P R E S S   R E L E A S E

<u>05.04.06</u> : UK Energy Research Centre Dispels Myths Surrounding Intermittent Renewable Energy. Most comprehensive assessment on intermittency ever undertaken finds reports suggesting renewable energy is costly or limited by intermittency are out of step with majority of expert analysis.

The UK Energy Research Centre (UKERC) today launches a definitive report on the costs and impacts of intermittent energy supplied by renewable sources, such as wind. Some commentators have suggested that renewable energy is made much more costly, or is drastically limited by intermittency.

However, the report finds that these views are out of step with the vast majority of international expert analysis. Intermittency need not present a significant obstacle to the development of renewable sources.

The report finds that :

- Renewable energy, such as wind power, leads to a direct reduction in CO_2 emissions
- The output of fossil fuel plant will need to be adjusted more often to cope with fluctuations in wind output, but any losses this causes are small compared to overall savings in emissions
- 100% ‘back up’ for individual renewable sources is unnecessary; extra capacity will be needed to keep supplies secure, but will be modest and a small part of the total cost of renewables. It is possible to work out what is needed and plan accordingly
- None of the 200+ studies UKERC reviewed suggested that the introduction of significant levels of intermittent renewable energy would lead to reduced reliability
- If wind power were to supply 20% of Britain’s electricity, intermittency costs would be 0.5 - 0.8p per kilowatt an hour (p/kWh) of wind output. This would be added to wind generating costs of 3 - 5p p/kWh. By comparison, costs of gas fired power stations are around 3p p/kWh
- The impact on electricity consumers would be around 0.1p p/kWh. Domestic electricity tariffs are typically 10 - 16p p/kWh. Intermittency therefore would account for around 1% of electricity costs
- Costs of intermittency at current levels is much smaller, but will rise if use of renewables expands
- Wide geographical dispersion and a diversity of renewable sources will keep costs down

Commenting on the report, Energy Minister Malcolm Wicks said : "Our target is to have 10% of the UK's electricity produced from renewable sources by 2010 and a significant proportion of that will come from wind power. Suggestions that it is excessively expensive, or that traditional power stations are needed to back-up the energy produced by all our wind farms, are just two of the myths that have been peddled by their opponents. The UK Energy Research Centre's study demonstrates that these claims have been exaggerated. I welcome the report's contribution to the debate."

According to the report's chief author, Robert Gross, head of UKERC's Technology and Policy Assessment function, "The output of wind, wave and other renewables fluctuates and cannot be fully controlled. The extent to which this is likely to create problems, costs or even lead to black outs is the subject of a long running debate.

"Reports that suggest it is highly costly, or restricts the role of renewables are out of step with the majority of expert analysis, reflect regional problems that the UK can avoid, or both. However, costs will rise to a degree, and we can quantify the factors responsible."

About the report

This report reviews and assesses the evidence on the costs and supply system impacts of intermittent generation (wind, wave, tidal and solar power). Its focus is on the UK and on the immediate future – changes and developments anticipated within the next two decades or so. Its findings are based upon a systematic search of the international literature which revealed more than two hundred reports and studies.

The report has been produced by the Technology and Policy Assessment function (TPA) of the UK Energy Research Centre (UKERC). The function was set up to inform decision-making processes and address key controversies in the energy field. The subject of the report was chosen after extensive consultation with energy sector stakeholders. It addresses the following question: What is the evidence on the costs and impacts of intermittent generation on the UK electricity network, and how are these costs assigned?

The work was funded by UKERC and the Carbon Trust.

The Costs and Impacts of Intermittency:

An assessment of the evidence on the costs and impacts of intermittent generation on the British electricity network

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A report of the Technology and Policy Assessment Function of the UK Energy Research Centre, with financial support from the Carbon Trust

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Preface

This report has been produced by the UK Energy Research Centre's Technology and Policy Assessment (TPA) function.

The TPA was set up to inform decision making processes and address key controversies in the energy field. It aims to provide authoritative and accessible reports that set very high standards for rigour and transparency. The subject of the report was chosen after extensive consultation with energy sector stakeholders. It addresses the following question:

What is the evidence on the costs and impacts of intermittent generation on the UK electricity network, and how are these costs assigned?

This UKERC report was part funded by the Carbon Trust and was undertaken by a team of experts from Imperial College London and the Supergen Future Network Technologies Consortium. The work was overseen by a panel of experts, and provides a systematic review of more than 200 reports and studies from around the world.

The report provides a detailed review of the current state of understanding of the engineering and economic impacts of intermittent, or renewable energy sources, such as wind and solar power. It seeks to provide a review of this complex topic that is accessible to the non-specialist.

This report is the first output of the UKERC's TPA function, which was established to produce a wide variety of policy relevant reports on the energy sector to stimulate and inform debate between policymakers, researchers and the wider energy community.

About UKERC

It is the UK Energy Research Centre's (UKERC) mission to be the UK's pre-eminent centre of research, and source of authoritative information and leadership, on sustainable energy systems.

UKERC undertakes world-class research addressing the whole-systems aspects of energy supply and use while developing and maintaining the means to enable cohesive research in energy.

To achieve this we are establishing a comprehensive database of energy research, development and demonstration competences in the UK. We will also act as the portal for the UK energy research community to and from both UK stakeholders and the international energy research community.

Executive Summary

Overview

1. The output of many types of renewable electricity generation, such as wind, wave and solar, is intermittent in nature. Output varies with environmental conditions, such as wind strength, over which the operator has no control. Assimilating these fluctuations has the potential to affect the operation and economics of electricity networks, markets and the output of other forms of generation. It can affect the reliability of electricity supplies and the actions needed to ensure demand meets supply every instant.

2. This report aims to understand and quantify these impacts, and therefore addresses the question 'What is the evidence on the impacts and costs of intermittent generation on the British electricity network, and how are these costs assigned?' It is based on a review of over 200 international studies.

3. The studies have been categorised and assessed. The review process has been overseen by an expert group and the final report has been peer-reviewed by international experts. Stakeholders were consulted through a workshop, and materials produced throughout the assessment process were posted on the UKERC website.

4. This study focuses only on the electricity system implications of the uncontrollable variability of some renewable energy sources, often referred to as *intermittency*[1]. It therefore does not address: the basic costs of renewable generation relative to conventional generation; the environmental impacts of renewable generation; or the direct costs of extending the transmission system to accommodate new generation. The report focuses on incremental developments to the existing electricity system, with a timeframe approximately twenty years into the future. It does not consider the long term potential to reconfigure electricity networks in order to maximise the use of sustainable energy technologies, nor the costs or options for doing so.

The benefits of renewable generation

5. Renewable electricity generation helps to reduce the need to operate power stations burning fossil fuels such as coal and gas. This means that carbon dioxide emissions are reduced.

6. It is sometimes said that wind energy, for example, does not reduce carbon dioxide emissions because the intermittent nature of its output means it needs to be backed up by fossil fuel plant. Wind turbines do not displace fossil generating *capacity* on a one-for-one basis. But it is unambiguously the case that wind energy can displace fossil fuel-based *generation*, reducing both fuel use and carbon dioxide emissions.

7. Wind generation does mean that the output of fossil fuel-plant needs to be adjusted more frequently, to cope with fluctuations in output. Some power stations will be operated below their maximum output to facilitate this, and extra system balancing reserves will be needed. Efficiency may be reduced as a result. At high penetrations (above 20%) energy may need to be 'spilled' because the electricity system cannot always make use of it. But overall these effects are much smaller than the savings in fuel and emissions that renewables can deliver at the levels of penetration examined in this report.

[1]Terminology is controversial, many lean towards the term 'variable' others toward 'intermittent'. Neither term is perfect; the outputs of thermal plant are variable too, and can be intermittent, e.g. during faults. There are no unambiguous terms to capture the difference between renewable and conventional plants, except perhaps exogenously variable (e.g. wind) and controlled-variable (e.g. gas), which would be ungainly. So we have, despite its flaws, stayed with the much used term 'intermittent'.

Impacts on reliability of electricity systems

8. None of the 200+ studies reviewed suggest that introducing significant levels of intermittent renewable energy generation on to the British electricity system must lead to reduced reliability of electricity supply[2]. Many of the studies consider intermittent generation of up to 20% of electricity demand, some considerably more. It is clear that intermittent generation need not compromise electricity system reliability at any level of penetration foreseeable in Britain over the next 20 years, although it may increase costs. In the longer term much larger penetrations may also be feasible given appropriate changes to electricity networks, but this report does not explore the evidence on this topic.

9. The introduction of significant amounts of intermittent generation will affect the way the electricity system operates. There are two main categories of impact and associated cost. The first, so called system balancing impacts, relates to the relatively rapid short term adjustments needed to manage fluctuations over the time period from minutes to hours. The second, which is termed here 'reliability impacts', relates to the extent to which we can be confident that sufficient generation will be available to meet peak demands. No electricity system can be 100% reliable, since there will always be a small chance of major failures in power stations or transmission lines when demands are high. Intermittent generation introduces additional uncertainties, and the effect of these can be quantified.

System balancing impacts

10. The vast bulk of electricity in Britain is supplied through market arrangements comprising bilateral contracts of varying durations between generators and suppliers (wholesalers of electricity). However relatively small, but crucial, adjustments are needed to ensure demand and supply balance each instant. These are made by the system operator, the company with a statutory duty to ensure that electricity supply continuously meets demand. The system operator balances the system by purchasing services from generators or adjustable loads. To ensure these services are available in the timescales required, the system operator enters into contracts for system balancing reserves.

11. System balancing entails costs which are passed on to electricity consumers. Intermittent generation adds to these costs. For penetrations of intermittent renewables up to 20% of electricity supply, additional system balancing reserves due to short term (hourly) fluctuations in wind generation amount to about 5-10% of installed wind capacity. Globally, most studies estimate that the associated costs are less than £5/MWh of intermittent output, in some cases substantially less. The range in UK relevant studies is £2 - £3/MWh.

System reliability impacts and additional system capacity requirements

12. To maintain reliability of supplies in an electricity system, peak demand must not exceed the production capability of the installed generation at that moment. Historically central planners sought to ensure that installed generation capacity could meet forecast peak demand within a planning horizon. In liberalised markets, individual market participants are responsible only for ensuring adequate generation capacity is available to meet their own contracts to supply electricity. In either case, a system margin can be measured which is the amount by which the total installed capacity of all the generating plant on the system exceeds the anticipated peak demand.

13. Unless there is a large amount of responsive or controllable demand, a system margin is needed to cope with unavailability of installed generation and fluctuations in electricity requirements (e.g. due to the weather). Conventional plant – coal, gas, nuclear – cannot be completely relied upon to generate electricity at times of peak demand as there is, very approximately, a one-in-ten chance that unexpected failures (or "forced outages") in power plant or electricity transmission networks will cause any individual conventional generating unit not to be available to generate power. Even with a system margin, there is no absolute guarantee in any electricity system that all demands can be met at all times.

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[2]Reliability is generally assessed by the indicators such as 'loss of load probability'. Potential limitations of such measures are discussed below and in the main report.

14. The risk of demand being unmet can be characterised statistically, and the measure commonly used to quantify this risk is called Loss of Load Probability (LOLP). This measures the likelihood that any load (demand) is not met, and it is usually a requirement of electricity systems that LOLP is kept small[3].

15. Intermittent generation increases the size of the system margin required to maintain a given level of reliability. This is because the variability in output of intermittent generators means they are less likely to be generating at full power at times of peak demand. The system margin needed to achieve a desired level of reliability depends on many complex factors but may be explored by statistical calculations or simplified models. Intermittent generation introduces new factors into the calculations and changes some of the numbers, but it does not change the fundamental principles on which such calculations are based.

16. Intermittent generators can make a contribution to system reliability, provided there is some probability of output during peak periods. They may be generating power when conventional stations experience forced outages and their output may be independent of fluctuations in energy demand. These factors can be taken into account when the relationship between system margin and reliability is calculated using statistical principles.

17. There is some debate over the extent to which existing measures of reliability, particularly LOLP, fully capture the changes that arise when intermittent sources are added to the network. This is because intermittent generation changes the nature of the unreliability that may arise (for example, increasing the number of occasions in which relatively small curtailments of demand may be required). These aspects may be represented by using different statistics to calculate risk, in addition to a simple LOLP.

18. *Capacity credit* is a measure of the contribution that intermittent generation can make to reliability. It is usually expressed as a percentage of the installed capacity of the intermittent generators. There is a range of estimates for capacity credits in the literature and the reasons for there being a range are well understood. The range of findings relevant to British conditions is approximately 20 – 30% of installed capacity when up to 20% of electricity is sourced from intermittent supplies (usually assumed to be wind power). Capacity credit as a percentage of installed intermittent capacity declines as the share of electricity supplied by intermittent sources increases.

19. The capacity credit for intermittent generation, the additional conventional capacity required to maintain a given level of reliability and thus the overall system margin are all related to each other. The smaller the capacity credit, the more capacity needed to maintain reliability, hence the larger the system margin. The amount by which the system margin must rise in order to maintain reliability has been described in some studies as "standby capacity", "back-up capacity" or the "system reserves". But there is no need to provide *dedicated* "back-up" capacity to support individual generators. These terms have meaning only at the system level.

Costs of maintaining reliability

20. The additional capacity to maintain reliability entails costs over and above the direct cost of generating electricity from intermittent sources. There has been some controversy over how to estimate the costs associated with the additional thermal capacity required to maintain reliability. In part this reflects the fact that under current market arrangements there is no single body with responsibility to purchase system margin. This is one reason why costs are less transparent than they are for system balancing services. Some studies have assessed the costs of the capacity required to maintain reliability based on assumptions about the nature of plant providing 'system reserves'. Others have assessed only the change in the total costs of the electricity system as a whole[4]. There is broad agreement between both approaches on the total change to system costs.

[3]e.g. the LOLP of the pre-privatised electricity system in Great Britain was planned not to exceed 9% - nine winters per century.

[4]The change in total system cost can be characterised as the cost of building and operating intermittent plant, ***minus*** the cost associated with displaced fuel use, ***minus*** the costs of thermal plant that can be displaced (or new investment avoided) because of the capacity credit of the intermittent plant.

21. We have identified the need for an agreed definition for reporting the 'system reliability costs of intermittency'. We suggest that this be based on the difference between the contribution to reliability made by intermittent generation plant and the contribution to reliability made by conventional generation plant. This comparison should be drawn between plants that provide the same amount of energy when operated at maximum utilisation. This provides a measure of the cost of maintaining system reliability and is in addition to the direct costs of intermittent plant. In the main text and Annex 2, we explore this relationship in depth and show that it can be expressed as follows: System reliability cost = fixed cost of energy-equivalent thermal plant (e.g. CCGT) minus avoided fixed cost of thermal plant (e.g. CCGT) displaced by the capacity credit of intermittent plant (e.g. wind). It should be noted that all forms of generation have the potential to impact on system costs, and this is an important topic for ongoing and future research[5].

22. The comparison with conventional generating plant at maximum utilisation (i.e. on 'baseload') is crucial to this calculation. Policymakers and others often seek to compare the average costs of different types of generating plant on a 'like with like' basis. For example, they may wish to compare the cost of wind power with the cost of coal power. This comparison uses levelised costs (£/MWh) that assume that plants are operating at maximum utilisation. If intermittency costs are calculated in any other way there is a danger that comparisons of this nature will not be meaningful[6].

23. Using the definition set out in paragraph 21, the cost to maintain system reliability lies within the range £3 - £5/MWh under British conditions. Again, relative to a comparitor plant operated at maximum utilisation. Impacts can also be expressed in MW terms; additional conventional capacity to maintain system reliability during demand peaks amounts to around 15% to 22% of installed intermittent capacity.

24. This assumes around 20% of electricity is supplied by well dispersed wind power. Current costs are much lower; indeed there is little or no impact on reliability at existing levels of wind power penetration. The cost of maintaining reliability will increase as the market share of intermittent generation rises.

Comparing different electricity systems

25. It is tempting to read across the results of studies on intermittency costs from one country to another, or from one system to another. This can be another source of controversy. The greatest care must be taken in trying to make such comparisons. The impacts and costs of intermittent generation can be assessed only in the context of the particular type of system in which they are embedded. The impacts depend on:

- The quality of the environmental resource on which renewable generation depends, for example the strength of the wind and the degree to which it fluctuates.

- The robustness of the electricity grid and the capacity to transfer power from generators to consumers.

- Regulatory and operating practices, in particular how far ahead the use of system balancing reserve is planned (known as 'gate closure'). The closer to real time reserves are committed, the more reliable will be forecasts of intermittent generation, which can reduce the need for more expensive fast-acting reserve.

- Accuracy of forecasting of intermittent output. Better forecasting can improve the efficiency with which intermittency is managed, both by the system operator after gate closure and by markets over longer timescales. Weather patterns in some regions are more predictable than in others.

- The extent to which intermittent generators are geographically dispersed or are located in a particular area. If wind generators are located close together their output will tend to fluctuate up and down at the same time, increasing variability of the total output and increasing the costs of both system balancing and maintaining reliability.

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[5]Variable/operating costs cancel, which is why the expression is concerned only with capital costs.

[6]Studies that do assume 'dedicated' back up is needed, and neglect the comparator plant described in points 21 & 22, give rise to much higher costs.

26. Some conditions in Britain (quality of wind resource, robustness of the grid, relatively late gate closure) will tend to mitigate the impacts of intermittency and keep associated costs relatively low. Others (notably the relative lack of interconnection and relatively small geographical area over which resources are dispersed) will tend to increase the costs of managing the system relative to other regions. Comparisons between Britain and other countries must be treated with the greatest of caution.

Intermittency costs in Britain

27. The aggregate 'costs of intermittency' are made up of additional short-run balancing costs and the additional longer term costs associated with maintaining reliability via an adequate system margin. Intermittency costs in Britain are of the order of £5 to £8/MWh, made up of £2 to £3/MWh from short-run balancing costs and £3 to £5/MWh from the cost of maintaining a higher system margin. For comparison, the direct costs of wind generation would typically be approximately £30 to £55/MWh. If shared between all consumers the impact of intermittency on electricity prices would be of the order 0.1 to 0.15 p/kWh.

28. These estimates assume that intermittent generation is primarily wind, that it is geographically widespread, and that it accounts for no more than about 20% of electricity supply. At current penetration levels costs are much lower, since the costs of intermittency rise as penetrations increase. If intermittent generation were clustered geographically, or if the market share were to rise above 20%, intermittency costs would rise above these estimates, and/or more radical changes would be needed in order to accommodate renewables.

Recommendations for reporting the costs of intermittency

29. When reporting the costs associated with intermittent electricity generation, we recommend that:

a) there be a clear statement of which costs are included and those which are excluded, i.e. short-run balancing costs versus long-run capacity requirements;

b) there be a clear statement of the methodological basis for calculating intermittency impacts;

c) when comparing the costs of intermittent sources versus baseload conventional generation the method described in paragraph 21 be used;

d) that the context of the system into which intermittent generation is being embedded be clearly described.

Recommendations for UK-relevant research and policy

30. We recommend that additional steps are put in place to continuously monitor the effect of intermittent generation on system margin and existing measures of reliability. The effectiveness of market mechanisms in delivering adequate system margin also needs to be kept under review.

31. Intermittent generation can make a valuable contribution to energy supplies, but to ensure reliability of supply, additional investment in thermal capacity is also required. In the short run older plant is likely to provide system margin but, in the long run, investment in new capacity will be needed. Flexible and reliable generation is an ideal complement to intermittent renewables. Policy should encourage and not impede investment in plant that is well suited to complement renewable energy sources and contribute to both reliable operation and efficient system balancing.

32. We recommend that more research be undertaken on the following topics:

- Renewable energy deployment scenarios in which intermittent generation is clustered in particular regions of the UK, including the system impacts of very large offshore wind farms.

- Measures of reliability appropriate to intermittent sources. In particular the merits of, and options for, going beyond 'loss of load probability', (LOLP) in characterising the reliability of an electricity system at high levels of intermittent generation. LOLP measures the likelihood of a capacity shortfall rather than its severity.

- Using these improved measures of reliability, there is a need for on-going monitoring of the British market to assess how actual market response (i.e. decisions to invest in new generation or maintain existing generation in-service) compare to those that would be consistent with the improved reliability measures.

- The definition of an agreed convention for reporting the costs associated with maintaining system reliability.

- Further work on the development of methodologies for assessing the system cost implications of new generating technologies (intermittent or otherwise), in terms of the impacts on the utilisation of incumbent generation.

- The extent to which intervention may be needed to ensure that adequate investment in appropriate thermal plant to maintain reliability is delivered, and the policy options available to do so.

- The implications of different combinations of thermal plant on the costs and impacts of integrating renewable energy in the short to medium term. In particular, the relative impacts of different sizes and types of thermal generation, and of inflexible versus flexible plant, on efficiency of system operation and integration of wind and other renewables.

- Options for managing the additional power fluctuations on the system due to intermittency – including new supply technologies, the role of load management, energy storage etc. Opportunities and challenges for re-optimisation of the electricity system in the long term to cope with intermittent generation, including research on much higher penetrations of renewable sources than the relatively modest levels considered in this report.