



Renewable Energy and Combined Heat and Power Resources in the UK

Jim Watson, Julia Hertin, Tom Randall and Clair Gough

April 2002

Renewable Energy and Combined Heat and Power Resources in the UK

Jim Watson, Julia Hertin and Tom Randall

Environment and Energy Programme
SPRU, University of Sussex, Falmer, East Sussex, BN1 9RF

Clair Gough

Manchester School of Management, UMIST

Email contact: w.j.Watson@sussex.ac.uk

Tyndall Centre Working Paper No. 22
April 2002

Contents

1. Introduction.....	3
2. Renewable energy sources.....	4
2.1 Introduction.....	4
2.2 Energy from waste.....	6
2.3 Hydro power.....	9
2.4 Wind Power.....	11
2.5 Biofuels.....	14
2.6 Wave power.....	17
2.7 Tidal power.....	19
2.8 Photovoltaics.....	20
3. Regional Renewable Energy Assessments.....	23
3.1 South East.....	24
3.2 South West.....	24
3.3 London.....	25
3.4 East Midlands.....	25
3.5 West Midlands.....	26
3.6 Eastern.....	26
3.7 North West.....	27
3.8 North East.....	28
3.9 Yorkshire and the Humber.....	28
3.10 Scotland.....	29
3.11 Wales.....	30
3.12 Northern Ireland.....	30
4. Combined Heat and Power (CHP).....	32
4.1 Current CHP Capacity and Short-term Projections.....	32
4.2 The Long-term Potential for CHP in the UK.....	33
ANNEX: Key studies - methodologies and assumptions.....	35

1. Introduction

The aim of the report is to construct a comprehensive picture of the renewable energy and CHP resource base in the UK. It provides a synthesis of existing studies assessing the scope for the deployment of different renewable energy technologies and combined heat and power facilities. Drawing on regional assessments and resource maps, it gives an indication of the geographical location of these energy resources. Most of the report was completed in July 2001. Further material on the regional renewable energy resource studies was added later in early 2002.

Overall, the report is concerned with what is *possible* rather than with what is *likely*. However, for most technologies the assessment of purely physical potentials will not provide a realistic view of what is possible. Studies address this problem through distinction between, for example, ‘accessible’, ‘practicable’ and ‘cost-effective resources’. This report addresses this problem in two ways:

- It focuses on ‘practicable resources’, considering costs and other constraints only where this is inevitable (e.g. because costs are the dominant factor in the assessment or because the available sources make assumptions about constraints); and
- It gives details, where possible, about the assumptions made by the different studies regarding physical, technical, economic, and political restrictions.

The report draws heavily on a number of sources, most of which are summarised in the Annex to this report:

- An assessment of renewable energy sources in the UK carried out by ETSU (referenced as ETSU 2000);
- The report by the Royal Commission on Environmental Pollution, *Energy -The Changing Climate* (referenced as RCEP 2000);
- The Department of Trade and Industry New and Renewable Energy Programme website at <http://www.dti.gov.uk/renewable> (referenced as DTI web);
- An assessment of CHP potential by the ETSU (referenced as ETSU 1997); and
- Regional assessments of renewable energy by government offices in the English regions, Scotland, Wales and Northern Ireland and an analysis of these by OXERA and ARUP published in February 2002¹.

¹ OXERA and ARUP Regional Renewable Energy Assessments Report to DTI and DTLR (February 2002)

2. Renewable energy sources

2.1 Introduction

The UK government ‘proposes that 5% of UK electricity requirement should be met from renewables by the end of the year 2003 and 10% by 2010’². There are a variety of renewable energy sources and technologies that can contribute to meeting this commitment. While some are already used on a significant scale, others are still at an early stage of development. This report covers all renewable energy sources that could make a significant contribution to UK electricity generation in 2010. It covers technologies embedded in distribution systems as well as those which are not. This is necessary because the amount of additional generation to be embedded by 2010 will partly depend on the development of non-embedded renewable generation.

In 1998, the UK generated **372 TWh electricity**, of which about **10.4 TWh or 2.8%** was produced from renewable sources³. More than two thirds of this contribution stems from hydro power. The DTI estimates on the basis of a central GDP growth projection that annual UK electricity demand will be **371 TWh** (assuming high energy prices) or **390 TWh** (assuming low energy prices) **in 2010** (ETSU 2000). The DTI consultation document *New and Renewable Energy - Prospects for the 21st Century* presents three scenarios illustrating potential ways of achieving the 10% renewable energy target. It specifies the potential share of a range of renewable energy sources to UK electricity generation under a ‘trends continued’, a ‘high wind’ and a ‘constrained wind’ scenario. Table 1 shows how much **electricity output** each of these sources would need to generate to meet the target, assuming a **total electricity demand of 380 TWh**. It should be noted that the figures refer to renewable capacity *in addition* to that already installed.

Table 1 – Technology Scenarios for the UK 10% renewables target

Electricity Output (GWh)	Trends continued	High wind	Constrained wind
energy crops	1900	1150	6100
Offshore wind	4950	6850	3050
onshore wind	8000	9900	4950
small hydro	400	400	400
waste incineration	6100	4950	6500
other biomass	1900	1150	1900
Landfill gas	6100	4950	6500
Other	1900	1150	1150
<i>Existing</i>	<i>7600</i>	<i>7600</i>	<i>7600</i>

Source: Calculations from ETSU/DTI *New and renewable energy: Prospects in the UK for the 21st century: Supporting analysis* Appendix D, 2000 and DTI Energy Paper 65, projecting a total electricity demand of 380 TWh. Figures are rounded.

Note: These figures are in fact higher than those which would satisfy a strict interpretation of the Renewables Obligation – this requires 10% of electricity sales by UK suppliers to come from renewables by 2010, and assumes total *sales* in 2010 will be **324TWh** (this excludes Northern Ireland, transmission losses and power use within the electricity industry).

² Department of Trade and Industry *New and renewable energy - Prospects for the 21st century: Conclusion in response to the public consultation* London, 2000.

³ DTI *Digest of UK Energy Statistics 2000* (July 2001).

To achieve the expansion of renewable energy to meet the 10% target, a number of policy initiatives are now in place⁴, including:

- A subsidy scheme to encourage the deployment of renewable energy schemes in the form of the **Renewables Obligation**, which came into force on 1st April 2002. This obliges all electricity suppliers to source a percentage of their electricity from renewable sources. The percentage will increase in stages from 3% in 2002 to 10.4% in 2010. The Performance and Innovation Unit (PIU) in the Cabinet Office has recently recommended that a further target of 20% of electricity from renewables by 2020 should be adopted⁵.
- **Exemption of renewable energy from the Climate Change Levy**, a tax on business use of energy which has been in place since April 2001. The normal rate for electricity of 0.43p/kWh is not paid by users of renewable energy.
- A public **R&D programme**, currently funded at £18m per year from the DTI's budget.
- The provision of **capital grants** to offshore wind, energy crops and solar photovoltaic (PV) schemes. These grants come from a number of sources including lottery funding (£50m for wind and biomass), the DTI (£39m for offshore wind and £10m for PV), DEFRA (£29m for planting energy crops).
- An **additional £100m** for renewables announced by Tony Blair in March 2001 is in the process of being allocated following the advice of the PIU. The PIU recommendations included £25m for offshore wind, £34m for energy crops (including £18m for R&D into advanced technologies), £10m for PV schemes, £10m for community household renewable technologies, £5m for wave and tidal demonstrations, and £10m for R&D into next generation renewables.

The potential contribution of the eight most important renewable energy sources will now be examined in turn:

- Energy from waste (combustion of industrial and municipal waste, landfill gas)
- Hydro (small-scale and large-scale)
- Wind (onshore and offshore)
- Biofuels (agricultural and forestry waste, energy crops)
- Wave power
- Tidal power (basin and flow)
- Solar (photovoltaics and thermal)

⁴ Performance and Innovation Unit Renewable Energy in the UK - Building for the Future of the Environment Cabinet Office (November 2001).

⁵ Performance and Innovation Unit The Energy Review Cabinet Office (February 2002).

2.2 Energy from waste

A range of technologies allows the production of energy from waste. The main processes are:

- combustion of raw waste;
- combustion after processing;
- biological processes that occur when the waste is land-filled (landfill gas);
- biological processes under controlled conditions (anaerobic digestion);
- gasification of waste by heating in a low-oxygen atmosphere;
- pyrolysis of waste by heating in an oxygen-free atmosphere to produce a liquid oil.

The potential for recovering energy from waste and the mix of technologies used is largely dependent on the amount and composition of generated waste, and on waste management practices. Landfill gas combustion and solid waste combustion are considered to have the most significant potential in the near future. The other technologies are less developed and they are expected to develop on a smaller scale, at least in the near term. Due to a lack of detailed information about industrial waste, the section on solid waste only covers municipal waste.

2.2.1 Landfill gas

Landfill gas is (and is expected to remain over the next years) a major option for the generation of energy from waste. Landfilling is the main disposal method for the UK's waste, with between 80 and 90% of all waste produced by households and commerce taking this route. It is estimated that there are over 10,000 landfill sites in the UK. Landfill gas is formed spontaneously when the waste deposited in landfills breaks down as a result of the action of microbes. It consists of a mixture of carbon dioxide and methane, with a large number of trace components. The methane content of the gas (typically around 40-60% by volume) makes it a potential fuel. Landfill gas is collected through a series of wells drilled into the waste. A wide variety of designs of wells and collection systems are available. The choice will depend to some extent on site-specific factors, such as type and depth of waste (DTI web).

Exploitation of landfill gas for electricity generation is based on established and proven technology. The common types of engine used to combust landfill gas and convert it into energy are gas turbines, dual-fuel (compression ignition) engines and spark ignition engines. Engine sizes available range from a few hundred kilowatts to several megawatts. Fuel conversion efficiency for the generating sets can range from 26% (typically for gas turbines) to 42% (for dual-fuel engines). Landfill gas can be used to produce electricity, combined heat and power, or heat only. In the UK, there are currently around 150 sites generating electricity for the grid (DTI web). It is predicted that just over 600MW of landfill gas capacity will be built in total under NFFO. A similar amount is expected to be built outside NFFO to 2005, resulting in a total capacity of 1190 MW. This capacity will produce a total electricity output of approximately 8.9 TWh per year (Ekins and Cotton 2001, p18).

Resource potential

Because it is relatively straightforward to assess the resource potential for landfill gas, variations between different projections are small (see Table 2). Resource assessments are also less dependent on inherently uncertain cost estimates because landfill gas is a

comparatively cheap renewable resource. The resource is largely determined by the number and size of landfill sites. Different assumptions may be made about the required minimum size of the landfill site, often taken to be 200,000 tonnes of waste in place, deposited over the previous 10 to 15 years.⁶ The DTI estimates the total landfill gas resource to be equivalent to around **6.75TWh per year** (around **2% of current UK electricity demand**). This equates to around **850MW of installed capacity**.⁷ ETSU estimates that the current potential for energy recovery from landfill gas is equivalent to **5 TWh per year, rising to 6.8 TWh in 2010**. It should be noted that the realistic landfill gas resource is thought to be limited by the **availability of gas** rather than cost. ETSU estimates that the entire landfill gas resource can be exploited at 4.5p/kWh.⁸ The number of schemes in the UK is also expected to rise as EU directives to control methane emissions to the atmosphere are put into effect. Ekins estimates that all viable landfill gas capacity (8.9 TWh) will have been commissioned by 2005, half of it under NFFO (p.18). In the longer term, **beyond 2020 / 2025, the number of new landfill gas recovery schemes is expected to decline** as the implementation of the EU Landfill Directive diverts organic wastes away from landfill and thus reduces the potential for methane generation.

Table 2 - Landfill gas resource estimates for the UK

	Installed 1997 (ETSU)	Contract 2001 (Biogas Assoc.)	Current resource (DTI web)	Current resource (ETSU)	Cost effec. resource for 2010 (ETSU)*	Potential 2010 (Ekins)	Gov't target scenarios for 2010
Generation (GWh/yr)	821	~4500**	6750	5000	6800	8900	trends: 6100 high wind: 4950 low wind: 6500
Capacity (MW)	147.3	600	850			1190	

* Figure derived from cost curve, assuming lowest discount rate (8%) and highest electricity price (7p/kWh).

** Own calculations.

Opportunities and barriers

Environmental: Exploitation of landfill gas is generally complementary to environmental protection measures. Strengthening the control of landfill gas for environmental reasons provides opportunities for its exploitation as a fuel. The combustion of landfill gas provides an additional incentive to maximise gas collection, thereby minimising emissions. Negative environmental effects of these schemes are comparable to those from flaring off landfill gas at sites that do not have gas utilisation equipment. Gas utilisation equipment generates some noise, but siting and design can reduce noise levels.

Economic: Of all 'new' renewable energy technologies, landfill gas projects have been closest to full commercialisation. The Non-Fossil Fuel Obligation (NFFO) has strongly encouraged the exploitation of landfill gas, but some projects operate without NFFO support. The DTI expects future costs of landfill gas schemes to decrease further because of increased

⁶ ETSU 2000, p111.

⁷ DTI New and Renewable Energy Programme website: <http://www.dti.gov.uk/renewable>.

⁸ ETSU 2000, p111.

sales volumes and increased competition between suppliers of generator sets. It is seen to be likely that gas collection costs will have to be borne as part of a landfill site's environmental control system and will no longer be costed into the overall landfill gas utilisation scheme.

Other: Because the plant is added on to an existing regulated site (the landfill site), obtaining planning permission is a much smaller problem than for most other renewable technologies.

2.2.2 Municipal solid waste combustion

Incineration is an established way of processing household wastes. The main aim of municipal solid waste incineration (MSW) is to reduce the waste to a small volume of sterile ash and thereby provide savings in transport costs and landfill requirements. The heat produced during incineration can be used for electricity production, or for combined heat and power (CHP), with the heat often used in district heating schemes. The technology is well established and fully commercial. A typical MSW plant has the capacity to produce between 7 and 40 MW_e.

To date, all of the plant recovering energy from MSW combustion has been supported by the NFFO. Under NFFO 1 to 3, a total of 143 MW has been built. NFFO 4 and 5 can be expected to lead additional capacity, possibly another 100 MW (ETSU 2000, p.116). In most cases, new energy recovery plants have replaced old waste incinerators.

Resource potential

The resource potential is largely determined by the amount and composition of municipal waste generated in the UK. ETSU estimates that the calorific value of all current municipal waste amounts to a **physical resource of 13500 GWh per year** (see Table 3).

Table 3 –municipal solid waste combustion resource estimates for the UK

	Installed 1997 (ETSU)	Installed 1998 (DTI Statistics)	Current potential (ETSU)*	Cost effective resource for 2010 (ETSU)**	Potential 2010 (Ekins) ⁺	Gov't target scenarios 2010 ⁺⁺
Generation (GWh/yr)		6600	13500	6300	4600	trends: 6100 high wind: 4950 low wind: 6500
Capacity (MW)	143	180			600	
Waste treated (m tonnes)	2	2.5***	27			

* Refers to physical resource regardless of economic or technological feasibility.

** Assumes an 8% discount rate and an electricity price of 7p/kWh.

*** Refers to the year 2000 and to energy from all categories of waste, not only municipal waste.

⁺ Includes industrial as well as municipal waste.

⁺⁺ Refers to energy from all categories of waste rather than only from municipal waste.

ETSU projects that increases in waste are balanced by increases in recycling, leading to a **stable physical resource** until 2025. According to the ETSU assessment, **6300 GWh** (little

less than half of the physical resource) can be exploited in 2010 at a cost of 7p/kWh, assuming a discount rate of 8%. The main reasons for this discrepancy are seen to be competitive costs of landfill disposal, uncertainty of local decision-making, and the difficulty of securing both waste and power contracts. Ekins claims that the current and expected **waste arisings in the UK are insufficient** to supply even the amount of municipal and industrial waste capacity contracted under NFFO. He therefore projects that just over **600 MW** of energy from waste capacity will be commissioned by 2005, but does not expect significant capacity to be built after that. This corresponds to an **energy production of approximately 4600 GWh** (Ekins and Cotton 2001, p.18).

Opportunities and barriers

Environmental: Increasing environmental pressures tend to act in favour of energy production from MSW, because they promote a shift from landfill to incineration. However, there are environmental objectives which are in conflict with MSW incineration, for example minimisation of waste and the increase of recycling rates. Uncertainty over environmentally motivated changes in waste management and regulation are a barrier to a more rapid and efficient exploitation of the resource.

Economic: The development of the resource has significantly benefited from support through NFFO. Although prices for electricity produced through MSW combustion have fallen significantly and are now close to market prices, it is doubtful whether MSW projects can be successful without support. NFFO contracts provide a long-term guarantee for sales and prices, assumed to be vital for the viability of the project.

Other: The need for planning permission can be a major hurdle to MSW combustion because there is often major local opposition to waste incinerators. Uncertainty about planning decisions adds to the financial risks of MSW projects. Developers also need to invest significant resources to determine a suitable location. Moreover, the lack of experience of the UK waste disposal industry with integrated systems is seen as a barrier to the rapid implementation of waste combustion technology (ETSU 2000, p. 117f).

2.3 Hydro power

Hydroelectric power currently accounts for around 2% of the UK's total installed electricity generating capacity. The amount of power produced at a site depends on the rate of flow and the volume of water available. Hydroelectric schemes are generally divided into two broad categories: large-scale (more than 5MW) and small-scale (less than 5MW). Systems of a few tens of kilowatts are often referred to as "micro hydro"; these are not usually connected to the electricity grid.

Hydroelectric schemes have long operating lives. The civil engineering works can last for decades with suitable maintenance. The mechanical and electrical plant has a life from 15 to 50 years. The decommissioning of a redundant small-scale hydro scheme does not cause any problems. Hydro technology is fully commercialised.

Resource potential

The overall potential for additional hydro power in the UK is fairly limited because the most suitable locations are already developed (see Table 4). The physical potential for the development of both large- and small-scale hydro-electric power in the UK is largely

determined by the number of suitable catchment areas and the rainfall in these areas. Using mean annual rainfall areas, land area and land elevation as basis of calculations, ETSU estimates the **total physical resource** for hydro-power to be **40 TWh per year or 13 GW of installed capacity**. It notes, however, that the **accessible resource is considerably smaller** due to geographical and environmental constraints (ETSU 2000, p.97). **Large-scale resource** is thought to be only available in Scotland, according to ETSU up to 1 GW or **3 TWh per year** (ETSU 2000, p.98). There is an estimated **accessible small-scale resource of several hundred MW**. The **cost-effective resource is thought to be between 300 and 550 MW (< 10p/kWh) and between 40 and 110 MW (< 5p/kWh)** (ETSU 2000, p.98). Some new generation capacity could also be generated through the refurbishment of existing large-scale plant.

Table 4 – Hydro Power resource estimates for the UK

	Installed 1997 (ETSU)	Estimate 2000 (Ekins)	Cost effective resource 2010/ 2025 (ETSU)*	Potential 2010 (Ekins)	Physical potential (ETSU)	Gov't target scenarios 2010**
Generation (GWh/year)	small: 333 large: 3955 total: 4288	small: 203 large: 4789 total: 4992	Small: 1900	small: 920 large: 4870 total: 5790	40,000	trends: 400 high wind: 400 low wind: 400
Capacity (MW)	small: 95 large: 1,265 total: 1360				13,000	

* Figure derived from cost curve, assuming lowest discount rate (8%) and highest electricity price (7p/kWh).

** Includes small hydro only.

Opportunities and barriers

Environmental: Environmental impacts are probably the largest constraint for the exploitation of the remaining hydro-power resource. The main effects from hydro schemes stem from the construction of the scheme, the diversion of water flow and water flow regulation. Detrimental effects include: disturbance of the river ecology, damage to fish and organisms passing through hydro turbines, visual intrusion from engineering structures, noise, and change of groundwater levels. Environmental impacts are particularly relevant as suitable catchment areas are often located in National Parks and environmentally sensitive areas, such as Snowdonia and parts of the Scottish Highlands.

Economic: The economics of hydro schemes are characterised by a long lifetime, low running costs, the absence of fuel costs on the one hand but relatively high initial capital costs on the other. This is particularly problematic for large schemes. Initial costs are very dependent on the details of a particular scheme (e.g. land prices and rents), but they are well understood and unlikely to be significantly reduced in the future. Approximately half of current small-scale capacity is financially supported through NFFO. The potential for commercially viable projects is limited as the most attractive sites have already been utilised. Economic opportunities for large hydro could arise for pumped storage schemes, which allow to transform base-load generation into peak supply.

Other: The geographical distribution of hydropower resources also constitutes an important barrier to further exploitation. There is an excess of generating capacity in Scotland where most of the large-scale resource is located. Because transmission capacity to England and Wales is limited, incentives to create new capacity in Scotland are small. Furthermore, many potential small hydro sites are in remote areas where there is no local power demand. The need to develop grid connection and transmission infrastructure would make many of these schemes uneconomic. Finally, obtaining the necessary planning permission and water rights and securing the necessary land through rent or purchase is a complex process, and can be a major barrier.

2.4 Wind Power

Wind power is generally seen as the UK's largest renewable energy resource. Wind power uses a technically proven technology to convert the movement of air into electrical energy. Wind power is growing rapidly. Between 1992 and 1998, wind power capacity increased by a factor of 6.5, and electricity output from wind generators increased by a factor of 26 due to improved technologies and better siting.

Wind turbines are being developed over a range of power outputs from a kilowatt to several megawatt units and are available commercially up to 2MW. Turbines are often grouped together in wind farms, for economy and ease of operation. The machines are usually spaced 5 to 10 rotor diameters apart to ensure they do not interfere with each other's performance. As a result, a wind farm of about 20 turbines usually extends over some 3-4 km² of land, although only about 1% of this area is actually occupied. Design lifetimes of wind turbines are around 25 years, though experience of operating modern wind turbines is limited to around 15 years. The reliability of wind turbines has increased, with modern turbines now operating with a typical availability of 95-98% (ETSU 2000 p.171).

Wind farms can also be developed in offshore locations. The technology for offshore deployment is similar to that for onshore, but the harsher climate and relative inaccessibility place more stringent requirements on the initial design and subsequent reliability. In addition, because the foundations of a machine account for a much greater proportion of the total project cost, machines of at least megawatt rating need to be deployed to minimise cost. In October 2000 the first two British offshore wind turbines were installed off the coast of Blyth, Northumberland. Recently, the UK Government announced a capital grant scheme for offshore wind power projects to help the UK achieve the 10% renewables target⁹.

Resource potential

The resource for wind energy is largely determined by the availability of land or sea area for the siting of wind turbines and wind speed. Weather patterns provide the UK with one of the best wind resources in Europe. A minimum annual mean wind speed (AMWS) of 7.0 m/s is currently thought to be necessary for commercial viability. Hardly any land area in the UK has an AMWS of more than 10 m/s. Because mean wind speeds increase with the elevation of the land, the most suitable areas tend to be on hills. According to ETSU, about 33% of UK land area (around 100,000 km²) has an annual mean wind speed equal to, or larger than, 7.0 m/s (ETSU 2000 p.178). However, only a proportion of this land could be used due to

⁹ DTI 'Liddel Starts the Wind of Change' Press Release, 7th December 2000.

physical constraints (roads, lakes, unsuitable structure of sea bed etc.). The British Wind Energy Association estimates that the UK has 65,252 km² of land area suitable for wind generation (BWEA p.4).

The **total physical resource** for both onshore and offshore wind is a somewhat irrelevant measure, not only because it is far larger than the total UK electricity demand (370,000 GWh/year in 1998), but also because it would be impractical to exploit it. As a result of various restrictions, the disparity between the physical and the practicable resource is very large for both onshore and offshore wind (see Table 5). ETSU estimates the **practicable resource for onshore wind at 58 TWh**. This number reduces to **8 TWh if the ability of the current network to accept new generation capacity** from wind turbines is taken into consideration. It should be noted that all estimates are very sensitive to a variety of assumptions, for example about siting, height of turbine towers, and the severity of various physical constraints. The cited assessments take account to a varying degree of public concern over visual intrusion and network restrictions.

Table 5 – Onshore Wind power resource estimates for the UK

	Installed 1999 (DTI Statistics)	Accessible resource (ETSU)*	Practic. resource (ETSU)**	Practic. I resource (ETSU) ⁺	Cost- effective II resource (ETSU) ⁺⁺	Potential 2010 (BWEA)	Resource 2010 (Ekins) ⁺⁺⁺	Gov't target scenarios 2010
Generation (GWh/yr)	884	317,854	57,911	8,180	57,911	9,915	9,800	trends: 8,000 high wind: 9,900 low wind: 4,950
Capacity (MW)		109,679	19,469	2,750		3,773		

* Takes into account physical restrictions such as roads and towns, considers nationally-designated areas such as National Parks and SSSI to be unsuitable for wind turbines, and assumes a maximum turbine density of 9MW/km².

** Same restriction as 'accessible resource', but also places restrictions on spacing of wind farms (e.g. minimum distance) and those arising from the built rate likely to be met by the European wind industry.

⁺ Same restrictions as 'practicable resource I' but also takes network restrictions into account.

⁺⁺ Figure derived from cost curve, assuming lowest discount rate (8%) and highest electricity price (7p/kWh).

⁺⁺⁺ Unlike projections for other resources, this figure is not a modelling output but an assumed value based on projections of generation to be built under NFFO contracts and on internal BWEA projections. This is because the relatively low cost of wind power would have seen to lead to unrealistically high contributions to the mix.

The offshore resource is much greater than the onshore resource (see Table 6). It is limited only by water depths, sea bed structure and the use of maritime areas for other activities. The practicable resource is limited by the electricity network¹⁰. Again, estimates are extremely sensitive to assumptions about what characterises a suitable location (water depths, sea bed structure, distance from shore, interference with shipping lanes, etc.). While the **total physical resource** is several times higher than the UK electricity demand, the **accessible resource has been (rather arbitrarily) estimated at 100 TWh (ETSU)**. Those assessments that aim to identify **feasible energy options** project a much more modest contribution of

¹⁰ A study of the implications for electricity network development of significant offshore wind expansion has been recently completed for the DTI. PB Power Electrical Network Limitations on Large-Scale Deployment of Offshore Wind Energy DTI Publication 01/773 (2001).

several thousand GWh. It is worth noting that neither of them provides a detailed explanation of the assumed figures or a thorough analysis of ‘non-physical’ restrictions.

Table 6 – Offshore wind power resource estimates for the UK

	Installed 1999 (DTI Statistics)	Accessible resource (EC Study)*	Accessible resource (ETSU)**	Cost- effective resource (ETSU)***	Potential 2010 (Ekins)	Gov't target scenarios 2010
Generation (GWh/year)	--	~ 3,000,000	100,180	100,180	13,280	trends: 4,950 high wind: 6,850 low wind: 3,050
Capacity (MW)	--	1,000,000				

* Takes only account of physical restrictions (e.g. max. water depth 40m, max. distance from shore 30 km). Quoted in ETSU 2000.

** Calculated on the basis of the ‘accessible resource (EC Study)’ but reinforced constrictions in relation to physical suitability for development. No network restrictions taken into account.

*** Figure derived from cost curve, assuming lowest discount rate (8%) and highest electricity price (7p/kWh).

Opportunities and barriers

Environmental: Although wind turbines do not generate pollution, and do not have any major direct environmental impacts, there are a number of environmental issues that might prevent the exploitation of the resource. The main public concerns is visual intrusion caused by the turbine as well as related power transmission infrastructure. Visual effects are a particular matter of concern because suitable areas are often located in protected areas and exposed on hills. Other environmental issues concern land utilisation, noise, electromagnetic interference, and a concern about potential impacts on birds. In the past, planning applications for onshore wind farms have often failed. Local opposition and wider public opinion are important barriers to the development particularly of onshore wind turbines.

Economic: Cost is not a major barrier to wind power because it is one of the cheapest renewable energy sources. According to ETSU projections, the vast majority of the accessible UK resource can be developed at a cost between 2 and 5p/kWh (onshore) and 2 and 4.5p/kWh (offshore) (p.185). The costs of installing wind energy plant are site-specific, usually related to the terrain and distances from grid lines and access roads. On average, current capital costs for onshore turbines are around £750 per kW of installed capacity. Operation and maintenance costs are on average about 0.5p/kWh (DTI web). Currently, capital costs for offshore wind are significantly higher, probably about £1000/kW (ETSU 2000 p.185). It is expected that capital costs of onshore and offshore developments will fall further, due to economies of scale in manufacture and technical improvements.

Other: Recently, the UK Ministry of Defence has raised concerns that wind farms could interfere with radar and low flying military aircraft. There is some speculation that this concern may affect large numbers of suitable sites¹¹. It is yet unclear to what extent this will constitute a barrier for the development of wind energy in the future. Offshore wind turbines would also interfere with fishing and shipping.

¹¹ *The Guardian* 31st May 2001, p4.

2.5 Biofuels

Biofuels covers technologies that use organic material as a fuel. Currently, there are two main types of biofuels that are used commercially to generate heat and electricity, energy crops and agricultural and forestry waste. Some energy crops can also be converted into liquid fuels, but the technologies that enable this will not be covered here because they are used to produce transport fuel rather than electricity.

2.5.1 Energy crops

Energy crops are plants grown specifically for use as a fuel. As a natural carbon-based source of energy they resemble in many ways fossil fuels. Their main environmental advantage, however, is that energy crops are carbon-neutral because carbon is removed from the atmosphere when plants are re-grown. Energy crops are expected to make a substantial contribution to the 10% renewables target. Under the new Renewables Obligation, schemes using energy crops will be eligible for capital grants.

Perennial crops are currently preferred, such as varieties of deciduous trees, or grasses, such as Miscanthus. The most advanced energy crop for northern European conditions is coppiced willow, grown on a rotation of 2 to 4 years (Short Rotation Coppice, or SRC). Of the grasses, those of tropical origin use sunlight more efficiently, and produce higher yields than native plants and are significantly dryer. They are, however, less well adapted to the climate in the UK and experience of producing these crops on a commercial scale is still limited. Current thinking is that their range will be restricted to the more temperate climates of the south of England.

The harvested biofuel is collected and combusted in a power plant, either a biomass plant or as supplement in a fossil fuel power station. The latter option can be economically attractive because it allows to share costs for infrastructure and labour. Because of the relatively low density of biofuels, the cost of transport is high. This imposes strict limits on the maximum economic size of a biomass power plant, perhaps 30 MW and 40 km distance (Royal Commission p.140). Because harvest is seasonal, fuel storage generates additional costs.

Because of high transport costs and low calorific values, there is a strong incentive to increase the efficiency of energy use. This could be achieved through advanced conversion techniques such as gasification and pyrolysis, but these technologies are still in an early stage of development. Another option to increase efficiency is the use of heat, for example in district heating schemes.

Resource potential

The **physical resource** of energy crops is defined by the availability of suitable land, average yield, calorific value of the crop, and conversion efficiency (see Table 7). If economic and political constraints are largely ignored, the **potential for energy crops could be as high as 190 TWh** (RCEP 2000, p 138). This projection assumes that 22.5 % of total UK land area would be used for growing energy crops. However, in reality the resource is constrained by the availability of land. The key issue in the assessment of a **practicable and cost-efficient resource** is the profitability of alternative land uses. Farmers will only grow energy crops if returns are comparable to those from food production. This is largely determined by the size

and structure of agricultural subsidies. Under current conditions, energy crops cannot compete with food production, and they will usually be grown on areas withdrawn from conventional agriculture. ETSU estimates the size of set aside land could reach 1 million hectares by 2010, allowing the generation of 17,000 GWh at a maximum cost between 5 and 6p/kWh.

Table 7 – Energy Crop resource estimates for the UK

	Installed 2001 (British Biogen)	Cost effective resource 2010 (REAG)*	Cost effective resource 2010 (ETSU)**	Potential 2010 (Ekins)	Gov't target scenarios 2010
Generation (GWh/year)	<i>very small</i>	high: 188,340 low: 65,700	17,000	8338	trends: 1,900 high wind: 1,150 low wind: 6,100
Capacity (MW)	<i>very small</i>				

* 'High' assumes 5.5 million hectares of land used and average yield of 21 dry tonnes/ha per year. 'Low' assumes 2.8 million hectares of land used and average yield of 15 dry tonnes/ha per year. Both scenarios assume a discount rate of 8% and an electricity price of 10p/kWh (1991 prices) (RCEP 2000 p.138).

** Figure derived from cost curve, assuming lowest discount rate (8%) and highest electricity price (7p/kWh).

Opportunities and barriers

Environmental: Planting of energy crops on the scale assessed above would change both the appearance and the ecology of the countryside. Effects on biodiversity could be positive as well as negative, depending on the design and management of the plantations and the previous land use.

Economic: Energy crops are a relatively new and undeveloped option that has not yet become fully competitive. Although studies indicate that on wide-scale deployment these costs will be reduced, a significant exploitation of this resource will in the near term only be possible with financial support. Both capital and fuel costs are substantial. According to ETSU, the current price of 8.65p/kWh could decrease to 4.5p/kWh in 2010. The equipment and building costs of a typical 33 MW plant could amount to £34m, the fuel cost to £1.50/GJ (corresponds to 1.2p/kWh at 30% efficiency) (p.83).

Other: Energy crops cannot be readily grown in the uplands because the ground conditions are unsuitable for mechanical harvesting.

2.5.2 Agricultural and forestry waste

Agricultural and forestry wastes fall into two main groups - dry combustible wastes (e.g. forestry residues, straw and chicken litter) and wet wastes (e.g. farm slurries). The first group can be converted to electricity and/or heat by combustion to produce heat and/or power. Technologies as well as economic and environmental issues are similar to those described in the section on energy crops. The second group is best used to produce methane-rich biogas through the process of anaerobic digestion.

Straw is available from cereal and other crops such as oilseeds. It is produced seasonally and is localised, with highest production centred in East Anglia. As straw is a low-density material, transport and storage can be a significant part of the fuel cost. This has led to the adoption of large high-density bales. Straw is a relatively low heating value fuel, with an energy content of around 18GJ/dry tonne. Only one project in the UK has been granted a contract under the NFFO to generate electricity from straw. This is a 31MW plant in Cambridgeshire, which uses around 200,000 tonnes/year of straw. An increasing number of UK farms have straw-fired boilers to help meet their on-site heat requirements.

Wood for fuel, in commercial quantities, can be produced as a by-product of forestry management and occurs in sawmills. The residual material from these operations is a clean fuel that can be converted to useful energy. Wood has a relatively low calorific value of around 19GJ/dry tonne. When harvested, wood has a moisture content in the order of 55% by weight. Contracts to generate electricity from forestry residues have been allocated under the NFFO. Outside of the NFFO, electricity generation from wood fuel is restricted in the UK to locations where sawmill or paper-making residues are co-fired with fossil fuels in existing plant.

Poultry litter is the bedding material from broiler houses. It usually comprises material such as wood shavings, shredded paper or straw, mixed with droppings. As received, the material has a calorific value slightly lower than that for wood at 9-15GJ/tonne. It has a high variable moisture content of between 20% and 50%. The technology has been proven in recent years, and several UK plants are in operation. The technology used is based on a conventional steam cycle. Transport and storage of the fuel needs to be carefully controlled so that odour does not escape into the surrounding environment.

Wet agricultural wastes (farm slurries) are derived from three major sources: cattle, pigs and poultry. Farm slurries can be turned into fuel through anaerobic digestion. Typically, 40-60% of the organic matter present is converted to biogas; the remainder consists of a stabilised residue with some value as a soil conditioner. The technology is now well developed and a range of digesters are commercially available. Six projects have received NFFO contracts to generate electricity from farm slurries using anaerobic digestion.

Resource potential

Although the exploitation of this resource is proceeding quite rapidly, its ultimate potential is limited (see Table 8). The RCEP estimates that 4 million tonnes of straw, 1 million air-dry tonnes of poultry litter, and 1.7 million dry tonnes of forestry waste could be used for energy production each year.

Table 8 – Agricultural and Forestry Waste resource estimates for the UK

	Installed 1996 (ETSU)	Installed 2001 (British Biogen)	Accessible potential (ETSU)**	Current resource (ETSU)	Cost effect. resource 2010 (ETSU)*	Resource 2010 (Ekins)***
Generation (GWh/yr)	182		Slurry: 2860		13900	5918.8
Capacity (MW)	26	~110		poultry litter: 135		
Weight (ktonnes)				Straw: 3937 Wood: 1144 Poultry litter: 1300		

* Figure derived from cost curve, assuming lowest discount rate (8%) and highest electricity price (7p/kWh).

Opportunities and barriers

Environmental: There are few environmental concerns regarding the use of forestry residues as fuel. For example, machinery can compact the soil and after a site has been cleared there is more water run-off, could lead to soil erosion. These are manageable by using good forestry practice. Anaerobic digestion of farm slurries has clear advantages in terms of preventing odour problems and the spread of disease. However, they need to be carefully managed to avoid serious environmental problems such as water pollution.

Economic: Investment and maintenance costs are similar to those for energy crops. However, agricultural and forestry wastes tend to have lower fuel costs because they are usually by-products from other activities.

2.6 Wave power

Ocean waves are caused by winds as they blow across the surface of the sea. The energy that waves contain can be harnessed and used to produce electricity. Due to the direction of the prevailing winds and the size of the Atlantic Ocean, the UK and north-western Europe have one of the largest wave energy resources in the world.

The UK wave energy resource can be subdivided into two categories: shoreline and offshore. The main technology for shoreline wave power is the Oscillating Water Column (OWC). This consists of a partially submerged, hollow structure that is open to the sea below the water line. This encloses a column of air on top of a column of water. Waves cause the water column to rise and fall, which alternately compresses and depressurises the air column. This trapped air is allowed to flow to and from the atmosphere via a turbine. The rotation of the turbine is used to generate electricity.

Offshore wave devices exploit the more powerful wave regimes available in deep water. Several different types of offshore device have been developed, but none has yet been deployed commercially. Since the decommissioning of a prototype shoreline 75kW OWC on the Hebridean island of Islay, no further UK wave power capacity has been installed. However, three projects were awarded contracts under the third round of the Scottish Renewables Obligation (SRO-3).

Resource potential

Although wave power technology is still at an early stage of development, it is recognised to offer a significant potential for electricity generation *in the long term*. ETSU estimates the **total accessible resource to be between 700 and 840 TWh** and the **total practicable resource 52.5 TWh** (see Table 9).

There is, however, considerable uncertainty about the time scale for this development and the cost at which the resource is likely to be exploited. This is reflected in varying degree of financial support that research into this technology received. The government provided support for research into wave power devices from 1974 but the budget was radically reduced in 1983. At the time, the decision to cut wave power funding was extremely controversial¹². More recently research was confined to desk studies attempting to improve the economic performance of devices. Both ETSU and Ekins **do not expect wave power to make a substantial contribution to electricity generation by 2010**, but expect the technology to take off between 2010 and 2025. The RCEP expresses its regrets about the low levels of research funding but acknowledges that much further work needs to be done to assess the practicability of wave power technologies (RCEP 2000, p141).

Table 9 – Wave power resource estimates for the UK

	Installed 2000 (ETSU)	Accessible resource (ETSU)*	Practicable resource (ETSU)**	Cost-efficient resource 2010 (ETSU) ⁺	Resource 2010 (Ekins)
Generation (GWh/year)	<i>very small</i>	shoreline: ~2,000 nearshore: 100-140,000 offshore: 600- 700,000	shoreline: 400 nearshore: 2,100 offshore: 50,000	shoreline: 0 nearshore: 0 offshore: 0	Nearshore: 150 Offshore: 0
Capacity (MW)	<i>very small</i>				

* Draws on findings of an independent study carried out during the mid-1980s. Does not include areas where power levels 'are so low that their exploitation would be uneconomic' (ETSU 2000 p.166).

** Takes account of technical, economic, and environmental restrictions. Particularly, it assumes that deployment is limited for environmental reasons to 400 devices (ETSU 2000 p.166).

⁺ Figure derived from cost curve, assuming lowest discount rate (8%) and highest electricity price (7p/kWh).

Opportunities and barriers

Environmental: Wave power devices could be a hazard to fish and marine mammals, though this could be addressed through the design of the device. They also may have a variety of effects on the wave climate. This could influence the shore and shallow sub-tidal areas and the communities of plants and animals they support. Installation of the support structures and cable-laying will disturb species on the sea bed and local mammals. Finally, shoreline and nearshore devices will have a visual impact. As a result, public concern and planning issues are a potentially significant barrier to the exploitation of wave power.

¹² For more details, see D Ross Power from the Waves Oxford University Press, 1995.

Economic: Due to the small number of operational schemes, cost data is still uncertain. According to ETSU, the unit costs for a wave power device with current technology are thought to be £1050-£1800 per kW of installed capacity. However, studies assert that maintenance costs are low. The high capital costs are expected to fall in the future.

Other: Technological uncertainty is one of the main barriers to further investment in wave power schemes. It is still unclear whether wave power devices and connecting cables will operate reliably over long periods under adverse conditions, particularly offshore. Wave energy devices may also be potential navigation hazards for shipping. For most devices this could be overcome through design (e.g. painting, radar reflectors, lights).

2.7 Tidal power

There are two ways of exploiting the natural rise and fall of tidal waters: tidal stream and tidal barrage. The technology used in tidal streams is akin to that used in wind turbines. Although speeds of the water are lower than wind, the greater density of water results in much higher energy densities and requires turbine diameters of at least 10m. The maximum diameter is limited by the bending moments caused by the water flow. The technology is still in the early stages of development. So far, projects have been small, in the order of tens of kW. But if proved successful, the schemes could have long operating lives and relatively low operating costs. One full-size prototype scheme is under construction in the UK.

Energy can also be generated by constructing a barrage across an estuary, allowing tidal waters alternately to fill the estuary through sluice gates and then to empty it through turbines. Electricity is generated using large axial flow turbines of diameters up to 9m. The technology is proven in Europe and elsewhere. Tidal barrages have very long lifetimes. According to ETSU, their design life could be about 120 years, with maintenance and replacement of turbine generators at 40 year intervals.

Resource potential

The UK has a number of excellent tidal stream sites around its coastline, with tidal velocity ranging from 2.5 to 6 m/s. On the basis of assumptions about the efficiency of turbines and taking into account restrictions such as shipping routes, ETSU estimates the **accessible resource to be about 4,000MW** (see Table 10). Projections of the **cost-effective or 'feasible' resource in 2010** are significantly lower due to environmental, economic and other restrictions (see below). Estimates vary **between 0.7 and 1.9 TWh**. It is worth noting that ETSU assumes that the cost-effective resource does not increase after 2010.

The potential for generating electricity from turbines in tidal barrages has been extensively researched. The UK has a very large potential resource due to the high tidal range along the west coast of England and Wales where there are many estuaries and inlets available. Potential schemes range from 30 MW to 8.6 GW. A study funded by the EU estimated that the **technically feasible resource** in the UK could be as much as **50 TWh**.

However, the cost-effective resource is limited by very high investment costs (which are unlikely to be significantly reduced). Only a major change in market conditions favouring large long-term projects is thought to revive the prospects for the technology (ETSU 2000 p.195).

Table 10 – Tidal power resource estimates for the UK

	Installed 2000 (RCEP)	Access. (ETSU)	Tech. Feasible (EU study)**	Predicted 2010 (ETSU)	Cost effective resource 2010 (ETSU)*	Resource 2010 (Ekins)	Gov't target scenarios 2010
Generation (GWh/yr)	<i>very small</i>	stream: 36,000	barrage: 50,000	Stream: 700	1,900	stream: 1,780 barrage: 0	-
Capacity (MW)		stream: 4000		Stream: 322			-

* Figure derived from cost curve, assuming lowest discount rate (8%) and highest electricity price (7p/kWh).

** Study cited in ETSU 2000 p. 195.

Opportunities and barriers

Environmental: The environmental impacts of tidal stream turbines would be similar to that of offshore wave power devices (see above). In particular, they would have visual impacts that are likely to be judged unacceptable at some of the promising sites (ETSU 2000 p. 152). Tidal barrages across an estuary changes radically its appearance and ecology and especially its bird life. Local opposition on environmental grounds is therefore likely to be a major barrier.

Economic: Due to the lack of commercial projects, the cost of tidal stream power is uncertain. ETSU estimates that capital costs could amount to £1200–1400/kW for current technologies and £400–900/kW for (unproven) vertical axis turbines. Uncertainties about the reliability and cost of these technologies are the main barrier to the exploitation of tidal stream power. High capital costs are the most important barrier to tidal barrages. It is unlikely that they will be commercially viable without public financial support, despite very low running costs.

Other: Much of the tidal power resource is located in remote areas with small power demand and limited capacity to export electricity out of the area. Problems of grid connection are particularly relevant for tidal barrages because they produces large amounts of electricity but only at certain times. Tidal barrages will also disrupt fisheries and navigation.

2.8 Photovoltaics

Solar radiation can be converted directly into electricity using photovoltaic (PV) cells. PV materials are usually solid-state semiconductors which generate electricity when exposed to light. PV cells produce a direct current, which is usually converted to alternating current by an inverter. The semiconductor materials currently in volume production are mono-crystalline silicon (crystalline), poly-crystalline silicon (crystalline), amorphous silicon (thin film), and cadmium telluride (thin film). Systems are expected to have a lifetime of at least 25 years, with low maintenance requirements.

One of the main advantages of PV is that installations are silent, small, without significant environmental effects and low visual impact. Stand alone modules provide electricity locally without the need for grid connection or other installations requiring substantial space or investment. It has therefore proved very cost-effective where grid connection and diesel generation are too expensive or not feasible. R&D and developments in manufacturing

techniques over recent years have steadily reduced the cost and improved the performance of PV systems. As a result, grid-connected PV systems are being increasingly deployed around the world, particularly when integrated into buildings. This integration is achieved by using PV to replace conventional roofing or cladding materials such as tiles or natural stone. Most building-integrated PV projects in the UK have national, regional or European Commission financial support. In the UK it is estimated that installed PV capacity rose from 172kW in 1992 to about 400kW in 1996, and is now about 1MW (DTI website). Worldwide, the market for PV has been growing and is likely to continue to expand.

One of the main disadvantages of PV cells is that they convert a small proportion of the energy in the sunlight into electricity (typically between 5 and 13 %), but large amounts of energy have to be used in their manufacture. As a result, PV cells have a long energy pay-back period (the time over which they generate the amount of electricity used in manufacture). Depending on technology and solar radiation, the energy pay-back period can be between 2.5 and 4 years. PV is currently also one of the most expensive renewable technologies, particularly under British weather conditions (ETSU assumes a solar radiation of 1000 kWh/m²/year on a horizontal surface).

Resource potential

Like in the case of wind power, the total physical resource of PV is very large and not necessarily indicative of what might be realistically achieved (see Table 11).

Table 11 - Photovoltaic resource estimates for the UK

	Gov't target scen. 2010	Pract. Res. 2025 (ETSU)	Mkt. Pot. 2010 (ETSU)	Tech. Pot. 2010 (ETSU)	5% land (RCEP)	70,000 roofs (PV Group)	Res. 2010 (Ekins)**	Cost Effect. Res. 2010	Installed (DTI)
Generation (GWh/yr)	-	266000	32500	7200			0	0	
Capacity (MW _p)	-				62500	140	0	0	1

* Figure derived from cost curve, assuming lowest discount rate (8%) and highest electricity price (7p/kWh).

** 'Cost expected to be too high to make a significant contribution by 2020' (Ekins, p.4).

*** Assumes application of PV to all surfaces of all available buildings in the UK. Includes only roof area that is likely to be suitable for PV. Allowance is made for shading.

ETSU estimates the **practicable resource** to be **266 TWh in 2025** (calculated as electricity generated by the application of PV to all surfaces of available domestic and non-domestic buildings, allowing for 10% non-suitable surfaces and 25% shading, ETSU 2000 p.141). The resource for 2010 is not specified by ETSU but can be assumed to be only a little larger due to higher efficiency of cells and inverters and possible growth in the building stock. RCEP reports on an estimate that arrays covering an area equivalent to 5% of the UK land surface would provide an capacity of 62.5GW (RCEP 2000 p.132). An earlier ETSU study estimated **'feasible' potentials** assuming that PV systems would only be installed in the context of new-built offices, office refurbishment, superstores, new-built domestic and prestige public buildings. It calculated a **'technical potential'** (considering only technical constraints) of **7.2TWh per year** and a **'market potential'** (considering technical and other constraints) of **32.5GWh for 2010**.

Opportunities and barriers

Environmental: PV does not have any significant direct environmental impacts. However, the manufacture of PV materials has significant environmental effects, particularly through the use of a number of hazardous materials. For example, amorphous silicon manufacture requires the use of silicon tetrafluoride. Cadmium, tellurium, copper and indium are also employed in other PV devices. Some of these materials do not only present a health hazard but could also become scarce as a result of high world-wide demand.

Economic: High costs of cells and ancillary equipment in relation to electricity output are the main barrier to further exploitation of PV for electricity generation. Module costs per unit area are dependent on the type of PV material used but typically range between £200 and £400 per square metre for crystalline silicon, amorphous silicon and cadmium telluride. Inverter costs are in the region of £600-1000/kW. Costs are lower for building-integrated PV system because structural costs are low and no additional land area is required. Installed costs are likely to be in the range of £5/Wp (Watt peak) to £10/Wp (DTI). It is also expected that further development of PV material, manufacturing improvements and higher-volume production will bring costs of PV modules down over the next 25-30 years. The PV Government-Industry Group estimates that 'by 2020 PV could come within the range of prices of the technologies in the Renewables Obligation' (p.22).

Others: Other barriers to the installation of PV cells include building regulations, planning guidance (in designated conservation areas), and difficulties related to connecting PV modules to the electricity grid.

3. Regional Renewable Energy Assessments

In March 2000, the DTI and DETR initiated a series of regional assessments of renewable energy resources in the English regions¹³. These assessments have been carried out in a ‘bottom up’ manner by the eight regional government offices, often with a considerable amount of consultation with local stakeholders. Similar exercises have also been carried out by the executives in Northern Ireland, Scotland and Wales. Each assessment provides a regional framework for the development of renewables by focusing on the potential renewable resource. As a result, the assessments often go further than the national 10% target, and result in a set of regional targets which do not have to be binding.

The results of the regional assessments have now been analysed for the DTI by OXERA and ARUP¹⁴. Most of the assessments have been published, though it was difficult for SPRU to obtain copies of some of them. Whilst a range of different methodologies were used for the regional assessments (see below for details), OXERA and ARUP have attempted a summary of their results which is reproduced in Table 12. As their analysis shows, the regional projections do not guarantee delivery of the government’s overall 10% target for the UK. This is the case even though the target is made more attainable by expressing it as a percentage of expected electricity *sales* by UK suppliers (expected to be 324TWh¹⁵) rather than overall *demand* (expected by ETSU to be around 380TWh).

Table 12 - A Summary of the Regional Assessments for 2010

Low	Low (TWh)	% of target	High (TWh)	% of target
East of England	4.3	13.3	4.3	13.3
East Midlands	1.8	5.6	2.0	6.1
London	0.2	0.7	0.6	1.9
North East	0.9	2.7	2.0	6.3
North West	2.8	8.6	3.2	9.7
South East	1.4	4.4	3.3	10.1
South West	1.2	3.7	2.5	7.8
West Midlands	2.5	7.7	2.9	8.9
Yorkshire and the Humber	1.2	3.8	3.6	11.0
Scotland	3.6	11.1	3.6	11.1
Wales	1.3	4.2	4.4	13.4
Total	21.3	66	32.3	100

Note: The table excludes Northern Ireland since it is not yet formally included in the Renewables Obligation.

Source: OXERA and ARUP [The Regional Renewables Assessments](#) (February 2002).

To gain a greater insight into the different approaches of the regional assessments, a summary of each assessment is given below.

¹³ P Ward, DETR ‘Objectives of the Regional Planning Targets’ Presentation to CREA conference, March 2001.

¹⁴ OXERA and ARUP, [op. cit.](#)

¹⁵ See DTI [The Renewables Obligation: Statutory Consultation](#) (August 2001).

3.1 South East

The renewable energy assessment for the South East was published in January 2001¹⁶. The assessment concluded with two targets - one for 2010 and another for 2015 (see Table 13). The reason for this is that it was thought to be impractical to generate 10% of the region's electricity from renewables by 2010. The 2015 target is designed to give developers in the region a further five years to achieve this aim.

Table 13 - Renewable Energy Targets for South East England

Technology	Existing (MW)	Total by 2010 (MW)	Total by 2015 (MW)
Energy from Waste	72	288	298
Hydro	0	1	16
Offshore Wind	0	200	400
Onshore Wind	1	123	148
Biomass	0	105	180
Photovoltaics	0	15	40
Other	0	18	48
Total	73	750	1130

To achieve the 10% target by 2015, the assessment assumes the deployment of a broad portfolio of technologies. Alongside the current dominant options (onshore wind and energy from waste) are significant contributions from biomass, offshore wind and photovoltaics. In comparison with assessments for other UK regions, the South East study envisages a particularly high contribution from photovoltaics.

3.2 South West

The renewable energy assessment for the South West region was published in February 2001¹⁷. The assessment gives a range of possible contributions for renewable energy within the region (see Table 14). If development results in renewable energy capacity at the high end of this range in 2010, it is probably that this capacity will account for between 11 and 15% of electricity *generation* in the region. The reason for the uncertainty is the proposed combined cycle gas turbine power station near Plymouth which would add significantly to the region's generation portfolio.

¹⁶ Government Office for the South East Development of a Renewable Energy Assessment and Targets for the South East January 2001.

¹⁷ Government Office for the South West Renewable Energy Assessment and Targets for the South West February 2001

Table 14 - Renewable Energy Targets for South West England

Technology	Total by 2010 MW	GWh/year
Energy from Waste	13-39	95-290
Hydro	1-3	4-13
Offshore Wind	0-50	0-160
Onshore Wind	122-253	306-632
Biomass	59-144	442-1080
Photovoltaics	12	10
Other *	0-44	1-90
Total	207-545	855-2275

* Composed of tidal and wave power technologies.

3.3 London

The renewable energy assessment for London was published in December 2001¹⁸. As Table 15 shows it envisages a modest contribution from renewable energy within London, which is limited by the lack of space for wind and energy crop schemes. At most, the assessment expects that only 2.1% of London's electricity will be supplied from renewables in 2010. This figure includes electricity from the biodegradable fraction of municipal waste incineration (excluding this yields a figure of 274GWh per year – 0.9% of electricity demand). Besides energy from waste, the assessment identifies other significant technologies as solar photovoltaics and wind energy.

Table 15 - Renewable Energy Targets for London

Technology	Existing Output (GWh)	Prospective Output in 2010 (GWh)
Energy from Waste*	413.9	622
Hydro	Negligible	5.1
Wind	Negligible	21.5
Photovoltaics	0.4	16.2
Total	414.3	664.8

* Composed of sewage gas, landfill gas, forestry wastes and biodegradable household waste incineration.

3.4 East Midlands

The renewable energy assessment for the East Midlands was completed in 2001, though it is difficult to obtain a published version. The results, summarised in Table 16, are taken from a summary provided by OXERA and ARUP in their report to the DTI and DTLR. These show that, like many other regions, renewable energy in the East Midlands is expected to be dominated by energy from waste plants, wind power and biomass in 2010. At least half of wind power developments are expected to be offshore due to the limited availability of good wind sites onshore outside national parks and other environmentally sensitive sites.

¹⁸ ETSU Development of a Renewable Energy Assessment and Targets for London Report to the Government Office for London and the GLA (December 2001).

Table 16 - Renewable Energy Prospects in the East Midlands

Technology	Total by 2010 Capacity (MWe)	Electricity (GWh/yr)
Energy from Waste	56-81	438-627
Small Hydro	12	39
Onshore wind	121	319
Offshore wind	100	350
Biomass	86	642
Photovoltaics	5	14
Total	380-406	1802-1991

3.5 West Midlands

The West Midlands regional renewable energy assessment was published in November 2001¹⁹. The summary in Table 17 shows how the development of renewables may proceed to provide between 7 and 9% of the region's electricity. In practice, the regional government office expects a slower expansion of renewables than the Table implies²⁰. This is because most of the energy from waste resources in the region have already been tapped, leaving remote wind and biomass resources as the most important options. To use these options would require significant investment in electricity network infrastructure.

Table 17 - Renewable Energy Prospects in the West Midlands

Technology	Total by 2010 Capacity (MWe)	Electricity (GWh/yr)
Energy from Waste	111-164	877-1269
Onshore Wind	512	1,345
Biomass	35	256
Hydro	3	10
Photovoltaics	4	11
Total	665	2499-2981

3.6 Eastern

The regional study for the Eastern region was published in mid-2001²¹. The final report from the study gives two possible targets for 2010 - a business as usual target and an elevated target (shown in Table 18). The regional assessment claims that the technical renewable energy potential in the region (75,000GWh/year) would correspond to a target of 40%. However, there seems to be some confusion since the report suggests that the region's total electricity demand in 2010 will only be 31,000GWh/year. Perhaps the author's meant to conclude that only 40% of the technical potential is required to supply all of the region's electricity.

¹⁹ Halcrow Group Renewable Energy: Prospects for the West Midlands Government Office of the West Midlands (November 2001).

²⁰ Personal communication with regional sustainable development department.

²¹ East of England Sustainable Development Round Table Making Renewable Energy a Reality: Setting and Challenging Target for the Eastern Region (no date)

Table 18 - Renewable Energy Targets for Eastern England

Technology	Existing (GWh/yr)	Potential (GWh/yr)	2010 Target (GWh/yr)
Energy from Waste		7,000	1,250*
Other		1,000	600
Offshore Wind		53,000	1,300
Onshore Wind		5,000	1,700
Biofuels		7,000	700
Photovoltaics		2,000	-
Total	600	75,000	4,300 (excl. waste)

* During the consultation process that led to the Eastern regional assessment, energy from waste was excluded from the regional target on the grounds that it was not felt by many stakeholders to be renewable.

Under the assessment's elevated target, renewables would supply around 14% of Eastern region's electricity in 2010. This would be achieved mainly through the deployment of onshore wind, offshore wind and biomass plants. As shown in the Table, the assessment has chosen to exclude energy from waste schemes from its definition of renewable energy.

3.7 North West

The results of the North West regional study were published in March 2001²². The main output of the study is a series of technology specific targets for the region, to be achieved by 2010. These are summarised in Table 19 together with the current status of renewable energy deployment in the North West.

Table 19 - Renewable Energy Targets for North West England

Technology	Existing Capacity, MW	Total Capacity by 2010 (MW)
Energy from Waste	75.3 (437GWh*)	236.3
Hydro	1.6 (9GWh)	5.6
Offshore Wind	0	103
Onshore Wind	24.86 (87GWh)	107.1
Biofuels	0	122
Photovoltaics	0.25	12.5
Total	102.01	586.5

* This figure excludes electricity generated from a 10.5MW municipal and solid waste plant in Bolton (this plant is included in the capacity figure).

As the table shows, the North West targets have been expressed in terms of the capacity of renewable energy deployed rather than the amount of electricity generated. This makes it difficult to compare the targets to the national resource assessments cited in section 2 of this report. Nevertheless, the assessment shows that the emphasis is being placed on the current dominant options (wind and energy from waste), with the addition of significant capacities of offshore wind and biomass plants by 2010.

²² Sustainability Northwest From Power to Prosperity: Advancing Renewable Energy in Northwest England March 2001. This report is accompanied by a series of detailed technical reports. See <http://www.snw.org.uk/renewables>.

3.8 North East

The regional study for the North East was published in October 2000²³. The study first examines the available renewable energy resource in the region, broken down by technology. It then suggests technology specific targets for the region to achieve by 2010. In many cases the resource figure and the suggested target are the same. This is because the available resource is often calculated by taking into account economic and other constraints.

As Table 20 shows, the assessment expects that renewable energy capacity in the North East will be dominated by onshore wind power, biomass and energy from waste plants. This is similar to the current situation, with biomass as the significant newcomer.

Table 20 - Renewable Energy Targets for North East England

Technology	Existing, MW	Target for 2010, MW (GWh/yr)	
Energy from Waste	38	32-52	(240-390)
Hydro	6.1	0.5	(2.4)
Offshore Wind	0	4	(10)
Onshore Wind	7.6	210.1-360.1	(560.3-1210.4)
Biofuels	0	25.3-50.3	(190.1-451.6)
Photovoltaics	0.1	1-6	(0.7-4.2)
Total	52	272.9-468.9	(1003.5-2069.6)

The assessment gives the 2010 regional target as a range of capacities, from 270 to 470MW. The report's authors estimate that this would represent between 5% and 9% of the region's installed capacity in 2010, and would meet 5-12% of the region's electricity demand.

3.9 Yorkshire and the Humber

Yorkshire and the Humber are behind most other regions in their assessment process, and are expected to publish their results shortly. The scenarios being considered for renewable energy expansion to 2010 are available²⁴, and are summarised in Table 21.

Table 21 - Renewable Energy Prospects in Yorkshire and the Humber

Technology	Existing Capacity (MWe)	Total by 2010	
		Low Scenario	High Scenario
Energy from Waste	31.9	110.2	125.5
Onshore Wind	26.6	81.9	304.5
Offshore Wind	0	0	160
Biomass	26.7	46.7	177.7
Hydro	0	0.4	1
Photovoltaics	0.2	3.4	16.2
Other	0	0.3	60
Total	85.4	242.9	844.9

²³ Government Office for the North East Proposed Targets for the Development of Renewable Energy in the North East to 2010 Final Report, October 2000.

²⁴ See consultation web pages at <http://www.etsu.com/y&h-re-study>

The results include a ‘low’ scenario which assumes that wind energy schemes will be viewed favourably by the planning system and that photovoltaics will be encouraged to some extent. Otherwise, this scenario is characterised as ‘business as usual’. The ‘high’ scenario sees a much more rapid expansion of many renewable technologies in the region due to the removal of many planning, financial and policy barriers. It includes the deployment of two offshore wind farms, a significant commitment to energy crops and even the emergence of fuel cells (which are presumably fuelled by either biomass or hydrogen derived from renewables). Taking into account power exports from the region, this ‘high’ scenario would mean that the region can supply 10% of its electricity from renewables.

3.10 Scotland

The results of the Scottish study of renewable resources were published in December 2001²⁵. In 2000, 8.75% of Scotland’s electricity was generated from renewable sources²⁶. This figure is particularly high because of Scotland’s historical use of hydro resources in the north of the country. An assessment of Scotland’s renewable energy resource for 2010 is summarised in Table 22.

Table 22 - Renewable Energy Resources in Scotland for 2010

Technology	Capacity (GW)	Energy (GWh)
Onshore wind	11.50	45,000
Offshore wind	25.00	82,000
Wave	14.00	45,700
Small hydro	0.30	1,000
Tidal stream	7.50	33,500
Landfill Gas	0.07	555
Forestry Residues	0.09	700
Energy Crops	0.14	1,100
Agricultural Wastes	0.40	3,500
Municipal Solid Waste (MSW)	0.10	900
Total	59.10	213,955

As Table 22 implies, Scotland’s renewable energy resources are considerable. If all were utilised, they would supply over 50% of the UK’s current electricity demand. The results in the Table take into account a variety of constraints on individual technologies due to costs, siting (particularly of wind resources), network constraints (which particularly limit the amount of renewables that may be connected in more remote areas), and constraints due to the limited availability of forestry wastes.

²⁵ Garrad Hassan and Partners Scotland’s Renewable Resource 2001 – Executive Summary Report to the Scottish Executive (December 2001).

²⁶ Hansard (House of Commons Daily Debates) Written Answer by Brian Wilson MP (19th July 2001).

3.11 Wales

The most recent renewable energy assessment for Wales was published in 2001²⁷. It gives three alternative scenarios for the development of renewable energy in Wales to 2010 (see Table 23).

Table 23 - Renewable Energy Development in Wales to 2010

Technology	Existing Capacity (MWe)	Total by 2010	
		Low Scenario	High Scenario
Energy from Waste	14.4	35	58.5
Hydro	160	165	180
Offshore Wind	0	60	450
Onshore Wind	152.6	247.9	573.3
Biomass	0.2	25.2	94.2
Photovoltaics	0.2	1.1	4.6
Tidal	0	0	38
Total	327.2	534.2	1398.6

The ‘low scenario’ shown in the Table represents a business as usual case for Wales. In this, most of the additional renewable energy capacity to 2010 is accounted for by onshore and offshore wind farm development. Perhaps as a result of the particularly acute planning difficulties for wind schemes in Wales, the assessment expects future developments to be smaller than those of the past. The ‘high scenario’ in the assessment incorporates considerable change in the environment for renewables. Many of the current obstacles to development – due to planning, economics, electricity network constraints etc. – are expected to be overcome. Four offshore wind farms are constructed (instead of just one under the low scenario), as are many more onshore farms, biomass plants burning coppiced crops and large numbers of photovoltaic arrays.

3.12 Northern Ireland

A new renewable energy assessment for Northern Ireland was published as a consultation document from the Department for Trade, Enterprise and Investment in late 2001²⁸. This draws on a previous study of the potential for renewable energy completed two years earlier²⁹. This gives figures for both technical and accessible potential for renewable energy, and an assessment of the maximum contribution in both 2010 and 2025 (see Table 24). The latter sets of figures take into account assumptions about deployment rates, public acceptability and economics.

²⁷ AEAT Technology Review of Strategic Study of Renewable Energy Resources in Wales (September 2001).

²⁸ DETI Renewable Energy in Northern Ireland: Realising the Potential (2001).

²⁹ Northern Ireland Department of Economic Development Renewable Energy in the Millennium: The Northern Ireland Potential (June 1999).

Table 24 – Renewable Energy Resources in Northern Ireland

Technology	Resource (GWh/yr)		Maximum Contribution (GWh/yr)	
	Technical	Accessible	2010	2025
Energy from Waste	1160	1160	222	336
Hydro	260	68	25	25
Wind	106000	56000	160	160
Biomass	7386	657	166-189	256-279
Total	114806	57885	573-596	777-798

Note: Figures exclude solar PV technology which is regarded by the study authors as particularly uncertain despite a maximum contribution of 400GWh/yr in both 2010 and 2025.

The assessment states that the maximum contribution figure for 2010 is equivalent to 115MWe installed. It would be made up of a combination of onshore wind, biomass and energy from waste plants. Whilst solar PV technologies are also thought to have significant potential for Northern Ireland, these have been excluded from the latest assessment on the grounds of cost and uncertainty.

Besides the resources identified by the Northern Ireland study, a further 126-216MWe could be available from offshore wind resources, giving a total for 2010 of 240-330MWe. This may be compared with the current installed capacity of 25MWe, which generates less than 2% of Northern Ireland's electricity. The consultation process to determine the final target is still underway.

4. Combined Heat and Power (CHP)

CHP is the simultaneous generation of usable heat and power (usually electricity) in a single process, to produce higher energy efficiencies. CHP uses a variety of fuels and technologies across a wide range of sites, and scheme sizes. The basic elements of a CHP plant comprise one or more prime movers (a reciprocating engine, gas turbine, or steam turbine) driving electrical generators, or other machinery, where the steam or hot water generated is utilised for either industrial processes, or in community heating and space heating. CHP is usually much smaller than electricity only plant, and attached to a site that consumes the majority, if not all, of the heat and power produced.³⁰

The main unit used by the UK Government to measure CHP capacity is electricity generation measured in MWe. For a CHP scheme to be included in Government statistics for CHP energy production it must meet the standards set down in the Government's Quality Assurance programme for CHP (CHPQA)³¹. CHPQA is based on the energy efficiency and environmental performance of CHP plant compared to good alternative energy supply options. CHP production meeting the CHPQA criteria is described by the UK Government as 'Good Quality CHP', and as such it is eligible for exemption from the Climate Change Levy, enhanced Capital Allowances, a level playing field within Business Rating, and a proposed exemption from plant and machinery rating.

For a small number of large schemes, used primarily for electricity generation, not all the useful heat is used. In these cases, only a portion of the electricity produced is included as 'Good Quality CHP', recognising the reduced environmental benefits based on the heat used.

4.1 Current CHP Capacity and Short-term Projections

The DTI, Digest of United Kingdom Energy Statistics 2000 includes statistics for UK CHP electricity production up to 1999, and predicted production for the next 3 years based on applications for future CHP plants (See Table 25).

Table 25 - Recent and projected capacity of CHP

	1995	1996	1997	1998	1999	Predicted		
						2000	2001	2002
Number of sites	1220	1282	1287	1307	1313	1322	1328	NA
Net number of sites added during year	53	62	5	20	6	9 ⁽¹⁾	6 ⁽¹⁾	NA
Electrical capacity (MWe)	3390	3463	3628	3885	4239	4600 ⁽²⁾	5100 ⁽²⁾	5800 ⁽²⁾
Net capacity added during year (MWe)	249	73	165	257	354	361	500	700

(1) Schemes likely to be commissioned

(2) Projections net of new, upgraded and retired schemes

Source: DTI Digest of United Kingdom Energy Statistics 2000, pp150-151

³⁰ DUKES 2000, pp. 147.

³¹ DETR The CHPQA Standard Issue 1, Nov 2000. See http://www.chpqa.com/html/chpqa_documents.html

These figures show that almost half of the CHP required by the government's 2010 CHP target (10,000MWe) has already been installed.

4.2 The Long-term Potential for CHP in the UK

The most recent, comprehensive assessment of the future potential of CHP in the UK (excluding community heating) was conducted by ETSU for the Department of the Environment, Transport and the Regions (DETR) in 1997. Other earlier assessments have been made, and a summary of their findings is made in the ETSU report. The ETSU assessment uses a combination of modelling and qualitative approaches to calculate the potential for CHP. The future potential for CHP was calculated for 6 scenarios (See Table 26). A base case using a 15% discount rate, 10 year capital investment period (the typical lifetime of a modern CHP plant) and the Energy Paper 65³² fuel price scenario is used. 'High' and 'Low' case scenarios are also used. The 'High' case uses an 8% discount rate and a 10 year investment period, with a high fuel price scenario. The 'Low' case uses a 25% discount rate and a 5 year investment period, with a low fuel price scenario.

For low temperature and commercial and public building sector applications of CHP, a quantitative, iterative method was used to find the least cost solution for a selected application (e.g. paper mill or hotel). It considered heat and demand profiles using 6 separate tariff periods depending on time of day and season, and opportunities for the import and export of heat and power. This data was compared against cost saving curves. This assessment also considered competition between CHP and other energy efficiency measures that may be more financially attractive. For high temperature applications, ETSU claim detailed models of CHP potential have not yet been developed. Therefore a more qualitative, tailored analysis was used. Their analysis draws on an assessment of high temperature CHP made as part of the DETR Greenhouse Gas Emissions study³³. The assessment method for high temperature CHP was based upon identifying known opportunities for CHP applications in industry sub-sectors and then identifying the number of current UK plants in which such technologies can be applied. The potential for CHP in community heating was not assessed by ETSU, but several previous studies are summarised in section 8 of their report.

To assess sector size and energy consumption, ETSU collect what it considered to be the most up-to-date data, but acknowledged that *'This area of investigation could involve many more months of effort and ultimately might be required to establish more details of potentials in sensitive areas'*³⁴. The examination of site specific demand profiles was undertaken in some cases, though for others typical example data for the sector was used.

Table 26 - Future potential of UK CHP electricity production in 2010

	High Case	Base Case	Low Case
Potential output (MWe)	16810	14720	10005

Source: ETSU Assessment of CHP potential Final report, 1997

³² DTI Energy Projections for the UK Energy Paper 65, March 1995.

³³ Published in the 4th Annual Report, June 1996.

³⁴ See p14.

Overall, the ETSU assessment gives an optimistic view of the future CHP market. Under all scenarios, the UK target of 10GWe by 2010 is achieved. However, it should be noted that the analysis is now rather out of date, and might produce different results if it were repeated now.

A more recent assessment of the potential for CHP development over the coming 20 years was produced by Forum for the Future and Cambridge Econometrics in late 2000. This is more equivocal than the ETSU analysis since the UK target is not met under a business as usual scenario (see Table 27).

Table 27 – CHP Modelling Results for 2010 and 2020

	Base Case			CHP Scenario		
	2000	2010	2020	2000	2010	2020
Potential CHP Output (MWe)	4,600	6,600	8,600	4,600	10,100	19,700

Source: Forum for the Future and Cambridge Econometrics Combined Heat and Power to 2020 (October 2000).

The results of the Forum for the Future study derive from the application of an economic model of the UK economy. The authors found that the largest determinant of the speed of CHP expansion was the difference between the price of the dominant CHP fuel (i.e. natural gas) and the price of electricity. The ‘CHP scenario’ showed how faster deployment could be achieved by using a number of policy support measures. These included full exemption from the climate change levy and a prominent role for CHP within industry negotiated agreements.

Recent events tend to reinforce the cautious analysis of the Forum for the Future Study. In the short-term, one of the greatest uncertainties for CHP developers stems from the reform of the UK electricity trading arrangements. On 27th March 2001, the existing Electricity Pool was replaced by New Electricity Trading Arrangements (NETA). NETA is designed to increase competition in the electricity market and so put downward pressure on prices for final customers.

During the run-up to this change, the Government claimed NETA would provide a boost CHP³⁵. However, the initial experience of NETA has not backed up this assertion. The first two months of NETA have fostered greater wholesale price volatility than was the case under the previous Pool system. For example, spill prices for surplus CHP electricity fell from around £20/MWh early in 2001 to £12/MWh in after 2 months of NETA³⁶.

According to the Combined Heat and Power Association (CHPA), ‘just as when the electricity industry was privatised in 1989, it is clear that transitional arrangements for small generators are once again urgently needed.’³⁷ In response, the government and the Office of the Gas and Electricity Markets (OFGEM) have reviewed of the impact of NETA on small generators. It remains to be seen whether the conclusions will remove some of the barriers NETA has created for both CHP and renewables³⁸.

³⁵ DETR Generating interest in CHP Energy Efficiency Best Practice Programme (14 May 2000).

³⁶ ‘UK Volatility forcing CHP, renewables to the wall’ *Power in Europe* Issue 350 (7 May 2001).

³⁷ David Green, CHPA ‘NETA goes live: but will small generators survive?’ Press Release 57, 15 March 2001.

³⁸ For further analysis, see A Smith and J Watson The Renewables Obligation: Can it Deliver? Tyndall Centre Briefing Note No.4 (April 2002) and D Green ‘Small is Beautiful? The Embedded Generators Story’ Institute of Energy Conference *NETA the Experience: Where do we go from here?* London (31st October 2001).

ANNEX: Key studies - methodologies and assumptions

British Wind Energy Association, 2000. Planning for wind energy: A guide for regional targets. BWEA, London.

The BWEA analyses the contribution of onshore wind power to the Government target of 10% renewable electricity. The assessment is based on the UK Government 'High Wind' scenario for 2010 (see section 2.1), which projects a contribution of 26% from onshore wind power. Assuming a future total electricity consumption of 380 TWh (corresponds with Energy Paper 65 central scenarios), BWEA calculates the total capacity needed to achieve this target assuming a nominal wind turbine load of 30%, the number of wind turbines to be built and the total land area required. Taking into account the potential for onshore wind power and the electricity demand in the different parts of the UK, BWEA derives regional targets for onshore wind electricity.

Ekins, P., Cotton, R., 2001. UK renewables to 2020. Paper to the Chatham House conference: 'Can renewables deliver?'.

The study is based on a multi-sectoral model of the UK economy. Renewable energy projections are based, amongst other things, on energy demand projections, characteristics of existing and planned power stations, and assumptions about capital and generation cost. The costs of developing renewable energy technologies are based on resource cost curves. The model also takes account of existing and planned government policies (e.g. Renewables Obligation, NETA). The figures which come closest to an assessment of the renewable resource base are the outputs of the Accelerated Renewables Scenario. The scenario assumes that all available renewable electricity generating capacity is developed at a price of 4.3p/kWh (2000 prices) or less, subject only to a limit of 20% on the proportion of supply derived from intermittent renewables. This scenario arrives at a potential renewable contribution of 13% to total electricity supply by 2010 (thereby going beyond the government target of 10%). Figures market as 'Resource 2010 (Ekins)' refer to outputs from the Accelerated Renewables Scenario.

ETSU, 1997. Assessment of CHP potential. Final report. A report produced for the DETR. RYCA 18501113. July 1997.

This assessment uses a combination of modelling and qualitative approaches to calculate the potential for CHP. The future potential for CHP was calculated for 6 scenarios. A base case using a 15% discount rate, 10 year capital investment period (the typical lifetime of a modern CHP plant) and the Energy Paper 65³⁹ fuel price scenario is used. 'High' and 'Low' case scenarios are also used. The 'High' case uses an 8% discount rate and a 10 year investment period, with a high fuel price scenario. The 'Low' case uses a 25% discount rate and a 5 year investment period, with a low fuel price scenario.

ETSU, 2000. New and renewable energy: Prospects in the UK for the 21st century: Supporting analysis. London.

The ETSU assessment is based on the MARKAL energy model developed by the International Energy Agency (also used by DTI for Energy Paper 65). The key input to the model is an assessment of how much resource could be supplied by technologies as a function of the economic costs of exploitation (resource cost-curves). The resource cost-curves are derived on cost and resource data collected by ETSU. They are based on a wide range of assumptions, particularly that costs for exploiting the resource will fall over time.

³⁹ DTI Energy Projections for the UK Energy Paper 65, March 1995.

ETSU provides resource cost-curves for two time scales (2010 and 2025) and two discount rates (8% and 15%) for prices up to 7p/kWh. The detailed assumptions and scenarios underlying MARKAL and the ETSU assessment are described in the ETSU report on p.16ff and 250ff.

Photovoltaic (PV) Government – Industry Group, 2001. Final Report. 26 March 2001.

The PV Group report explores the potentials for a 10 year programme which results in the installation of 70,000 systems between now and 2010. It draws on work carried out by BP Solar to estimate approximate cost of running market support programmes for this programme through a simplified model. The model is built around a 2 kilowatt peak PV installation, with costs declining over 10 years in line with industry expectations (e.g. £8,500 in 2000 down to c.£4,000 by 2010 at the lower end of the price scale). Each system is assumed to deliver between 1400 and 1600 kWh per year after allowing for UK sunlight conditions and losses associated with DC/AC conversion. Each system is assumed to have a maximum 30 year life. Domestic electricity pricing is assumed to be held constant at 7p/KWh nominal.

Royal Commission on Environmental Pollution, 2000. Energy - the changing climate. The Stationery Office, London.

The Royal Commission report assesses the potential contribution of all available renewable energy technologies to reducing greenhouse gas emissions in the medium and long term. It draws on a range of published and unpublished material, each based on different assumptions and methodologies.

Tyndall°Centre

for Climate Change Research

The inter-disciplinary Tyndall Centre for Climate Change Research undertakes integrated research into the long-term consequences of climate change for society and into the development of sustainable responses that governments, business-leaders and decision-makers can evaluate and implement. Achieving these objectives brings together UK climate scientists, social scientists, engineers and economists in a unique collaborative research effort.

Research at the Tyndall Centre is organised into four research themes that collectively contribute to all aspects of the climate change issue: Integrating Frameworks; Decarbonising Modern Societies; Adapting to Climate Change; and Sustaining the Coastal Zone. All thematic fields address a clear problem posed to society by climate change, and will generate results to guide the strategic development of climate change mitigation and adaptation policies at local, national and global scales.

The Tyndall Centre is named after the 19th century UK scientist John Tyndall, who was the first to prove the Earth's natural greenhouse effect and suggested that slight changes in atmospheric composition could bring about climate variations. In addition, he was committed to improving the quality of science education and knowledge.

The Tyndall Centre is a partnership of the following institutions:

- University of East Anglia
- UMIST
- Southampton Oceanography Centre
- University of Southampton
- University of Cambridge
- Centre for Ecology and Hydrology
- SPRU – Science and Technology Policy Research (University of Sussex)
- Institute for Transport Studies (University of Leeds)
- Complex Systems Management Centre (Cranfield University)
- Energy Research Unit (CLRC Rutherford Appleton Laboratory)

The Centre is core funded by the following organisations:

- Natural Environmental Research Council (NERC)
- Economic and Social Research Council (ESRC)
- Engineering and Physical Sciences Research Council (EPSRC)
- UK Government Department of Trade and Industry (DTI)

For more information, visit the Tyndall Centre Web site (www.tyndall.ac.uk) or contact:

- External Communications Manager
- Tyndall Centre for Climate Change Research
- University of East Anglia, Norwich NR4 7TJ, UK
- Phone: +44 (0) 1603 59 3906; Fax: +44 (0) 1603 59 3901
- Email: tyndall@uea.ac.uk

Recent Working Papers

Tyndall Working Papers are available online at http://www.tyndall.ac.uk/publications/working_papers/working_papers.shtml

Mitchell, T. and Hulme, M. (2000). **A Country-by-Country Analysis of Past and Future Warming Rates**, Tyndall Centre Working Paper 1.

Hulme, M. (2001). **Integrated Assessment Models**, Tyndall Centre Working Paper 2.

Berkhout, F, Hertin, J. and Jordan, A. J. (2001). **Socio-economic futures in climate change impact assessment: using scenarios as 'learning machines'**, Tyndall Centre Working Paper 3.

Barker, T. and Ekins, P. (2001). **How High are the Costs of Kyoto for the US Economy?**, Tyndall Centre Working Paper 4.

Barnett, J. (2001). **The issue of 'Adverse Effects and the Impacts of Response Measures' in the UNFCCC**, Tyndall Centre Working Paper 5.

Goodess, C.M., Hulme, M. and Osborn, T. (2001). **The identification and evaluation of suitable scenario development methods for the estimation of future probabilities of extreme weather events**, Tyndall Centre Working Paper 6.

Barnett, J. (2001). **Security and Climate Change**, Tyndall Centre Working Paper 7.

Adger, W. N. (2001). **Social Capital and Climate Change**, Tyndall Centre Working Paper 8.

Barnett, J. and Adger, W. N. (2001). **Climate Dangers and Atoll Countries**, Tyndall Centre Working Paper 9.

Gough, C., Taylor, I. and Shackley, S. (2001). **Burying Carbon under the Sea: An Initial Exploration of Public Opinions**, Tyndall Centre Working Paper 10.

Barker, T. (2001). **Representing the Integrated Assessment of Climate Change, Adaptation and Mitigation**, Tyndall Centre Working Paper 11.

Dessai, S., (2001). **The climate regime from The Hague to Marrakech: Saving or sinking the Kyoto Protocol?**, Tyndall Centre Working Paper 12.

Dewick, P., Green K., Miozzo, M., (2002). **Technological Change, Industry Structure and the Environment**, Tyndall Centre Working Paper 13.

Shackley, S. and Gough, C., (2002). **The Use of Integrated Assessment: An Institutional Analysis Perspective**, Tyndall Centre Working Paper 14.

Köhler, J.H., (2002). **Long run technical change in an energy-environment-economy (E3) model for an IA system: A model of Kondratiev waves**, Tyndall Centre Working Paper 15.

Adger, W.N., Huq, S., Brown, K., Conway, D. and Hulme, M. (2002). **Adaptation to climate change: Setting the Agenda for Development Policy and Research**, Tyndall Centre Working Paper 16.

Dutton, G., (2002). **Hydrogen Energy Technology**, Tyndall Centre Working Paper 17.

Watson, J. (2002). **The development of large technical systems: implications for hydrogen**, Tyndall Centre Working Paper 18.

Pridmore, A. and Bristow, A., (2002). **The role of hydrogen in powering road transport**, Tyndall Centre Working Paper 19.

Turnpenny, J. (2002). **Reviewing organisational use of scenarios: Case study - evaluating UK energy policy options**, Tyndall Centre Working Paper 20.

Watson, W. J. (2002). **Renewables and CHP Deployment in the UK to 2020**, Tyndall Centre Working Paper 21.

Watson, W.J., Hertin, J., Randall, T., Gough, C. (2002). **Renewable Energy and Combined Heat and Power Resources in the UK**, Tyndall Centre Working Paper 22.