Tyndall°Centre
for Climate Change Research

UK Electricity Scenarios for 2050

Jim Watson

November 2003

Tyndall Centre for Climate Change Research Working Paper 41

UK Electricity Scenarios for 2050

Dr. Jim Watson

Tyndall Centre for Climate Change Research
and
SPRU – Science and Technology Policy Research
Freeman Centre
University of Sussex
Brighton BN1 9QE

Email: w.j.watson@sussex.ac.uk

Tyndall Centre Working Paper No. 41
November 2003

Summary

The recent energy White Paper included a commitment to a 60% reduction in UK carbon emissions by 2050. To achieve this reduction will require radical changes to energy supply and demand. Many of the most important changes are likely to affect the UK electricity system. A decarbonised electricity system will require large contributions from renewable and other low carbon energy sources (e.g. fuel cells, micro CHP and possibly nuclear). It will also need to facilitate significant amounts of electricity storage technologies, and substantial reductions in demand. At the same time, it is essential that the operational security of the electricity system be maintained.

This paper builds on the work of the Royal Commission on Environmental Pollution (RCEP) report: *Energy – The Changing Climate*. The RCEP report includes four scenarios that explore options for a 60% reduction in UK carbon emissions by 2050. The paper elaborates these scenarios, and applies them to the UK electricity system. The paper establishes electricity generating plant capacities, load factors and annual outputs for each scenario. It also compares these outputs with electricity demand figures from the RCEP report.

The analysis in this paper shows that the RCEP scenarios imply a radically different electricity system to the one we have today. In all scenarios, the system is more decentralised with more generating capacity and a greater contribution from renewable energy sources. At the same time, electricity demand has been held at 1998 levels or reduced by up to a third. The scenarios include large variations in the capacities and types of generating technology that will be required to meet this demand. At one end of the spectrum, scenario 1 includes four times as much generating capacity as the UK has today, with substantial investments in nuclear, renewable and fossil fuel power stations. At the other, scenario 4 includes a modest capacity increase, most of which will be met by renewables, coupled with a 33% reduction in electricity demand.

The next phase of the Tyndall Centre's work on electricity system security includes some detailed modelling work that builds on the scenarios that have been elaborated in this paper. This modelling will assess the operational security implications of these scenarios on a seasonal, daily and hourly basis. It will be complemented by economic and regulatory analysis to develop regulatory incentives that will support the development of secure sustainable electricity systems.

1 Introduction

The recent energy White Paper (DTI, 2003) included a commitment to a 60% reduction in UK carbon emissions by 2050. To achieve this reduction will require radical changes to energy supply and demand. Many of the most important changes are likely to affect the UK electricity system. A decarbonised electricity system will require large contributions from renewable and other low carbon energy sources (e.g. fuel cells, micro CHP and possibly nuclear). It will also need to facilitate significant amounts of electricity storage technologies, and substantial reductions in demand. At the same time, it is essential that the operational security of the electricity system be maintained.

The purpose of this working paper is to establish a set of scenarios for the UK electricity system in 2050, principally for the Tyndall Centre project: Security of Decarbonised Electricity Systems. The scenarios will be used in this project to help investigate how the operational security of a decarbonised UK power system can be managed and maintained. The paper builds on four scenarios developed by the Royal Commission on Environmental Pollution (RCEP), all of which include a 60% reduction in UK carbon dioxide emissions. The methodology behind the scenarios and the detailed outputs are set out in Appendix E of the RCEP report, *Energy – the Changing Climate* (RCEP, 2000).

It is important to be aware that the RCEP scenarios differ from many other recent UK energy scenario exercises. For example, those developed by the government's Strategy Unit for its energy policy review (DTI, 2003) are not designed to meet a specific emissions reduction target. Instead, they set out a framework for exploring different socio-economic futures, and analysing these to see what consequences they have for the energy system and the environment.

The four RCEP scenarios were developed using a relatively simple set of guidelines. To achieve a 60% carbon emissions reduction, each scenario included a different mix of energy supply technologies and different assumptions about reductions in energy demand across four kinds of end-use: electricity, low grade heat, high grade heat and transport. These scenarios can be summarised as follows:

- *Scenario 1:* No increase on 1998 energy demand by 2050. Energy supplied by a combination of renewables and either nuclear power stations or large fossil fuel power stations at which carbon dioxide is recovered and disposed of.
- *Scenario 2:* Demand reductions, including a 50% reduction in low grade heat demand and a 25% reduction for other kinds of end-use. Energy supplied by renewables, with no nuclear power stations or routine use of large fossil fuel power stations.
- *Scenario 3:* Demand reductions, including a 50% reduction in low grade heat demand and a 25% reduction for other kinds of end-use. Energy supplied by a combination of renewables and either nuclear power stations or large fossil fuel power stations at which carbon dioxide is recovered and disposed of.
- *Scenario 4:* Very large demand reductions, including a 66% reduction in low grade heat demand and a 33% reduction for other kinds of end-use. Energy supplied by renewables with no nuclear power stations or routine use of large fossil fuel power stations.

2 RCEP Scenario Data

From these simple outlines, the RCEP developed mixes of energy supply technologies for 2050. These are summarised in Table 1. The data in Table 1 are presented using an unusual measure – the annual average rate of energy supply in GW. This is used for all forms of energy supply including electricity, heat and transport fuels. The RCEP states that this measure is more useful for their analysis than more common measures (e.g. TWh and million tonnes of oil equivalent, MTOE).

The annual average rate is calculated by multiplying the maximum rate (for example, the capacity of an electricity generating plant) by a load factor. Similarly, the output of a plant during a year is derived by multiplying the annual average rate by 8760 (the number of hours in a year).

Energy Source	**1998**	**Scen 1**	**Scen 2**	**Scen 3**	**Scen 4**
On-shore wind	0.10	6.5	3.3	0.2	3.3
Off-shore wind		11.4	11.4	11.4	5.7
Solar PV		10.0	5.0	0.5	0.5
Wave		3.75	3.75	3.75	3.75
Tidal stream		0.25	0.25	0.25	0.25
Tidal barrage		2.2	2.2	0.0	2.2
Total intermittent renewables		*34.1*	*25.9*	*16.1*	*15.7*
Hydro existing	0.59	0.59	0.59	0.59	0.59
Hydro new small scale	0.02	0.3	0.3	0.3	0.2
Energy crops		10.2	10.2	1.8	1.8
Agricultural & forestry waste	0.04	5.7	5.7	5.7	1.2
Municipal solid waste	0.15	1.9	1.9	0.0	0.0
Total renewable sources		*52.8*	*44.6*	*24.5*	*19.5*
Nuclear power baseload	11.4	52	0	19	0
Fossil fuels	266	106	106	106	106
Final Energy Consumption		**205**	**132**	**132**	**109**

Table 1: *Output from Energy Sources in 2050 under four RCEP Scenarios (Annual Average Rate, GW). Nuclear power stations are interchangeable with fossil-fuel power stations with carbon capture and sequestration. Fossil fuel figures are for all end uses including electricity, transport and heat [Source: RCEP, 2000]*

3 Electricity Generation Capacities

Since the data in Table 1 are expressed using the unusual 'annual average rate' measure, they are not in a suitable form for the analysis of future electricity system security. It is therefore necessary to extract from this data the capacities (in GWe) and outputs (in TWh) of electricity generating technologies under each scenario. To calculate the capacities of each electricity generating technology, the data in Table 1 were used together with additional information provided by the RCEP about the numbers and types of plants required. This information is reproduced below as Table 2.

Electricity Source	**Capacity of units (MW)**	**Number of units**			
		Scen 1	**Scen 2**	**Scen 3**	**Scen 4**
On-shore wind	1.5	10,100	5,000	360	5,020
Off-shore wind	1.5	18,000	17,700	18,000	8,800
Solar PV (GW peak)	0.004	15,000,000	7,500,000	750,000	750,000
Wave	1	7,500	7,500	7,500	7,500
Tidal stream	1	500	500	500	500
Tidal barrage	8600	1	1	0	1
Hydro new small scale	0.1	4,500	4,500	4,500	2,200
Energy crops	1-10	290-2,900	290-2,900	42-420	42-420
Agricultural & forestry waste	0.5-10	53-1,050	53-1,050	53-1,050	34-688
Muni. solid waste/landfill gas	8-60	3-20	3-20	3-20	0
Nuclear power baseload	1200	46	0	19	0
Fossil fuel (for back up)	40	1,000	760	475	460
Fossil fuel (for peak demand)	400	120	70	65	55
Micro-CHP	0.002	0	1,700,000	1,800,000	2,400,000

Table 2: *Numbers of Generating Plant in Four RCEP Scenarios. Nuclear power stations are interchangeable with fossil-fuel power stations with carbon capture and sequestration [Source: Calculations from data in RCEP, 2000]*

To arrive at capacity figures for each technology, judgements had to be made in some cases about likely load factors. This is because ranges of plant sizes and capacities were sometimes given by the RCEP report instead of a single average figure. For medium and large scale CHP, a load factor of 0.6 was used since this is the current average for UK CHP plants. For micro-CHP, an initial load factor of 0.28 was taken from equipment supplier data (Watson, 2003). It is likely that the use of these scenarios within the Tyndall Centre's work will require some adjustment to these load factors so that the supply and demand for heat can be matched.

For some other technologies, the RCEP figures imply slightly different load factors for the same technology in each scenario. A summary of load factors is given in Table 3, and the resulting generating plant capacities for all technologies in GWe are shown in Table 4.

Electricity Source	Scen 1	Scen 2	Scen 3	Scen 4
On-shore wind	0.43	0.44	0.37	0.44
Off-shore wind	0.42	0.43	0.42	0.43
Solar PV (GW peak)	0.17	0.17	0.17	0.17
Wave	0.50	0.50	0.50	0.50
Tidal stream	0.50	0.50	0.50	0.50
Tidal barrage	0.26	0.26	-	0.26
Hydro existing (incl. pumped storage)	0.19	0.19	0.19	0.19
Hydro new small scale	0.67	0.67	0.67	0.91
Energy crops	0.60	0.60	0.60	0.60
Agricultural & forestry waste	0.60	0.60	0.60	0.60
Municipal solid waste/landfill gas	0.60	0.60	-	-
Nuclear power baseload	0.94	-	0.83	-
Fossil fuel (for back up)	0.29	0.31	0.39	0.41
Fossil fuel (for peak demand)	0.05	0.08	0.06	0.07
Micro-CHP	-	0.28	0.28	0.28

Table 3: *Load Factors of UK Generating Plant Implied by Four RCEP Scenarios. Nuclear power stations are interchangeable with fossil-fuel power stations with carbon capture and sequestration [Source: Calculations from data in RCEP, 2000 and DTI, 1999]*

Electricity Source	1998	Scen 1	Scen 2	Scen 3	Scen 4
On-shore wind	0.14	15.15	7.50	0.54	7.53
Off-shore wind	0.00	27.00	26.55	27.00	13.20
Solar PV (GW peak)	0.00	60	30.00	3.00	3.00
Wave	0.00	7.50	7.50	7.50	7.50
Tidal stream	0.00	0.50	0.50	0.50	0.50
Tidal barrage	0.00	8.60	8.60	0.00	8.60
Hydro existing (incl. pumped storage)	4.26	4.26	4.26	4.26	4.26
Hydro new small scale	0.00	0.45	0.45	0.45	0.22
Energy crops	0.00	7.72	7.72	1.37	1.37
Agricultural & forestry waste	0.08	4.00	4.00	4.00	0.85
Municipal solid waste/landfill gas	0.47	1.33	1.33	0.00	0.00
Nuclear power baseload	13.00	55.20	0.00	22.80	0.00
Fossil fuel (for back up)	55.10	40.00	30.40	19.00	18.40
Fossil fuel (for peak demand)	(all)	48.00	28.00	26.00	22.00
Micro-CHP	0.00	0.00	3.40	3.60	4.80
Total	**73.05**	**279.71**	**160.21**	**120.02**	**92.23**

Table 4: *Capacity of UK Generating Plant Implied by Four RCEP Scenarios (GW). Nuclear power stations are interchangeable with fossil-fuel power stations with carbon capture and sequestration [Source: Calculations from data in RCEP, 2000 and DTI, 1999]*

4 Electricity Generated by Each Technology

Using the data in Tables 2 to 4, it is now possible to determine how much electricity generation will be required from each technology under each scenario. Data for generation in TWh are presented in Table 5.

Source	1998	Scen 1	Scen 2	Scen 3	Scen 4
On-shore wind	0.89	56.94	28.91	1.75	28.91
Off-shore wind	0	99.86	99.86	99.86	49.93
Solar PV	0	87.60	43.80	4.38	4.38
Wave	0	32.85	32.85	32.85	32.85
Tidal stream	0	2.19	2.19	2.19	2.19
Tidal barrage	0	19.27	19.27	0.00	19.27
Hydro existing (incl. pumped storage)	6.85	6.85	6.85	6.85	6.85
Hydro new small scale	0	2.63	2.63	2.63	1.75
Energy crops	0	40.56	40.56	7.18	7.18
Agricultural & forestry waste	0.32	21.02	21.02	21.02	4.47
Municipal solid waste/landfill gas	2.92	7.01	7.01	0	0
Nuclear power baseload	100.14	455.52	0	166.44	0
Fossil fuel (for back up)	247.14 (all)	101.61	83.22	65.70	65.70
Fossil fuel (for peak demand)		20.15	20.15	13.14	13.14
Micro-CHP	0	0	8.34	8.83	11.77
Total	**358.25**	**954.07**	**408.32**	**424.00**	**236.62**

Table 5: *Electricity Generation Implied by Four RCEP Scenarios (TWh). Nuclear power stations are interchangeable with fossil-fuel power stations with carbon capture and sequestration [Source: Calculations from data in RCEP, 2000 and DTI, 1999]*

5 Relating Electricity Supply to Electricity Demand

Having established electricity generating plant outputs and capacities from the four RCEP scenarios, it is also important to understand what the scenarios say about electricity demand. As with energy supply, demand figures given in the RCEP report are stated as annual average rates. However, there is sufficient supporting information to be able to extract electricity demand figures from these.

As the RCEP report states, these demand figures were established using simple rules. For scenario 1, it was assumed that demand in 2050 would remain the same as 1998. For scenarios 2 and 3, a 25% reduction from the 1998 level was assumed. For scenario 4, a 33% reduction from the 1998 level was assumed. Electricity supply and demand figures for each scenario in TWh are stated in Table 6.

	1998	**Scen 1**	**Scen 2**	**Scen 3**	**Scen 4**
Electricity Demand	280.32	280.32	210.24	210.24	183.96
Electricity Supply	358.25	954.07	408.32	424.00	236.62
Difference	**77.93**	**673.75**	**198.08**	**213.76**	**52.66**

Table 6: *Electricity Supply and Demand Implied by Four RCEP Scenarios (TWh).*
[Source: Calculations from data in RCEP, 2000 and DTI, 1999]

These demand figures require some further explanation when they are compared to the figures for electricity supply from Table 3. In some cases, electricity supply is much larger than electricity demand. Some system losses are to be expected. For example, the difference between supply and demand for 1998 can be explained by consumption of electricity within power stations (e.g. for pumped storage) and losses in the transmission and distribution system.

Losses cannot explain the very large differences in the supply and demand figures. The disparity is particularly large for scenario 1. To find out why this is the case, it is necessary to understand the process of supply-demand matching that was undertaken by the RCEP. This process included the following priorities for the use of fossil fuels in each scenario:

- The first priority is transport;
- The second priority is the generation of electricity to provide backup for intermittent renewables and extra power at peak periods;
- The third priority is the provision of high grade heat; and
- The fourth priority for any fossil fuel remaining is the provision of low grade heat.

It is clear from this that a lot of the electricity generated is not consumed as electricity in some scenarios. Instead it is used to make up for shortfalls in fossil fuel availability for high and low-grade heat. The main technology for this is electrically powered heat pumps. In scenario 1, the RCEP states that most of the demand for low grade heat and over a third of the demand for high grade heat are met in this way.

6 Conclusions

This paper has built on the work of the Royal Commission on Environmental Pollution to develop some alternative scenarios for the UK electricity system in 2050. Each scenario is designed to reduce national carbon emissions by 60% from current levels by this date. The paper has established electricity generating plant capacities, load factors and annual outputs for each scenario. It has also compared these outputs with electricity demand figures from the RCEP report.

The analysis has shown that the RCEP scenarios imply a radically different electricity system to the one we have today. In all scenarios, the system is more decentralised with more generating capacity and a greater contribution from renewable energy sources. At the same time, electricity demand has been held at 1998 levels or reduced by up to a third. Some key features of the scenarios include:

- A shift in the role of fossil fuel electricity generation – away from baseload or mid-range duty, and towards backup for intermittent renewables;
- In two scenarios, a significant expansion of nuclear power (or fossil fuel stations with carbon sequestration);
- Significant action to halt or reverse growth in energy demand, which implies large improvements in energy efficiency;
- In some scenarios, very large mismatches between electricity generation and electricity demand. This is explained by the use of electricity to provide substantial amounts of high and low grade heat; and
- No link between the expanded use of renewables to generate electricity and the production of hydrogen. All hydrogen within the scenarios is produced from fossil fuels.

Having completed this analysis, it is important to consider whether the RCEP scenarios provide a wide enough range of possibilities for the next stage of the Tyndall Centre's assessment of electricity system security in 2050. They do not cover all possible outcomes. This is not feasible using just four scenarios, each of which has to deliver a 60% cut in carbon emissions. Possibilities that are not covered might include greater contributions from micro-CHP. By 2050, a large proportion of households might have these units installed – perhaps ten times the number included in the RCEP scenarios. Similarly, there may be a need to consider a larger contribution from some renewables such as energy crops, wave or tidal power.

For the Tyndall Centre's research on UK electricity system security, the development of scenarios using other combinations of technologies might not be necessary. The RCEP scenarios might include a wide enough range of electricity system futures for 2050 to test the limits of system security. Crucially, they cover possibilities in which the system is still quite centralised (e.g. in scenario 1) and others in which it is almost wholly decentralised (e.g. in scenarios 2 and 4). They also include a range of possibilities for the contribution of intermittent renewables – particularly wind.

The need for additional scenarios will be kept under review as the next phase of research progresses. The next phase will include some detailed modelling work that builds on the four electricity scenarios that have been elaborated in this paper. This modelling will assess the operational security implications of these scenarios on a seasonal, daily and hourly basis. It will be complemented by economic and regulatory analysis to develop regulatory incentives that will support the development of secure sustainable electricity systems.

Acknowledgements

This paper was developed as part of Tyndall Centre project T2.24: Security of Decarbonised Electricity Systems. The author would like to thank a number of Tyndall Centre colleagues for their comments on earlier drafts, particularly Dusko Nedic and Kevin Anderson.

References

DTI (Department of Trade and Industry) (2003) **Our Energy Future: Creating a Low Carbon Economy** The Stationery Office, London.

DTI (Department of Trade and Industry) (1999) **Digest of UK Energy Statistics** The Stationery Office, London.

RCEP (Royal Commission on Environmental Pollution) (2000) **Energy – The Changing Climate** RCEP, June.

Watson,J. (2003) Co-Provision in Sustainable Energy Systems: The Case of Micro-generation **Energy Policy,** Special Issue on System Change, Forthcoming.

Tyndall°Centre
for Climate Change Research

The trans-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

Tyndall°Centre
for Climate Change Research

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.

Tyndall°Centre
for Climate Change Research

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.

Paavola, J. and Adger, W.N. (2002). **Justice and adaptation to climate change**, Tyndall Centre Working Paper 23.

Xueguang Wu, Jenkins, N. and Strbac, G. (2002). **Impact of Integrating Renewables and CHP into the UK Transmission Network**, Tyndall Centre Working Paper 24

Xueguang Wu, Mutale, J., Jenkins, N. and Strbac, G. (2003). **An investigation of Network Splitting for Fault Level Reduction**, Tyndall Centre Working Paper 25

Brooks, N. and Adger W.N. (2003). **Country level risk measures of climate-related natural disasters and implications for adaptation to climate change**, Tyndall Centre Working Paper 26

Tompkins, E.L. and Adger, W.N. (2003). **Building resilience to climate change through adaptive management of natural resources**, Tyndall Centre Working Paper 27

Dessai, S., Adger, W.N., Hulme, M., Köhler, J.H., Turnpenny, J. and Warren, R. (2003). **Defining and experiencing dangerous climate change**, Tyndall Centre Working Paper 28

Brown, K. and Corbera, E. (2003). **A Multi-Criteria Assessment Framework for Carbon-Mitigation Projects: Putting "development" in the centre of decision-making**, Tyndall Centre Working Paper 29

Hulme, M. (2003). **Abrupt climate change: can society cope?**, Tyndall Centre Working Paper 30

Turnpenny, J., Haxeltine A. and O'Riordan, T. (2003). **A scoping study of UK user needs for managing climate futures. Part 1 of the pilot-phase interactive integrated assessment process (Aurion Project)**, Tyndall Centre Working Paper 31

Xueguang Wu, Jenkins, N. and Strbac, G. (2003). **Integrating Renewables and CHP into the UK Electricity System: Investigation of the impact of network faults on the stability of large offshore wind farms**, Tyndall Centre Working Paper 32

Pridmore, A., Bristow, A.L., May, A. D. and Tight, M.R. (2003). **Climate Change, Impacts, Future Scenarios and the Role of Transport**, Tyndall Centre Working Paper 33

Dessai, S., Hulme, M (2003). **Does climate policy need probabilities?,** Tyndall Centre Working Paper 34

Tompkins, E. L. and Hurlston, L. (2003). **Report to the Cayman Islands' Government. Adaptation lessons learned from responding to tropical cyclones by the Cayman Islands' Government, 1988 – 2002,** Tyndall Centre Working Paper 35

Kröger, K. Fergusson, M. and Skinner, I. (2003). **Critical Issues in Decarbonising Transport: The Role of Technologies,** Tyndall Centre Working Paper 36

Ingham, A. and Ulph, A. (2003) **Uncertainty, Irreversibility, Precaution and the Social Cost of Carbon,** Tyndall Centre Working Paper 37

Brooks, N. (2003). **Vulnerability, risk and adaptation: a conceptual framework**, Tyndall Centre Working Paper 38

Tompkins, E.L. and Adger, W.N. (2003). **Defining response capacity to enhance climate change policy**, Tyndall Centre Working Paper 39

Klein, R.J.T., Lisa Schipper, E. and Dessai, S. (2003), **Integrating mitigation and adaptation into climate and development policy: three research questions**, Tyndall Centre Working Paper 40

Tyndall°Centre
for Climate Change Research

Watson, J. (2003), **UK Electricity Scenarios for 2050**, Tyndall Centre Working Paper 41