical problems associated with high penetration of renewables such as wind, wave and tidal therefore need to be studied in the context of the entire GB electricity system, and very likely also including the island of Ireland.

These issues have been considered for the UK in several recent studies[64] [65] [66] [67], and it is not within the scope of this study to examine the UK case further. However, the following conclusions for Case 3 can be drawn for Scotland:

- Dealing with the technical issues raised by almost complete decarbonisation of electricity production needs to be studied on a GB, or possibly GB plus Ireland basis, due to geographical averaging and greater diversity of demand.
- It can be done, and there is time to implement the radical changes that will be needed;
- As the solution for England and Wales is likely to contain some element of nuclear generation, there will be times when electricity demand in Scotland is being supplied in part by nuclear generation from south of the border.
- If on the other hand it is desired to achieve the 2030 target for Scotland without relying on large volumes of export and import with England & Wales or other systems, the solutions are technically more difficult and likely to be more costly than a GB basis.
- The most likely contributions to a solution for Scotland are:
    - ‘despatchable’ renewables;
    - gas-fired ‘peaking’ stations;

- renewables which incorporate storage, such as reservoir hydro or tidal barrages;
- a mix of variable renewables (i.e. not all wind);
- sub-sea connection to the Scandinavian systems;
- greatly expanded use of deferrable demand, district heating, electric storage heating and cooling, electric vehicle charging;
- further pumped storage;
- possibly other electricity storage technologies;
- coal with carbon capture.

Again, it is not possible at this stage to identify which mix of the above options would be optimal, or the feasible contributions of each.

It should also be noted that in these circumstances there may not be customers willing to buy output from the remaining thermal generators in Scotland, unless fitted with carbon capture technology.

Case 4: Effect of Demand Reduction

The cases studied so far have assumed that electricity demand continues to grow. However, UK and Scottish Government policy is for electricity demand to be reduced. This is considered in more depth in the report by Pöyry energy consultants[68], which shows that based on figures in the recent BERR Renewable Energy Strategy (RES) consultation[69], application of current policies is expected to cause UK electricity demand to fall by 8% to 2020. The effect of this scenario is shown below in Table 3.2, assuming demand then remains constant from 2020 onwards. This is thought to be a relatively unambitious scenario.

Year	**2008**	**2020**	**2030**
Demand (Case 1 assumptions)	42	45.4	47.7
Demand (RES consultation scenario)	42	38.6	38.6
Saving over Case 1	n/a	**6.8**	**9.1**
Demand (Pöyry medium reduction scenario)	42	33.6	31.1
Saving over Case 1	n/a	**11.8**	**16.6**

Table 3.2 Effect of alternative scenarios for reduction of Scottish gross consumption [TWh/y]

Further analysis by Pöyry in their report produces three feasible scenarios for electricity demand to 2030. The Medium scenario is also included here as a more ambitious scenario, and shows reduction to 80% in 2020 and 74% in

2030. These figures are for the UK, and are assumed to be feasible also for Scotland. They broadly reflect other published UK and EU efficiency and demand reduction targets.

The net results for Scotland are shown in Table 3.2. Under the less onerous scenario (i.e. application of current policies), gross consumption drops to 38.6 TWh in 2030, so that the renewable capacity defined for Case 1 would now meet 79% of gross consumption.

Therefore compared to Case 2, only 1.4 GW of renewables capacity (producing 4.4 TWh) needs to be added between 2020 and 2030 to meet the 90% target in 2030.

Under the more onerous Pöyry Medium scenario, gross consumption drops to 31.1 TWh in 2030, so that the renewable capacity defined in Case 1 would meet 97% of gross consumption. Therefore the renewable capacity assumed to be built by 2020 is more than adequate to meet the assumed 2030 targets.

The conclusion is that relatively small year-on-year improvements in energy efficiency, if sustained, have a very significant effect by 2020 and 2030. This will significantly reduce the need for new renewables capacity in Scotland in order to meet targets, or permit much greater levels of export, or surplus electricity to enable some decarbonisation of heat and transport (see Case 5 below).

If the 2030 assumed target is met, then only 10% of Scottish gross consumption needs to be met by other generation. This is 3.1 TWh under the Pöyry Medium scenario. This is tiny in comparison with the current capacity of Longannet and Peterhead, and so it is entirely feasible that no coal or gas station will remain in Scotland. In this case, Scotland would be a major exporter of renewable electricity, and would depend on connections to other systems for security during periods of low renewables generation. The maximum demand in Scotland under the Pöyry Medium scenario would be around 4,500 MW, and it is certainly possible for this to be met by interconnections with England and Wales, or other systems.

Case 5: Electrification of Heat Supply and Transport

Heat

There are policy papers expected shortly from both UK and Scottish Governments on energy efficiency and heat supply. Heat supply is an important constituent of energy consumption in all sectors, and makes up 45% of Scottish final energy use, i.e. 78 TWh/y (2002 figures)[70].

A wide variety of policy options are being discussed for reducing emissions in the heat sector, and supply of heat from electricity is seen as a significant option. One reason for this is of course that the electricity could be produced from low-carbon sources such as renewables, clean coal or nuclear: another is that the heat could be produced using electrically-driven heat pumps.

To assess the feasibility of electrification of heat supply, it is assumed here that 10% of current heat supply in Scotland is transferred to electricity in future years. This is 7.8 TWh, equivalent to 17% of 2020 gross electricity consumption, or 28% of 2020 renewables production under Case 1 assumptions. Therefore even this modest fraction of the existing heat demand represents a major increase in the renewable production required to meet targets. However it is also important to recognise that a dramatic reduction in heat demand in buildings is possible in the 20 year period covered by this study. In such circumstances transferring 10% of heat supply to electricity could require around 5 TWh.

Note that if the electric heat supply was provided by heat pumps, which is feasible by 2020, then even with a conservative coefficient of performance for the heat pumps of 2.0, the increase in electricity production is reduced to 3.9 TWh, or with the predicted level of heat demand reduction, around 2.5 TWh.

Although this level of electric heating results in a substantial increase in electricity production, including renewables, it should be noted that the demand for heat matches well with the availability of wind and wave on seasonal timescales.

More significantly, heat can be stored on timescales of hours, in storage radiators, hot water systems, and in building fabric. Therefore electric heating has the potential to be controlled to match variability in renewables supply on timescales of hours. A substantial heat load which could be switched off at short notice would be equivalent to a generator which could be started at short notice, in order to meet sudden loss of renewable or conventional generation, or loss of an interconnection circuit.

For these reasons, it is concluded that electrification of heat is unlikely to increase the need for additional interconnection capacity, and is likely to assist in achieving security of supply objectives.

This report has not considered combined heat and power (CHP) schemes, except to note that such projects could form part of the conventional thermal generation included in the figures assumed in Cases 1 and 2. Clearly such schemes, and district heating schemes (DH), offer benefits in reduction of emissions from the heating sector, but do not directly affect progress towards the renewable electricity targets.

Transport

The transport sector consumes 29% of Scottish final energy use, or 51.5 TWh[71]. Electrification is seen as one of only a few feasible supply-side options for reducing emissions from transport. This would include electrification of railways, and electric vehicles. However, as emissions from passenger cars and vans greatly outweigh emissions from rail (66%

compared to 2% of total UK transport emissions in 2006)[72], it is justified to consider only cars and vans at this stage.

Electric cars supplied by non-fossil electricity are approximately 4 to 5 times more energy-efficient than petrol or diesel vehicles[73]. Therefore, transferring around 10% of Scottish transport energy consumption (i.e. 5 TWh) to electricity will require approximately 1 TWh of additional electricity production. This is relatively small compared to the volumes of renewable energy production discussed in this report, and small compared to possible effects of electrification of heat.

Therefore it is concluded that the electrification of cars and vans is not a significant issue for Scottish electricity generation in the context of this report, i.e. its likely effect in 2020 and 2030 is small compared to the uncertainties in demand growth/reduction, closure of conventional generation, and growth of renewable generation. If policy assumed say 30% or greater penetration by electric cars and vans in 2020 or 2030, then it will be worth quantifying the effects on demand for electricity in greater detail.

Electric vehicles offer a ‘storage’ function, in that it is likely that most private cars would be recharged overnight or when the driver is at work, thus in principle allowing the charging to be carried out at any time over a large fraction of the day, i.e. deferrable on timescales of hours. Similarly to heat loads, this could be useful for matching with the output of variable renewables, or for providing a ‘reserve’ function in case of sudden loss of generation or interconnection.

Further, it has been proposed that when connected to the charging equipment, the batteries could be used to provide energy to the grid.

Therefore, as for electrification of heat, it is concluded that electrification of cars and vans is unlikely to increase the need for additional interconnection capacity, and is likely to assist in achieving security of supply objectives. Because of the uncertainties about the rate of growth of electric vehicles, and how they might be used and charged, it is not possible at this stage to quantify their contribution to security of supply in Scotland in 2030.

Conclusions from Alternative Cases

Uncertainties

The major uncertainty in this study is the retiral programme for the large generators, especially Torness, and the possible construction of replacements. This is more significant than the uncertainties in growth of renewable generation capacity. Many factors will affect the decisions to close these large generators. Currently, generators have to give very little warning of such a decision. With substantial demand reduction measures, it is entirely possible that there could be no large coal or gas power stations in Scotland in 2030.

There is considerable uncertainty about the mix of renewable generation, especially post 2020 when it may be the case that the available onshore wind sites have been developed. However, this is not a major issue, as the likely renewable technologies (wind, wave, tidal) share similar characteristics: low capacity factor (0.3 to 0.4), high fixed cost but low or zero marginal costs, variable on timescales of hours, predictable a few hours ahead but (except for tidal) with increasing uncertainty at longer timescales. Other possible technologies such as biomass and hydro are more controllable and predictable. Also, there are advantages in a mix of renewable technologies: lower variability, and probably lower overall forecast errors. Therefore, a mix dominated by wind and in later years wave/tidal is a conservative assumption.

Future electricity demand is also a major uncertainty. It is clear that assumptions about relatively small rates of demand growth or demand reduction have a major effect on gross electricity consumption in 2020 and 2030, and a major effect on the volume of renewable generation needed to meet targets.

Related to this issue, transfer of a relatively small part of heat supply to electricity would have a significant effect on electricity demand, and so the rate at which this is achieved is another uncertainty. This is less significant for electrification of transport: a large shift would be necessary before this became a significant issue.

Targets for 2011 and 2020

Scottish Government renewable electricity targets for 2011 and 2020 are very likely to be achieved.

Without additional measures being taken, security of supply is likely to be an issue on closure of Torness (estimated around 2024), and may be an issue before then. There are several options available to address these issues, in addition to building new conventional generation capacity, so this is not a reason to restrict the expansion of renewables. However it is necessary to investigate the issue now. This is a highly technical problem, and work is under way within the electricity supply industry and academia on these issues.

Assumed Target for 2030
A target has been assumed for 2030, based on indications of thinking within Scottish and UK government, which appears onerous: 90% of gross electricity consumption to come from renewables.

The build rates to achieve this post 2020 (around 500 MW per year) are achievable. If electricity demand reduces rather than grows, the new renewable capacity required is greatly reduced.

Several options are available to deal with the effects of a very high penetration of variable renewable generation. Interconnection with other electricity systems is a great benefit, though less so if, as is likely, the rest of the UK and possibly Ireland follow policies for electricity which include a large fraction of variable renewables. Therefore these issues need to be studied on a UK or UK plus Ireland basis.

The most likely contributions to a solution for a high penetration of variable renewables in Scotland are:

- 'despatchable' renewables such as biomass;
- gas-fired 'peaking' stations;
- a mix of variable renewables (i.e. not all wind);
- renewables which incorporate storage, such as reservoir hydro or tidal barrages;
- sub-sea connection to the Scandinavian systems;
- greatly expanded use of deferrable demand, district heating, electric storage heating and cooling, electric vehicle charging;
- further pumped storage;
- possibly other electricity storage technologies;
- coal with carbon capture.

There is no reason to believe that 90% renewable electricity in Scotland cannot be achieved: some radical developments may be needed, but there is time available to develop them. Indeed there is no reason at present to consider that 100% renewable electricity is impossible: it will just be more expensive.

It is reasonable to ask if the costs of accommodating a high fraction of variable renewables will be so high that other carbon mitigation options would be cheaper. This will not be clear for some time. However it is clear that the UK Committee on Climate Change does regard decarbonisation of electricity generation (by renewables, clean coal and nuclear) as 'low hanging fruit' compared to other options[74].

Exports and Imports
The volumes of exports and imports vary widely over the timescale of this study, dependant mainly on the expectations for closure of the major thermal stations, and to a lesser extent on the operating regime for these stations when for a large part of the year their production will effectively be exported.

It is not at all clear how these stations will operate, and whether electricity prices will be high enough to provide sufficient income to allow them to operate at low load factor. Although in a perfect market system these plants will either operate profitably or be shut down and replaced by others which do operate profitably in the high-renewables environment, if necessary with very high electricity prices at times of low renewable production, there is a potential danger that rapid growth of renewables will be too fast for the market to adjust efficiently.

With high penetration of variable renewables such as wind, wave and tidal, there will be periods of high import from the rest of the UK. If on the other hand it is desired to achieve the 2030 target for Scotland without relying on large volumes of export and import with England & Wales or other systems, the solutions are technically more difficult and likely to be more costly than a GB basis.

During periods of import from England and Wales, it is likely that the operating generators in England and Wales will include some nuclear stations. If it was desired that nuclear generated-electricity not be imported, then there would be a necessity to take some action such as preventing electricity suppliers within Scotland from purchasing nuclear-generated electricity.

Electrification of Heat and Transport

Electrification of some fraction of transport could be accommodated without great difficulty, as the volume of energy required is relatively small.

Electrification of heat would create greater difficulty, because the volumes are larger. The renewable generation capacity required to meet targets could be significantly increased.

However both heat and transport loads would provide some form of deferrable demand, which will help management of the electricity system with high levels of variable renewable generation.

Chapter 6: Conclusions

How our electricity generation mix has changed over recent years

At the beginning of the 21st century, the conventional model of large, remote electricity generation had led to Scotland being dependent on just five power stations for the overwhelming bulk – around 90% – of its electricity needs.

But Figure 1.2 shows how by 2007 (the last year for which we have reliable data), the mix had begun to shift quite dramatically. Large-scale conventional and nuclear generation was still dominant, but its share had fallen to 80% while the proportion of our electricity coming from renewables had almost doubled to around 20%. Most significantly, non-hydro renewables had seen their contribution rise from 0.6% to 7.3%, virtually all of which was from onshore wind farm developments encouraged by the Renewables Obligation (Scotland).

The overwhelming bulk of the reduction in large-scale generation was in the nuclear sector – its share of electricity generation fell from over 33% in 2000 to 25% in 2007 – largely due to planned and unplanned outages and reductions in nuclear generation. If fossil-fuelled stations are to continue to operate, rather than be replaced by renewables; carbon capture and storage technology will be necessary to achieve the required emissions reductions.

Future projections of electricity generation – Case 1

The Garrad Hassan analysis shows that by 2030 in a plausible 'business as usual' future electricity generation scenario (the "base case") renewable electricity sources are likely to make up:

- 68% of Scotland's generating capacity
- 58% of our total electricity generation and
- 64% of our domestic electricity demand.

Figures 4.1 and 4.2 shows the contribution to Scotland's generating capacity and to Scotland's annual electrical output of each source of electricity under the base case scenario

Source	% of total generating capacity	% of electrical output
Onshore wind	46.3	33.4
Natural flow hydro	13.7	15
Offshore wind	6.3	6.8
Pumped storage hydro	4.6	1.5
Biomass	0.8	1.5
Energy from waste	0.6	1.2
Wave and tidal	0.1	0.1
Thermal	27.5	40.5
Total	*100*	*100*

Table 4.1 – percentage contributions of each electricity source to capacity and output under the base case scenario

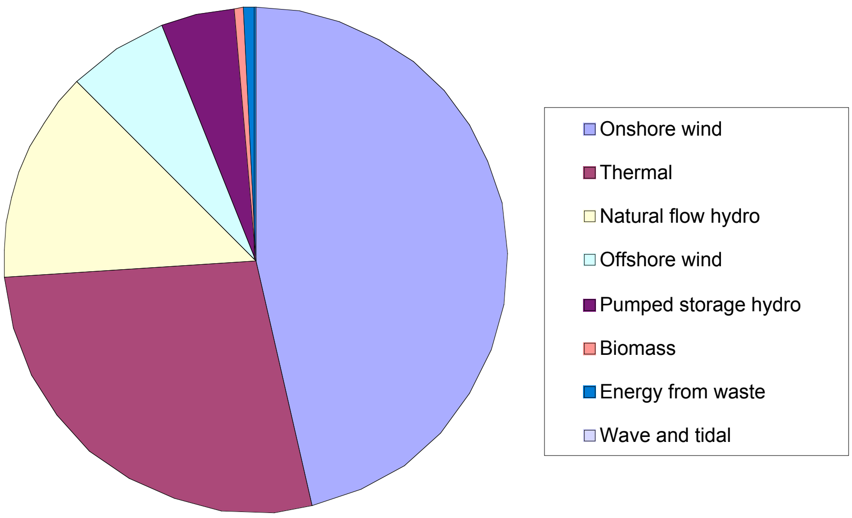


Fig 4.1 Case 1 generating capacity in 2030

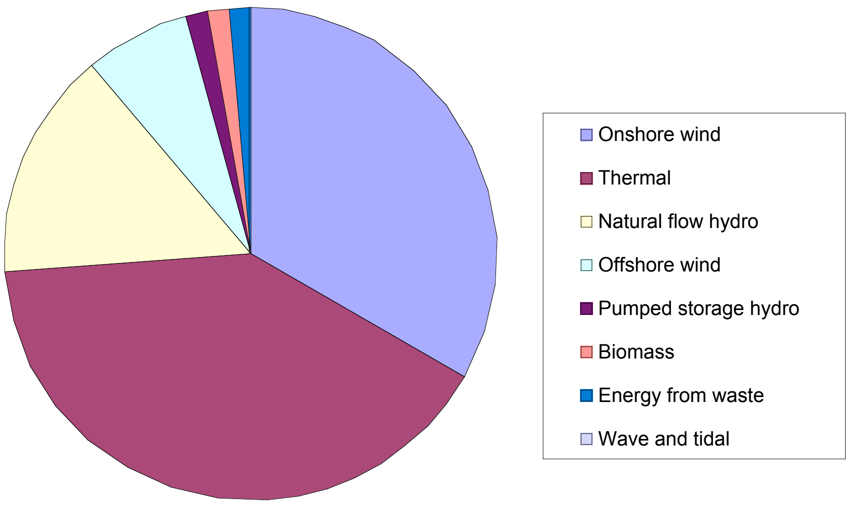


Fig 4.2 Case 1 electrical output in 2030

Future projections of electricity generation – Case 2

The alternative cases developed by Garrad Hassan to 2030 differ from the base case in various ways. Case 2 foresees a far greater role for renewables (represented in the scenario as rapid growth in wave and tidal power in the 2020s) than does the base case, meaning that renewables make up:

- 75% of Scotland's generating capacity

- 67% of our total electricity generation and
- 93% of our domestic electricity demand.

Figures 5.1 and 5.2 and Table 5.1 shows the contribution to Scotland's generating capacity and annual electricity output under the alternative scenario.

Source	% of total generating capacity	% of electrical output
Onshore wind	35.9	26.3
Natural flow hydro	10.6	11.8
Offshore wind	4.9	5.3
Pumped storage hydro	3.6	1.2
Biomass	0.6	1.2
Energy from waste	0.5	0.9
Wave and tidal	22.5	21.3
Thermal	21.3	31.9
Total	*100*	*100*

Table 5.1 – percentage contributions of each electricity source to capacity and output under the alternative scenario

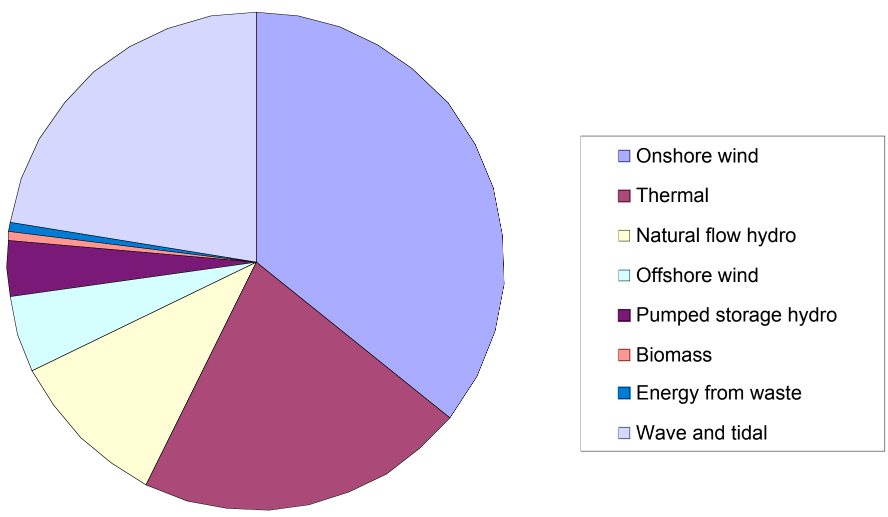


Fig 5.1 Case 2 generating capacity in 2030

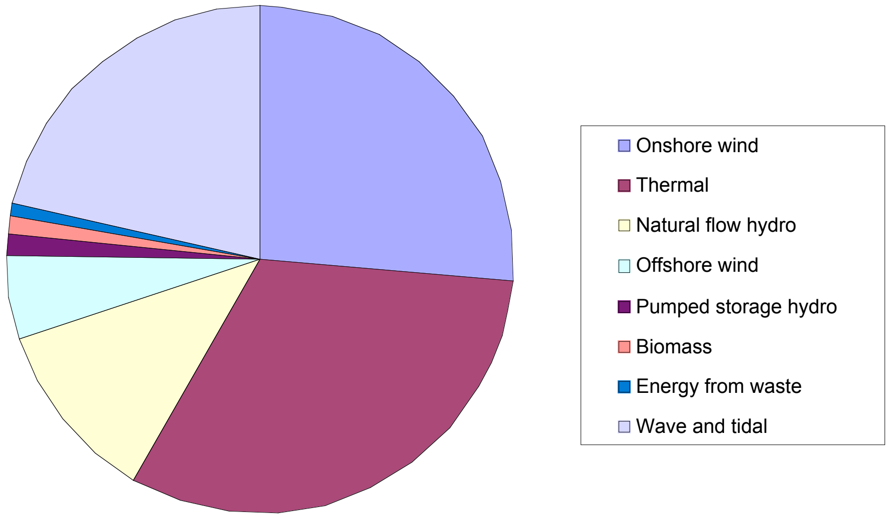


Fig 5.2 Case 2 electrical output in 2030

Case 3 – High renewables penetration elsewhere

Case 3 differs from Cases 1 and 2 in that it assumes that the electrical systems to which Scotland is connected will be following a similar path, i.e. decarbonising their electricity supply via a rapid expansion of renewable capacity. Should this be the case, the assumptions made for the first two scenarios – that Scotland would be able to export significant amounts of electricity during periods of excess supply, and rely on imports when demand exceeds domestic supply – can no longer be relied upon.

Instead, measures such as additional peaking capacity (probably gas-fired) or developing renewables that are either despatchable (e.g. biomass) or which incorporate a storage function (e.g. tidal barrage) would be required to provide security of supply. However, there is no reason to suppose that the rest of the UK will in fact pursuing a generation scenario similar to Scotland; instead, the generation mix in England and Wales is more likely to be based upon a combination of renewables, thermal generation with CCS, and baseload nuclear, but its capacity to act as a buffer for variation in Scottish generation may still be lower than assumed in Cases 1 & 2.

Case 4 – Effect of demand reduction

Cases 1 and 2 were based on the assumption that Scotland's annual electricity consumption, if not its peak demand, would increase significantly to 2030. These assumptions could be seen as unduly pessimistic; both Scottish and UK energy policy is for a significant reduction in electricity demand.

Rather than the increased demand of earlier scenarios, Case 4 takes projections of electricity demand from two different sources, and compares it to the existing projections of electricity supply. The first of these assumes an

8% reduction in demand to 2020, which then remains constant to 2030. This scenario puts the annual demand at 38.6 TWh/y in 2030, and is described as 'relatively unambitious'. A second scenario assumes a considerably greater demand reduction of 20% by 2020 and 26% by 2030. This would give an annual demand of 31.1 TWh/y in 2030.

The three demand projections: the increase assumed for Cases 1 and 2 (line 1), the 8% reduction by 2030 (line 2) and the 26% reduction by 2030 (line 3) are shown as numbered horizontal dashed lines against the Case 1 and Case 2 generation scenarios in figure 6.1.

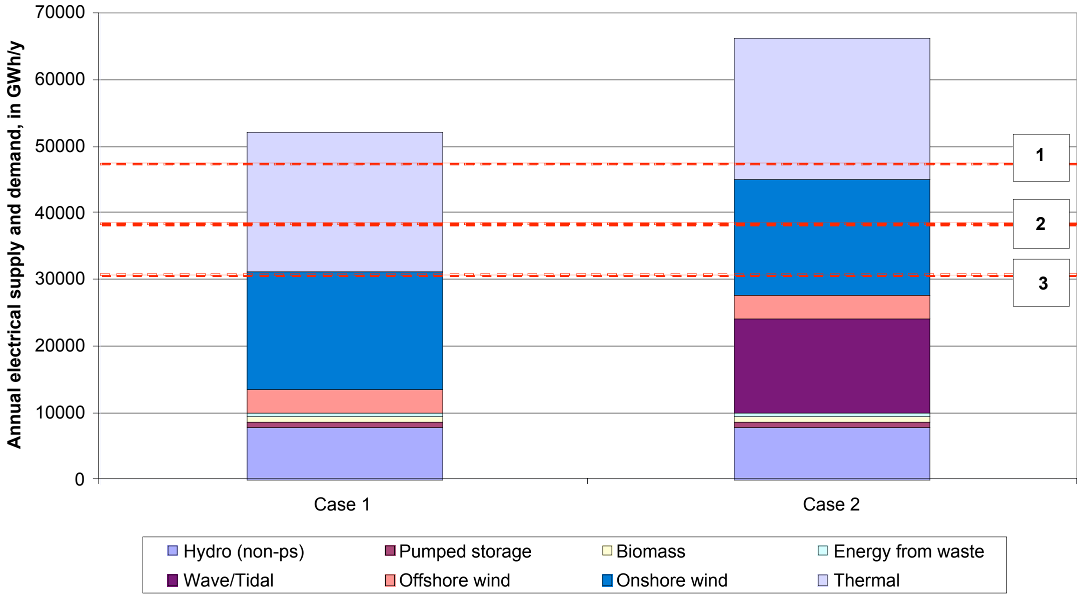


Figure 6.1: the 2030 electrical output scenarios from Cases 1 and 2 compared with three different demand scenarios

	13.6% demand increase (line 1)	8% demand reduction (line 2)	26% demand reduction (line 3)
Case 1	63.6%	78.7%	97.7%
Case 2	93.2%	115%	143%

Table 6.1: percentage of Scotland's electricity demand that can be met by renewables for a combination of supply and demand scenarios in 2030

It can be seen that for Case 1, the more modest demand reduction would still require a certain amount of thermal generation capacity, while the more ambitious demand reduction more or less coincides with the renewable output. But with Case 2 (Case 1 with additional wave and tidal capacity), renewables provide enough output to comfortably meet either of the demand reduction scenarios.

While it is possible that some thermal generation plant might be retained to provide peaking capacity, it is more likely that operators would not find this economically viable under such demand reduction scenarios.

Case 5 – Electrification of heat supply and transport

Case 5 assumes that 10% of the current demand for heating is electrified, adding between 2.5 and 7.8 TWh/y to Scotland's projected electricity demand, depending on the use of heat pumps and the level of home energy demand reduction. While electrification of heating demand places an additional burden on the electricity supply, it is both storable and deferrable and generally coincides with periods of high renewables output. For these reasons, it should act to improve the security of supply.

This case also assumes that 10% of transport is electrified. While this currently represents some 5 TWh of energy each year, electric transport is many times more efficient than that powered by fossil fuels, so the additional electricity demand is only in the region of 1 TWh each year.

This relatively modest addition to Scotland's annual demand should present little difficulty to our system of electricity supply, and the storage function provided by a fleet of electrical vehicles could provide both for deferrable demand and for a reserve function in the event of capacity loss elsewhere on the system.

Ensuring security of supply

As the proportion of electricity derived from variable energy sources such as wind, wave and tidal power increases, care must be taken to ensure that security of supply is not compromised. The analysis carried out by Garrad Hassan indicates that under either the base case or case 2, the worst-case situation (minimal output from variable sources of renewable energy coinciding with a period of peak demand) would not result in power shortages, although Scotland might be forced to rely upon imports of electricity from elsewhere in the UK. Achieving the considerable potential to manage and reduce electricity demand (case 4) would result in an even greater margin of safety.

The system can be made yet more secure by increasing the capacity of interconnectors to England and Wales, Northern Ireland and elsewhere in Europe, enabling electricity to be exported during periods of excess production and imported when very low (or very high) winds mean that Scotland's variable renewable sources are not operating. This remains true, although less effective, even if the rest of the UK pursues a decarbonisation strategy.

The role of decentralised energy

Cases 1 and 2 developed by Garrad Hassan foresee new build capacity of 500 MW of thermal electricity generation coming on stream, probably gas-fired although other fuels are possible. Given the disadvantages of large-scale, centralised generation (inefficiency, unaccountability, potential instability), the construction of any additional thermal capacity provides an opportunity to reinforce a decentralised model of energy supply.

Decentralised energy[75], or DE, is typified by highly efficient combined heat and power (CHP) installations that are located close to energy users, whether they are businesses or communities. Instead of losing over two-thirds of the energy input as waste heat – as is presently the case for large-scale fossil fuelled power stations such as Longannet – localised small-scale CHP plants can achieve combined electrical and thermal efficiencies of over 80%.

When the fossil-fuelled plants at Longannet and Peterhead come to the end of their working lives, consideration should be given to replacing them – should any replacement be needed - with a more stable, and far more efficient, network of decentralised CHP installations. This could provide a similar electricity generation capacity, but by supplying heat to communities and businesses would have the additional advantage of displacing very considerable amounts of carbon emissions that would otherwise result from space or industrial heating demands. However, should any additional thermal generating plant be designed to provide peaking capacity, the intermittent nature of such plants' operation can make them less suitable for use as CHP plants.

Conclusions

The analysis carried out by Garrad Hassan demonstrates that there is enormous potential to increase the generation of electricity from renewable sources during the next two decades, and that by 2030 renewable energy can meet between 60% and 143% of Scotland's projected annual electricity demand, depending on the level of investment in energy saving and new renewables.

Decommissioning large, centralised generation capacity at Cockenzie, Hunterston B and Torness will not compromise Scotland's energy security, and the projected electricity mix in 2030 will ensure that Scotland's electricity needs will be met even if the supply of electricity from variable sources of renewable energy falls to zero during a period of peak demand. The base scenarios assume increased energy consumption and stable peak demand; additional security of supply, reduced carbon emissions and significant financial savings can be achieved by taking action to manage and reduce our demand for electricity through energy efficiency measures, and by electrification of some degree of heat and transport demand.

While the bulk of Scotland's electricity will be supplied from sustainable, low-carbon sources by 2030, some scenarios include a role for fossil-fuelled power generation for the foreseeable future. If Scotland is to achieve the carbon emissions reductions targets embedded within the Climate Change (Scotland) Bill under these scenarios, it is essential that:

- No new unabated coal fired power stations are built in Scotland, and

- All existing fossil fuelled power stations are fitted with carbon capture and storage technology as soon as possible (or closed).

However, combining increased development of offshore renewables with a realistic programme of demand reduction means that Scotland's renewable resource can meet – and exceed – our annual electricity demand, even when a significant proportion of heating and transport demand are electrified. Under such a scenario, it is entirely feasible for all centralised thermal generation to be closed by 2030, with our security of supply relying on interconnectors, storage and deferrable demand. Any new thermal plant with CCS would provide additional security, with the development of such technology justified by the global need for carbon abatement.

This report shows for the first time that a truly sustainable energy future is achievable for Scotland. Rather than burdening future generations with an inefficient, uneconomic and carbon intensive model of electricity production, we can demonstrate that a healthy, modern economy can be powered by electricity that doesn't cost the earth.

Appendix I: the present situation

Year	2000	2001	2002	2003	2004	2005	2006	2007	Mean 2000-07
Generation	50401	49140	49653	49415	49937	49237	52222	48217	49778
Consumption (inc own consumption by autogenerators)	34740	34387	35360	35011	34842	35744	34354	34463	34863
Net export	9600	8694	8034	8177	8573	7315	10941	7362	8587
Losses, generation own consumption etc	6061	6059	6259	6227	6522	6178	6927	6392	6328
Net export as fraction of generation [%]	19.0	17.7	16.2	16.5	17.2	14.9	21.0	15.3	17.2

Table 1.1 Scotland's electricity generation and consumption 2000-2007 [GWh]

Year	2000	2001	2002	2003	2004	2005	2006	2007	Mean 2000-07
Coal	16624	15408	14861	14566	13081	12160	17529	13853	14760
Gas	8671	8523	11034	10025	10835	9367	10309	11182	9993
Nuclear	16918	18097	15828	18394	18013	18681	14141	12344	16552
Oil	2604	2375	2210	2034	1391	1903	2095	1413	2003
Hydro pumped storage	613	534	622	670	786	643	1184	1198	781
Hydro natural flow	4665	3738	4455	2902	4475	4612	4225	4697	4221
Wind and wave	217	245	406	449	848	1281	2023	2644	1014
Landfill gas	69	109	157	228	339	395	424	487	276
Other biofuels	21	110	80	146	170	197	291	398	177
Total	**50401**	**49140**	**49653**	**49413**	**49938**	**49240**	**52221**	**48216**	**49778**
Renewables as fraction of generation [%]	9.3	7.8	9.1	6.2	9.3	9.8	8.6	10.6	8.8
Renewables as fraction of consumption [%]	13.5	11.2	12.8	8.7	13.3	13.5	13.1	14.8	12.6

Table 1.2 Electricity generation in Scotland subdivided by source, 2000-2007 [GWh]

Appendix II: Case 1 - Meeting current targets

Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Thermal	**5100**	**5100**	**5100**	**5100**	**5100**	**5100**	**5100**	**5100**	**3900**	**3900**	**3900**	**3900**
Longannet	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400
Cockenzie	1200	1200	1200	1200	1200	1200	1200	1200	0	0	0	0
Peterhead	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
Other thermal (gas, oil, CHP etc)	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**500**
Existing 2008	0	0	0	0	0	0	0	0	0	0	0	0
Post 2008	0	0	0	0	0	0	0	0	0	0	0	500
Nuclear	**2410**	**2410**	**2410**	**2410**	**2410**	**2410**	**2410**	**2410**	**2410**	**1200**	**1200**	**1200**
Hunterston B	1210	1210	1210	1210	1210	1210	1210	1210	1210	0	0	0
Torness	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200
Pumped storage	**740**	**740**	**740**	**740**	**740**	**740**	**740**	**740**	**740**	**740**	**740**	**740**
Foyers	300	300	300	300	300	300	300	300	300	300	300	300
Cruachan	440	440	440	440	440	440	440	440	440	440	440	440
Hydro (exc pumped storage)	**1383**	**1432**	**1432**	**1432**	**1432**	**1432**	**1439**	**1439**	**1483**	**1533**	**1583**	**1633**
Existing 2008	1383	1383	1383	1383	1383	1383	1383	1383	1383	1383	1383	1383
Post 2008		49	49	49	49	49	56	56	100	150	200	250
Wind onshore	**1400**	**2452**	**3651**	**4413**	**4897**	**5579**	**6854**	**6854**	**6870**	**6870**	**7400**	**7400**
Existing 2008	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
Post 2008		1052	2251	3013	3497	4179	5454	5454	5470	5470	6000	6000
Wind offshore	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**1010**
Existing 2008	10	10	10	10	10	10	10	10	10	10	10	10
Post 2008		0	0	0	0	0	0	0	0	0	0	1000
Biomass	**79**	**131**	**131**	**131**	**131**	**131**	**131**	**131**	**131**	**131**	**131**	**131**
Existing 2008	79	79	79	79	79	79	79	79	79	79	79	79
Post 2008		52	52	52	52	52	52	52	52	52	52	52
Energy from Waste	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
Wave and tidal	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**23.5**
Existing 2008	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Post 2008		0	0	0	0	0	0	0	0	0	0	23
Total	**11223**	**12376**	**13575**	**14337**	**14821**	**15503**	**16785**	**16785**	**15645**	**14485**	**15065**	**16638**
Total renewables	2973	4126	5325	6087	6571	7253	8535	8535	8595	8645	9225	10298

Table 2.1 (continued overpage) Generation capacity to 2030, Case 1. Capacity in MW.

Year	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Thermal	**3900**	**3900**	**3900**	**3900**	**3900**	**3900**	**3900**	**3900**	**3900**	**3900**	**3900**
Longannet	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400
Cockenzie	0	0	0	0	0	0	0	0	0	0	0
Peterhead	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
Other thermal (gas, oil, CHP etc)	**500**	**500**	**500**	**500**	**500**	**500**	**500**	**500**	**500**	**500**	**500**
Existing 2008	0	0	0	0	0	0	0	0	0	0	0
Post 2008	500	500	500	500	500	500	500	500	500	500	500
Nuclear	**1200**	**1200**	**1200**	**1200**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Hunterston B	0	0	0	0	0	0	0	0	0	0	0
Torness	1200	1200	1200	1200	0	0	0	0	0	0	0
Pumped storage	**740**	**740**	**740**	**740**	**740**	**740**	**740**	**740**	**740**	**740**	**740**
Foyers	300	300	300	300	300	300	300	300	300	300	300
Cruachan	440	440	440	440	440	440	440	440	440	440	440
Hydro (exc	**1683**	**1733**	**1783**	**1833**	**1883**	**1933**	**1983**	**2033**	**2083**	**2133**	**2183**
Existing 2008	1383	1383	1383	1383	1383	1383	1383	1383	1383	1383	1383
Post 2008	300	350	400	450	500	550	600	650	700	750	800
Wind onshore	**7400**	**7400**	**7400**	**7400**	**7400**	**7400**	**7400**	**7400**	**7400**	**7400**	**7400**
Existing 2008	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
Post 2008	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000
Wind offshore	**1010**	**1010**	**1010**	**1010**	**1010**	**1010**	**1010**	**1010**	**1010**	**1010**	**1010**
Existing 2008	10	10	10	10	10	10	10	10	10	10	10
Post 2008	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
Biomass	**131**	**131**	**131**	**131**	**131**	**131**	**131**	**131**	**131**	**131**	**131**
Existing 2008	79	79	79	79	79	79	79	79	79	79	79
Post 2008	52	52	52	52	52	52	52	52	52	52	52
Energy from Waste	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
Wave and tidal	**23.5**	**23.5**	**23.5**	**23.5**	**23.5**	**23.5**	**23.5**	**23.5**	**23.5**	**23.5**	**23.5**
Existing 2008	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Post 2008	23	23	23	23	23	23	23	23	23	23	23
Total	**16688**	**16738**	**16788**	**16838**	**15688**	**15738**	**15788**	**15838**	**15888**	**15938**	**15988**
Total renewables	10348	10398	10448	10498	10548	10598	10648	10698	10748	10798	10848

Table 2.1 (concluded) Generation capacity to 2030, Case 1. Capacity in MW.

Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Thermal												
CF	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
GWh	24572	24572	24572	24572	24572	24572	24572	24572	18790	18790	18790	18790
Other thermal (gas, oil, CHP etc)												
CF	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
	0	0	0	0	0	0	0	0	0	0	0	2409
Nuclear												
CF	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78
	16467	16467	16467	16467	16467	16467	16467	16467	16467	8199	8199	8199
Pumped storage												
CF	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
	777.9	777.9	777.9	777.9	777.9	777.9	777.9	777.9	777.9	777.9	777.9	777.9
Hydro (excluding pumped storage)												
CF	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36
	4361.4	4516	4516	4516	4516	4516	4538	4538	4677	4834	4992	5150
Wind onshore												
CF	0.35	0.35	0.34	0.33	0.32	0.31	0.3	0.29	0.29	0.29	0.28	0.27
	4292.4	7518	10874	12757	13727	15150	18012	17412	17453	17453	18151	17502
Wind offshore												
CF	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
	35.04	35.04	35.04	35.04	35.04	35.04	35.04	35.04	35.04	35.04	35.04	3539
Biomass												
CF	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
	484.43	803.3	803.3	803.3	803.3	803.3	803.3	803.3	803.3	803.3	803.3	803.3
Energy from Waste												
CF	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
	613.2	613.2	613.2	613.2	613.2	613.2	613.2	613.2	613.2	613.2	613.2	613.2
Wave and tidal												
CF	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	72.1
Total (Gwh)	51605	55304	58660	60543	61513	62936	65820	65220	59618	51508	52363	57856
Total renewables	9788	13487	16843	18726	19696	21119	24003	23403	23582	23740	24596	27680
Total renewables as % of total generation	19.0	24.4	28.7	30.9	32.0	33.6	36.5	35.9	39.6	46.1	47.0	47.8
Total renewables as % of Scottish gross consumption	23.3	32.1	39.7	43.8	45.7	48.5	54.6	52.9	53.0	53.1	54.7	61.3

Table 2.2 (continued overpage) Electricity production and assumed capacity factor (CF) to 2030, Case 1 [GWh]

Year	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Thermal											
CF	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
GWh	18790	18790	18790	18790	18790	18790	18790	18790	18790	18790	18790
Other thermal (gas, oil, CHP etc)											
CF	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
	2409	2409	2409	2409	2409	2409	2409	2409	2409	2409	2409
Nuclear											
CF	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78
	8199	8199	8199	8199	0	0	0	0	0	0	0
Pumped storage											
CF	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
	777.9	777.9	777.9	777.9	777.9	777.9	777.9	777.9	777.9	777.9	777.9
Hydro (excluding pumped storage)											
CF	0.36	0.37	0.37	0.38	0.38	0.39	0.39	0.4	0.4	0.41	0.41
	5308	5617	5779	6102	6268	6604	6775	7124	7299	7661	7840
Wind onshore											
CF	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27
	17502	17502	17502	17502	17502	17502	17502	17502	17502	17502	17502
Wind offshore											
CF	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
	3539	3539	3539	3539	3539	3539	3539	3539	3539	3539	3539
Biomass											
CF	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
	803.3	803.3	803.3	803.3	803.3	803.3	803.3	803.3	803.3	803.3	803.3
Energy from Waste											
CF	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
	613.2	613.2	613.2	613.2	613.2	613.2	613.2	613.2	613.2	613.2	613.2
Wave and tidal											
CF	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
	72.05	72.05	72.05	72.05	72.05	72.05	72.05	72.05	72.05	72.05	72.05
Total (Gwh)	58014	58324	58486	58808	50775	51111	51282	51631	51806	52168	52348
Total renewables	27838	28147	28309	28632	28798	29134	29305	29654	29829	30191	30371
Total renewables as % of total generation	48.0	48.3	48.4	48.7	56.7	57.0	57.1	57.4	57.6	57.9	58.0
Total renewables as % of Scottish gross consumption	61.3	61.7	61.7	62.1	62.2	62.6	62.7	63.1	63.1	63.6	63.6

Table 2.2 (concluded) Electricity production and assumed capacity factor (CF) to 2030, Case 1 [GWh]

Sources

[1] IPCC, 2007. *Climate change synthesis report, 2007: Summary for policymakers*. Available at: http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr_spm.pdf [Accessed 24th May 2009]

[2] Parts per million: a weight to weight ratio used to describe concentrations.

[3] Scottish Parliament, 2008. *Climate Change (Scotland) Bill*. Online. Available at: http://www.scottish.parliament.uk/s3/bills/17-ClimateChange/index.htm [accessed 24th May 2009]

[4] This figure was correct at the time of going to print, in the draft legislation.

[5] AEA Technology, 2008. *Greenhouse Gas Inventories for England, Scotland Wales and Northern Ireland: 1990-2006*. Available at: http://www.airquality.co.uk/reports/cat07/0809291432_DA_GHGI_report_2006_main_text_Issue_1r.pdf [Accessed 24th May 2009]

[6] Scotland's Renewable Resource 2001 Garrad Hassan & Partners Ltd. Scottish Executive 2001

[7] Scottish Parliament, 2008. *Climate Change (Scotland) Bill*. Online. Available at: http://www.scottish.parliament.uk/s3/bills/17-ClimateChange/index.htm [Accessed 15th April 2009]

[8] The baseline year for some of the Kyoto gases is different, but for the majority it is 1990.

[9] Scottish Executive, 2003. *Securing a Renewable Future: Scotland's Renewable Energy*. Online. Available at: http://www.scotland.gov.uk/Resource/Doc/47034/0014765.pdf [Accessed 15th April 2009]

[10] Scottish Government, 2007. *Renewable energy potential (News release)*. Online. Available at: http://openscotland.gov.uk/News/Releases/2007/11/27095600 [Accessed 15th April 2009]

[11] Scottish Government, 2008. *Renewable energy targets (News release)*. Online. Available at: http://openscotland.gov.uk/News/Releases/2008/09/09103722 [Accessed 15th April 2009]

[12] Scottish Government, 2008. *World to compete for Saltire Prize (News release)*. Online. Available at: http://www.scotland.gov.uk/News/Releases/2008/04/02151533 [Accessed 15th April 2009]

[13] Scottish Government, 2008. Saltire Prize – Challenge timeline. Online. Available at: http://www.scotland.gov.uk/Topics/Business-Industry/Energy/saltire-prize/detail/Timeline [Accessed 15th April 2009]

[14] Scotland's Renewable Resource 2001 Garrad Hassan & Partners Ltd. Scottish Executive 2001

[15] Department for Business, Enterprise and Regulatory Reform, 2008. *Aggregate energy balance 2007*. Online. Available at: http://stats.berr.gov.uk/energystats/dukes1_1-1_3.xls [Accessed 15th April 2009]

[16] Scottish Government/FREDS, 2008. *Making Scotland a leader in green energy*. Online. Available at: http://www.scotland.gov.uk/Resource/Doc/243461/0067751.pdf [accessed 30th May 2009]

[17] Scottish Executive, 2007. *Energy efficiency and microgeneration: a draft for consultation*. Online. Available at: http://www.scotland.gov.uk/Resource/Doc/169519/0047225.pdf [Accessed 15th April 2009]

[18] Scottish Government, 2007. *Energy efficiency panel (News release)*. Online. Available at: http://www.scotland.gov.uk/News/Releases/2007/09/18082827 [Accessed 15th April 2009]

[19] Scottish Government, 2008. *New 'one-stop' energy shop (News release)*. Online. Available at:

http://www.scotland.gov.uk/News/Releases/2008/06/04100843 [Accessed 15th April 2009]

[20] Scottish Government, 2008. *New 'one-stop' energy shop (News release)*. Op cit.

[21] Scottish Government, 2008. *Blueprint to help fuel poor (News release)*. Online. Available at: http://www.scotland.gov.uk/News/Releases/2008/11/19160352 [Accessed 15th April 2009]

[22] Scottish Government, 2009. *Energy efficient housing prize (News release)*. Online. Available at: http://www.scotland.gov.uk/News/Releases/2009/02/03100504 [Accessed 15th April 2009]

[23] Scottish Government, 2009. *Heating scheme to help families (News release)*. Online. Available at: http://www.scotland.gov.uk/News/Releases/2009/05/03141505 [accessed 30th May 2009]

[24] Office of Public Sector Information, no date. *Scotland Act 1998, Schedule 5*. Online. Available at: http://www.opsi.gov.uk/Acts/acts1998/ukpga_19980046_en_14#sch5 [Accessed 15th April 2009]

[25] Office of Public Sector Information, no date. *Electricity Act 1989, Section 36*. Online. Available at: http://www.opsi.gov.uk/ACTS/acts1989/ukpga_19890029_en_4#pt1-pb7-l1g36 [Accessed 15th April 2009]

[26] Scottish National Party, 2007. *Manifesto 2007*. Online. Available at: http://www.snp.org/system/files/manifesto+programme.pdf [Accessed 15th April 2009]

[27] Office of Public Sector Information, no date. *Scotland Act 1998, Schedule 5*. Op cit.

[28] Department of Trade and Industry, 2007. *Meeting the energy challenge*. Online. Available at: http://www.berr.gov.uk/files/file39387.pdf [Accessed 15th April 2009]

[29] Department for Energy and Climate Change, 2009. *Sites for nuclear power stations.* Online. Available at: http://www.nuclearpowersiting.decc.gov.uk/nominations/ [accessed 30th May 2009]

[30] Department of Energy and Climate Change, 2009. *Statement by Rt Hon Ed Milliband MP to the House of Commons on carbon capture and storage, 23rd April 2009*. Online. Available at: http://www.decc.gov.uk/en/content/cms/news/090423_ccs_sta/090423_ccs_sta.aspx [accessed 31st May 2009]

[31] Department for Environment, Food and Rural Affairs, 2007. *UK Energy Efficiency Action Plan 2007*. Online. Available at: http://ec.europa.eu/energy/demand/legislation/doc/neeap/uk_en.pdf [accessed 30th May 2009]

[32] OFGEM, 2009. *Smart metering*. Online. Available at: http://www.ofgem.gov.uk/Markets/RetMkts/Metrng/Smart/Pages/SmartMeter.aspx [accessed 31st May 2009]

[33] European Commission, 2008. *An EU energy security and solidarity action plan*. Online. Available at: http://register.consilium.europa.eu/pdf/en/08/st15/st15944.en08.pdf [Accessed 15th April 2009]

[34] Scottish Government, no date. *European energy policy & Scotland*. Online. Available at: http://www.scotland.gov.uk/Resource/Doc/917/0058867.doc [Accessed 15th April 2009]

[35] European Parliament, 2001. *Directive 2001/80/EC on the limitation of emissions of certain pollutants into the air from large combustion plants.* Online. Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2001:309:0001:0021:EN:PDF [Accessed 15th April 2009]

[36] http://www.scotland.gov.uk/Topics/Statistics/Browse/Environment/seso
/sesoSubSearch/Q/SID/132 (accessed May 09)

[37] Wood Mackenzie, *The future of electricity generation in Scotland*, for Scottish Council for Development & Industry, 9 Dec 2008

[38] http://www.scotland.gov.uk/Topics/Statistics/Browse/Environment/seso
/sesoSubSearch/Q/SID/98 and http://www.scotland.gov.uk/Topics/Statistics/Browse/Environment/seso
/sesoSubSearch/Q/SID/205 (accessed May 09)

[39] DBERR, Digest of UK Energy Statistics 2008, Table 5.8
http://www.berr.gov.uk/energy/statistics/publications/dukes/page45537.html (accessed May 09)

[40] Scottish Renewables, http://www.scottishrenewables.com (accessed May 09)

[41] We have assumed in all the cases a further 250 MW of thermal generation and 250 MW of CHP is introduced in 2019. This assumption is from National Grid.

[42] Wood Mackenzie, *The future of electricity generation in Scotland*, for Scottish Council for Development & Industry, 9 Dec 2008

[43] Wood Mackenzie, *The future of electricity generation in Scotland*, for Scottish Council for Development & Industry, 9 Dec 2008

[44] DECC, *Energy Markets Outlook,* December 2008

[45] National Grid, *Transmission Networks Quarterly Connections Update April 09*, 17 April 2009. http://www.nationalgrid.com/NR/rdonlyres/CC350758-2BC3-4ECE-9A69-038CAEB1CF5F/33696/TNQCUApril09v2.pdf (accessed May 09)

[46] DECC, *Energy Markets Outlook,* December 2008

[47] National Grid, *Transmission Networks Quarterly Connections Update April 09*, 17 April 2009. http://www.nationalgrid.com/NR/rdonlyres/CC350758-2BC3-4ECE-9A69-038CAEB1CF5F/33696/TNQCUApril09v2.pdf (accessed May 09)

[48] Scottish Government/Forum for Renewable Energy Development in Scotland, *Scottish hydropower resource study, final report,* Aug 2008

[49] National Grid, *Transmission Networks Quarterly Connections Update April 09*, 17 April 2009. http://www.nationalgrid.com/NR/rdonlyres/CC350758-2BC3-4ECE-9A69-038CAEB1CF5F/33696/TNQCUApril09v2.pdf (accessed May 09)

[50] National Grid, *Transmission Networks Quarterly Connections Update April 09*, 17 April 2009. http://www.nationalgrid.com/NR/rdonlyres/CC350758-2BC3-4ECE-9A69-038CAEB1CF5F/33696/TNQCUApril09v2.pdf (accessed May 09)

[51] National Grid, *Transmission Networks Quarterly Connections Update April 09*, 17 April 2009. http://www.nationalgrid.com/NR/rdonlyres/CC350758-2BC3-4ECE-9A69-038CAEB1CF5F/33696/TNQCUApril09v2.pdf (accessed May 09)

[52] DECC, *Energy Markets Outlook,* December 2008

[53] The contribution of variable-output wind power to system security, that is the 'capacity credit' of wind, is estimated by determining the capacity of conventional plants displaced by wind power, whilst maintaining the same degree of system security, in other words an unchanged probability of failure to meet the reliability criteria for the system. Alternatively, it is estimated by determining the additional load that the system can carry when wind power is added, maintaining the same reliability level.

[54] Electricity Networks Strategy Group (DECC and Ofgem), *Our electricity transmission network: a vision for 2020,* March 2009

[55] European Wind Energy Association, *Wind Energy – the Facts,* Earthscan 2009, ISBN 978-1-84407-710-6

[56] Electricity Networks Strategy Group (DECC and Ofgem), *Our electricity transmission network: a vision for 2020,* March 2009

[57] Scottish Government/Forum for Renewable Energy Development in Scotland, *Scottish hydropower resource study, final report,* Aug 2008

[58] Electricity Networks Strategy Group (DECC and Ofgem), *Our electricity transmission network: a vision for 2020,* March 2009

[59] Scottish Government, *Renewable Energy Targets,* 9 Sep 2008

http://openscotland.gov.uk/news/releases/2008/09/09103722 (accessed May 09)

[60] Scottish Government, Climate Change Bill

http://www.scottish.parliament.uk/s3/bills/17-ClimateChange/index.htm (accessed June 09)

[61] Committee on Climate Change, *Building a low-carbon economy: the UK's contribution to tackling climate change (the First Report of the Committee on Climate Change,* Dec 2008

[62] For Table 2.2, see Appendix II

[63] Element Energy (for BERR), *Potential for microgeneration: study and analysis,* Nov 2005. http://www.berr.gov.uk/files/file27558.pdf (accessed May 09)

[64] DECC, *Energy Markets Outlook,* December 2008

[65] Electricity Networks Strategy Group (DECC and Ofgem), *Our electricity transmission network: a vision for 2020,* March 2009

[66] Pöyry Energy (Oxford) Ltd, *Implications of the UK meeting its 2020 renewable energy target, a report to WWF-UK and Greenpeace UK*, Aug 2008

[67] Committee on Climate Change, *Building a low-carbon economy: the UK's contribution to tackling climate change (the First Report of the Committee on Climate Change,* Dec 2008

[68] Pöyry Energy (Oxford) Ltd, *Implications of the UK meeting its 2020 renewable energy target, a report to WWF-UK and Greenpeace UK*, Aug 2008

[69] BERR, UK Renewable Energy Strategy Consultation, June 2008.

http://www.decc.gov.uk/en/content/cms/consultations/cons_res/cons_res.aspx (accessed May 09)

[70] Scottish Government, *Energy Policy – an overview,* Sep 2008.

http://www.scotland.gov.uk/Resource/Doc/237670/0065265.pdf (accessed May 09)

[71] Scottish Government, *Energy Policy – an overview,* Sep 2008.

http://www.scotland.gov.uk/Resource/Doc/237670/0065265.pdf (accessed May 09)

[72] Committee on Climate Change, *Building a low-carbon economy: the UK's contribution to tackling climate change (the First Report of the Committee on Climate Change,* Dec 2008

[73] DJC MacKay, *Sustainable Energy – without the hot air*, 2008

http://www.withouthotair.com/ (accessed May 09)

[74] Committee on Climate Change, *Building a low-carbon economy: the UK's contribution to tackling climate change (the First Report of the Committee on Climate Change,* Dec 2008

[75] Greenpeace/WADE, 2006. *Decentralising UK energy: cleaner, cheaper, more secure energy for the 21st century*. Available at: http://www.greenpeace.org.uk/files/pdfs/migrated/MultimediaFiles/Live/FullReport/7441.pdf [accessed 25th May 2009]