Statement on wind power

by the Energy Committee at the Royal Swedish Academy of Sciences

Wind power provides emission-free electricity and will play an important role in future electricity supply. Like hydropower it converts a medium's mechanical motion directly to electricity. There are, however, limitations connected with its intermittency, i.e. the variations with time of the electricity produced from a wind power plant. One main question is therefore how electricity systems are influenced by, and can be adapted to, a fast and large increase of wind power in the total electricity mix. How can the transmission grid receive the energy generated and what infrastructure expansions are required for the distribution of the electricity from wind to the users? How will the wind energy's intermittency be balanced in the best way with reserve power?

In the long-term future, power balancing must be made with non-fossil energy sources, and hydropower may be particularly important in this role. Large scale storage of the energy generated from wind and demand management are important issues, as well as the optimum geographic location of new wind power stations for improving efficiency.

The Energy committee arranged a workshop on the pros and cons of wind energy in Stockholm on 12 February 2009. This workshop was primarily focused on the Swedish situation. Additional information was obtained from the workshop on power grids at IVA (The Royal Swedish Academy of Engineering Sciences) in Stockholm on 4 February 2009, from the symposium on Wind Energy on 13–14 October arranged by the European Physical Society in Greifswald, Germany, and from the symposium Energy 2050 arranged by the Royal Swedish Academy of Sciences in Stockholm on 19–20 October 2009.

The result of the Energy Committee's analysis of wind power is summarized in the following points.

1. Wind power installation is increasing rapidly in the world

Wind power installation is increasing rapidly in the world, mainly in North America, Europe and Asia. During 2008 it increased by 29% to reach 120 GW installed power according to the Global Wind Energy Council (GWEC) which estimated that the installed power will increase to 332 GW during the next three years (until 2013). The highest amount of installed wind power is to be found in the USA (25 GW), followed by Germany (24 GW), Spain (17 GW), China (12 GW) and India (9 GW).

Wind energy is often characterized by installed power (GW) rather than by the amount of electricity produced (GWh or TWh). The installed power expresses the maximum capacity at optimum conditions of the wind power plant, while electricity produced under the prevailing conditions for the wind power plants is more relevant for the users and for energy system planning. The current totally installed power of 120 GW gives rise to a total annual electricity production of 260 TWh, i.e. 1.3% of the global electricity production.

2. Wind power is intermittent

On an annual basis it is generally estimated that a wind power plant produces and delivers energy that corresponds to its maximum capacity only during part of the 8,760 hours in a year. The actually produced energy is quantified by the installed power multiplied by the year's hours (8,760) and a capacity factor. The capacity factor is the ratio of the actual energy produced in a given period, to the hypothetical maximum possible, i.e. running full time at rated power [1].

Statistics of wind energy around the world show that this capacity factor on average is 23%, which corresponds to 2000 maximum-capacity hours in a year. Ireland has one of the highest European capacity factors, 32.5%, compared with the English average of 23.3% and the German average of less than 20%. There are some places in the world, for example in southern South America, where capacity factors of well above 50% may be reached [2]. The expected capacity factor for the North Sea is expected to reach 45% (4,000 hours).

3. Wind power has to be replaced by back-up power when wind conditions are unfavourable

Production of electricity currently takes place with base power sources (for example nuclear-, hydro-, bio-, coal-, gas- and oil power), and intermittent power sources (solar and wind power, along with wave power that is currently being developed). If wind power is part of a larger energy system, the wind power intermittency leads to a need for quick replacement of power (termed back-up) when the wind is too weak or too strong [3]. In some countries which have relatively large amounts of wind-based electricity production (such as Denmark and Germany), a significant portion of the base-power production is generated by coal power plants, which are also used as back-up for wind power. Gas power, as used for example in Ireland, is first-rate among fossil-based sources for this back-up function.

Wind power does not replace the electricity generating capacity of fossil power sources on a one-to-one basis. If used also for balancing wind power, the fossil-fuel plants must be adjusted more frequently to cope with the fluctuations which result in reduced efficiency. In countries with a large supply of hydropower, like Sweden, the hydropower plants will be used as back-up for wind power in addition to supplying base electricity. Similarly to the situation for fossil-fuel plants, the need to also balance wind power, affects the hydropower base electricity supply in a negative way. The hydropower capacity for both wind-power back-up and base electricity supply is further limited by different water-court decisions, referring to maximum and minimum water storage levels and maximum flow changes. The fact that the back-up power source cannot operate at its optimal capacity leads to a smaller amount of electricity being produced by the back-up source compared to a situation without wind power [4].

The Research and Library Services of the Northern Ireland Assembly [5] has estimated that *"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."*

4. International power lines

A key element for implementing large amounts of intermittent energy is an efficient high voltage transmission grid. There are currently a lot of initiatives all over the world to find solutions that satisfy both economic and environmental criteria. In the US, for example, it would be necessary to build in the next 15 years an additional power transmission system of 15,000 miles of very high voltage lines. The system would bring electricity to the big cities along the East Coast. The transmission system would cost up to USD 100 billion [6]. In China the transmission grid has been expanded to accommodate more than 22 GW of power from the Three Gorges hydro-electric facility [7]. The Chinese are also pioneers in developing very high-voltage power lines: it took them only four years to construct a 640 km long 1000 kV line. [8].

An increased integration of power-transmission systems in Europe can decrease the strain on domestic back-up power sources. A recent policy report from EASAC [9] concluded that a European power grid is urgently required to meet the ambitious European goals on renewable energy and that the transmission capacity of existing networks should be improved through the application of appropriate control technologies. The report also indicated that operation of the grid requires a more coordinated approach based on substantially enhanced levels of data sharing than is the situation today, and that effective market mechanisms must be developed to produce correct pricing signals.

5. Too much installed wind power may give rise to 'spilling' of wind electricity

Strong wind power expansion may result in 'spilling' of wind electricity, i.e. to situations when the wind power plants produce more energy than can be consumed in a given region and a channel needs to be found for the surplus. For example in Denmark, which has a very high penetration of wind power, the electricity production by wind power is 20% of the total Danish electricity production [10]. But over the last 5 years only about half of that wind power production was accommodated within the Danish electricity system [11, 12]. The rest was sold at a loss to neighbouring countries, Germany, Sweden and Norway.

Denmark also profits from imported hydropower from Sweden and Norway as a back-up for its wind-power electricity. The Nordic countries have a well-developed interconnection network that today can accommodate Danish intermittent electricity. However, if the total Nordic intermittent electricity production approaches the same portion as in Denmark, there is a risk of large amounts of spill wind. This means that new power lines allowing large amounts of power to be exchanged with the rest of Europe would have to be built. Obviously, coordinated efforts will be important for the increasing penetration of wind power into the electricity market.

It should also be mentioned in this context that in Germany a study on wind power has concluded that a doubling of the presently installed power, implying an increase from 7 to 15% wind electricity, will be difficult to integrate into the present German electricity system [13].

6. Scenarios for global wind production in 2050

The IEA 2008 Blue Map Scenario [14] assumes large investments in non-CO_2 emitting energy sources for the period 2010–2050 resulting in an annual global production of 19,000 TWh of renewable energy by 2050. The scenario includes new generation capacity comprising 2,200 fossil plants with carbon sequestration, 1,300 nuclear plants, solar panels on 8,600 km^2 of land and 700,000 large wind turbines producing 5,000 TWh annually by 2050. For the wind energy an estimated USD 700 billion would have to be invested according to the scenario. The Global Wind Energy Council (GWEC) Outlook 2008 [15] lists three scenarios – reference, moderate, advanced – for 2020 and 2050. According to the moderate scenario, wind power will provide 1,740 TWh by 2020 and 4,818 TWh by 2050, which is consistent with the Blue Map Scenario.

7. Wind power penetration into the electricity market

With the exception of a few countries, wind power has not yet reached a high level of penetration of the electricity market. In Germany (which alongside the US is the biggest wind power producer), wind represents 7% of the electricity market. Denmark, another big EU wind power producer, has the highest penetration of wind power of all countries with 20% of the produced electricity and 10% of the consumed electricity coming from wind.

The German study [13] referred to above states that it should be possible to integrate 12.5% wind in the German electricity market by 2020. In another recent design study of power systems in Europe and the US, the design and operation of wind power with penetration levels of 10–20% of gross demand was discussed with regard to cost and feasibility [16].

In order to secure a reliable electricity supply of a system, the installed power of intermittent energy sources should not exceed that of the base power sources needed for back-up purposes. This restriction may become less important in the future if methods for handling the intermittency such as pumped or battery storage and extended continental and inter-continental power grids are introduced at a large scale.

8. Costs of wind power

One of the larger independent investigations of the costs of generating electricity in Europe is the EU project CASES (Cost Assessment of Sustainable Energy Systems), which started in 2006 and ended in 2008. The project included participation of 26 partners from 20 countries [17]. The project shows the cost for the complete life cycle for producing energy carriers in different ways. The full cost for electricity generated by wind power, excluding the costs for expanding the electricity power line network and the back-up power, is according to this study 6 eurocent per kWh, comparable to the costs for electricity generated from coal power plants, but twice as high as for electricity generated by nuclear power and bio-fueled Combined Heat and Power. However, wind power compares favourably with the other renewable alternatives.

A recent Life Cycle Analysis from the Institute of Energy Economics in Stuttgart presented at the symposium Energy 2050 in Stockholm [18] gives a cost of 10 eurocent per kWh for wind power. The specific investment cost was assumed to be 1,300 euro/kWh, the full load hours 2,450 h/a and the interest rate 7.5% to be compared with

1,000 euro/kWh, 2,628 h/a and 5% assumed by CASES. At the symposium it was also shown that the cost of German wind power is currently between 4 and 6 eurocent per kWh more expensive than conventional fossil power, but within a few decades this difference may level away as a consequence of increasing fossil-fuel prices [19].

To secure a healthy development of Renewable Energy Technologies (RET) it has been proposed [21] that the direction of technical development should not primarily be determined by policies, but by the basic physical properties of the energy source and the associated potential for inexpensive energy production. For the economical optimization of an intermittent source, the total power system must be considered with a focus on the possible number of full loading hours and the degree of utilization, defined as the electric energy delivered to the grid compared to the installed power on a yearly basis. This will increase the cost efficiency and economical competitiveness of RET investments, and could enhance faster diffusion of new innovations and installations without overoptimistic subsidies.

Concerning intermittent energy sources it is very difficult to make estimates of the additional costs for infrastructure, i.e. power grid and suitable storage capacity. A citation from a UKERC report [4] is appropriate. *"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."*

9. Environmental aspects of wind power

The placement of wind power plants is very important from an environmental perspective, both on sea and on land. Apart from visual impact and noise, animal life and in particular bird life can be affected in a negative way. Birds and bats are killed in collisions with the rotor blades, especially in head wind and when there is limited visibility by fog and haze. Sound and vibrations from sea based wind power plants do not seem to affect the marine fauna in a negative way.

To avoid noise from wind power plants they are usually not placed within 400 meters of residential areas, even if 300 meters is sufficient for an acceptable noise level. Overall it is recommended that wind power plants should not be built where large flocks of birds pass regularly during migration, e.g. some coastal areas. Deep-sea sandbanks where large amounts of sea birds assemble to feed should also be avoided.

Little is known about wind power plants in forest environments in respect of both their environmental influence and impacts on their efficiency. However, the habitat of the natural fauna, e.g. game birds, will be affected when roads for heavy lorries are constructed into remote areas, electric cables are installed and regular service done. Expansion of wind power plants should be avoided along forest ridges and other places where thermal-flying birds dwell. National parks, nature reserves and other environments of fundamental interest for nature conservation and outdoor life must of course be excluded as sites for wind power plants.

10. The wind power share of future electricity production

Wind power will grow in importance in future electricity supply. In the next few decades it will to some degree replace fossil power but it will, at the same time also depend on fossil-based power for the balancing of its intermittency. In the long term, 2050 and beyond, when wind power is expected to have a substantial share of the electricity market, CO_2 emission-free electricity plants that are well suited for balancing the wind intermittency will be required.

Predictions of the future penetration of wind power into the electricity market are critically dependent on a number of policy measures and will be especially influenced by climate driven energy policies. Very large investments will also be necessary as is shown by the IEA's Blue Map Scenario which includes 5,000 TWh wind electricity by 2050 at a cost of USD 700 billion. This implies an average 8% increase of wind electricity per year over the next 40 years. This is considered to be a very high growth rate for a global energy system, i.e. an energy system so large that it affects the entire world [21]. The Energy Committee's scenario for electricity production in the year 2050 [22] includes 5,000 TWh wind electricity out of a total of 45,000 TWh. Wind electricity thus has a share of 11% of the 2050 global electricity production in this scenario. This fraction is within presently reached penetration of wind energy in a single country and within the calculated future projections of its penetration [2, 14].

Future large continental and intercontinental power grids may enable higher penetrations of wind energy since contributions of wind power from a larger area will tend to reduce its intermittency. Also, large-scale storage systems (thermal storage as is being considered for Concentrating Solar Power or pumped water storage), small-scale battery systems, specially designed nuclear reactors and demand management could develop into cost-effective options for improving the penetration of wind and other intermittent power systems. These alternatives have been discussed from a technical point of view [3] but for the required large-scale systems, further studies on the social, environmental and economical implications are needed.

References

1. *Wind Power: Capacity Factor, Intermittency, and what happens when the wind doesn't blow?* Renewable Energy Research Laboratory, University of Massachusetts at Amherst, www.ceere.org/rerl/about_wind/RERL_Fact_Sheet_2a_Capacity_Factor.pdf

2. *Global potential for wind-generated electricity*, Xi Lu, Michael B. McElroy and Juha Kiviluoma, Proc Natl Acad Sci U S A. 2009 July 7; 106(27): 10933–10938.

3. *Sustainable energy – without the hot air*, David J C MacKay, book from UIT Cambridge, 2008, www.withouthotair.com/

4. *The Costs and Impacts of Intermittency: An assessment of the evidence on the costs and impacts of intermittent generation on the British electricity network*, Robert Gross, Philip Heptonstall, Dennis Anderson, Tim Green, Matthew Leach, Jim Skea, A report of the Technology and Policy Assessment Function of the UK Energy Research Centre, March 2006.

5. *Wind power and intermittency*, Research and Library Services, Northern Ireland Assembly, Research paper 13/09, January 2009, www.niassembly.gov.uk/io/research/2009/1309.pdf

6. http://graphics8.nytimes.com/images/blogs/greeninc/jointplan.pdf

7. *Power reform – Power grid corporations*, www.sp-china.com/powerReform/pgc.html

8. *China unveils 1000 kV AC transmission grid*, Barnie Badenhorst, Chris van der Merwe and Jacques de Vos, Energize, July 2009, page 41.

9. *Transforming Europe's Electricity Supply – An Infrastructure Strategy for a Reliable, Renewable and Secure Power System*, Policy report from the European Academies Science Advisory Council, June 11, 2009, www.easac.eu/document.asp?id=96&pageno=&detail=5&parent

10. *Danish energy statistics 2007*, http://193.88.185.141/Graphics/UK_Facts_Figures/Statistics/yearly_statistics/2007/energy%20statistics%202007%20uk.pdf

11. *An Assessment of Danish wind power: The real state-of play and its hidden costs*, Hugh Sharman, www.cepos.dk/fileadmin/user_upload/Arkiv/PDF/Wind_energy_-_the_case_of_Denmark.pdf

12. *Annual Statistics 2008 – Norden*, www.nordel.org

13. *Energiewirtschaftliche Planung für die Netzintegration von Windenergie in Deutschland an Land und Offshore bis zum Jahr 2020* (dena-Netzstudie), www.dena.de

14. *IEA Blue Map Scenario*, www.thebreakthrough.org/blog/2008/06/iea_calls_for_massive_clean_en.shtml

15. *Global Wind Energy Council (GWEC) Outlook 2008*, www.gwec.net/fileadmin/images/Logos/Corporate/GWEO_A4_2008_lowres.pdf

16. *Design and operation of power systems with large amounts of wind power*. H. Holttinen et al, IEA Wind task 25, VTT Research notes 2493, 2009.

17. *CASES (Cost Assessment for Sustainable Energy Systems*) www.feem-project.net/cases/, Last update September 2008.

18. *Life Cycle Analysis for Different Energy Sources*, Alfred Voss, Energy 2050 Symposium, Stockholm 2009, http://energy2050.se/uploads/files/voss.pdf

19. *Energy from wind*, Hermann-Jozef Wagner, Energy 2050 Symposium, Stockholm 2009, http://energy2050.se/uploads/files/wagner_h-j.pdf

20. *On the physics of power, energy and economics of renewable electric energy sources – Part II*, , Annika Skoglund et al., Renewable Energy (in press), 2009, www.elsevier.com/locate/renene

21. *Growth rates of global energy systems and future outlooks*, Mikael Höök, Li Junchen, Feng Lianyong, Kjell Aleklett, Submitted to International Journal of Forecasting, http://ees.elsevier.com/ijf/

22. *Statements on global energy resources and their utilization in a 40-year perspective*, A synthesis of the conclusions from the work done by the Energy Committee of the Royal Swedish Academy of Sciences, to be published.

The Energy Committee at the Royal Swedish Academy of Sciences

Sven Kullander, Professor em. of High Energy Physics, Uppsala University
Bengt Kasemo, Professor of Chemical Physics, Chalmers University of Technology
Bengt Nordén, Professor of Physical Chemistry, Chalmers University of Technology
Bertil Fredholm, Professor of Pharmacology, Karolinska Institutet
Dick Hedberg, PhD in Geology, Royal Swedish Academy of Sciences
Georgia Destouni, Professor of Hydrology, Hydrogeology and Water Resources, Stockholm University
Harry Frank, Professor of Innovation Technology for Energy, Mälardalen University
Karl Fredga, Professor em. of Genetics, Uppsala University
Karl Grandin, Professor, Director of the Center for History of Science
Karl-Göran Mäler, Professor em. of Economics, The Beijer Institute for Ecological Economics
Kerstin Niblaeus, Tech Dr., former Director of the General EU Council of Ministers
Peter Jagers, Professor of Mathematical Statistics, Chalmers University of Technology
Rickard Lundin, Professor of Space Physics, Swedish Institute of Space Physics

Contacts

Sven Kullander, Professor em., Chairman of the committee, +46 8 673 97 05, sven.kullander@kva.se
Helena Ledmyr, Ph.D., Administrator/Communications officer, +46 8 673 95 91, helena.ledmyr@kva.se