Strathprints Institutional Repository

Elders, Ian and Ault, Graham and Burt, Graeme and Tumilty, Ryan and Mcdonald, James and Koehler, J. (2006) *Electricity network scenarios for 2020.* [Report]

SuperGen Future Network Technologies Consortium

Electricity Network Scenarios for 2020

July 2006

Authors

Graham Ault

Ian Elders

Jim McDonald

Graeme Burt

Ryan Tumilty

EPSRC/SGFNT/TR/2006-001

In collaboration with the ITI-Energy Networks Project:

TABLE OF CONTENTS

1. Introduction

This report presents a set of scenarios for the development of the electricity supply industry in Great Britain in the years to 2020. These scenarios illustrate the varied sets of background circumstances which may influence the industry over the coming years – including political and regulatory factors, the strength of the economy and the level to which environmentally-driven restrictions and opportunities influence policy and investment decisions.

Previous work by the authors (Elders et al, 2006) has resulted in a set of six scenarios illustrating possible developments in the electricity industry in the period up to 2050. While such scenarios are valuable in gauging the long-term direction of the electricity industry and its economic and environmental consequences, shorter-range scenarios are useful in assessing the steps necessary to achieve these long-range destinations, and to determine their relationship to current trends, policies and targets.

In this chapter, a set of medium-range scenarios focused on the year 2020 is developed and described. These scenarios are designed to be consistent both with the current state of the electricity supply industry in Great Britain, and with the achievement of the ultimate electricity generation, supply and utilisation infrastructure and patterns described in each of the 2050 scenarios. The consequences of these scenarios in terms of the emissions of carbon dioxide are evaluated and compared with other predictions.

The SuperGen 2020 scenarios described in this report were developed as a collaborative effort between the SuperGen project team and the ITI-Energy Networks Project team both based at the University of Strathclyde.

2. GB Demand and Generation

2.1 Existing GB Demand and Generation

In 2004, the total volume of electricity supplied via the electricity network in Great Britain was approximately 355TWh (DTI 2005, National Grid 2005). 40% of this energy was supplied by gas-fired generating units, 33% from coal, 19% from nuclear and the remaining 8% from other sources including imports and renewables. The peak demand met by the transmission system was approximately 60GW.

Installed plant capacities in 2004 are shown in Table 1 below:

Table 1: Installed generation capacity in 2004 (DTI, 2005)

Plant Type	Capacity (GW)
Fossil-fuelled steam	31.1
CCGT	24.6
Nuclear	11.8
OCGT and diesel	1.4
Renewables	3.1
Total	**72**

A significant volume of this plant, and particularly the steam units will be relatively old by 2020. Table 2 shows the plant capacity which will have reached 40 and 45 years of age by that point.

Table 2: Ageing generation plant in 2020 (National Grid, 2005)

Plant Type	Capacity > 40 years old (GW)	Capacity > 45 years old (GW)
Fossil-fuelled steam	27.2	24.9
CCGT	0	0
Nuclear	4.8	2.4
OCGT and diesel[1]	0.5	0.4
Renewables	1.1	1.1
Total	**33.6**	**28.8**

While generating plant lifetimes are ultimately dependent on the actual condition of the plant, its market performance and regulatory compliance, 40 and 45 years have been used here to illustrate typical plant lifetimes, and the effect of limited life-extension on the generation portfolio in Great Britain. It should be noted that the renewable capacity shown in table 2 consists of hydro-generation; subject to the condition of major civil engineering works such as dams and aqueducts, it is expected that this plant would be life-extended indefinitely.

2.2 Short and Medium Term Forecasts and Scenarios for Demand and Generation

A detailed short-range forecast of the development of the British electricity system focussing in particular on the transmission system is produced annually by the transmission system operator, National Grid, in the form of its Seven Year Statement (National Grid, 2005). This document provides forecasts of the level of annual electricity demand to be supplied via the transmission system as well as the peak demand to be met. A range of forecasts is made – some on the basis of models and data provided by National Grid, while others are based on data supplied by distribution companies and large industrial customers. The range of forecasts consider factors such as variations in economic growth, energy efficiency, and the extent to which demand is satisfied from generation connected to distribution networks. The current Seven Year Statement presents forecasts extending to 2012. At the end of this period the range of peak demand forecasts is 56-71GW, with a 'base estimate' of 65GW. The high and low values of energy supplied by the transmission network in 2011/12 are 410TWh and 330TWh respectively, with a base estimate of 375TWh.

The Seven Year Statement also provides a list of new generation projects with which arrangements have been made leading to formal connection to the network. While not all of these developments will proceed to construction and commissioning, they provide an indication of the generation technologies which are currently of interest to developers. The projects listed in the 2005 Seven Year Statement are summarised in table 3. It should be noted that this does not represent all generation likely to be constructed up to 2012; lead times for construction of many generator types is significantly less than seven years. However, it can be seen that there is a strong focus on CCGT as the currently preferred form of conventional generation, with wind as the renewable energy source of choice for developers.

Table 3: New generation projects listed in National Grid Seven Year Statement (National Grid 2005)

Plant Type	Capacity (GW)
CCGT	8.8
Hydro	0.1
Wind	4.4
Total	**13.3**

Another significant forecast of the future of the electricity industry has been produced as part of the Updated Energy Projections (UEP) exercise conducted by the UK Government's Department of Trade

[1] Only transmission-connected OCGT and diesel plant, with a 2004 capacity of 1.1GW is included.

& Industry (DTI 2006). The latest results of this work forecast the demand for electricity, the mixture of fuel sources used by generators and the resulting emissions of carbon dioxide. The results are based on a number of assumptions – for example the rate of growth in output of renewable generators, and that economic growth over the period will be close to the long-term average.

Four scenarios, considering different future trends in fossil fuel price are considered, with more detailed discussion of two central-price cases which consider the effect of prices favouring coal or gas-fuelled generators. In these scenarios, electricity demand is forecast to be in the range 375-380TWh/year in 2020. Gas fired generation accounts for between 53% and 60% of this total, while coal-fired generation produces 15-20% of electricity. Renewable generation production is 53TWh/year. Carbon dioxide emissions from electricity production in 2020 are in the range 135-160MtCO_2/year over the range of four scenarios.

2.3 Long-Term Scenarios: 2050

A number of bodies have produced long-term scenarios of the UK's energy use or electricity industry, generally considering the year 2050. The Royal Commission on Environmental Pollution (2000) proposed a set of four scenarios as an illustration of mechanisms by which a reduction of 60% in the UK's emissions of carbon dioxide could be achieved by 2050. These scenarios consider UK energy use in its entirely, including transport and heat demand, as well as electricity and show the effects of different combinations of demand reduction, renewables, nuclear generation and carbon capture and storage. These scenarios were further analysed in terms of their effect on the British generation portfolio by the Tyndall Centre for Climate Change Research (Watson, 2003). This analysis showed that under the RCEP scenarios (and to achieve the carbon emission reduction targets set out), renewable energy could be required to meet the majority of the UK's electricity demand by 2050.

Another set of scenarios was produced for the UK Department of Trade and Industry (Marsh et al, 2003) to investigate methods by which carbon dioxide emissions from the energy sector could be reduced, and the effects on energy prices and demand, and the costs of carbon abatement. Three basic scenarios, delineated by economic and social factors were proposed, and the effects of these scenarios and variations on them were evaluated using an energy system model.

The scenarios already mentioned in this section were drawn upon by the authors in proposing a set of long-term scenarios (Elders et al, 2006) focussed more closely on the electricity industry to support the work of the Supergen Future Network Technologies Consortium. These scenarios (for the year 2050) specifically consider developments in electricity generation and end use, and in transmission and distribution, together with issues of markets and regulation. These scenarios were characterised in terms of four key parameters: The level of economic growth, the rate of technical advancement, the level of environmental concern in society, and the degree of central regulation and intervention in the industry. The scenarios are summarised in table 4 below.

Table 4: Summary of Supergen 2050 Electricity Industry Scenarios

2050 Scenario	Economic Growth	Environmental Focus	Technological Growth	Regulatory Structure	Renewable-Generated Electricity (%)
Strong Optimism	More than recently	Stronger	Revolutionary	Liberalised	50
Business as Usual	Same as recently	As at present	Evolutionary	Liberalised	30
Economic Downturn	Less than recently	Weaker	Evolutionary	Liberalised	10-20
Green Plus	Same as recently	Much stronger	Revolutionary	Liberalised	80
Technological Restriction	More than recently	Stronger	Evolutionary	Liberalised	40
Central Direction	Same as recently	Stronger	Evolutionary	Interventionist	50-60

These 2050 scenarios were used as the basis of the scenarios focussing on 2020 which are described in this chapter.

3. Identification and Development of 2020 Scenarios

As noted previously, an important aim in identifying a set of 2020 electricity industry scenarios was to achieve consistency both with the current situation and with the set of 2050 scenarios previously developed. In order to achieve this objective consideration was given both to the likely trend in demand for electricity under each of the 2050 scenarios, and the technology mix which is anticipated. The effect of the underlying driving factors in each 2050 scenario is also taken into account in identifying a set of intermediate points (2020) in the development of each long-term scenario .

In considering the growth in demand for electricity, it was recognised that demand is likely to change gradually from its historic growth rate rather than making an abrupt transition directly towards the 2050 figure. In all cases, therefore, it is expected that electricity demand will have grown from today's value by 2050, although to different degrees in different scenarios. Beyond 2020, some scenarios will show continued growth in electricity use, while in others it will remain constant or decline. It was found that the 2050 scenarios could be divided into two groups. In one, comprising the "Green Plus" and "Economic Downturn" scenarios, electricity demand grows relatively modestly to 2020 as a result of environmental or economic pressures; in the remaining four scenarios the rate of electricity demand growth over the period is only slightly slower than today.

The technologies which were identified as being important to each of the 2020 scenarios were categorised into three groups according to their likelihood of being available for commercial deployment in 2020:

- Mature technologies which are currently seeing large-scale deployment, but which might see incremental improvements in scale or efficiency by 2020.
- Developing technologies which are currently seeing pilot or prototype use, but which might be expected to be available for deployment on a commercial scale by 2020.
- New technologies which are at an earlier stage of development, and may not have demonstrated their capability to achieve commercial viability and make a significant impact by 2020. Some of these technologies may achieve deployment in a commercial environment by 2020 in the form of pilot plants.

The rate at which individual technologies progress through these stages of development and the level of deployment which is achieved by 2020 will be dependent on the level of research and investment funding which is available to them, and the degree to which there is an economic, engineering or policy demand for the particular characteristics offered by the technology. Therefore, for each combination of technology and 2050 scenario the level of deployment called for by the scenario is tabulated, together with an estimate of the likely progress towards that goal in 2020.

A further consideration in relation to technology mix is the influence of the current fleet of generation and network plant. While it is reasonable to assume that the vast majority of current plant will have been replaced or at least substantially refurbished by 2050, this assumption cannot be made for 2020 scenarios. The rate at which existing plant is taken out of service will depend both on its age and condition, and on drivers present in the scenario which will promote either life-extension or early retirement. For example, scenarios in which there are strong economic constraints on new investment will promote the life-extension of existing power stations or network facilities in preference to investment in new plant with corresponding new network extensions.

As a result of this analysis, four groups of medium-term equivalents of the 2050 scenarios are identified. As already mentioned, two of these addressed cases – the 2050 “Economic Downturn” and “Green Plus” scenarios – in which electricity demand grows slowly. In these two cases, significant differences in the technology mix and degree of network development are apparent by 2020. Therefore, separate 2020 scenarios, labelled “Economic Concern” and “Environmental Awakening” are proposed to correspond to these 2050 scenarios.

In the remaining four “higher demand growth” situations, two reasonably similar sets of circumstances could be discerned. In one (“Strong Optimism”), strong economic growth leads to significant industry-led deployment of existing and developing technologies to meet – and to some extent limit – a growth in demand for energy services. In the other (“Technological Restriction”) economic growth is not matched by an accompanying maturing and availability of power technologies. Public perceptions of environmental responsibility become an increasing factor in the thinking of industry players. Beyond 2020 these two cases diverge in the level to which more advanced technologies are successfully brought to market and deployed. The situation in 2020 is represented by a scenario labelled “Continuing Prosperity”.

In the second pair of “high-growth” situations (“Business as Usual” and “Central Direction”), the influence of government and regulatory authorities is important in guiding and supporting technological innovation and environmental initiatives. Economically-driven growth in demand for energy services is less of an influence in these situations, and there is less focus on measures to restrict growth in demand for electricity, attention being instead turned to issues such as energy and supply security, and continued development of promising renewable technologies. These cases diverge after 2020 as the strength of central intervention increases in one case and relaxes in the other. The situation in 2020 is represented by a scenario labelled “Supportive Regulation”. Figure 1 below shows the relationship between the four 2020 scenarios and the six 2050 scenarios:

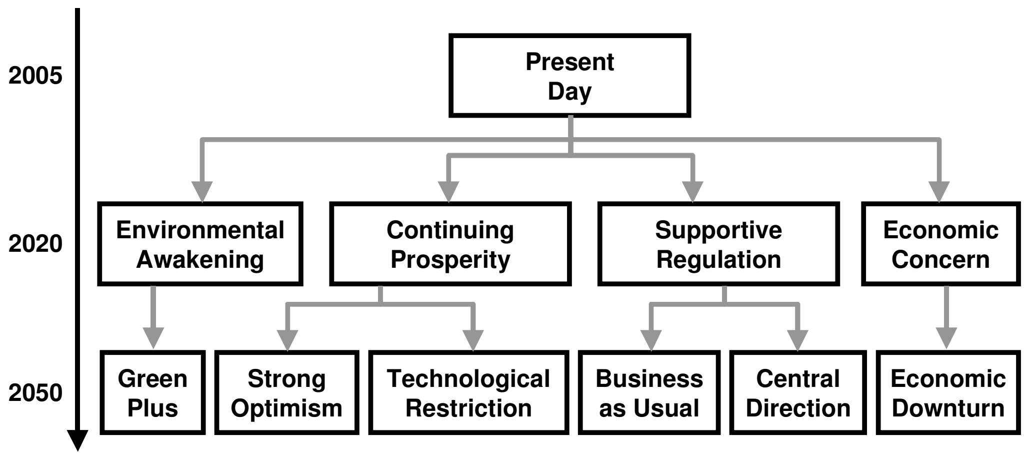

Figure 1: Relationship between 2020 and 2050 electricity industry scenarios

Table 5 characterises the four 2020 scenarios in terms of the four key parameters used to describe the 2050 scenarios:

Table 5: Summary of Supergen 2020 Electricity Industry Scenarios

2020 Scenario	**Economic Growth**	**Environmental Focus**	**Technological Growth**	**Regulatory Structure**
Continuing Prosperity	Increased	Slightly stronger	Strong	Liberalised
Economic Concern	Reduced	Reducing	Weak	Liberalised
Environmental Awakening	Current level	Stronger	Strong with environmental focus	Largely liberalised with some environmental intervention
Supportive Regulation	Current level	As at present	Moderate with central support	Mildly interventionist

In the following sections, each of these scenarios is described in more detail, and summaries of the 2020 generation mix envisaged in each case are given. In each case, the main generation and network technologies and their locations are illustrated graphically using the following key:

Local rural network	Offshore wind	Tidal generation
Local urban network	Onshore wind	Biomass
Interconnector	CCGT	Wave generation
Overhead AC transmission	CCGT with carbon capture	CHP
Overhead DC transmission	Coal generation	FACTS
Underground AC transmission	Coal with carbon capture	Microgrid
Demand-side participation	Nuclear	Energy storage

4. Scenarios for the GB Power System in 2020

This section describes the four scenarios for the GB power system in 2020 as identified and developed in the SuperGen Future Network Technologies project in collaboration with the ITI-Energy project.

4.1 Continuing Prosperity

The Continuing Prosperity scenario envisions a future in which buoyant economic growth is supported by strong research and development investment in electricity network and generation technology. These factors result in an electricity industry of increasing technical sophistication, in which long-term growth in demand for energy services is addressed through a combination of continuing investment in network infrastructure and strong promotion of load management measures such as energy efficiency and demand-side participation. Figure 2 shows the location of important generation technologies and developments of transmission and distribution networks.

Under this scenario, demand for electricity continues to grow year-on-year at a rate which reduces slightly from that of the present day, so that by 2020 the annual demand for electricity is approximately 415TWh. Peak demand for electricity grows at a similar rate to overall demand, increasing to around 66GW by 2020. Demand-side management is beginning to be applied to manage the increased demand on distribution networks as a means of avoiding significant network reinforcement. Smart metering is becoming increasingly widely adopted in all demand customer groups to underpin DSM and also support the integration of micro-generation.

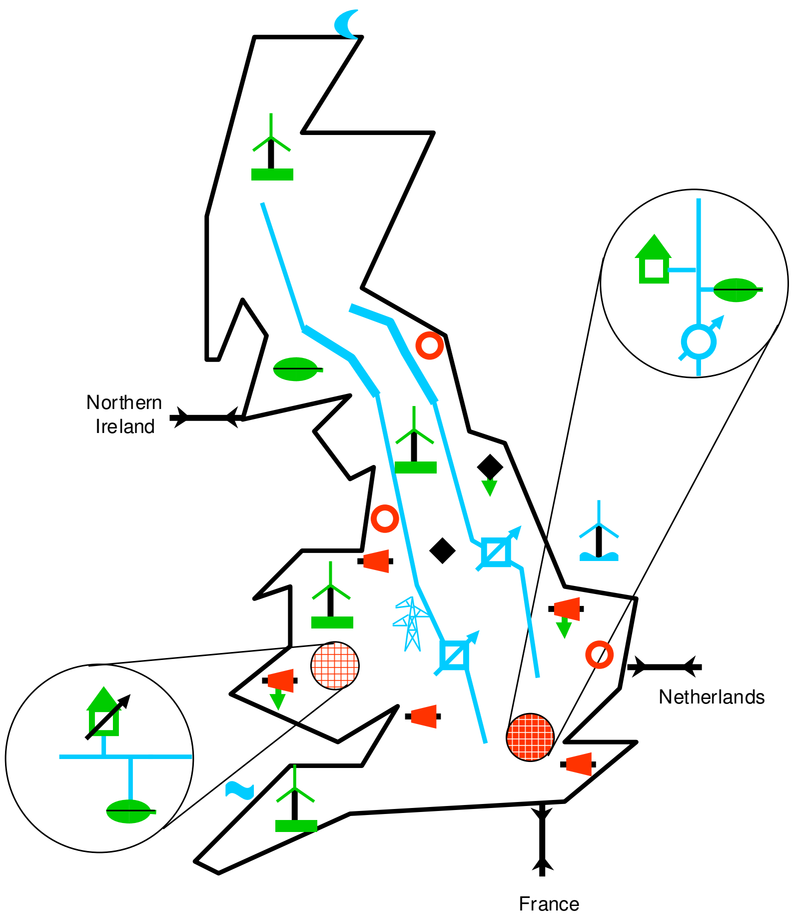

Figure 2: Generation and network technologies in 2020 "Continuing Prosperity" scenario.

There is continued investment in renewable energy, with wind generation having the largest installed renewable generation capacity. Of this, onshore wind dominates with 10GW of installed capacity in Scotland, Wales and northern and south-west England. Increasing concern over the visual impact of onshore wind is however fuelling a transition to offshore developments, and large offshore windfarms are being planned. By 2020 around 2GW of offshore wind capacity has been developed; it is mainly located around the coast of southern England to avoid congestion in the electricity network.

Biomass is the second largest renewable generator in terms of installed capacity. By 2020, 7GW of biomass generation is in operation, divided between energy crop fuelled systems in rural areas and refuse-burning plants in towns and cities. Small plants of up to 20MW tend to be usual in order to minimise the impact of the plants and associated transport infrastructure on the local area. These generators are usually connected to distribution networks.

Wave and tidal stream generation together account for 2GW of installed capacity, and there is a total of 2GW of hydro-generation. Taken together, renewable energy accounts for around 18% of electricity generated in Great Britain in 2020.

Non-renewable generation is dominated by natural gas-fired units, mainly in the form of CCGT, but with some CHP and a small but growing proportion of micro-CHP. To meet the growth in demand for electricity, some existing coal and nuclear units have been life-extended, but by 2020 are being replaced by new-build gas and coal-fired units. One or two of these stations, including IGCC-based clean-coal plant are generating commercially while participating in a carbon capture and storage scheme. Following a protracted planning process, new nuclear capacity is under construction, but has not yet begun operation.

The increase in demand for electricity, particularly at the time of peak load, is placing increased strain on transmission and distribution networks. Power electronic compensation and flow control devices are extensively deployed at transmission level to make maximum use of existing capacity, and there has been some upgrading of circuits within existing transmission corridors to increase their capabilities without significant additional environmental impact. Notably, the interconnector circuits between Scotland and England have been upgraded to operate at higher voltages in order to accommodate increased power transfers from renewable generation. Additionally, electricity imports from Europe have increased through the construction of a second interconnector.

There have been increases in small-scale generation connected to local distribution networks, including small-scale wind and biomass plants, together with gas-fuelled microturbine-based CHP systems of which 3GW of capacity has been installed. At the same time, average and peak loads on these networks have increased as a result of the general increase in demand for electricity. As a result, power flows in these networks are significantly more variable in 2020 than in 2006, and a variety of methods of responding to these pressures are being investigated. In networks with significant concentrations of non-intermittent generation, such as biomass, microgrid technology is being trialled with the objective of increasing the reliability of electricity supply, while in areas where intermittent generation is more common, local market structures – sometimes incorporating demand-side participation – are being examined.

Table 6: Generation technologies and electricity production in the Continuing Prosperity scenario

Generation technology	Installed Capacity (GW)	Electricity Production (%)
Offshore and onshore wind	12	6
Marine generation	2	2
Biomass	7	10
Hydro	2	1
Microgeneration	3	3
Nuclear	8	11
Large gas-fired units	44	55
Coal	9	12

The peak electricity demand and installed generation capacity under this scenario in the year 2020 are illustrated in Figure 3. The central portion of the illustration shows the existing peak electricity demand of 60GW as a green segment and the additional peak demand with the new total as a red segment. The plant margin (PM) is also illustrated.

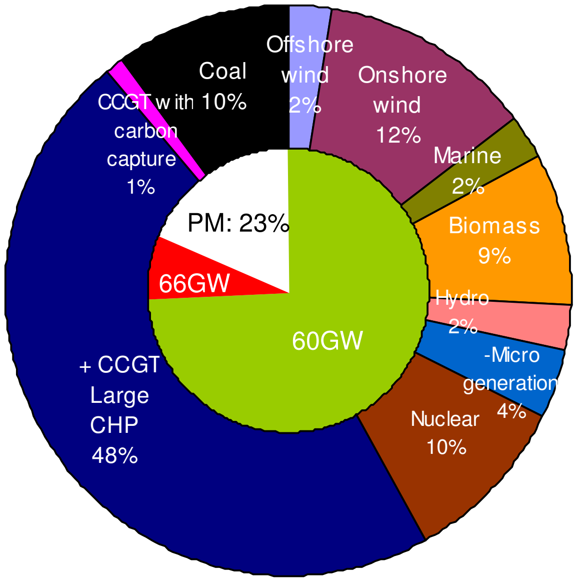

Figure 3: Electricity generation capacity, peak demand and generating plant margin in 2020 "Continuing Prosperity" scenario.

The electrical energy demand and proportion met by the different generation types in 2020 are illustrated in Figure 4. The central portion of the illustration shows the existing annual electrical energy demand as a green segment and the increase in demand with the new total as a red portion.

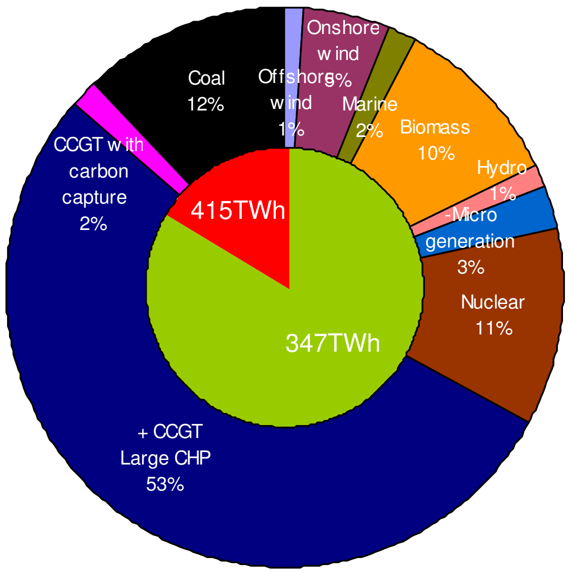

Figure 4: Electrical energy demand and generation output in 2020 "Continuing Prosperity" scenario.

4.2 Economic Concern

The Economic Concern scenario envisages a future in which the economy enters a period of moderate decline, perhaps as a result of significant fuel price increases or because of unfavourable conditions in the wider global economy. As a result, the availability of finance for investment in the electricity network and for research into generation and network technologies is restricted. Concern over the economy tends to replace environmental issues in the public consciousness; therefore pressure to achieve targets on emissions and thus deployment of renewables tends to reduce in this scenario. Figure 3 shows the location of important generation technologies and developments of the transmission and distribution networks.

Demand for electricity is depressed by the economic situation in this scenario. There is less inclination on the part of the public to buy new electricity consuming devices and appliances, and lack of growth in the industrial and commercial sectors also restricts electricity demand. There is interest in reducing expenditure on energy through the deployment of low-cost energy efficiency measures; expenditure on more expensive initiatives and devices is regarded as poor value under the tighter financial situation. By 2020, demand for electricity has risen only modestly to 360TWh/year, with the rate of increase declining to zero as 2020 is approached. There is some industrial and commercial interest in demand-side management schemes as a cost-saving measure to reduce the purchase of expensive peak energy. Peak demand for electricity is restricted to a level similar to that in 2006, at 60GW.

Renewable generation continues to develop in this scenario, but the deployment of intermittent generation such as wind and marine devices becomes increasingly restricted by network constraints which are considered uneconomic to alleviate. Onshore wind capacity has reached 7GW by 2020, with a few hundred megawatts of pilot offshore wind capacity having been installed. Wind accounts for about 5% of electricity produced in Great Britain. Few new wind generation schemes are in prospect, and results from the offshore pilots indicate that the extra costs over onshore schemes and their susceptibility to network constraints will make them commercially unattractive. No wave or tidal generation is installed in this scenario.

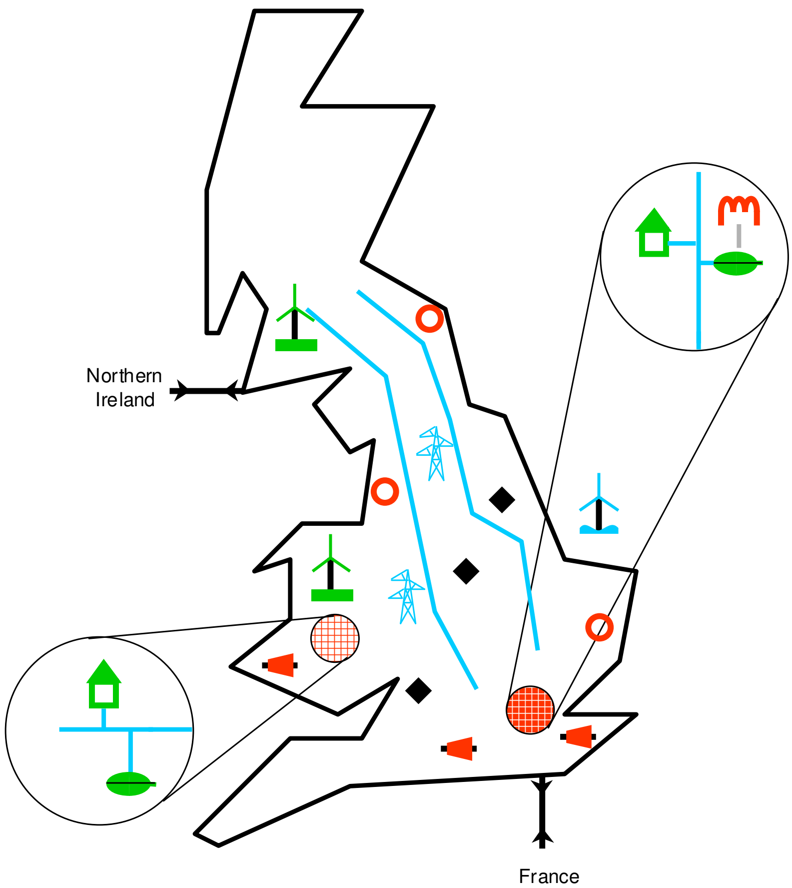

Figure 5: Generation and network technologies in 2020 "Economic Concern" scenario

Biomass develops reasonably strongly in this scenario, with waste-fuelled generation in urban areas being integrated into local heating schemes associated with new buidling developments. In rural areas, small combustion-based systems are fuelled by energy crops grown in the surrounding area. By 2020, 7GW of biomass capacity has been installed, supporting 10% of British electricity consumption.

Large generation dominates in this scenario, supplying 85% of all electricity produced in Great Britain. Existing coal and nuclear stations have been life-extended in order to postpone investment in replacement capacity. Some new capacity has been constructed, being a mixture of CCGT and coal-fired steam plant. Investors increasingly prefer coal over gas in order to reduce their exposure to continuing uncertainty over future gas prices. New stations tend to reuse existing sites in order to avoid investment in transmission network extension. While some existing nuclear stations remain in operation through life-extension, construction of new nuclear capacity has been frustrated by high costs and uncertainty over the financial risks of such projects.

Transmission and distribution networks remain largely unchanged today under this scenario. Existing plant is life-extended, often through the application of condition monitoring technology, and is replaced either like-for-like or with more cost-effective modern equivalent plant tailored to the demands actually placed on it (rather than being driven by any possible future requirements). The capabilities of the transmission system become an important factor influencing the location of new generation. At distribution level, networks remain largely passive, and there is a focus on postponing or avoiding major investment to an even greater level than for transmission networks. Generation connected to distribution networks is mainly confined to biomass fuelled plants of a few megawatts in rural areas, whose location is influenced by the topology of the network as much as the location of the biomass resource. Small scale wind generation is generally discouraged on the grounds that its intermittent output cannot be accommodated by distribution networks without investment to avoid power quality problems. Micro-CHP technology does not develop to the point of being economically attractive to individual households or businesses.

Table 7: Generation technologies and electricity production in the Economic Concern scenario

Generation technology	Installed Capacity (GW)	Electricity Production (%)
Offshore and onshore wind	8	4
Marine generation	0	0
Biomass	7	10
Hydro	2	1
Microgeneration	0	0
Nuclear	7	12
Large gas-fired units	36	53
Coal	13	20

The peak electricity demand and installed generation capacity under this scenario in the year 2020 are illustrated in Figure 6. The central portion of the illustration shows the existing peak electricity demand of 60GW as a green segment and the plant margin (PM).

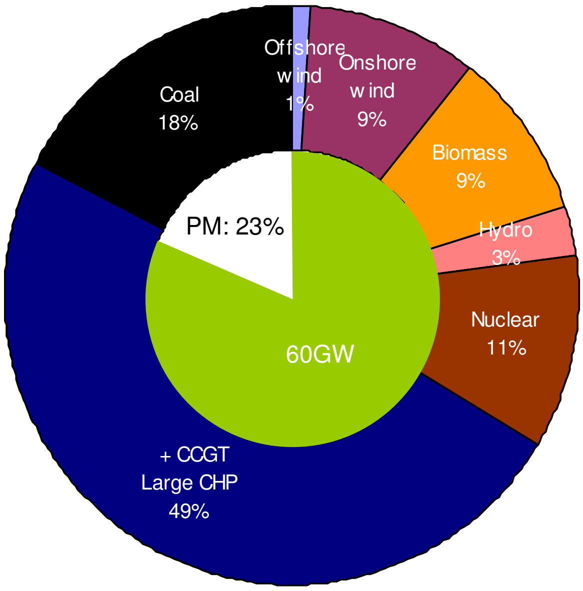

Figure 6: Electricity generation capacity, peak demand and generating plant margin in 2020 "Economic Concern" scenario.

The electrical energy demand and proportion met by the different generation types in 2020 are illustrated in Figure 7. The central portion of the illustration shows the existing annual electrical energy demand as a green segment and the increase in demand with the new total as a red portion.

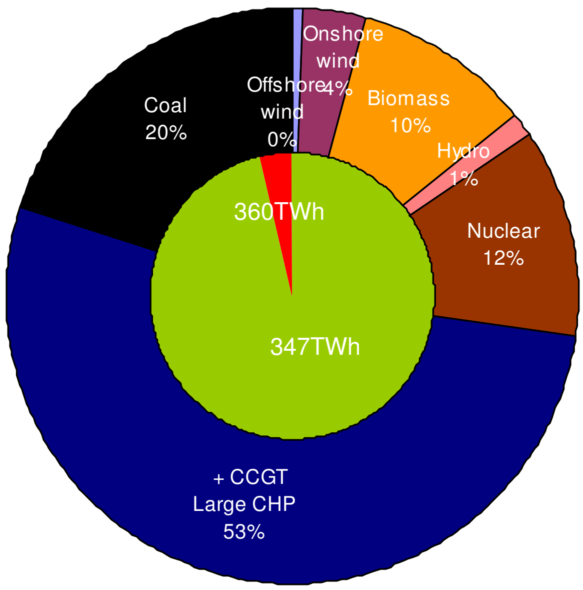

Figure 7: Electrical energy demand and generation output in 2020 "Economic Concern" scenario.

4.3 Environmental Awakening

The Environmental Awakening scenario considers a future in which the impact on the environment of the electricity industry, including generation, networks and end use, is a matter of increasingly important and popular concern. This awareness has its foundation in the heightened public awareness of climate change and the environment evident in 2006. Figure 4 shows the location of important generation technologies and developments of transmission and distribution networks for this scenario.

By 2020 in this scenario, electricity demand will have reached a peak, and is beginning a gradual but steady decline as a result of the take-up of energy efficiency measures promoted by the increased public environmental consciousness. Advanced approaches to energy management in buildings and growing number of smart meters for all customer classes are evidence of the concern for efficient use of electrical energy. The decline in energy consumption extends into the 2030s, by which time the use of fossil fuelled CHP systems for space and water heating begins to give way to the use of renewably generated electricity in devices such as ground source heat pumps. Under this scenario, electricity demand in 2020 is 360TWh/year. Participation in demand-side management schemes by commercial and industrial concerns results in the demand for electricity being less variable with time of day and the annual peak demand is also comparable with 2006 at 60GW.

There is strong investment in new renewable generation capacity such that renewables account for almost a third of the generation portfolio measured by plant capacity. Onshore wind generation has the largest share of renewable capacity, with rapid installation of relatively large developments giving a total capacity of about 12GW by 2020. Important concentrations of onshore wind are found in Scotland, Wales and north and south-west England. However, increasing resistance to the visual impact of onshore wind turbines, and negative perceptions of their effect on the local environment result in the maximum size of developments falling from a peak of 500MW to 100MW or less in 2020 and a reduction in their rate of construction as suitable sites become scarce. By 2020 most onshore wind development is taking place in community-scale schemes connected to local distribution networks. Large-scale wind generation focus has switched to offshore developments. By 2020, 3GW of offshore wind generation capacity is in operation, with considerably more in planning and development. Initial development has focussed on relatively sheltered sites around the north-east of Scotland and the south-east of England, but developments are in prospect in other, more challenging areas. Taken together, onshore and offshore wind generation accounts for around 8% of electrical energy production in 2020.

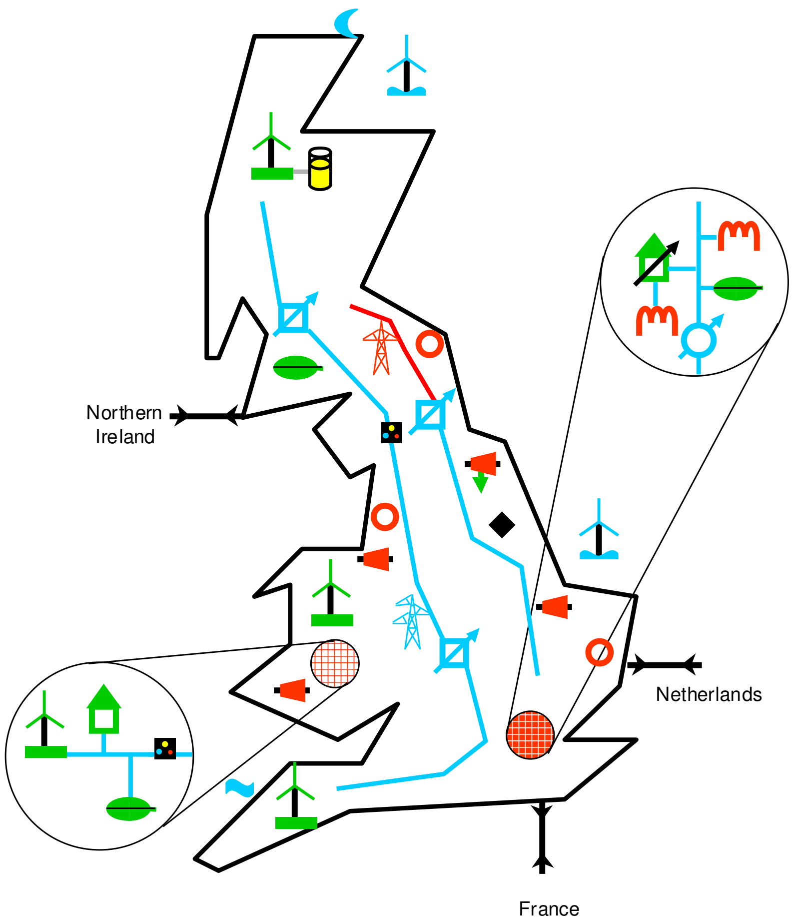

Figure 8: Generation and network technologies in 2020 "Environmental Awakening" scenario

By 2020, the Environmental Awakening scenario foresees that marine energy sources, in the form of wave and tidal-stream devices are achieving commercial success, with exploitation of tidal energy around the northern coast of Scotland, and wave energy in south-western England. About 2.5 GW of capacity has been installed, in developments of tens of megawatts each.

Biomass generation develops strongly in this scenario, in the form of relatively large generating units connected to higher-voltage distribution networks or lower-voltage parts of the transmission system. Refuse-fuelled urban plants participate in local CHP schemes. Almost 10GW of biomass plant is in operation. In total, renewables account for just over 25% of electricity production in Great Britain.

Large generation plant is dominated by gas-fuelled units, mainly in the form of CCGT, but with some gas fired CHP units. Existing nuclear capacity is life-extended and retained for as long as possible in recognition of its low-carbon credentials and to allow the build-up of renewable capacity in preference to investment in fossil-fuelled replacements. No new construction of nuclear capacity is in prospect though, and the remaining nuclear stations are approaching decommissioning dates. Coal-fired generation capacity is declining rapidly, with plants which survive the Large Combustion Plant Directive being rendered uneconomic by high carbon prices and reducing emissions allocations under international programmes. Carbon capture and sequestration has seen initial application to commercial-scale plants fuelled by gas and coal, but reservations over the long-term bulk transport and storage of carbon dioxide are being expressed on environmental and safety grounds.

The electricity network is experiencing progressively increased pressure as a result of the growth in renewable generation in more remote areas. Some extension of the transmission network into these areas has been undertaken to permit connection of renewable generators, but there is significant pressure to reduce the environmental impact of electricity networks in general, and thus general network reinforcement has not been possible. HVDC technology has however been introduced to one of the interconnector routes between Scotland and England as a first step towards an offshore interconnector intended to accommodate the output of wind, wave and tidal generation which is in prospect. Undergrounding of sections of network as they fall due for refurbishment is an increasing trend.

Power-electronic based flow management and control devices have been extensively deployed to maximise utilisation of the existing network, while prototype bulk energy storage devices have been integrated into one or two of the most recent renewable energy projects in Scotland to improve their market performance and access to the network.

Local distribution networks have seen a large increase in the volume of generation connected to them. As discussed above, smaller scale wind and biomass plants are an element of this growth, but another important influence is the rapid development of domestic micro-CHP plants using gas-fuelled microturbine technology. Some models on the market include a small amount of battery-based energy storage to improve the proportion of domestic load they can support. Small-scale power electronic compensation and control systems are increasingly deployed in distribution networks. Various new approaches to network management, particularly at distribution voltages, are employed to manage the progressively more active nature of the power networks. Constraining of renewable generation is viewed as a cost-effective means of achieving large scale integration of these energy sources.

Table 8: Generation technologies and electricity production in the Environmental Awakening scenario

Generation technology	Installed Capacity (GW)	Electricity Production (%)
Offshore and onshore wind	15	8
Marine generation	2.5	2
Biomass	9	14
Hydro	2	1
Microgeneration	6	5
Nuclear	7	11
Large gas-fired units	35	52
Coal	4.5	7

The peak electricity demand and installed generation capacity under this scenario in the year 2020 are illustrated in Figure 9. The central portion of the illustration shows the existing peak electricity demand of 60GW as a green segment and the plant margin (PM).

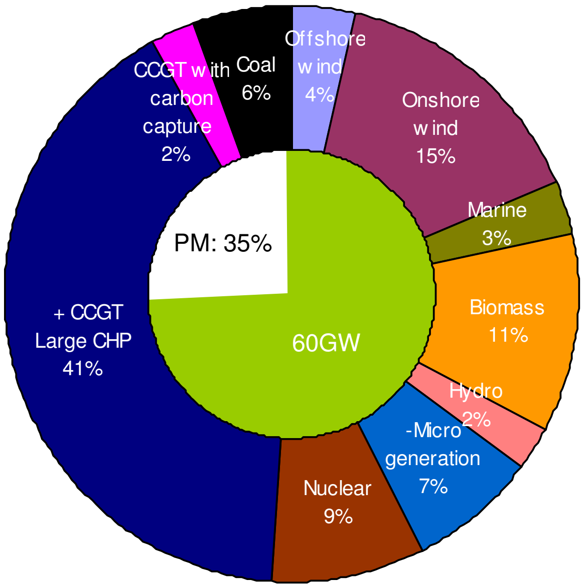

Figure 9: Electricity generation capacity, peak demand and generating plant margin in 2020 "Environmental Awakening" scenario.

The electrical energy demand and proportion met by the different generation types in 2020 are illustrated in Figure 10. The central portion of the illustration shows the existing annual electrical energy demand as a green segment and the increase in demand with the new total as a red portion.

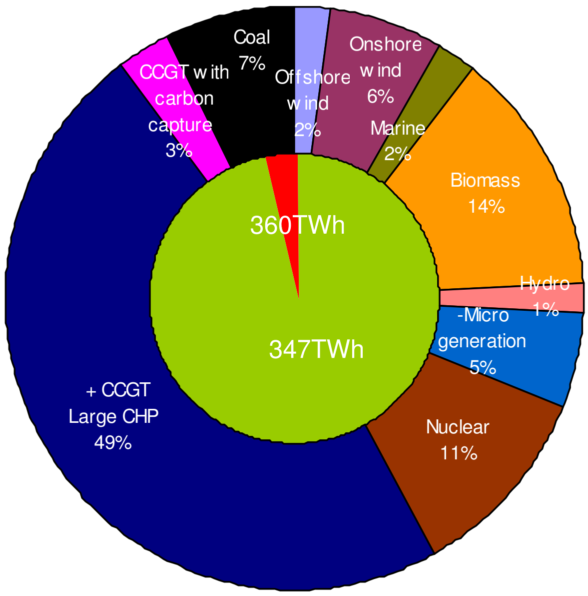

Figure 10: Electrical energy demand and generation output in 2020 "Environmental Awakening" scenario.

4.4 Supportive Regulation

The Supportive Regulation scenario describes a future in which the government and regulatory authorities exert a gradually increasing influence over the development of the electricity industry. This development is brought about by increasing public concern over issues such as energy security, and strategic planning issues associated with power generation and network infrastructure. Figure 5 shows the location of important generation technologies and developments of transmission and distribution networks under this scenario.

In this scenario, demand for electricity continues to grow relatively strongly and reaches approximately 415TWh/year by 2020. This growth is restricted to some extent by government sponsored energy efficiency initiatives, but a more important central influence on demand is government promotion of demand-side participation. DSP schemes are seen as providing increased security of supply in response to growing peak demand at a lower cost and environmental impact than increased generation capacity and network expansion. As a result, while peak demand continues to rise beyond current levels, it is restricted to about 63GW in 2020.

The deployment and development of low and zero carbon generation technologies is supported by government and regulatory authorities, both through research and development funding to improve technology, and through favourable market arrangements and incentives for qualifying generation developments. Wind power is a beneficiary of these arrangements, such that by 2020 9GW of generation capacity has been installed. Of this, almost 90% is in the form of relatively large onshore developments whose location is increasingly driven by central and regional government policies on suitable areas for development. Somewhat over 1GW of offshore wind capacity has been installed, initially in areas such as the south-east of England and the Irish Sea, but research into the development of deeper water sites is benefiting from government support to the extent of larger scale developments at the advanced planning stage.

Marine generation has also benefited from central support, so that by 2020 2GW of wave and tidal-stream capacity has been installed. Initial deployment has been focussed on two main geographical areas, with wave generation along the Atlantic coast of south-west England and tidal developments on the north coast of Scotland.

Biomass has been a beneficiary of government policy with increasing incentives for the production of energy crops being provided through agricultural subsidy. 8GW of mainly small-scale biomass generation has been installed, with a limited quantity of urban waste-fuelled generation participating in local heating and cogeneration schemes associated with industrial and commercial developments. Taken together, renewables account for a little over 20% of electricity production in 2020. Increasing pressure for diversity of energy sources influences government policy in relation to large generation. The most notable consequence is the resumed construction of nuclear generation. The first one or two of a planned fleet of new nuclear power stations has been recently commissioned in 2020, while existing stations have been kept in operation for as long as possible through life-extension. Nuclear output in 2020 is similar to today, accounting for 18% of electricity produced. Coal-fuelled generation is another beneficiary of the increased focus on diversity, with new power stations being constructed to replace older, less efficient plant. New coal fired plant is a mix of relatively traditional steam units, and newer technology such as IGCC. Large gas-fuelled generation using combined cycle technology remains the largest single source of electricity both by installed capacity and electricity produced, supporting about half of the annual electricity demand. Government incentives for the development of pilot carbon capture and storage schemes are being taken up, with about 5% of gas and advanced coal generation participating.

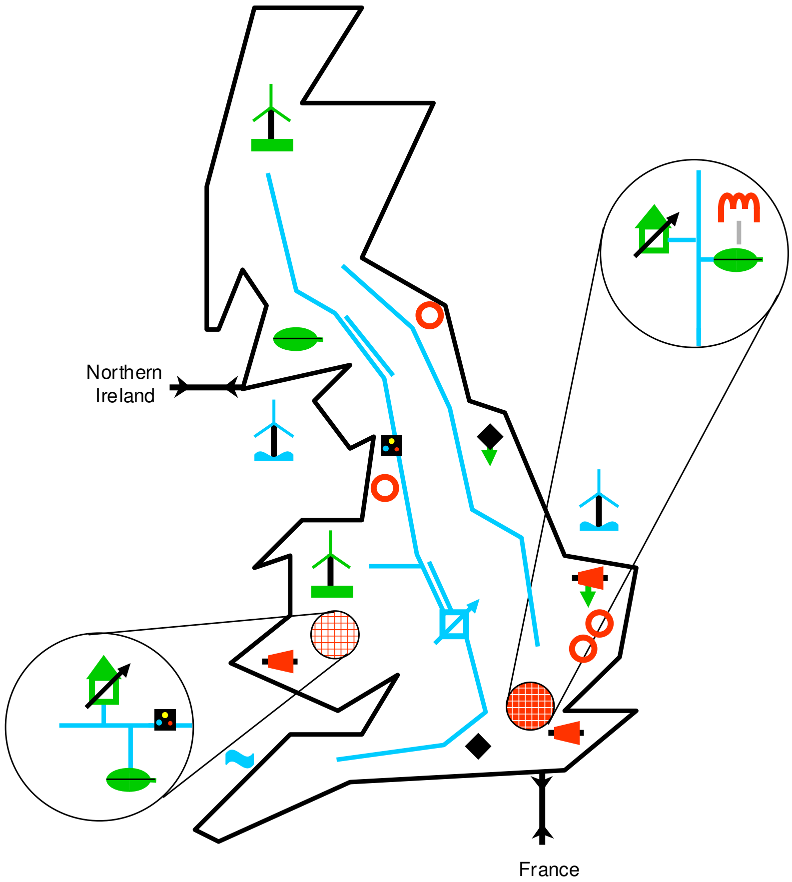

Figure 11: Generation and network technologies in 2020 "Supportive Regulation" scenario

Network development has focussed on maintaining supply reliability (mainly through ageing asset renewal programmes) and the connection of renewable developments in designated areas of Britain. Transmission network reinforcement has focussed on improving the capacity of existing corridors through increases in the capacity of plant as it falls due for replacement or refurbishment, and deployment of power-electronic based devices to influence patterns of power flow and manage voltage levels in steady state and transiently. Network extensions have been planned in concert with policies for the development of renewable generation resources in Scotland, Wales and south-west England.

Distribution networks have been affected by increases in the amount of generation connected to them. At the same time, there is increased regulatory pressure to maintain and improve the quality and reliability of electricity supply. Wind generation developments mainly influence higher distribution voltages (e.g. 33kV to 132kV), while biomass is concentrated more in the middle range of voltages (e.g. 11kV and 33kV). Biomass generation tends to be controlled to balance local peaks in electricity demand, a task which is also the goal of government incentives for industry and large commercial electricity users to participate in demand-side control programmes. Neither domestic-scale DSP nor micro-CHP are encouraged by central policy, and thus see minimal deployment.

Volatility of output from wind generation connected to distribution networks is absorbed in part by DSP programmes, but there remains an increased level of variation in power transferred between the distribution system and the transmission network. Improvements to control systems at the interface between transmission and distribution are necessary to avoid power quality problems. Reliability of the local electricity supply is improved by increased undergrounding of lower-voltage distribution networks.

Table 9: Generation technologies and electricity production in the Supportive Regulation scenario

Generation technology	Installed Capacity (GW)	Electricity Production (%)
Offshore and onshore wind	10	6
Marine generation	2	2
Biomass	8	12
Hydro	2	1
Microgeneration	0.25	0
Nuclear	13	18
Large gas-fired units	38	49
Coal	12	12

The peak electricity demand and installed generation capacity under this scenario in the year 2020 are illustrated in Figure 12. The central portion of the illustration shows the existing peak electricity demand of 60GW as a green segment and the additional peak demand with the new total as a red segment. The plant margin (PM) is also illustrated.

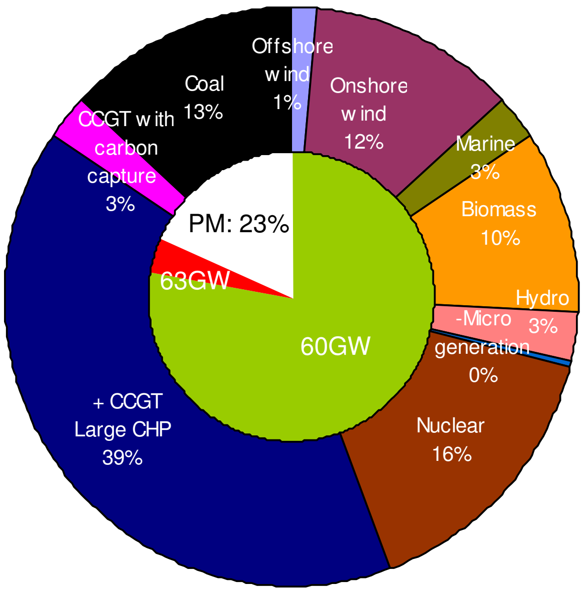

Figure 12: Electricity generation capacity, peak demand and generating plant margin in 2020 "Supportive Regulation" scenario.

The electrical energy demand and proportion met by the different generation types in 2020 are illustrated in Figure 13. The central portion of the illustration shows the existing annual electrical energy demand as a green segment and the increase in demand with the new total as a red portion.

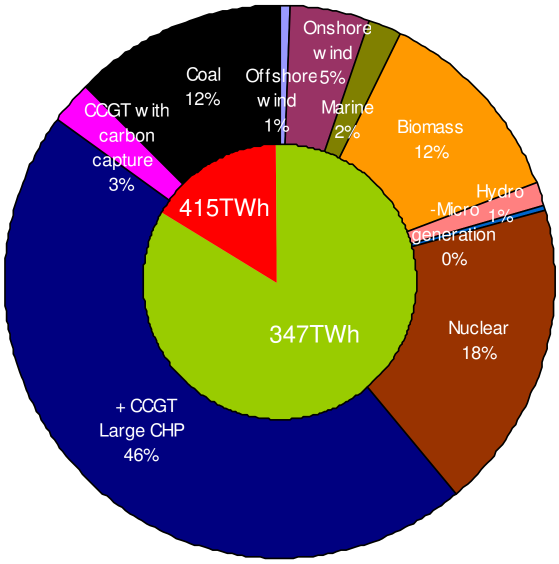

Figure 13: Electrical energy demand and generation output in 2020 "Supportive Regulation" scenario.

5. Conclusions and Summary

This report has proposed a set of four scenarios for the electricity industry in Great Britain in 2020. The scenarios are summarised in table 12 below. While these scenarios have a diverse range of outcomes in terms of the generation mix and level of demand for electricity, they all exhibit a significant reduction in the carbon dioxide emissions from electricity production.

Table 12: Summary of 2020 Supergen scenarios

Scenario	Average annual demand growth (%)	Renewable electricity production (%)	Fossil-fuelled electricity production (%)	CO_2 emissions ($MtCO_2$/year)
Continuing Prosperity	1.0	19	70	129
Economic Concern	0.2	15	73	127
Environmental Awakening	0.2	25	64	96
Supportive Regulation	1.0	21	61	111

As might be expected given the shorter timescale over which they develop, the scenarios described here show a much narrower range of outcomes than the 2050 Supergen scenarios. Nonetheless, they illustrate the range of future situations which might arise given their underlying assumptions. It is clear that if substantial decarbonisation of the British electricity industry is to be achieved, considerable and sustained effort and investment will be required in the coming years.

6. References

Bozzolo, M., M. Brandani, A. Traverso and A.F. Massardo (2003). Thermoeconomic Analysis of Gas Turbine Plants With Fuel Decarbonization and Carbon Dioxide Sequestration, *Journal of Engineering for Gas Turbines and Power*, 125(4): 947-953.

Dettmer, R (2005). The Right Stuff?, *IEE Review*, 51(3): 44-48.

DTI (2005). Digest of United Kingdom Energy Statistics 2005, London: Department of Trade and Industry.

(2006) "UK Energy and CO_2 Emissions Projections: Updated Projections to 2020", London: Department of Trade and Industry.

Elders, I., G. Ault, S. Galloway, J. McDonald, M. Leach, E. Lampaditou and J. Köhler (2006). Electricity network scenarios for the United Kingdom in 2050, in T. Jamasb, W.J. Nuttall and M.G. Pollitt (eds), *Future Electricity Technologies and Systems*, Cambridge: Cambridge University Press.

Howard, B. and C. Olszak (2004). *Fuelling Landscape Repair: A Bioenergy Industry as a Sustainable Land-use and Energy Option for Australia*, Barton, ACT: Rural Industries Research and Development Corporation.

Marsh, G., P. Taylor, D. Anderson, M. Leach and R. Gross (2003*). Options for a Low Carbon Future – Phase 2*, Harwell: AEA Technology, available from http://www.dti.gov.uk/energy/environment/research/climate-change/page21988.html

National Grid (2005). *GB Seven Year Statement*, Warwick: National Grid Company plc.

Royal Commission on Environmental Pollution (2000). *Energy: The Changing Climate*, London: Her Majesty's Stationery Office.

Spath, P.L. and M. K. Mann (2000), *Life Cycle Assessment of a Natural Gas Combined-Cycle Power Generation System*, Report NREL/TP-570-27715, Golden, CO: National Renewable Energy Laboratory.

Watson, J. (2003). *UK Electricity Scenarios for 2050*, Brighton: Tyndall Centre for Climate Change Research.