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WIND POWER AND INTERMITTENCY

Paper providing an overview of wind power development and the issue of intermittency. The economics of wind power development and the technology's carbon balance are also considered

EXECUTIVE SUMMARY

Generating energy from the wind is one of the best developed renewable energies currently available. The technology takes the form of onshore and offshore wind farms, with the onshore variety being more prevalent.

Wind power produces no carbon during electricity generation. The UK Government suggests onshore wind could produce up to 80% of current CO_2 electricity demand, they suggest offshore wind farms could produce up to ten times this amount. More conservative estimates suggest both technologies could provide 40% of current needs.

The world's wind power capacity reached 93,864 megawatts (MW) in 2007. Germany currently has the largest levels of penetration on a global scale, accounting for 23.7% of the world's total installed capacity.

As of June 2008 Northern Ireland was home to 32 wind farms, housing a total 268 individual turbines (of varying capacity) with a combined generating capacity of 405.8MWs. By the same date, the Planning service had received applications for a further 1204MWs of capacity.

Wind, as a power source, is inherently variable; fluctuations in wind speed ensure the technology can only generate electricity in favourable conditions – too little or too much wind prevents generation. Other factors, including turbine location, may constrain a wind farms generation capacity.

To account for this calculations of wind farm total yearly generation potential include a load factor - actual power produced, expressed as a percentage of a system's theoretical capacity. Northern Ireland's load factor is 32.5%, the most favourable in the UK. This means Northern Ireland's wind farms are likely to produce just over a third of the energy they could potentially generate if they ran at full capacity. Coal fired and nuclear generators have a load factor of between 65 and 85%, whereas a combined cycle gas turbine's load factor is 70-85%.

Wind energy has a capacity credit, a figure equivalent to the amount of conventional energy generation it can reliably replace. The British Wind Energy Association and their European counterparts place this figure at 25%, whilst German utility company EON Netz (leading figures in German wind farm development) suggest a figure of just 8%.

The UK Parliament, Economic Affairs Committee concludes:

- Increasing (all) renewables penetration to 40% by 2020 would require conventional energy reserves of between 7-10GW to ensure system security. This would increase the yearly cost of maintaining a reserve by between £500m and £1bn. They add that reserve increase will not affect CO_2 reductions from occurring.

- The scheduled closure of conventional and nuclear power stations in coming years will necessitate the construction of 20-25GWs of generating capacity, in a scenario where like is replaced with like;

- Incorporating 30 GW of additional renewable capacity into the grid, to meet the EU's 2020 target, will require a further 14-19 GW of new fossil fuel and nuclear capacity to replace plants due to close and to meet new demand – almost doubling the total new installed electricity generating capacity required by 2020, compared to a scenario where renewable generation was not expanded.

- Technological solutions are required to alleviate the problem of intermittency;

- Cost-effective energy storage could solve the problem of intermittency, although no viable solution is imminent.

In 2006, the UK Energy Research Centre (UKERC) conducted a systematic review of intermittency literature. They found that, with renewables penetration of 20% or below, *intermittent generation need not compromise electricity*. The group noted two costs of intermittent energy source use: system balancing cost; and system reliability cost. According to the UKERC, system balancing is likely to cost GB £2-£3/MWh of intermittent output, whereas, system reliability cost was estimated to be £3-£5/MWh of intermittent output. The total cost of intermittency, therefore, is estimated at £5-£8/Mwh, assuming 20% penetration is reached.

Such cost must be measured against potential fossil fuel and other variable cost savings which may arise from the introduction of renewable energy.

Due to a significant increase in the renewables energy penetration target in 2008 (from 20% to 40%, with wind accounting for 28.5%) UKERC have revised their conclusions. The group now argue that intermittency will be more problematic as: capacity credits will decrease; load factors may halve; system balancing needs will increase; fossil fuel plant operation will be negatively affected; transmission constraints will become more significant; and *spilling/curtailment* will become more likely.

The group remain optimistic that with the right policy and technology response these issues may be averted.

Energy storage may hold the key to wind power expansion. However, at the current level of technological development, no appropriate solution exists. An innovative system, which will use wind energy to power a large scale electric car network, will begin testing in Denmark during 2010. The system will utilise the car batteries as storage and will allow for energy to be fed back into the grid when necessitated by demand. This could provide a solution to Denmark’s wind energy problems and allow them to fully utilise electricity currently exported to neighbouring countries.

The European Wind Energy Agency provides the following breakdown of the cost of installing a single commercial-scale wind turbine onshore (at 2001 prices):

- Investment cost of 900-1,100 €/KW;
- An O&M cost of 1.2c€/KW;
- A discount rate of 5-10% per year;
- Electricity production rates of 6-8 c€/KW at low speeds and 4-5 c€/KW at higher speeds.

They add that the costs associated with the construction of a similar turbine offshore would beapproximately 50% higher.

At present a number of support mechanisms are available for wind farm developers in the UK, these include:

- Renewables Obligation Certificates (ROCs);
- Levy Exemption Certificates (LECs);
- Renewable Energy Guarantee of Origin (REGOs); and
- The EU Emissions Trading Scheme (ETS)

Wind farms currently employ around 102,100 people throughout the EU, approximately 4,000 in the UK and 1,500 in the Republic of Ireland. Skill shortages exist inthe following areas:

- Research and Development;
- Operation and Maintenance;
- Projects managers;
- Professionals responsible for securing building permits;
- Financiers; and
- Sales managers.

Wind farms are not entirely carbon neutral, producing certain amounts of green house gas during their lifecycle, particularly during the manufacturing and construction. It is, however, expected that technology's carbon payback periods will be relatively short. Tests carried out by turbine manufacturer Vestas concluded that clean energy generation would offset any carbon footprint within 3 – 6 months of operation, depending upon the specific turbine model installed.

CONTENTS

1.0 INTRODUCTION

Generating electricity from the wind is one of the best-developed forms of renewable energy currently available. The benefits of the technology are summed up by Friends of the Earth, as follows:

> *"Wind power relies on relatively simple mechanical processes, once built the running costs are very low, and it has benefited from recent technological advances in the aeronautics industry. The fuel is free and inexhaustible and there are no waste products. This means it can compete with the cost energy based on conventional fossil fuels. And as oil and gas prices continue to rise, wind power can only become more competitive".*[i]

Current commercial wind turbine technology takes the form of onshore and offshore wind farms. Both systems work on the same basic principle; turbines capture the energy from the wind using propeller blades connected to a rotor. The force of the wind is converted into mechanical force, turning the blades which turn the rotor. The rotor itself is connected to an electricity generator, via a gearbox. The electricity produced by large-scale multi-megawatt commercial systems can then be entered into the grid.[ii]

The major difference between onshore and offshore wind farms is the scale of the latter. Offshore farms encounter fewer geographical limitations (estimates suggest that providing 10% of the UK's energy from wind would require the setting aside of 1% of the regions land base)[iii] and can therefore be much larger systems. Offshore farms also benefit from stronger, more consistent winds. They are, however, more expensive and more technologically challenging undertakings.[iv]

The prevalent arguments in favour of wind farm deployment highlight the technologies' carbon neutrality. During operation wind farms produce few CO_2 emissions. Some emissions *are* produced during the design, manufacture, transportation and construction of wind farms, but this is balanced by CO_2 free electricity (see section on life-cycle analysis for further details). The UK Government suggests onshore wind could produce up to 80% of current CO_2 electricity demand, they suggest offshore wind farms could produce up to ten times this amount. More conservative estimates suggest both technologies could provide 40% of current needs.[v]

2.0 CURRENT AND FUTURE CAPACITY

In 2007 the total global installed wind power capacity reached 93,864 megawatts (MW). Germany was the world leader with 22,247MWs (23.7% of global capacity) of installed capacity, followed by the US (16,818MWs, or 17.9% of the global capacity). In the same year, the UK's total installed capacity was significantly lower than the global leaders, at 2,389MWs. Global estimates predict a155% growth in total installed capacity by 2012. If this was to come to pass the total global generation capacity would reach 240,000MWs.[vi]

As of June 2008 Northern Ireland was home to 32 wind farms, housing a total 268 individual turbines (of varying capacity) with a combined generating capacity of

405.8MWs. At the same juncture the Planning Service had received applications for a further 48 wind farm developments, which could potentially add a further 1204MWs to the regions total generating capacity. If all proposed applications were built to the specifications submitted Northern Ireland's total generating capacity would reach 1609.8MWs.[vii]

3.0 INTERMITTENCY

Intermittency complicates the task of calculating actual levels of electricity produced by specific generating capacities in a given time. Wind, as a power source, is inherently variable, fluctuations in wind speed ensure the technology can only generate electricity in favourable conditions – if there is too little, or too much wind, a turbine will not generate electricity. This problem is not unique to wind generation; it is common to a number of renewable energy sources.[viii]

The problems resulting from the wind's natural fluctuations may be enhanced, to a greater or lesser extent, by the placement of the wind farm. A number of factors enter into wind turbine siting decisions; the roughness of the land; obstacles (both upstream and downstream); the proximity of each turbine to the next and the arrangement of turbines in a farm (as the wind passes through a turbine a wake effect is created affecting the speed of the wind coming out the other end); and turbulence.[ix]

The combination of intermittency and turbine siting are responsible for the difference in theoretical and actual wind farm output. Figures for yearly electricity generation are often quoted in megawatt hours (MWH). To calculate the yearly MWH of a particular wind farm or a specific region's wind power capacity it is necessary to multiply the capacity figure by the number of hours in a year (8,760). Therefore, Northern Ireland's current installed capacity yields a theoretical yearly output of 3,554,808MWH.

To calculate the likely actual output, however, it is necessary to factor in the issues outlined above. This requires the inclusion of what is known as a *load factor.* The load factor is actual power produced, expressed as a percentage of a system's theoretical capacity. Northern Ireland's load factor is considered to be 32.5%. This means the actual yearly electricity output of the region's installed capacity is approximately 1,155,313MWH (total capacity x 8,760 x 0.325). Northern Ireland's load factor compares favourably with the rest of the UK. Average load factors for the remaining regions are: Scotland, 28.4%; Wales 25.3%; and England 23.3%.[x] Comparisons of wind energy's load factor to that of other electricity generation technologies demonstrate less favourable results. Figures provided by the British Wind Energy Association (BWEA) rate wind energy as the second lowest in terms of load factor. The complete BWEA list is as follows:[xi]

1. Sewage Gas - 90%
2. Farmyard Waste - 90%
3. Energy Crops - 85%
4. Landfill Gas - 70-90%
5. Combined Cycle Gas Turbine (CCGT) - 70-85%
6. Waste Combustion - 60-90%
7. Coal - 65-85%

8. Nuclear Power - 65-85%
9. Hydro - 30-50%
10. Wind Energy - 25-40%
11. Wave Power 25%

BWEA argue that wind power's capacity credit should be considered in conjunction with its load factor. Capacity credit is a measure of theconventional generation capacity wind power can replace, without affecting the security of the overall system.

According to "Wind Energy – The Facts", a publication compiled by *leading* industry experts and coordinated by the European Wind Energy Association, wind energy's typical capacity credit is 25%[xii], or *"about the same as the installed capacity multiplied by the load".* The implication here is that by having capacity credit, wind energy is, despite its inherent fluctuations, reliable. Wind power's capacity credit, however, decreases as the technology becomes more prevalent. It is believed that this trend will not become problematic until wind power exceeds 20% penetration.[xiii]

EON Nets, the utility firm central to Germany's wind power development, has carried out extensive research into the practical difficulties raised by intermittency. Such research has led to the conclusion that:

"Wind energy is only able to replace traditional power stations to a limited extent"

The company's 2005 wind energy report, produced at a time when Germany was home to one third of world's and half of Europe's installed wind power capacity, found that the relative contribution of wind energy to the guaranteed capacity of the supply system (its capacity credit) was 8%. In addition they estimated, as wind power penetration increased this contribution would decrease to an estimated 4% by 2020. In real terms the predicted 48,000MWs of wind energy to be installed by 2020 would only replace 2,000MWs of traditional generation.[xiv]

In 2008 the UK Parliament Economic Affairs Committee published a detailed overview of intermittency, from a UK context, as part of their report on the Economics of Renewable Energy. The report put forward the following findings:[xv]

- Increasing renewables penetration to the Government's 40% target by 2020 would necessitate increasing the reserve of traditional power plants by about 7 – 10 gigawatts (GW)[xvi]. This will in turn increase balancing costs, currently £300m per year, by between £500m and £1bn per year.

- Increasing the reserve capacity of traditional power stations will have no significant impact on the CO_2 benefits associated with wind power;

- Currently, 20% of reserve capacity is required to ensure the system as a whole can accommodate peak demand. Traditional power plants have a 5% chance of being unavailable to meet peak demand. The chances of wind farms being unavailable are significantly higher;

- The scheduled closure of conventional and nuclear power stations in coming years will necessitate the construction of 20-25GWs of generating capacity, in a scenario where like is replaced with like;

- Incorporating 30 GW of additional renewable capacity into the grid, to meet the EU's 2020 target, will require a further 14-19 GW of new fossil fuel and nuclear capacity to replace plants due to close and to meet new demand – almost doubling the total new installed electricity generating capacity required by 2020, compared to a scenario where renewable generation was not expanded.

- Technological solutions are required to alleviate the problem of intermittency;

- Cost-effective energy storage could solve the problem of intermittency, although no viable solution is imminent.

3.1 ADDITIONAL COSTS OF WIND ENERGY INTERMITTENCY

In 2006 the UK Energy Research Centre (UKERC) conducted a systematic analysis of over 200 international studies on the subject of wind energy intermittency, applying their findings to energy systems in Great Britain. Central to their analysis was the assumption that intermittent renewables would not exceed 20% penetration in the UK over the next 20 years.

The UKERC's overarching conclusion was:

> "*It is clear that intermittent generation need not compromise electricity at any level of penetration foreseeable in Britain over the next 20 years, although it may increase costs.*"[xvii]

To this the group added:

> *"In the longer term much larger penetrations may also be feasible given appropriate changes to electricity networks…"*[xviii]

The report identifies two categories of impact and associated cost: system balancing impacts; and system reliability impacts. System balancing refers to the need to adjust the electricity system to ensure demand is met consistently. Electricity reserves are utilized to maintain a balanced system. Balancing occurs in electriricty systems based on conventional generation technology. The introduction of intermittent renewables, however, adds to the cost of balancing (costs which are passed onto the end consumer). According to the UKERC, system balancing is likely to cost GB £2-£3/MWh of intermittent output.[xix]

The report also found that integrating renewable energy into the system *"entails costs over and above the direct cost of generating electricity from intermittent sources".*[xx] In conventional generation systems an amount of reserve capacity is held back to be used when anticipated peak demand is exceeded or during unexpected failures. Intermittent generation increases the size of the required reserve capacity.

Intermittent renewable energy has a capacity credit of between 20-30% of total installed capacity (both renewable and conventional) meaning it could theoretically, reliably replace this amount of conventional generating capacity. UKERC therefore define the *"system reliability cost of intermittency"* as *"the difference between the contribution to reliability made by intermittent generation plant[s] and the contribution to reliability made by conventional plant[s]".* Based upon this calculation the report puts forward a figure of £3-£5/MWh to account for the additional reserve capacity necessitated by intermittent integration.[xxi]

The total cost of intermittency therefore, according to UKERC, is in the region of £5-£8/Mwh, assuming 20% penetration is reached. How this intermittency cost figures into the wider cost/benefit assessment of wind energy is difficult to quantify as it is largely context specific. Such cost must be measured against potential fossil fuel and other variable cost savings which may arise from the introduction of renewable energy. The UKERC report states therefore:

> *"Quantification of the cost of intermittency requires a comparison of the capital, operating and fuel costs of a system* ***with*** *a new intermittent generation against a credible counterfactual scenario* ***without*** *intermittent plant[s]. Both scenarios must provide the same level of energy, power quality and reliability".*[xxii]
> (Emphasis in original)

Such an assessment is beyond the scope of this paper.

The findings of the UKERC analysis are applicable to a scenario where intermittent renewable penetration does not exceed 20%. Subsequent changes to EU, and as a consequence UK, renewables targets have raised the bar to 40% penetration, with wind energy potentially accounting for 28.5% of total installed capacity. This has led the research group to alter their conclusions as follows:

- The capacity credit of wind energy decreases as total installed capacity increases, in other words *"a lot of capacity gets used a lot less";*
- System load factors may halve (Northern Ireland's load factor is currently 35%);
- System balancing needs increase.

In addition, the researchers predict that previously thought *"negligible impacts become significant",* namely:

- Fossil fuel plant operation will likely be affected (through increased reserve requirement) reducing efficiency, increasing wear and tear, and affecting economics;
- The potential for *"spilling"/"curtailment"* is likely to become significant as intermittent renewables become more prevalent; and
- Transmission constraints will become more apparent. [xxiii]

Whilst all of the above seem likely outcomes to increased intermittent renewable penetration (beyond 20%), the actual extent of their impact remains difficult to quantify.

This is because renewable penetration of this scale is unprecedented and because very few studies examining penetration beyond 25% exist.[xxiv]

There are, however, some perceived solutions. According to UKERC, these may take the form of:

- smart Networks and responsive loads;
- smart meters and responsive customers/appliances;
- policy support for back up and storage plants;
- interconnection upgrades; and
- diversification of the renewables portfolio.

UKERC conclude that new goals create new problems. The 40% target requires not only substantial and rapid technological development (in terms of both scale and type) but also an equally urgent advancement in policy change.[xxv]

4.0 ENERGY STORAGE

Energy storage is cited as a possible solution to the problems caused by intermittency as it would allow electricity generated from renewable sources at off-peak times to be stored for use during on-peak times (this is especially significant when off-peak periods coincide with periods of high wind). Beyond acting as an electricity reserve, energy storage has a number of other perceived benefits, it could serve to: stabilise the electricity market (particularly the differences in generation cost off and on peak); stabilise the energy grid; introduce new market opportunities; and enable efficient use of conventional generation technology.[xxvi]

A number of energy storage systems currently exist, including electrochemical batteries, supercapitors, flow batteries, flywheels (kinetic energy storage)[xxvii] and geological storage technologies. The suitability of each remains the subject of debate amongst stakeholders.[xxviii] One of the key issues in this debate centres upon a fundamental energy storage principle – energy versus power. In the context of short term wind fluctuations energy storage systems will be required to deliver at high power levels to balance the system. Conversely, during a period of extended calm conditions, a device which stores large amounts of energy that can discharge that energy in a sustained manner is preferable. None of the technologies currently available have been able to achieve both high power delivery and large energy storage.

Other factors come into play as well, namely the cost of available technologies and their efficiency.[xxix] The capital cost of large storage units remains high and as a result they have a pay-back period of many years. The efficiency rating of energy storage technologies ranges from 50 – 80%, depending on the specific system employed.[xxx]

Despite energy storage's limitations, it is promoted in both academic and governmental discourse as being *"very much the key to unlocking the door of renewable energy".*[xxxi] This is attested to by the number of innovative solutions currently being proposed or in the early stages of research and development.

One such innovation has been proposed in Denmark. The Danish wind system currently *"covers almost 20% of the Danish power consumption",* but it is recognised within the industry that *"only a limited amount the potential energy is utilised".*[xxxii] In addition to generating energy form the wind for domestic use, Denmark's proximity to and interconnection with neighbouring countries, allows energy to be exported. In 2003, Eltra, a transmission company operating in western Denmark, reported an export figure of 84% to neighbours Norway, Sweden and Germany. It is argued that Denmark is unable to absorb the large generation into its domestic system.[xxxiii] While these exports are profitable, earning €4.7bn in 2007[xxxiv], Denmark is searching for a way to retain and utilise more of its generation domestically.

A novel solution has been proposed, which, if successful, would integrate wind power and renewable transport. The solution is Project Better Place, an electric car infrastructure. The infrastructure will incorporate charging points and battery swapping stations. Users will plan their journeys around charging points using customised GPS software. The points will are to be situated to ensure the cars will always have 100 miles of driving capacity. For longer journeys battery swaps will be utilised. The end user will pay for the service in away similar to mobile phone contracts; users pay for a mileage contract appropriate to their travel needs.[xxxv]

The system will be launched in Denmark and Israel in the next few years (it is most suitable for smaller regions). The Danish model, however, will be unique as it will add value by attempting to solve the region's wind power problem. An agreement between Project Better Place and Danish energy company DONG will allow the latter to store its excess energy into the recharge grid, allowing the zero-emission cars to have a reliable source of renewable power and reducing the cost of energy storage for DONG.[xxxvi] The system will also allow electricity stored in batteries to be fed back into the grid to meet demand spikes.[xxxvii] Sales of the electric cars are expected to begin in 2011, following tests in 2010.[xxxviii]

5.0 ECONOMICS OF WIND

5.1 COSTS

The British Wind Energy Association (BWEA) states:

> *"Generating energy from the wind makes economic as well as environmental sense, wind is a free, clean and renewable fuel which will never run out."*

The factor underlying wind power economics are: investment costs (including foundations and grid connection); operation and maintenance (O&M); electricity production; turbine lifetime; and discount rates (the interest rate used to calculate the present-day costs of turbine installations).[xxxix]

EWEA cost breakdown (calculated at 2001 prices), for a new onshore medium-sized wind turbine of 850-1,500KW (with an approximate 20 year lifespan), includes:[xl]

- Investment cost of 900-1,100 €/KW;
- An average O&M cost of 1.2c€/KW;
- A discount rate[xli] of 5-10% per year;
- Electricity production rates of 6-8 c€/KW at low speeds and 4-5 c€/KW at higher speeds.

The costs of offshore wind turbines are approximately 50% higher than their onshore counterparts. They do however retain added value due to their exposure to much higher winds and their lower visual impact.

5.2 FINANCING

Throughout Europe wind farm expansion has been financed through a number of mechanisms. The vast majority of existing farms in the EU area have been funded through project finance (a project loan backed by the cash flow of the final product). EWEA states that the predictable nature of a wind farm's future cash flow ensures that they are suited to this form of financing. They suggest too, that with the expansion of wind energy, a number of larger firms have chosen to finance projects through balance sheet funding, although such a method has been largely confined to the construction of wind farms. In addition, a minority of projects have been supported by transactions in the structured finance markets (bond markets, etc).[xlii]

5.3 SUPPORT MECHANISMS

A number of support mechanisms, designed to directly or indirectly encourage the growth of *all* renewable energy sources, are in place in UK, examples of such mechanisms include:

Renewables Obligation Certificates (ROCs) are the most direct support mechanism employed by the UK Government. Generators receive one ROC for every 1MW of renewable energy they produce. ROCs can then be traded; the current price is approximately £20-30 per ROC.[xliii]

Generators receive a **Levy Exemption Certificates (LECs)** for 1MWH of renewable energy produced. Utility companies are required to purchase LECs to offer business customers exemption from the **Climate Change Levy**. Generators are allowed to sell LECs to utility companies at a price agreed between the two.[xliv]

The **Renewable Energy Guarantee of Origin (REGOs)** is awarded to generators for every 1KWH of green energy produced. REGOs have no direct monetary value but do have marketing value in the sense that they provide a certificate of authenticity.[xlv]

The EU Emissions Trading Scheme (ETS) places an extra cost upon carbon emissions. Holders of an ETS allowance can emit one tonne of Co_2, individual generators who exceed this may buy extra permits from companies who have not exceeded their limit. The ETS is therefore favourable to renewable energy producers.[xlvi]

5.4 EMPLOYMENT

Wind energy generation currently employs approximately 102,100 people in the European Union, of these 4,000 are employed in the UK and 1,500 in the Republic of Ireland. Its potential for providing green collar jobs is significant, direct employment amongst world leading countries is substantial: Germany for example employs 38,000 in the wind energy sector; Spain 20,500; and Denmark 17,000. The range of jobs offered within the sector is wide, with high and low skilled opportunities available to workers in the numerous industries which make up the sector: wind energy manufacture; development; construction, operation and maintenance; utilities; and consultancy.[xlvii]

There is also a notable skill shortage within the sector, largely on account of the sector's rapid growth (339% in the EU alone, 2000-2007). The shortages are mostly acutely felt in professions requiring a higher degree of experience and responsibility, namely:

- Research and Development;
- Operation and Maintenance;
- Projects managers;
- Professionals responsible for securing building permits;
- Financiers; and
- Sales managers.[xlviii]

EWEA have stated that the root of the problem does not stem from the quality of the University system, but is attributable to an imbalance between the number of engineers graduating and the needs of modern economies, which are reliant upon manufacturing and technology. They note a lack of quality secondary level education courses dealing with wind-related activities.[xlix]

6.0 LIFE CYCLE ANALYSIS

The lifecycle (approximately 20 years) of conventional wind energy technology consists of five distinct phases:

- **Construction –** comprising raw material production and the manufacture of the various components, foundations and grid connection cable.
- **Onsite erection and assembly –** physical erecting of individual wind turbines.
- **Transport –** includes transportation during the production of raw material, the transport of components to wind farm sites, and transport during operation.
- **Operation –** the maintenance of turbines during their lifetime, including oil changes, lubrication and transport for maintenance.
- **Dismantling –** includes the deconstruction and disposal (recycling) of wind farms at the end of their lifespan.

Of the above, construction is the most carbon intensive phase of a wind farm's lifespan. Tests carried out by turbine manufacturer Vestas concluded that the energy payback period (the length of time taken to offset carbon produced during a turbine's lifespan through carbon free energy production) was 6.8 months for their 3MW and 3.2 months for their 2MW onshore turbines. Offshore payback periods were found to be slightly shorter - 6.6 months for 3MW turbine and 3.1 months for 2MW models.[l]

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[i] Friends of the Earth, *Wind power: your questions answered* (2008) p. 4

[ii] BERR *Onshore/ Offshore Wind: How It Works* http://www.berr.gov.uk/whatwedo/energy/sources/renewables/explained/wind/onshore-offshore/page16091.html (accessed 13/01/09)

[iii] Friends of the Earth, *Wind power: your questions answered* (2008) p. 4

[iv] BERR *Onshore/ Offshore Wind: How It Works* http://www.berr.gov.uk/whatwedo/energy/sources/renewables/explained/wind/onshore-offshore/page16091.html (accessed 13/01/09)

[v] Friends of the Earth, *Wind power: your questions answered* (2008) p. 4

[vi] Global Wind Energy Council *Global wind report 2007*, second edition (May 2008) http://www.gwec.net/fileadmin/documents/test2/gwec-08-update_FINAL.pdf (accessed 13/01/09)

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[viii] The United Kingdom Parliament, Economic Affairs Committee *The Economics of Renewable Energy*, Chapter 4: *Renewables in the electricity system*, (November 2008) http://www.publications.parliament.uk/pa/ld200708/ldselect/ldeconaf/195/19502.htm (accessed 06/01/09)

[ix] Danish Wind Industry Association *Turbine Siting* http://www.windpower.org/en/tour/econ/guide.htm (accessed 05/01/09)

[x] Renewable Energy Foundation Late*st Data Encouraging for All Renewable Sectors* http://www.ref.org.uk/PressDetails/147 (accessed 13/01/09)

[xi] British Wind Energy Association, *Can we rely on the wind?* http://www.bwea.com/energy/rely.html (accessed 13/01/09)

[xii] Wind Energy – The Facts http://www.wind-energy-the-facts.org/en/glossary.html (accessed 13/01/09)

[xiii] British Wind Energy Association, *Can we rely on the wind?* http://www.bwea.com/energy/rely.html (accessed 13/01/09)

[xiv] EON Netz *Wind Report 2005*

[xv] The United Kingdom Parliament, Economic Affairs Committee *The Economics of Renewable Energy*, Chapter 4: *Renewables in the electricity system*, (November 2008) http://www.publications.parliament.uk/pa/ld200708/ldselect/ldeconaf/195/19502.htm (accessed 06/01/09)

[xvi] 1GW equals 1000MWs

[xvii] UKERC *The cost and impacts of intermittency: an assessment of the evidence on the costs and impacts of intermittent generation on the British electricity network* (2006) http://www.ukerc.ac.uk/Downloads/PDF/06/0604Intermittency/0604IntermittencyReport.pdf (accessed 22/01/09)

[xviii] UKERC *The cost and impacts of intermittency: an assessment of the evidence on the costs and impacts of intermittent generation on the British electricity network* (2006) http://www.ukerc.ac.uk/Downloads/PDF/06/0604Intermittency/0604IntermittencyReport.pdf (accessed 22/01/09)

[xix] UKERC *The cost and impacts of intermittency: an assessment of the evidence on the costs and impacts of intermittent generation on the British electricity network* (2006) http://www.ukerc.ac.uk/Downloads/PDF/06/0604Intermittency/0604IntermittencyReport.pdf (accessed 22/01/09)

[xx] UKERC *The cost and impacts of intermittency: an assessment of the evidence on the costs and impacts of intermittent generation on the British electricity network* (2006) http://www.ukerc.ac.uk/Downloads/PDF/06/0604Intermittency/0604IntermittencyReport.pdf (accessed 22/01/09)

[xxi] UKERC *The cost and impacts of intermittency: an assessment of the evidence on the costs and impacts of intermittent generation on the British electricity network* (2006) http://www.ukerc.ac.uk/Downloads/PDF/06/0604Intermittency/0604IntermittencyReport.pdf (accessed 22/01/09)

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