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Renewable sources of energy, with special emphasis on wind energy

Report of the Secretary General**

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** More detailed information is available in the Division for Sustainable Development, Department of Economic and Social Affairs.

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I. Introduction

1.. The present report summarizes the progress in wind energy to date and discusses the resource, technological, economic, environmental and sociological aspects of wind power today. It also summarizes the policy options available to stimulate the adoption of wind energy. An expanded version of the report contains brief case studies of five countries which accounted for 85 per cent of worldwide installed wind capacity in 1996, as well as recommendations with respect to critical policy options.[1]

II. Wind energy resource potential

2. *Worldwide potential.* The International Energy Agency (IEA) has estimated the world's total demand for electricity to be 12,500 TWh in 1993 and 20,907 TWh by the year 2010. In comparison to this, the world's wind resources are abundant. Only few comprehensive investigations of the world's wind energy potential have been carried out to date, but they all conclude that the overall resource is much larger than the world's total electricity demand. However, wind potential is area-specific and geographically uneven. Nevertheless, the overall resource potential is vast, considering the potential in offshore locations, sparsely populated remote areas and complex terrain as well as the possibility of conjunctive use of land.

3. *Worldwide installed capacity.* Since 1980, modern grid-connected wind turbines have been installed in more than 50 countries around the world. As shown in table 1, early installations were predominantly in industrialized countries. Activity in developing countries has also picked up significantly in recent years, particularly in India and China. Egypt and Cape Verde, which are not included in table 1, have also experienced notable wind energy growth recently.

Wind power implementation scenarios

4. The World Energy Council (WEC), in "New renewable energy sources – a guide to the future" (1994), has prepared two global scenarios on wind energy penetration up to the year 2020: (i) the "Current policies" scenario, where the existing general economic and technological trends are assumed to continue; and (ii) the "Ecologically driven" scenario, which, compared with the "Current policies" scenario, assumes a faster development of wind turbine efficiency, imposition of a substantial carbon tax on fossil fuels and less severe financial constraints on the development of wind energy. The overall results of the two scenarios are shown in table 2.

5. The two scenarios diverge substantially. The volume of wind-generated electricity is almost 2.5 times higher in the "Ecologically driven" scenario in 2020 than in the "Current policies" scenario. The relatively larger share of total worldwide kWh demand met through wind power in the "Ecologically driven" scenario is partly due to a projection of lower overall electricity use in this scenario. The penetration of wind power is assumed to start when the long-run marginal costs of conventional power become higher than those for wind power. Given this, wind penetration is assumed to be constrained primarily by financial resources and the growth of future wind turbine manufacturing capacity.

6. BTM Consult has recently evaluated the short-to-mid-term development of worldwide grid-connected wind power capacity. It projects the existing global installed capacity of 6.1 GW (1996) to increase to 17.5 GW by the year 2001 (a growth rate of almost 25 per cent a year) and to further increase to 33.5 GW in 2005, well in line with the 2010 WEC forecast in the "Current policies" scenario. In the short term, no capacity constraints in the manufacturing industry are foreseen; in fact strong competition between manufacturers is envisaged. Based on this study, global cumulative wind turbine capacity might reach roughly 375 GW in 2020, between the WEC "Current policies" and "Ecologically driven" estimates.

7. The above studies mainly concentrate on on-land siting of turbines. However, offshore applications are increasing, one in the Netherlands and two in Denmark. The latest Danish energy plan, Energy 21, projects the prospects for offshore turbines at more than 4,000 MW of installed capacity in Denmark before the year 2030.

8. Distinct markets exist for centralized grid-based systems and for decentralized remote communities which are off-grid. To date, the largest market has been in conventional centralized grid-connected applications. Decentralized (off-grid) systems have not been as common, since the off-grid communities are more difficult to access, often poor and often in developing countries, thus not providing commercially attractive markets. Small decentralized systems using wind energy may prove to be more cost-effective than extensions of the centralized transmission grid.

Table 1
Worldwide grid-connected wind capacity, in MW

	1991	*1992*	*1993*	*1994*	*1995*	*1996*
Europe						
Denmark	418	470	490	540	630	785
Germany	110	183	280	643	1 137	1 576
Greece	5	26	26	27	28	28
Italy	5	6	10	22	23	70
Netherlands	82	105	132	153	255	305
Spain	15	45	58	72	126	216
Sweden	8	12	24	40	67	105
United Kingdom	10	30	120	147	193	264
Other European	9	9	18	32	35	35
North America						
Canada	3	4	11	23	21	23
United States	1 575	1 584	1590	1 725	1 770	1 794
Other North America	–	–	–	2	12	22
Asia						
China	–	–	13	25	36	57
India	39	51	80	120	550	820
Japan	2	4	5	5	10	14
Other	6	10	19	18	26	62
Total by end of year	2 287	2 539	2 876	3 594	4 905	6 172
Annual growth	285	252	337	718	1 311	1 267

Source: "Review of progress in the implementation of wind energy by the member countries of the IEA" (Paris, International Energy Agency/Organisation for Economic Cooperation and Development, July 1997).

Table 2
Wind capacity and wind-generated electricity in WEC scenarios

	Projected worldwide wind capacity: year 2005	*Projected worldwide wind capacity and production: year 2020*		*Share of worldwide kWh demand: year 2020*
Scenario	*(GW)*	*(GW)*	*(TWh)*	*(Percentage)*
"Current policies"	62	180	376	1.5
"Ecologically driven"	83	474	967	4.8

Source: "New renewable energy resources – a guide to the future" (London, World Energy Council, 1994).

Wind resource assessment and siting

9. Wind resource assessment usually refers to the calculation of average wind speed over 10 to 20 years at a specific site or area. Accurate determination of the daily, monthly and annual average wind speed is of paramount importance for the siting of wind projects. As a rule of thumb, the power output of wind turbines increases by the third power of the wind speed, and thus the cost of wind energy decreases drastically with increased wind speed. Current methodologies generally predict wind resources with good accuracy, but this is not the case for all sites. Therefore, users must understand the models' proper use and known limitations, and further research in some areas is necessary. Site-specific studies are also necessary for validating model results.

III. Technological status and trends

A. Modern wind turbine technology

10. Modern wind turbine technology can be classified in three main categories: large grid-connected turbines, intermediate-sized turbines in hybrid systems and small stand-alone systems. Large grid-connected wind turbines, in the size range of 150 kW to 2,000 kW, account for by far the biggest market value among wind turbines, and the technology for these machines is becoming mature. The size of commercially available grid-connected wind turbines has evolved from 50 kW in the early 1980s to the 500-800 kW range today. The next generation of commercial machines in the 1,000-1,500 kW size range have been installed as prototypes since 1995 and were commercially introduced into the market in 1997. Today grid-connected wind turbines are often placed in wind farms of 10 to 100 MW, which are operated as a single plant.

11. Intermediate-sized wind turbines in the 25-150 kW range can operate in hybrid energy systems combined with other energy sources such as photovoltaics, hydro, diesel and/or storage. Such systems are particularly well-suited for small remote grids where fossil fuel use is limited by transportation, environmental, cost or other constraints, and for special applications such as water pumping, battery charging or desalination.

12. Small "stand-alone" wind turbines of less than 25 kW are used for water pumping, battery charging and heating. Among small battery charging wind turbines, the 25-150 watt range (i.e., rotors of 0.5 to 1.5 metres) is by far the most commercially successful. Probably some 200,000 small battery charging wind turbines for remote telecommunication stations are now in use. The main producers of small battery chargers are in the United Kingdom of Great Britain and Northern Ireland (marine and caravan leisure markets) and China (for semi-nomadic cattle raisers in the Mongolian region).

13. However, of the wind energy technologies currently in operation, the mechanical farm windpump remains the most numerous. One to two million units are in regular use worldwide, with over 50 known manufacturers active in this field. The main application for mechanical farm windpumps is for drinking water supply in rural areas. The present annual installation of windpumps is estimated at 5,000 to 10,000 units.

B. Recent technological developments

14. Two general types of wind turbines exist, named after the direction of their main shaft: horizontal axis wind turbines (HAWT) and vertical axis wind turbines (VAWT). VAWT machines have not lived up to their early promise and, today, only a very small fraction of wind turbines in operation are of the VAWT type. Hence, the present report focuses solely on the HAWT type.

15. Average turbine size has increased drastically over the past 15 years, and there are only a few technical barriers to further up-scaling of size, including transportation and availability of large cranes near the site. Electricity production efficiency is also rapidly improving, owing to higher towers, larger rotors and better aerodynamic performance. This increased size and efficiency lead directly to increased annual energy output per square metre of land occupied, which is important in regions with limited land availability.

16. The prime objective for industrial R&D in wind turbine technology is cost reduction. The cost of wind turbines and consequently, power production costs, have decreased steadily since the beginning of the 1980s. Wind turbine technology's progress ratio (i.e., the decline in costs each time the cumulative volume doubles) has been of the order of 15 per cent. This development is expected to continue in the future, perhaps at a slightly slower pace. Wind turbine noise emissions have also been lowered owing to better designed blades, improved manufacturing quality of mechanical parts and use of damper materials.

C. Wind turbine influence on the electricity grid

17. *Capacity credit.* The capacity credit of wind power can be determined by use of the "loss-of-load-probability" (LOLP), a measure of power availability commonly used by power utilities in planning the expansion of power generation capacity. Using the LOLP approach, at small wind energy penetration levels (up to 10 per cent of total kWh production) the capacity credit of many widely dispersed wind turbines in a large grid is approximately equal to the turbines' capacity factor, which is typically in the range of 20 per cent to 40 per cent. Even at higher wind energy penetration levels, the capacity credit of wind power can still be substantial. Cape Verde achieved a capacity credit of 75 per cent of the wind turbines' capacity factor at 25 per cent to 50 per cent wind energy penetration.

18. *Short-term prediction.* Based on general weather forecasting models and the wind speed at a site or in a region, power production from the wind turbines in a power utility's area can be predicted with good accuracy. Using such forecasting models, the power utility's dispatcher can obtain the predicted power production from wind turbines over the next 36 hours on a computer screen, thus minimizing dispatch difficulties. Such predictive tools can also help in determining the potential for peak load management in a grid system, in terms of wind power availability during peak load periods.

19. *Power quality.* Although concern has been expressed over wind energy's potential impact on power quality (e.g., real time power demand, voltage level, voltage flicker, harmonics, frequency variations), these can be resolved effectively through technical, operational and management measures.

IV. Economics of wind energy

20. The present section focuses on the economics of grid-connected wind turbines only, as they account for the bulk of the market value of installed turbines. The main parameters governing wind power economics are: (i) investment costs, including auxiliary costs for foundation, grid-connection, and so forth; (ii) operation and maintenance costs; (iii) electricity production/average wind speed; (iv) turbine lifetime; and (v) discount rate. Of these the most important are the turbines' production of electricity and the investment costs. As electricity production is highly dependent on wind conditions, choosing the right turbine site is critical to the economic results.

A. Capital cost and efficiency trends

21. In general, two trends have dominated grid-connected wind turbine development: (i) the average size of turbines sold on the market has increased substantially; and (ii) the efficiency of production has increased steadily. The average size of turbines sold in the Danish export market has increased from roughly 50 kW in 1985 to over 500 kW in 1996. Currently, the best-selling turbine has a rated capacity of 600 kW, but turbines are now sold with capacities as high as 1,500 kW. Moreover, electricity production efficiency, measured as annual energy production per swept rotor area (kWh/m^2) has increased by more than 5 per cent annually over the past 15 years.

22. Capital costs of wind energy projects are dominated by the cost of the wind turbine itself (ex-works). For a typical 600 kW turbine in Denmark, the turbine's share of total cost is approximately 80 per cent, while grid-connection accounts for approximately 9 per cent and foundation for approximately 4 per cent. Other cost components, such as control systems and land, account for only minor shares of total costs.

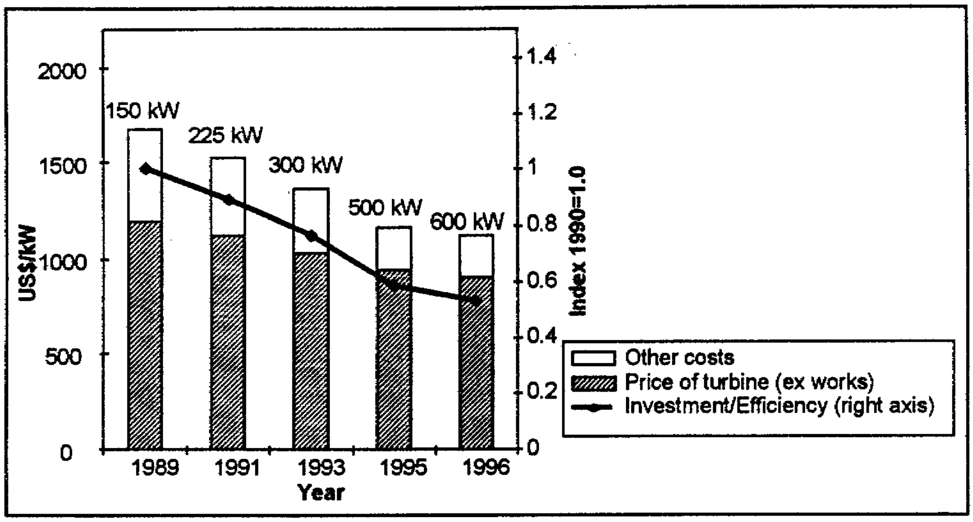
23. As shown in figure I, there has been a substantial decline in per-kW costs, turbine costs (4 per cent per year) and auxiliary costs. Thus, the general investment costs per kW declined by more than 5 per cent a year from 1989 to 1996. Combining the efficiency improvement and the decline in investment costs per capacity unit implies that the total investment per annual production ratio has improved by more than 45 per cent since 1989, or more than 8 per cent a year in real terms, also shown in figure I (right ordinate).

24. Wind energy project capital costs as reported by the International Energy Agency show substantial variation between countries, due to factors such as market structures, site characteristics and planning regulations: total wind project capital costs vary between approximately US$ 900 per kW and US$ 1,600 per kW in different countries.

B. Operation and maintenance costs

25. Operation and maintenance (O&M) costs constitute a sizeable share of total annual costs for the turbine. Only a limited number of turbines have existed for the full expected lifetime of 20 years. For this reason estimates of O&M costs are highly uncertain, especially in the later years. O&M costs are primarily influenced by turbine age, starting low and increasing over time. For a 150 kW turbine, annual O&M costs are estimated at approximately 1.2 per

Figure I
Wind turbine capital costs (ex-works) and other costs
(US$/kW in constant 1996 dollars)



Source: Privatejede Vindmøllers Økonomi (The Economics of Privately Owned Wind Turbines) (Danish Energy Agency, 1994) and P. Nielsen, Energy and Environmental Data, 1997.

cent a year of capital investment cost during the first two years of turbine life, rising to 7 per cent a year in years 16-20. For a 600 kW turbine, the corresponding O&M costs are approximately 1 per cent a year during the first two years, rising to 4.5 per cent a year in years 16-20.

C. Overall cost-effectiveness

26. The total cost per produced kWh (unit cost) is calculated by levelizing investment and O&M costs over the lifetime of the turbine, divided by the annual electricity production. The unit cost of generation is thus calculated as an average cost. In reality, actual costs will be lower than the calculated average at the beginning of the turbine's life (owing to low O&M costs) and will increase over the period of turbine use. Figure II shows the calculated unit cost for different sizes of turbines based on the above-mentioned investment and O&M costs, a 20 year lifetime and a discount rate of 5 per cent a year (in real terms). The turbines' electricity production is estimated for roughness classes one and two, corresponding to an average wind speed of approximately 6.9 metres per second (m/s) and 6.3 m/s, respectively, at a height of 50 metres above ground level. Figure II illustrates the trend towards larger turbines and greater cost-effectiveness. For a roughness class one site (6.9 m/s), for example, the average cost in 1996 United States dollars has decreased from approximately 8.8 cents per kWh for the 95 kW turbine to approximately 5 cents per kWh for a new 600 kW machine, an improvement of almost 45 per cent over a time span of 9-10 years.

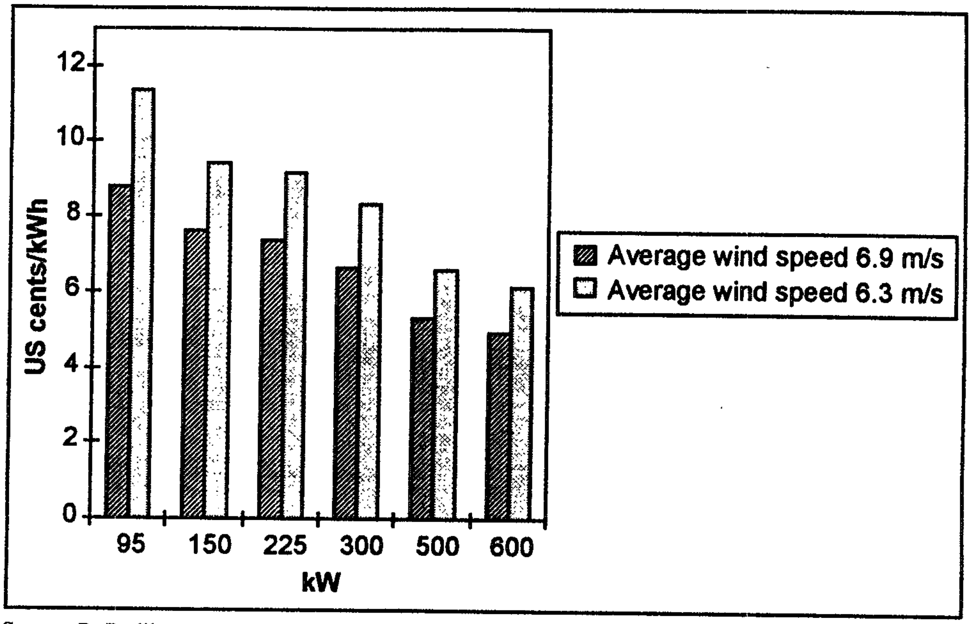
27. The discount rate has a significant influence on production costs and hence on the financial viability of wind projects. For a 600 kW turbine, changing the discount rate from 5 per cent to 10 per cent a year (in real terms) increases the production cost by a little more than 30 per cent, from 5 United States cents per kWh to 6.7 United States cents per kWh. In project-financed wind projects in the United States of America, for example, nominal discount rates for projects financed with 50 per cent debt – 50 per cent equity has been over 12 per cent a year, thus significantly raising project costs.

D. Comparison with the cost of conventional power

28. The cost of conventional electricity production is determined by three components: (i) fuel cost; (ii) operation and maintenance costs; and (iii) capital cost. When wind is substituted for conventional methods of generating electricity, the avoided cost depends on the consideration of each of the three components. It is generally accepted that implementing wind power avoids the full fuel cost and a considerable portion of the O&M costs of the displaced

Figure II

Total turbine costs per unit of electricity produced, based on a hub height of 50 metres
(US cents/kWh, constant 1996 prices)



Source: R. Redlinger and others, Risø National Laboratory Denmark.

conventional power plant. The level of avoided capital costs depends on the extent to which wind power capacity can displace investments in new conventional power plants and is thus directly tied to the capacity credit of wind plants. The capacity credit will depend on a number of different factors, for example the level of penetration of wind power and how the wind capacity is integrated into the overall energy system. In general, for marginal levels of wind penetration, the capacity credit for wind turbines is close to the annual average capacity factor. Thus, 25 per cent is considered a reasonable capacity credit for wind power when the volume of wind-generated electricity is less than 10 per cent of total electricity production. This capacity credit declines as the proportion of wind power in the conventional system increases; but even at high penetrations a sizeable capacity credit is still achievable, as discussed in section III.

29. Costs avoidable through wind electricity are shown in figure III, assuming that all fuel and O&M costs are avoided and that wind power is assigned a very conservative capacity credit of 0 per cent. For example, for Germany, for each kWh of electricity generated by wind power which displaces a kWh of coal power, approximately 7 United States cents per kWh are avoided in coal fuel and O&M costs, even if the wind plant receives no credit for displacing any coal plant capital costs. The estimated costs for a 600 kW on-land turbine at average sites in Denmark and the United Kingdom are also shown (5 United States cents and 4.5 United States cents per kWh, respectively). Therefore, if a wind turbine could be installed in Germany at an average cost of 5 United States cents per kWh and thus displace coal-generated electricity costing 7 United States cents per kWh, then a net 2 United States cents per kWh would be saved on every kWh of electricity generated by wind.

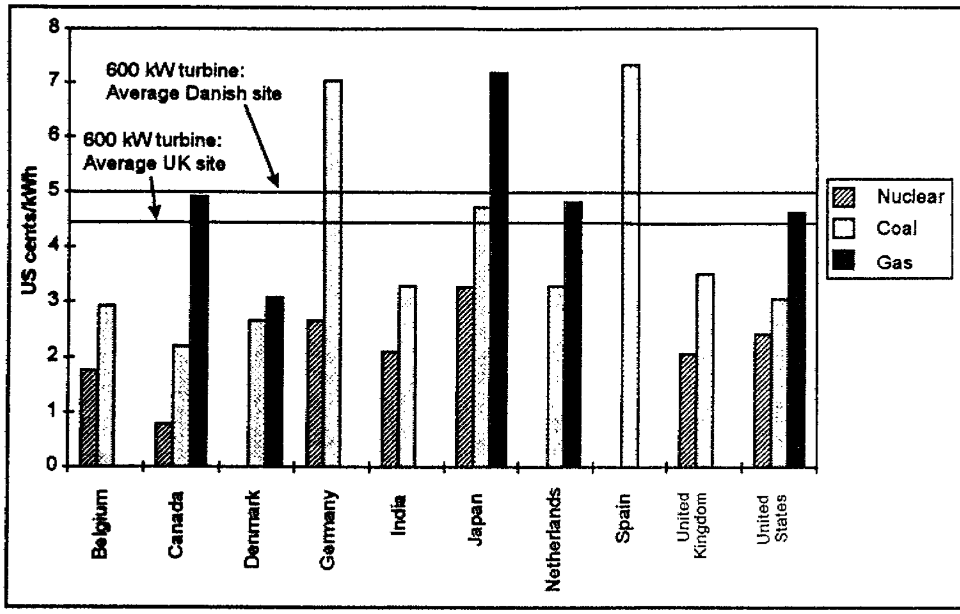
30. The 600 kW turbine is thus competitive, or nearly so, in terms of direct costs in a number of countries, especially in relation to technologies based on coal and gas. Such comparisons are conservative, as they assume no capacity credit for wind energy, making it difficult for wind energy to compete. Assuming a more realistic capacity credit for wind, such as 25 per cent, would raise the avoided costs and thus further improve wind's competitiveness, particularly in comparison with nuclear energy, whose costs are dominated by capital costs. Moreover, the environmental benefits of wind energy, for example in relation to acidification and global warming, are not included in the figure.

31. Figure III would change significantly if a higher capacity credit for wind were assumed. For example, for the United States, figure III shows avoided costs of 2.41, 3.04 and 4.62 United States cents per kWh for nuclear, coal and gas, respectively, assuming a wind capacity credit of zero. If the wind capacity credit were raised to 25 per cent, the

Figure III

Avoided costs of conventional power, excluding capacity credit, compared with production costs for wind-generated electricity

(1996 US cents/kWh)



Source: Based on the cost data from, "Projected costs of generating electricity" (Paris, IEA/OECD, 1993).

avoided costs would change to 3.00, 3.52 and 4.76 cents per kWh and at 50 per cent capacity credit, they become 3.59, 4.00 and 4.89 cents per kWh. This highlights the importance of capacity reliability and dispatchability, but this importance may change in the future as spot markets and financial options develop in competitive electricity systems to better handle power variability.

E. Economics of small-scale irrigation pumping

32. Large-scale electric applications have seen the most notable advances in wind energy in recent years and are the focus of the present report. Nevertheless, the most common type of wind energy application, in terms of number of installed units, remains the small-scale mechanical wind pump for irrigation water pumping. Such wind pumps are widely used in both developed and developing countries and can be particularly attractive when electric grid access is not readily available. In one study, which compared wind pumps with kerosene pump sets, diesel pump sets, solar PV systems, or solar rankine pump systems in various countries, wind pumps were found to be far more cost-effective than solar systems and in most cases they were also cheaper than kerosene and diesel pump sets. Financial cost-effectiveness is significantly influenced by subsidies, which are often available on kerosene or diesel; and the high capital cost of wind systems compared with kerosene or diesel sets makes the financial performance of wind pumps sensitive to prevailing interest rates.

V. Environmental and social considerations

A. Environmental impacts

33. The 1995 ExternE, "Externalities of Energy", study conducted by the European Commission represents one of the most comprehensive efforts to date to quantify monetary values of environmental externalities for a wide range of fuel cycles: coal, nuclear, oil, gas, hydro and wind. The study characterizes the wind energy fuel cycle as including the following environmental impacts: noise, visual amenity, global warming, acidification, public accidents, occupational accidents, land use, bird mortality and radio interference. Construction and installation of the wind turbines involve

energy use, which creates air emission impacts, though this depends on the nature of the energy resources in use at the time of construction. Based on two wind farm sites in the United Kingdom, the ExternE study quantified the externalities of wind energy as shown in table 3.

Table 3
Environmental externality values of wind-generated electricity

Category	*External costs (mECU/kWh)*[a]
Noise	0.07-1.1
Visual amenity	Not quantified
Global warming	0.15
Acidification	0.7
Public accidents	0.09
Occupational accidents	0.26

Source:
ExternE, "Externalities of Energy" study (European Commission, 1995).

[a] Mills of a European Currency Unit per kilowatt hour.

34. Noise values showed a wide variation depending on the population density surrounding the site. The study did not place a specific value on the visual amenity but estimated it to be very small outside of recreationally important designated scenic areas, and most likely well below 1.9 mECU/kWh. If one were to assume a median noise value of 0.6 mECU/kWh and a visual amenity value of 1.0 mECU/kWh, then summing the identified values in table 3 would result in a total environmental externality value for wind energy of 3 mECU/kWh (US$ 0.0038/kWh). Bird mortality impacts were estimated to be negligible in the United Kingdom (though perhaps higher in other locations including the United States), as were land use impacts owing to the very small land area used by the turbines themselves and their compatibility with both agriculture and animal life. While the total wind externality value is not trivial, it is considerably less than the electricity generating cost, especially because the global warming and acidification impacts are secondary impacts, stemming from an assumption of fossil-fuel-based primary energy use for turbine manufacturing. Excluding such secondary emissions (which were excluded by ExternE for all other fuel cycles) would lower the wind externality value to approximately 2 mECU/kWh (US$ 0.0025/kWh).

35. Comparisons with other fuels are difficult owing to differences in assumptions and methodologies. However, based on other ExternE fuel cycle studies, figure IV provides highly approximate externality estimates for the other fuel cycles in comparison with wind, in United States dollars. The possible ranges on these values are very large, and all numbers should be used only with extreme caution. Nevertheless, wind energy's environmental impacts appear to be no higher than those of any other fuel and considerably lower than those of fossil fuels. In addition, wind energy's environmental impacts are local, relatively predictable and primarily aesthetic.

B. Social considerations

36. As discussed above, visual and noise impacts are considered the most negative consequences of wind power. Because these impacts are entirely local in nature, they can cause significant local planning and siting concerns. It may be noted, however, that the noise from a wind farm at a distance of 350 metres is of the order of 45 decibels (approximately the same as that from a car travelling at 40 miles an hour at a distance of 100 metres) and as such the noise is less than the daytime rural background noise levels and is only slightly greater than the night-time levels.

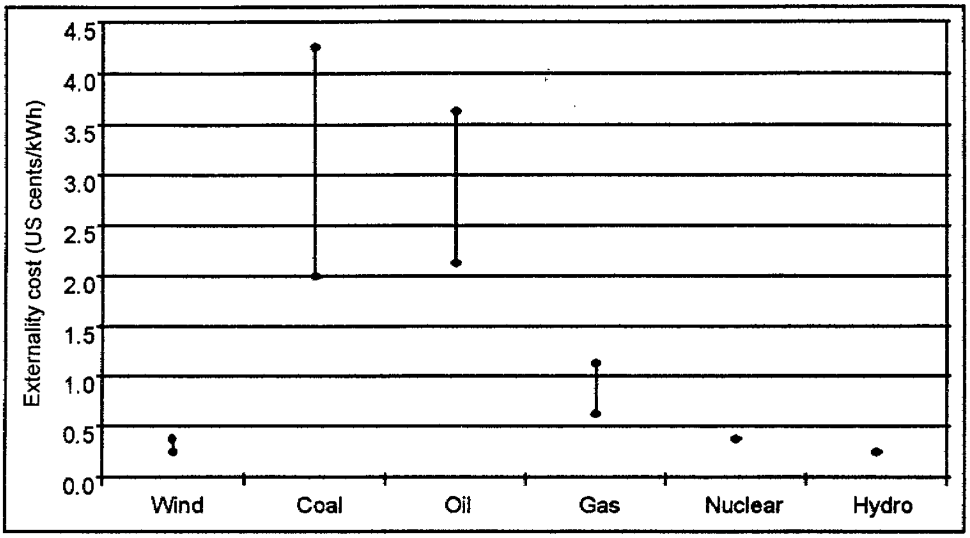
37. Job creation is another social consideration of great interest. Worldwide, employment in the wind energy industry is currently estimated to be approximately 30,000 to 35,000 jobs for supplying 1,200 MW of new installed wind capacity a year. In developing countries, the employment and balance of payments implications of modern high-technology wind turbines are less clear, as they will continue to require the import of equipment (though not fuel) and perhaps specialized labour.

VI. Incentive mechanisms to promote wind energy development

38. A variety of incentive mechanisms have been used to promote the development of wind energy projects and have led to the generation of considerable modern wind energy in a number of OECD countries and some developing countries. A number of these are described below.

39. *Power purchase agreements (PPA).* Perhaps the single most critical requirement of a successful wind energy project is a reliable market for selling the electricity produced. In a vertically integrated monopoly utility system, a utility which chooses to build wind power plants would of course

Figure IV
Estimated total environmental externality ranges, by fuel type



Source: ExternE, "Externalities of Energy" study (European Commission, 1995).

have a guaranteed market. However, much of wind power development has been carried out by independent power producers unaffiliated with any utility. In this case, a mechanism is necessary, by which the wind developer can sell its generated electricity to the utility. Creation of stable markets has thus been a prime objective of establishing PPAs.

40. *Production subsidy.* Where electricity generated by wind is more costly than that generated by conventional sources, wind energy may not be economically attractive at the going electricity rate. In that case, a production subsidy, paid per kWh of electricity generated, can lower the cost of wind energy and make projects economically viable. The subsidy would typically be paid either by the Government out of the general tax base or by utility customers through a surcharge on their utility bills. Such subsidies are meant to be time-limited and phased out over time as technological development makes wind energy fully competitive in the marketplace.

41. *Tax credits.* Tax credits can be provided based either on the capital cost of the project or on the kWh generated by the project. Tax credits based on capital cost are preferred by investors because the tax credit can be claimed regardless of the project's performance in actually generating electricity. For highly risky projects, investors might be willing to provide finance only under such generous conditions. On the other hand, tax credits based on the capital cost can be subject to abuse because investors simply interested in a tax shelter have little incentive to ensure that their projects actually produce electricity. Production tax credits, paid per kWh of electricity generated, reduce the scope for abuse by making payment contingent on project performance, thus increasing the risk to project investors.

42. *Renewables set-aside.* A renewables set-aside mandates that a certain percentage of total electricity generated must come from renewable sources. In some cases, this percentage can be further broken down into separate allocations for different technologies, such as wind, solar, biomass and the like. A set-aside policy thus creates a guaranteed market for electricity generated by renewable energy technologies which might not otherwise be able to compete in the prevailing generation market.

43. *Externality adders.* As traditional energy planning has largely ignored the environmental externalities of power production, some regulators have attempted to address this issue by increasing the hypothetical cost of conventional power plants through an environmental externality charge or "adder" in the planning stage. Such adders can improve the likelihood of wind energy plants being built by increasing the apparent cost of conventional technologies. Typically, externality adders are included only in the planning stage for resource selection but are not actually charged on operations, thus not affecting power plant dispatch once projects are built.

44. *Carbon tax.* Like the externality adder, the carbon tax adds to the cost of fossil-fuel-based energy by imposing a per-kWh tax on the basis of the carbon content of fuels and

their likely impact on global climate change. Carbon-free energy sources like wind energy can thus become considerably more competitive against fossil fuels because of such a tax. Unlike the externality adder, however, the carbon tax involves actual payment of money and is not merely a hypothetical charge used for planning purposes only.

45. *Preferential finance* covers concessional loans at below-market interest rates, official co-financing to attract commercial lenders, loan guarantees and the like.

46. *Research, development and demonstration grants.* Several Governments provide or have provided research, development and demonstration (RD&D) grants for wind turbine technologies as well as for resource assessment, environmental considerations and other related areas. According to the International Energy Agency, the United States had the largest wind R&D programme in 1996, followed by Japan, the Netherlands, Denmark and Italy. Total wind energy research and development funding by OECD Governments amounted to approximately US$ 70 million in 1996. Caution must be exercised in making cross-country comparisons owing to countries' different accounting systems. In addition, high RD&D spending does not in itself lead to wind energy success. Between 1973 and 1988, the United States and Germany spent roughly US$ 380 million and US$ 79 million, respectively, on wind RD&D, but Denmark came to dominate the world turbine manufacturing market, spending only US$ 15 million on RD&D during the same period. Successful RD&D spending must be carefully integrated with reliable long-term markets for wind-generated electricity.

VII. Recommendations

47. Designing appropriate policies in developing countries can benefit from experience gained in the use of the incentive mechanisms mentioned in section VI. Their practical application will, however, require strengthening the institutional capacity of policy and regulatory bodies. This is of particular importance for countries embarking on the privatization of public sector utilities. Key elements of a policy aimed at promoting renewable energy sources may well include many of the following.

48. *Establishment of rational pricing and well-designed incentive mechanism.* Price reforms in the conventional electricity sector may be necessary in many countries. Excessively subsidized conventional electricity would otherwise constitute a significant barrier to renewables. In addition, incentive mechanisms based on those described above should be tailored to the specific circumstances of developing countries.

49. *Provision of stable markets for wind-generated electricity.* Reliable markets for wind-generated electricity are the single most important factor for stimulating the further development of wind energy. Stable power purchase contracts have been a critical feature of the energy policies of all countries that have achieved wind energy success. Since a state of full and complete competitiveness has not yet been reached, some level of additional support will remain necessary for the next several years.

50. *Provision of stable wind turbine markets.* Countries should also encourage stability in markets for new wind turbines to ensure the industry's viability and stimulate technological development. It is not necessary for this market to be large, as market reliability is a much more important feature than market size.

51. *Alignment of energy projects' financial performance with society's environmental goals.* Efforts should be redoubled to introduce appropriate mechanisms that will better align energy projects' financial performance with society's environmental goals.

52. *Enhancement of community participation in project planning and in reaping project benefits.* The visual and noise impacts, while low, are nevertheless real and must be addressed through an open and straightforward planning process. Opposition is also considerably reduced when local residents are well informed and are able to profit financially from wind energy projects in their communities.

53. *Encouragement of decentralized projects in remote communities.* Wind energy can be highly cost-effective in remote communities not served by a central electricity transmission grid. However, as such communities are often poor and in developing countries, less effort has been made to address these markets; and the bulk of wind energy development has occurred in the context of centralized grid-based generation. Additional efforts should be directed towards making financing available and stimulating off-grid wind energy projects in remote communities, particularly in the context of rural electrification programmes in developing countries.

54. *Removal of institutional barriers to wind energy.* Stable professional communities should be developed that understand wind energy issues and can facilitate their countries' long-term wind energy development. Development of institutional capacity also includes information dissemination, development of appropriate

planning processes, suitable certification arrangements for turbines and perhaps wind energy demonstration programmes where no projects yet exist.

55. *Encouragement of research and development, particularly for wind resource assessment.* Technology development is already successfully addressed by the private sector and may not require significant public funding. However, public assistance would be required for accurate wind mapping to identify suitable sites for wind energy electricity generation. In developing countries, particularly least developed countries, dissemination of these technologies will nonetheless require extensive international cooperation.

Notes

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