WIND ENERGY - THE FACTS

PART V

ENVIRONMENTAL ISSUES

Acknowledgements

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PART V INTRODUCTION

The energy sector greatly contributes to climate change and atmospheric pollution. In the EU, 80 per cent of greenhouse gas emissions (GHGs) come from this sector (European Environment Agency, 2008). The 2008 European Directive promoting renewable energy sources recognises their contribution to climate change mitigation through the reduction of GHGs. Renewable energies are also much more sustainable than conventional power sources. In addition, they can help provide a more secure supply of energy, they can be competitive economically, and they can be both regional and local. Wind energy is playing an important role in helping nations reach Kyoto Protocol targets. The 97 GW of wind energy capacity installed at the end of 2007 will save 122 million tonnes of CO_2 every year (GWEC, 2008), helping to combat climate change.

Wind energy is a clean and environmentally friendly technology that produces electricity. Its renewable character and the fact it does not pollute during the operational phase makes it one of the most promising energy systems for reducing environmental problems at both global and local levels. However, wind energy, like any other industrial activity, may cause impacts on the environment which should be analysed and mitigated. The possible implications of wind energy development may be analysed from different perspectives and views. Accordingly, this part covers the following topics:

- environmental benefits and impacts;
- policy measures to combat climate change;
- externalities; and
- social acceptance and public opinion.

Environmental benefits of wind energy will be assessed in terms of the avoided environmental impacts compared to energy generation from other technologies. In order to compute these avoided environmental impacts, the life-cycle assessment (LCA) methodology has been used. LCA, described in the international standards series ISO 14040-44, accounts for the impacts from all the stages implied in the wind farm cycle. The analysis of the environmental impacts along the entire chain, from raw materials acquisition through production, use and disposal, provides a global picture determining where the most polluting stages of the cycle can be detected. The general categories of environmental impacts considered in LCA are resource use, human health and ecological consequences.

Focusing on the local level, the environmental impacts of wind energy are frequently site-specific and thus strongly dependent on the location selected for the wind farm installation.

Wind energy has a key role to play in combating climate change by reducing CO_2 emissions from power generation. The emergence of international carbon markets, which were spurred by the flexible mechanisms introduced by the Kyoto Protocol as well as various regional emissions trading schemes such as the European Union Emissions Trading Scheme (EU ETS), could eventually provide an additional incentive for the development and deployment of renewable energy technologies and specifically wind energy. Chapter V.3 pinpoints the potential of wind energy in reducing CO_2 emissions from the power sector, gives an overview of the development of international carbon markets, assesses the impact of Clean Development Mechanism (CDM) and Joint Implementation (JI) on wind energy, and outlines the path towards a post-2012 climate regime.

Wind energy is not only a favourable electricity generation technology that reduces emissions (of other pollutants as well as CO_2, SO_2 and NO_x), it also avoids significant amounts of external costs of conventional fossil fuel-based electricity generation. However, at present electricity markets do not include external effects and/or their costs. It is therefore important to identify the external effects of different electricity generation technologies and then to monetise the related external costs. Then it is possible to compare the external costs with the internal costs of electricity, and to compare competing energy systems, such as conventional electricity generation technologies and wind energy. Chapters V.4 and V.5 present the results of the empirical analyses of the avoided emissions and avoided external costs due to the replacement of conventional fossil fuel-based electricity generation by wind energy in each of the EU27 Member States (as well as at aggregated EU-27 level) for 2007 as well as for future projections of conventional electricity generation and wind deployment (EWEA scenarios) in 2020 and 2030.

Wind energy, being a clean and renewable energy, is traditionally linked to strong and stable public support. Experience in the implementation of wind projects in the EU shows that social acceptance is crucial for the successful development of wind energy. Understanding the divergence between strong levels of general support towards wind energy and local effects linked to specific wind developments has been a key challenge for researchers. Consequently, social research on wind energy has traditionally focused on two main areas: the assessment of the levels of public support for wind energy (by means of opinion polls) and the identification and understanding of the dimensions underlying the social aspects at the local level (by means of case studies), both onshore and offshore.

Chapter V.5, on the social acceptance of wind energy and wind farms, presents the key findings from the most recent research in this regard, in light of the latest and most comprehensive formulations to the concept of 'social acceptance' of energy innovations.

V.1 ENVIRONMENTAL BENEFITS

It is widely recognised that the energy sector has a negative influence on the environment. All the processes involved in the whole energy chain (raw materials procurement, conversion to electricity and electricity use) generate environmental burdens that affect the atmosphere, the water, the soil and living organisms. Environmental burdens can be defined as everything producing an impact on the public, the environment or ecosystems. The most important burdens derived from the production and uses of energy are:

- greenhouse gases;
- particles and other pollutants released into the atmosphere;
- liquid wastes discharges on water and/or soil; and
- solid wastes.

However, not all energy sources have the same negative environmental effects or natural resources depletion capability. Fossil fuel energies exhaust natural resources and are mostly responsible for environmental impacts. On the other hand, renewable energies in general, and wind energy in particular, produce significantly lower environmental impacts than conventional energies.

Ecosystems are extremely complex entities, including all living organisms in an area (biotic factors) together with its physical environment (abiotic factors). Thus the specific impact of a substance on the various components of the ecosystem is particularly difficult to assess, as all potential relationships should be addressed. This is the role of impact assessments: the identification and quantification of the effects produced by pollutants or burdens on different elements of the ecosystem. It is important because only those impacts that can be quantified can be compared and reduced.

Results from an environmental impact assessment could be used to reduce the environmental impacts in energy systems cycles. Also, those results should allow the design of more sustainable energy technologies, and provide clear and consistent data in order to define more environmentally respectful national and international policies. For all these reasons, the use of suitable methodologies capable of quantifying in a clear and comparable way the environmental impacts becomes essential.

This chapter describes the LCA methodology and, based on relevant European studies, shows the emissions and environmental impacts derived from electricity production from onshore and offshore wind farms throughout the whole life cycle. Also, the avoided emissions and environmental impacts achieved by wind electricity compared to the other fossil electricity generation technologies have been analysed.

The Concept of Life-Cycle Assessment

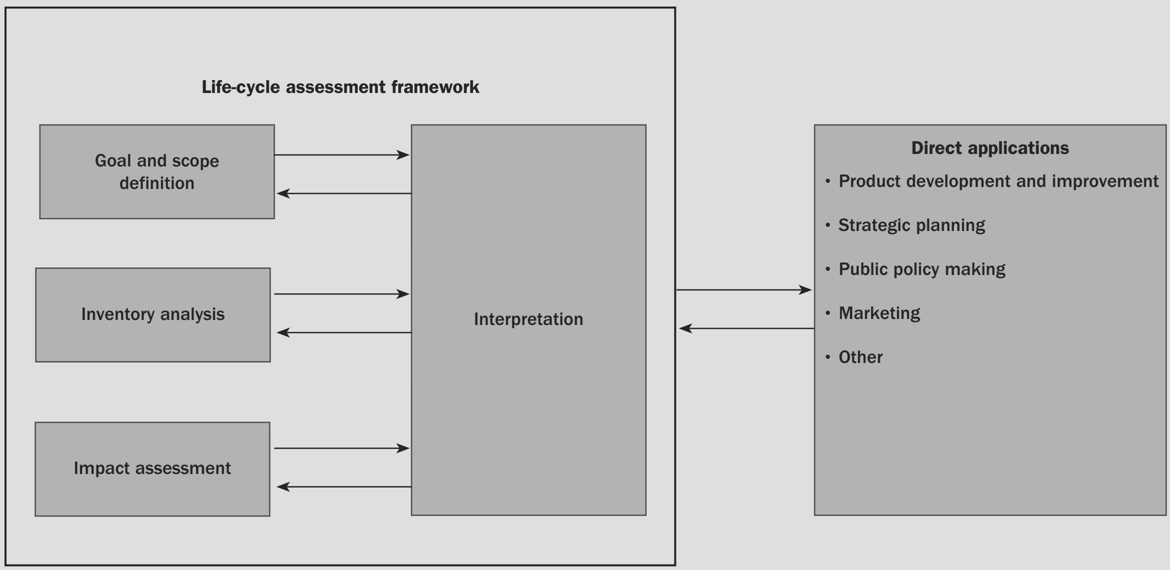
Life-cycle assessment (LCA) is an objective process to evaluate the environmental burdens associated with a product, process or activity by identifying energy and materials used and wastes released to the environment and to evaluate and implement opportunities to effect environmental improvements (ISO, 1999).

The assessment includes the entire life cycle of the product, process or activity, encompassing extracting and processing raw materials; manufacturing, transportation and distribution; use, reuse and maintenance; recycling; and final disposal (the so-called ‘cradle to grave’ concept).

According to the ISO 14040 and 14044 standards, an LCA is carried out in four phases:

1. goal and scope definition;
2. inventory analysis: compiling the relevant inputs and outputs of a product system;
3. impact assessment: evaluating the potential environmental impacts associated with those inputs and outputs; and
4. interpretation: the procedure to identify, qualify, check and evaluate the results of the inventory analysis and impact assessment phases in relation to the objectives of the study.

Figure V.1.1: Conceptual framework on LCA



Source: ISO 14040

In the phase dealing with the goal and scope definition, the aim, the breadth and the depth of the study are established. The inventory analysis (also called life-cycle inventory – LCI), is the phase of LCA involving the compilation and quantification of inputs and outputs for a given product system throughout its life cycle. LCI establishes demarcation between what is included in the product system and what is excluded. In LCI, each product, material or service should be followed until it has been translated into elementary flows (emissions, natural resource extractions, land use and so on).

The third phase, life-cycle impact assessment, aims to understand and evaluate the magnitude and significance of the potential environmental impacts of a product system. This phase is further divided into four steps. The first two steps are termed classification and characterisation, and impact potentials are calculated based on the LCI results. The next steps are normalisation and weighting, but these are both voluntary according to the ISO standard. Normalisation provides a basis for comparing different types of environmental impact categories (all impacts get the same unit). Weighting implies assigning a weighting factor to each impact category depending on the relative importance.

The two first steps (classification and characterisation) are quantitative steps based on scientific knowledge of the relevant environmental processes, whereas normalisation and valuation are not technical, scientific or objective processes, but may be assisted by applying scientifically based analytical techniques.

Impact Categories

The impact categories (ICs) represent environmental issues of concern to which LCI results may be assigned. The ICs selected in each LCA study have to describe the impacts caused by the products being considered or the product system being analysed. The selection of the list of ICs has to fulfil several conditions (Lindfors et al., 1995):

- The overall recommendation regarding the choice of ICs is to include all the ICs for which international consensus have been reached.
- The list should not contain too many categories.
- Double counting should be avoided by choosing independent ICs.
- The characterisation methods of the different ICs should be available.

Some baseline examples considered in most of the LCA studies are illustrated in Table V.1.1.

As there is no international agreement on the different approaches regarding ICs, different methods are applied in current LCAs. Moreover, some studies do not analyse all the ICs described in the previous table, while others use more than the previous impact categories mentioned.

LCA in Wind Energy: Environmental Impacts through the Whole Chain

The LCA approach provides a conceptual framework for a detailed and comprehensive comparative evaluation of environmental impacts as important sustainability indicators.

Table V.1.1: Baseline examples

Impact category	Category indicator	Characterisation model	Characterisation factor
Abiotic depletion	Ultimate reserve, annual use	Guinee and Heijungs 95	ADP[9]
Climate change	Infrared radiative forcing	IPCC model[3]	GWP[10]
Stratospheric ozone depletion	Stratospheric ozone breakdown	WMO model[4]	ODP[11]
Human toxicity	PDI/ADI[1]	Multimedia model, e.g. EUSES[5], CalTox	HTP[12]
Ecotoxicity (aquatic, terrestrial, etc)	PEC/PNEC[2]	Multimedia model, e.g. EUSES, CalTox	AETP[13], TETP[14], etc
Photo-oxidant formation	Tropospheric ozone formation	UNECE[6] Trajectory model	POCP[15]
Acidification	Deposition critical load	RAINS[7]	AP[16]
Eutrophication	Nutrient enrichment	CARMEN[8]	EP[17]

Source: CIEMAT

[1] PDI/ADI Predicted daily intake/Aceptable daily intake
[2] PEC/PNEC Predicted environmental concentrations/Predicted no-effects concentrations
[3] IPCC Intergovernmental Panel on Climate Change
[4] WMO World Meteorological Organization
[5] EUSES European Union System for the Evaluation of Substances
[6] UNECE United Nations Economic Commission For Europe
[7] RAINS Regional Acidification Information and Simulation
[8] CARMEN Cause Effect Relation Model to Support Environmental Negotiations
[9] ADP Abiotic depletion potential
[10] GWP Global warming potential
[11] ODP Ozone depletion potential
[12] HTP Human toxicity potential
[13] AETP Aquatic ecotoxicity potential
[14] TETP Terrestrial ecotoxicity potential
[15] POCP Photochemical ozone creation potential
[16] AP Acidification potential
[17] EP Eutrophication potential

Recently, several LCAs have been conducted to evaluate the environmental impact of wind energy. Different studies may use different assumptions and methodologies, and this could produce important discrepancies in the results among them. However, the comparison with other sources of energy generation can provide a clear picture about the environmental comparative performance of wind energy.

An LCA considers not only the direct emissions from wind farm construction, operation and dismantling, but also the environmental burdens and resources requirement associated with the entire lifetime of all relevant upstream and downstream processes within the energy chain. Furthermore, an LCA permits quantifying the contribution of the different life stages of a wind farm to the priority environmental problems.

Wind energy LCAs are usually divided into five phases:

1. **Construction** comprises the raw material production (concrete, aluminium, steel, glass fibre and so on) needed to manufacture the tower, nacelle, hub, blades, foundations and grid connection cables.
2. **On-site erection and assembling** includes the work of erecting the wind turbine. This stage used to be included in the construction or transport phases.
3. **Transport** takes into account the transportation systems needed to provide the raw materials to produce the different components of the wind turbine, the transport of turbine components to the wind farm site and transport during operation.
4. **Operation** is related to the maintenance of the turbines, including oil changes, lubrication and transport for maintenance, usually by truck in an onshore scheme.
5. **Dismantling:** once the wind turbine is out of service, the work of dismantling the turbines and the transportation (by truck) from the erection area to the final disposal site; the current scenario includes recycling some components, depositing inert components in landfills and recovering other material such as lubricant oil.

ONSHORE

Vestas Wind Systems (Vestas, 2005 and 2006) conducted several LCAs of onshore and offshore wind farms based on both 2 MW and 3 MW turbines. The purpose of the LCAs was to establish a basis for assessment of environmental improvement possibilities for wind farms through their life cycles.

Within the framework of the EC project entitled 'Environmental and ecological life cycle inventories for present and future power systems in Europe' (ECLIPSE), several LCAs of different wind farm configurations were performed[1]. The technologies studied in ECLIPSE were chosen to be representative of the most widely used wind turbines. Nevertheless, a wide range of the existing technological choices were studied:

- four different sizes of wind turbines: 600 kW (used in turbulent wind conditions), 1500 kW, 2500 kW and 4500 kW (at the prototype stage);
- a configuration with a gearbox and a direct drive configuration, which might be developed in the offshore context;
- two different kinds of towers: tubular or lattice; and
- different choices of foundations, most specifically in the offshore context.

Within the EC project NEEDS (New energy externalities development for sustainability)[2], life-cycle inventories of offshore wind technology were developed along with several other electricity generating technologies. The wind LCA focused on the present and long-term technological evolution of offshore wind power plants. The reference technology for the present wind energy technology was 2 MW turbines with three-blade upwind pitch regulation, horizontal axis and monopile foundations. An 80-wind-turbine wind farm located 14 km off the coast was chosen as being representative of the contemporary European offshore wind farm.

In the framework of the EC project 'Cost Assessment for Sustainable Energy Systems' (CASES)[3], an estimation of the quantity of pollutants emitted at each production stage per unit of electricity for several electricity generation technologies, among them onshore and offshore wind farms, is performed.

Finally, the Ecoinvent v2.0 database[4] (Frischknecht et al., 2007) includes LCA data of several electricity generation technologies including an onshore wind farm using 800 kW turbines and an offshore wind farm using 2 MW turbines.

LCI Results: Onshore Wind Farms

Results extracted from the above-mentioned LCA studies for onshore wind farms regarding several of the most important emissions are shown in Figure V.1.2. Bars show the variability of the results when several wind farm configurations are considered in a study.

Carbon dioxide emissions vary from 5.6 to 9.6 g/kWh in the consulted references. Methane emissions range from 11.6 to 15.4 mg/kWh. Nitrogen oxides emissions range from 20 to 38.6 mg/kWh. Non-methane volatile organic compounds (NMVOCs) are emitted in quantities that range from 2.2 to 8.5 mg/kWh, particulates range from 10.3 to 32.3 mg/kWh and, finally, sulphur dioxide emissions range from 22.5 to 41.4 mg/kWh. All of these quantities, with the only exception being particulates, are far below the emissions of conventional technologies such as natural gas (see Figure V.1.2).

Another main outcome of all the reviewed studies is that the construction phase is the main contributor to the emissions and hence the environmental impacts. As can be observed in Figure V.1.3, the construction phase causes about 80 per cent of the emissions. The operational stage, including the maintenance and replacement of materials, is responsible for 7–12 per cent of the emissions and the end-of-life stage of the wind farm is responsible for 3–14 per cent.

Regarding the construction stage, Figure V.1.4 shows the contribution of the different components. Important items in the environmental impacts of the

Figure V.1.2: Emissions from the production of 1 kWh in onshore wind farms throughout the whole life cycle

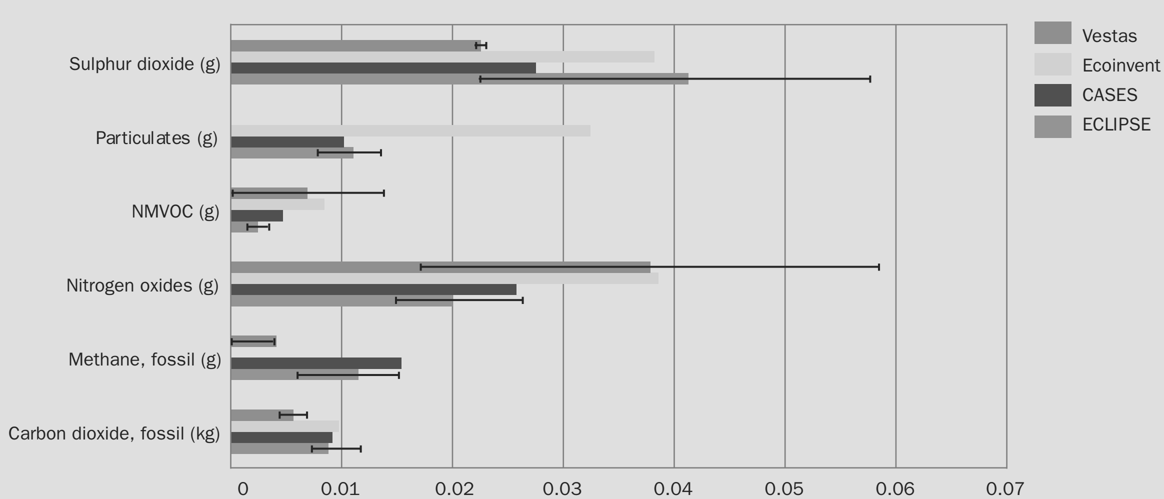
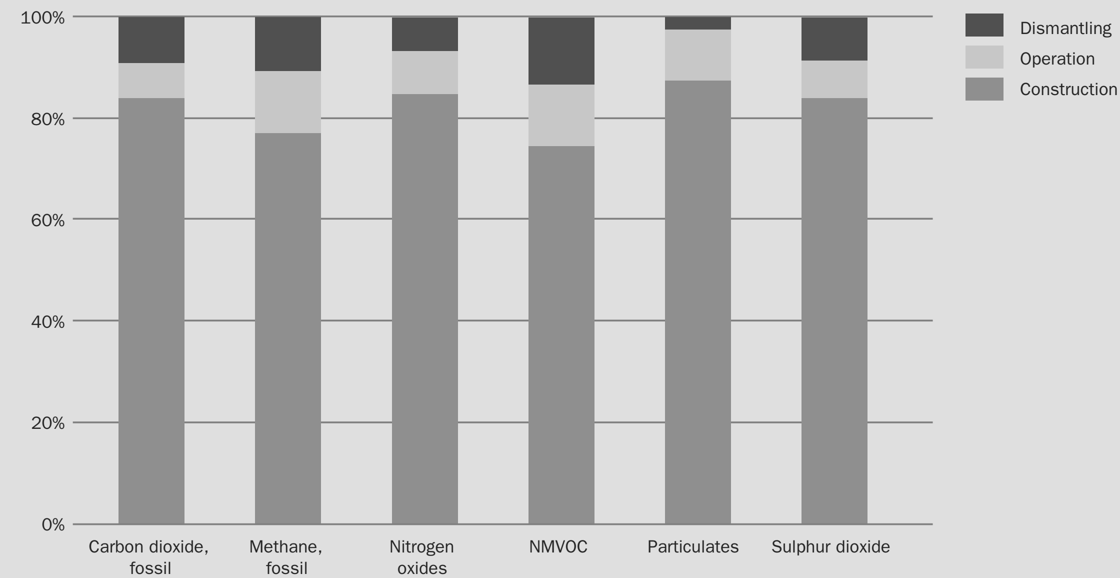
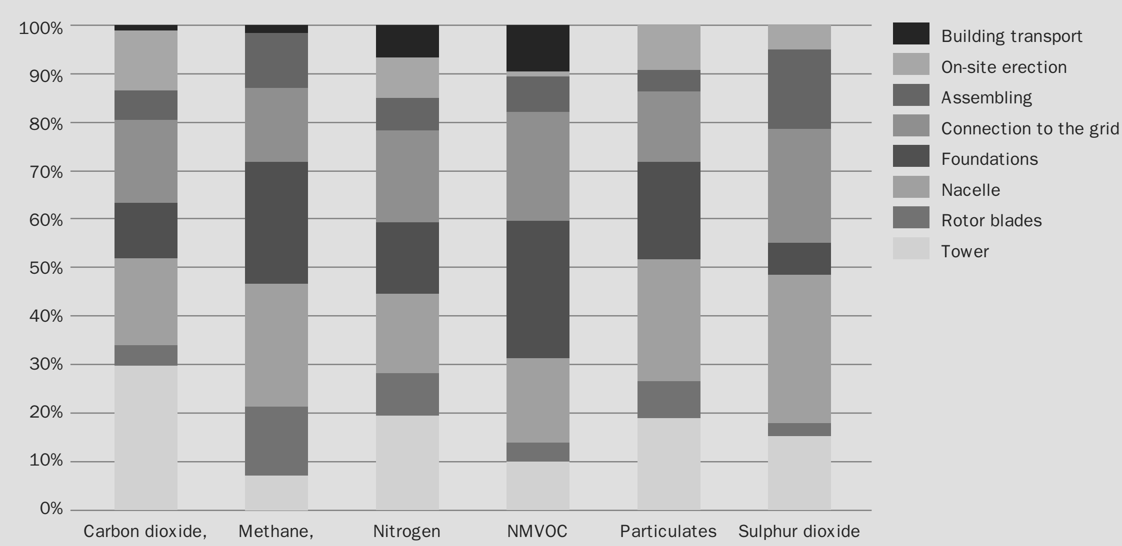


Figure V.1.3: Contribution of the different life-cycle phases to the relevant emissions



Source: Own elaboration using ECLIPSE results

Figure V.1.4: Contribution of the components of the construction phase to the different emissions



Source: Own elaboration based on ECLIPSE results construction phase of an onshore wind farm are the tower and the nacelle but not the rotor blades. Foundations are another important source of emissions, and connection to the grid also contributes an important share. Emissions from transport activities during the construction phase are only relevant in the case of nitrogen oxides (NO_x) and NMVOC emissions.

LCA Results: Onshore Wind Farms

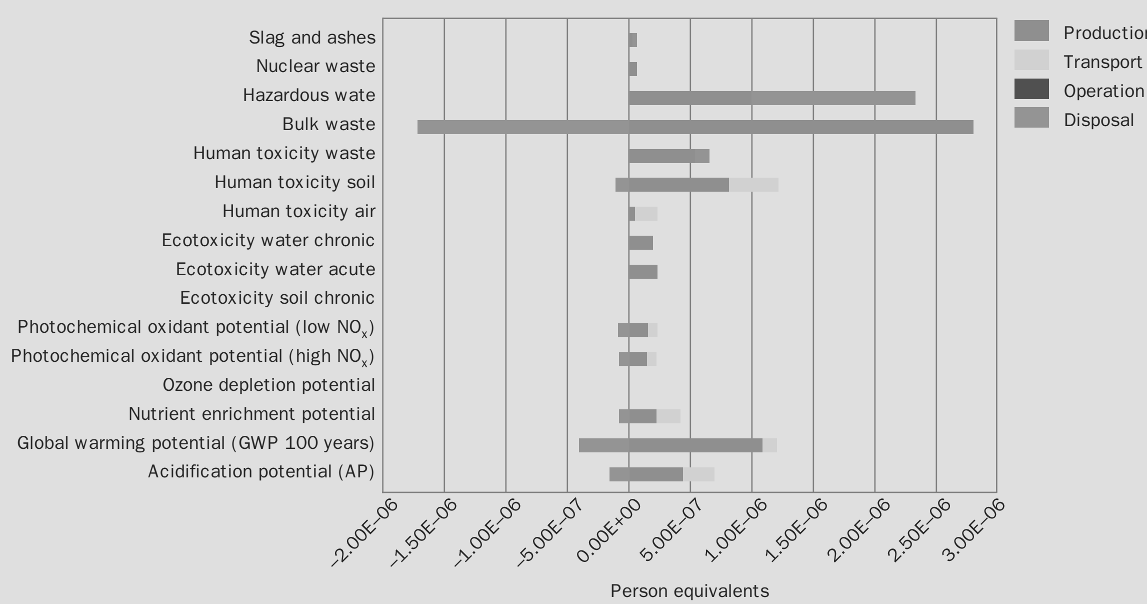
Results of LCAs have shown that wind farm construction is the most crucial phase because it generates the biggest environmental impacts. These impacts are due to the production of raw materials, mostly steel, concrete and aluminium, which are very intensive in energy consumption. The energy production phase from wind is clean because no emissions are released from the turbine. LCAs have also concluded that environmental impacts from the transportation and operation stages are not significant in comparison with the total impacts of the wind energy.

The contribution of the different stages to the ICs selected by the LCA of the Vestas V82 1.65 MW wind turbine is shown in Figure V.1.5.

In the Vestas study, the disposal scenario involves the dismantling and removal phases. Thus negative loads of recycling must be deducted, since some materials are returned to the technosphere. The disposal scenarios considered have great influence on the results.

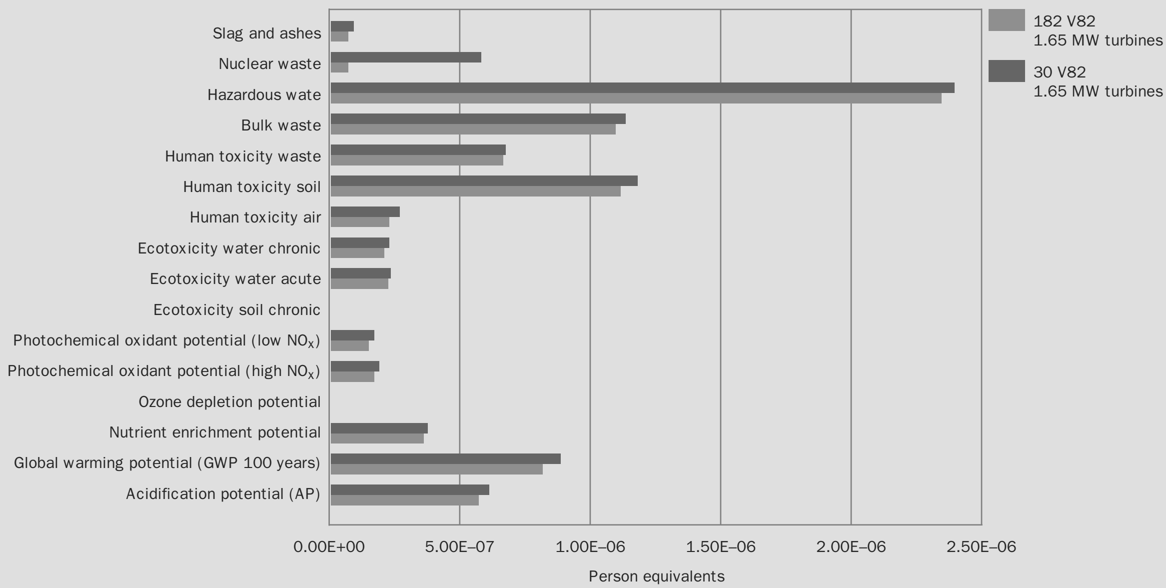
This study evaluated the influence of small- and large-scale wind power plants on the environmental impacts, based on the V82 1.65 MW wind turbine. According to Figure V.1.6, a variation in the size of the wind power plant from 182 to 30 turbines did not

Figure V.1.5: Environmental impacts by stages from 1 kWh



Source: Vestas Wind System A/S

Figure V.1.6: Comparison of environmental impacts between large- and small-scale wind power plants



Source: Vestas Wind System A/S

produce significant changes in the environmental impacts.

OFFSHORE

LCI Results: Offshore Wind Farms

Results extracted from the reviewed LCA studies for offshore wind farms regarding several of the most relevant emissions are shown in Figure V.1.7. Bars show the variability of the results when several wind farm configurations are considered in a single study.

Carbon dioxide emissions vary from 6.4 to 12.3 g/kWh in the consulted references. Methane emissions range from 2.8 to 16.9 mg/kWh. Nitrogen oxides emissions range from 18 to 56.4 mg/kWh. NMVOCs are emitted in quantities that range from 1.7 to 11.4 mg/kWh, particulates range from 10.5 to 54.4 mg/kWh and, finally, sulphur dioxide emissions range from 22.1 to 44.7 mg/kWh. All of these quantities are quite similar to those obtained for onshore wind farms, with the only exception being that particulates are far below the emissions of conventional technologies such as natural gas (see Figure V.1.7).

In Figure V.1.8, the contribution of different life-cycle phases to the emissions is depicted. In an offshore context, the contribution of the construction phase is even more important, accounting for around 85 per cent of the emissions and hence of the impacts.

Within the construction stage, Figure V.1.9 shows the contribution of the different components. Important items in the environmental impacts of the construction phase of an offshore wind farm are the nacelle and the foundations, followed by the tower. The rotor blades are not found to play an important part. Emissions from transport activities during construction phase are quite relevant in the case of NO_x and NMVOCs emissions.

Figure V.1.7: Emissions from the production of 1 kWh in offshore wind farms throughout the whole life cycle

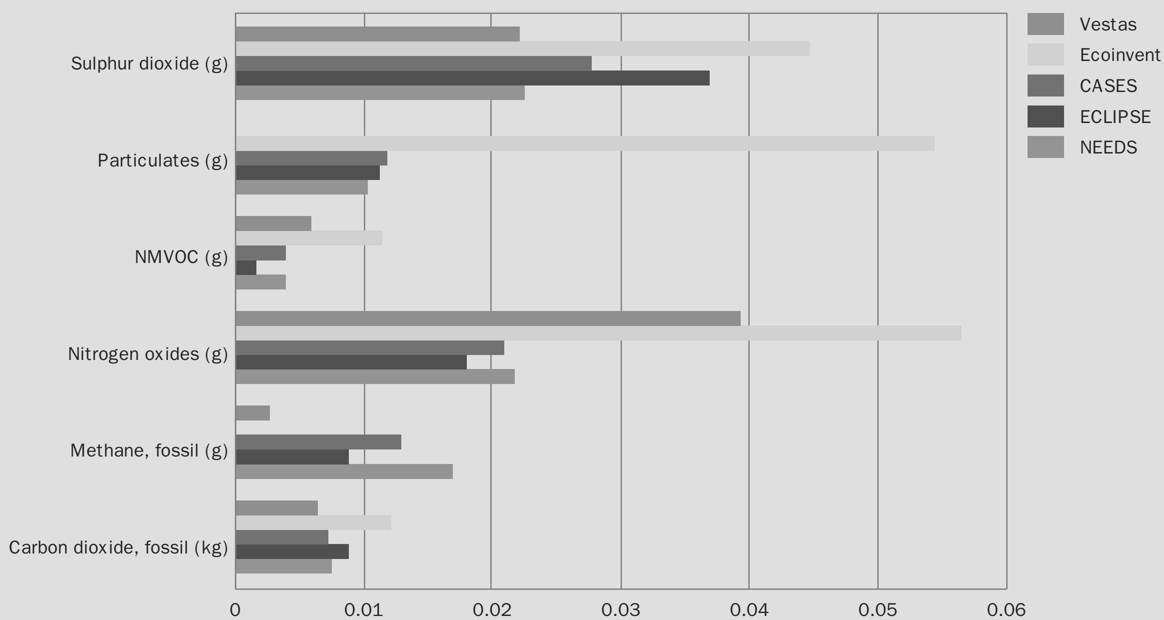
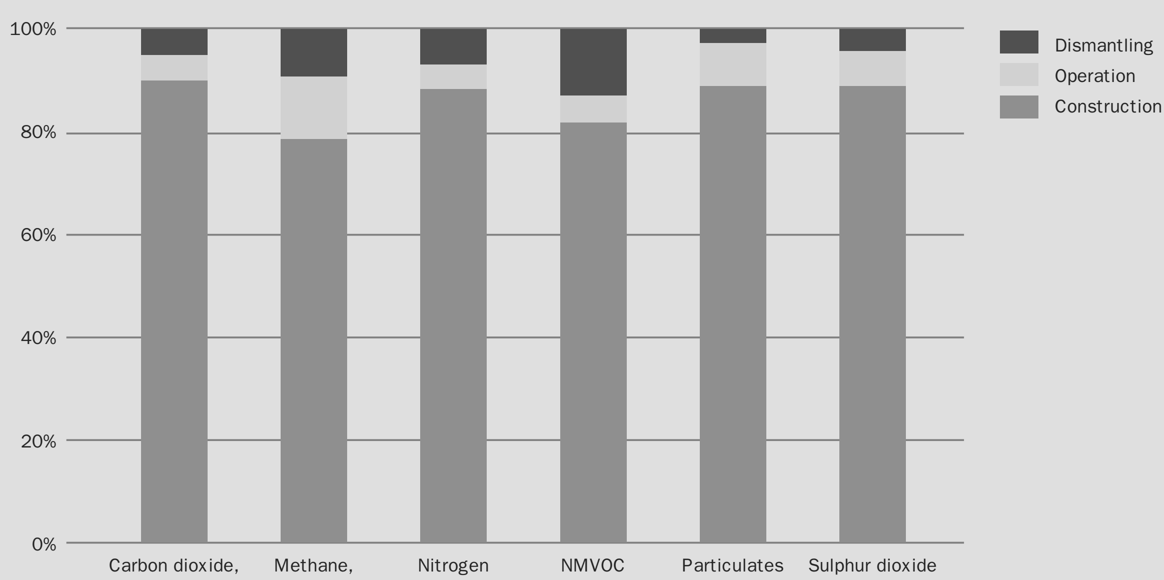
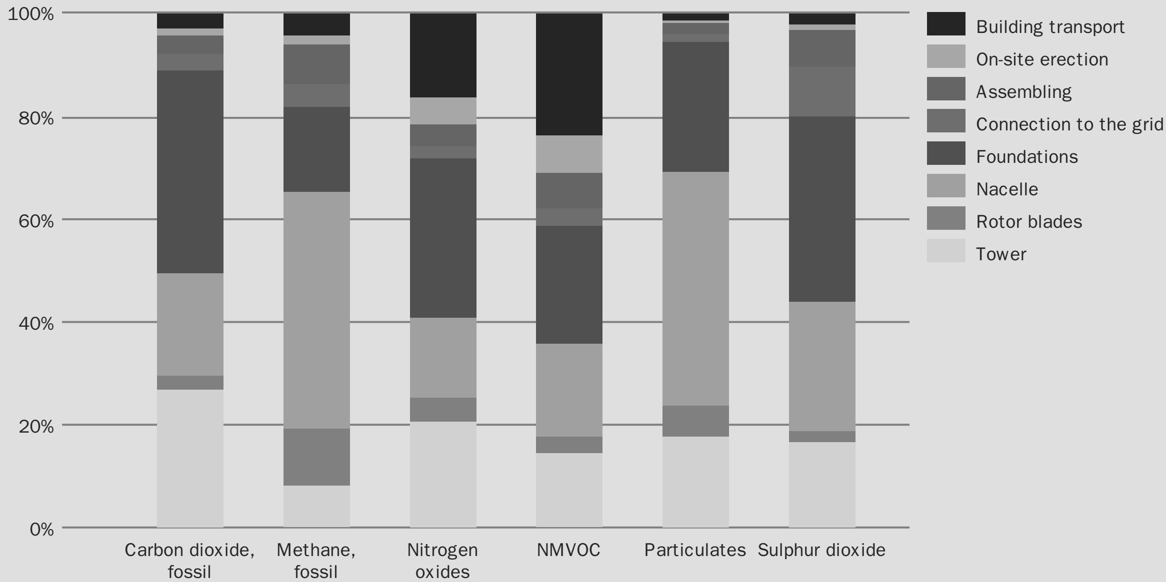


Figure V.1.8: Contribution of the different life-cycle phases of an offshore wind farm to the relevant emissions



Source: Own elaboration using ECLIPSE results

Figure V.1.9: Contribution of the components of the construction phase to the different emissions



Source: Own elaboration using ECLIPSE results

LCA Results: Offshore Wind Farms

As far as offshore technology is concerned, Vestas Wind Systems A/S and Tech-wise A/S, on behalf of Elsam A/S, have developed a project titled 'LCA and Turbines'. The goal of the project was to create a life-cycle model for a large Vestas offshore turbine. Based on this offshore model, an analysis was carried out to identify the most significant environmental impacts of a turbine during its life cycle (Elsam-Vestas, 2004). Environmental impacts are shown in Figure V.1.10.

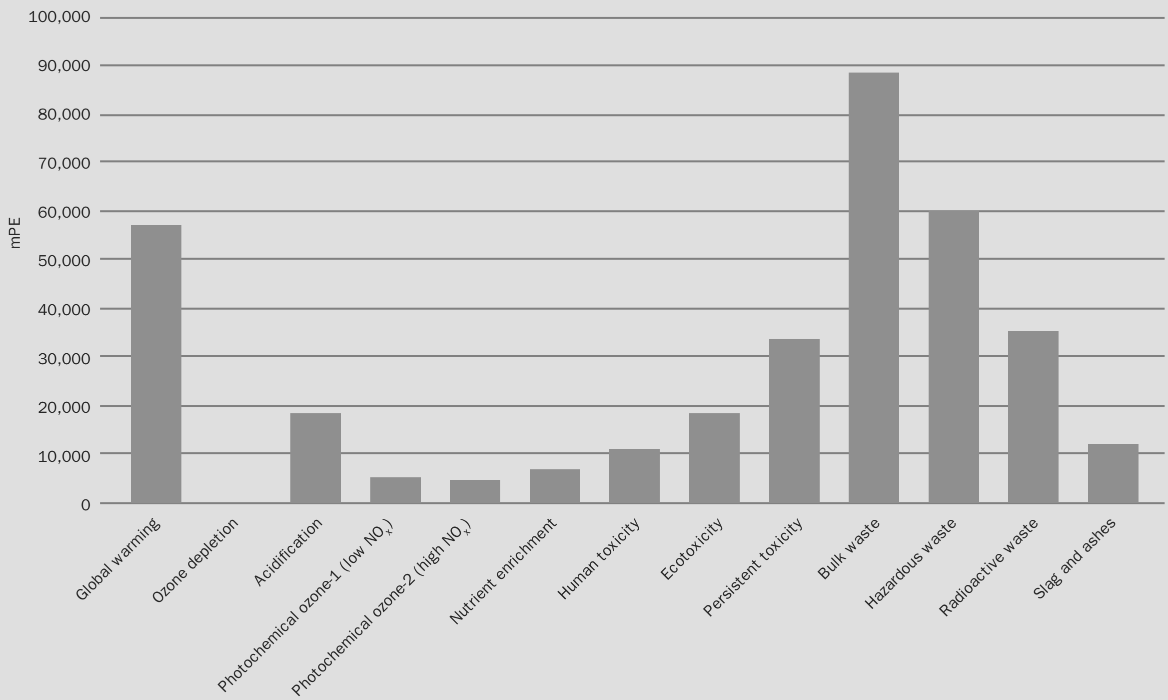
Results showed that the volume of waste is the largest normalised impact from a turbine. The bulk of waste is produced during the manufacturing phase, primarily from the steel production needed for the foundation and the tower.

The environmental impacts of the life phases and component systems are illustrated in Figure V.1.11. The largest environmental impacts are found in the manufacturing phase. The disposal scenario also makes a very important contribution to the entire environmental impact. In the disposal scenario, about 90 per cent of the steel and iron could be recycled, while 95 per cent of the copper could be recycled. With less recycling, there is more waste. The other two life phases (operation and removal) do no contribute significantly to the environmental impacts.

The environmental impacts produced from the manufacturing phase by components shows that the foundation has the highest contribution to several impact categories. Tower and nacelle manufacturing also have a significant contribution. The impacts distribution is showed in Figure V.1.12.

A comparison between the onshore and offshore impact of the same wind turbine (a Vestas V90 3.0 MW) was carried out by Vestas (Vestas, 2005) (see Figure V.1.13). Results of this LCA show similar environmental profiles in both cases. Offshore wind turbines

Figure V.1.10: Environmental impacts of Vestas 2.0 MW



Source: Vestas Wind System A/S

produce more electricity (11,300–14,800 MWh/turbine) than onshore wind turbines (6900–9100 MWh/turbine). However, offshore turbines are more resource demanding. Thus these two parameters are offset in some cases.

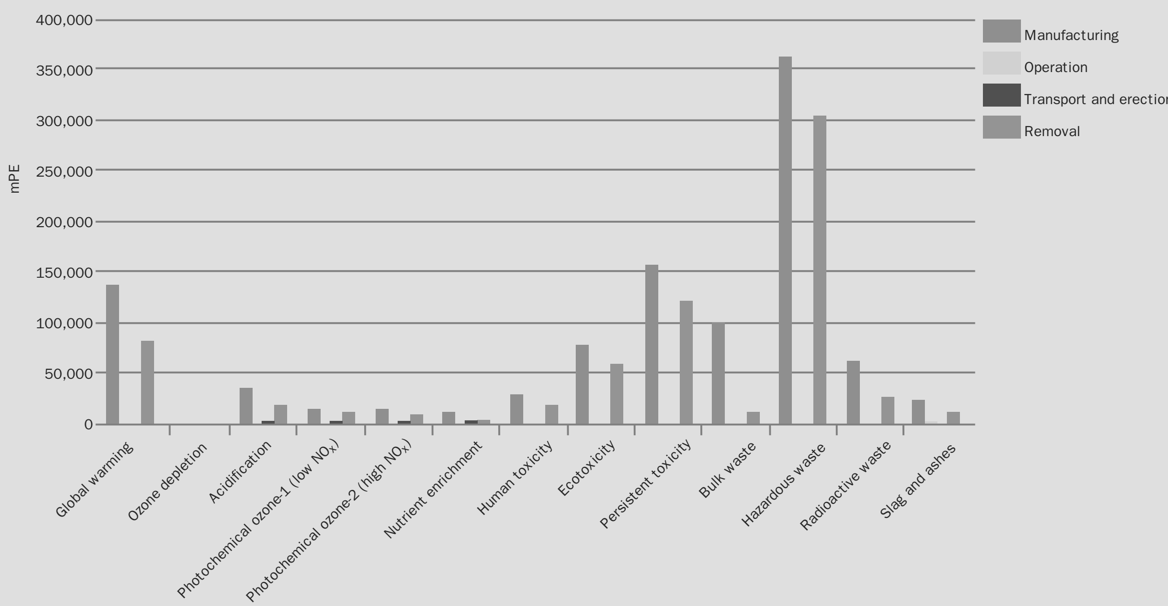
Energy Balance Analysis

The energy balance is an assessment of the relationship between the energy consumption of the product and the energy production throughout the lifetime. The energy balance analysis in the case of the Vestas V90 3.0 MW shows that, for an offshore wind turbine, 0.57 years (6.8 months) of expected average energy production are necessary to recover all the energy consumed for manufacturing, operation, transport, dismantling and disposal.

As far as an onshore wind turbine is concerned, the energy balance is similar but shorter than the offshore one, with only 0.55 years (6.6 months) needed to recover the energy spent in all the phases of the life cycle. This difference is due to the larger grid transmission and steel consumption for the foundations in an offshore scheme.

The V80 2 MW turbines installed in Horns Rev only needed 0.26 years (3.1 months) to recover the energy spent in the offshore installation. The same turbines installed in the Tjaereborg onshore wind farm had an energy payback period of about 0.27 years (3.2 months).

Figure V.1.11: Contribution of environmental impacts by life-cycle stages: Vestas 2.0 MW



Source: Vestas Wind System A/S

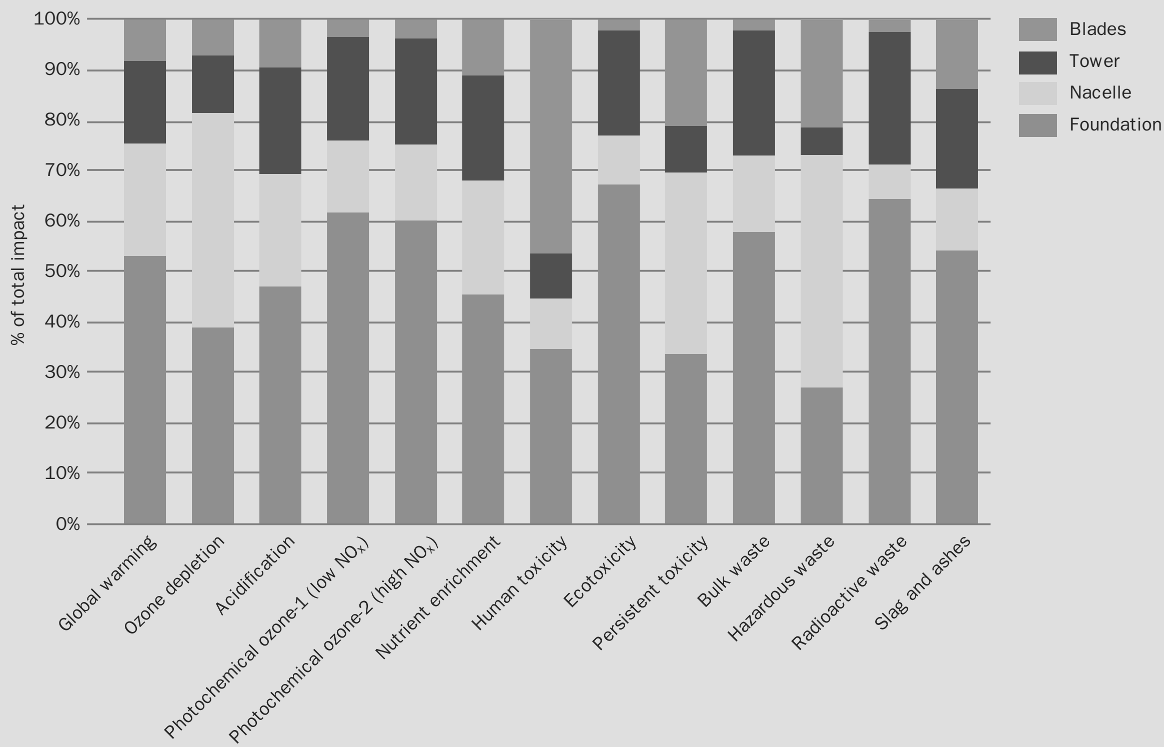
Comparative Benefits with Conventional and Renewable Technologies Systems

Several studies have been conducted by different institutions and enterprises in order to quantify the environmental impacts of energy systems. The Vestas study[5] also analysed the environmental impacts produced by average European electricity in 1990, using data from the Danish method for environmental design of industrial products (EDIP) database, compared with the electricity generated by an offshore wind power plant and an onshore wind power plant. The reason for using data from 1990 is that the EDIP database did not include reliable updated data. The comparison shows that wind electricity has a much better environmental profile than the average Danish electricity for the year of the project. The impacts are considerably lower in the case of wind energy than European electricity in all the analysed impacts categories. However, the comparison is not quite fair, as the system limits of the two systems differ from each other (current data for wind turbines and 1990 data for European electricity). The comparison was made to see the order of magnitude (See Figure V.1.14).

Vattenfall Nordic Countries have carried out LCAs of its electricity generation systems. The results of the study showed that:

- Construction is the most polluting phase for technologies that do not require fuel, but instead use a renewable source of energy (hydro, wind and solar power).
- The operational phase dominates for all fuel-burning power plants, followed by fuel production.
- Wind energy generates low environmental impact in all the parameters analysed: CO_2, NO_x, SO_2 and

Figure V.1.12: Contribution of the components of the construction phase to the different impacts



Source: Vestas Wind System A/S

particulate matter emissions and radioactive waste. Only the use of copper from mines presents a significant impact.

- The demolition/dismantling phase causes a comparatively low impact since, for example, metals and concrete can be recycled.

AVOIDED EMISSIONS

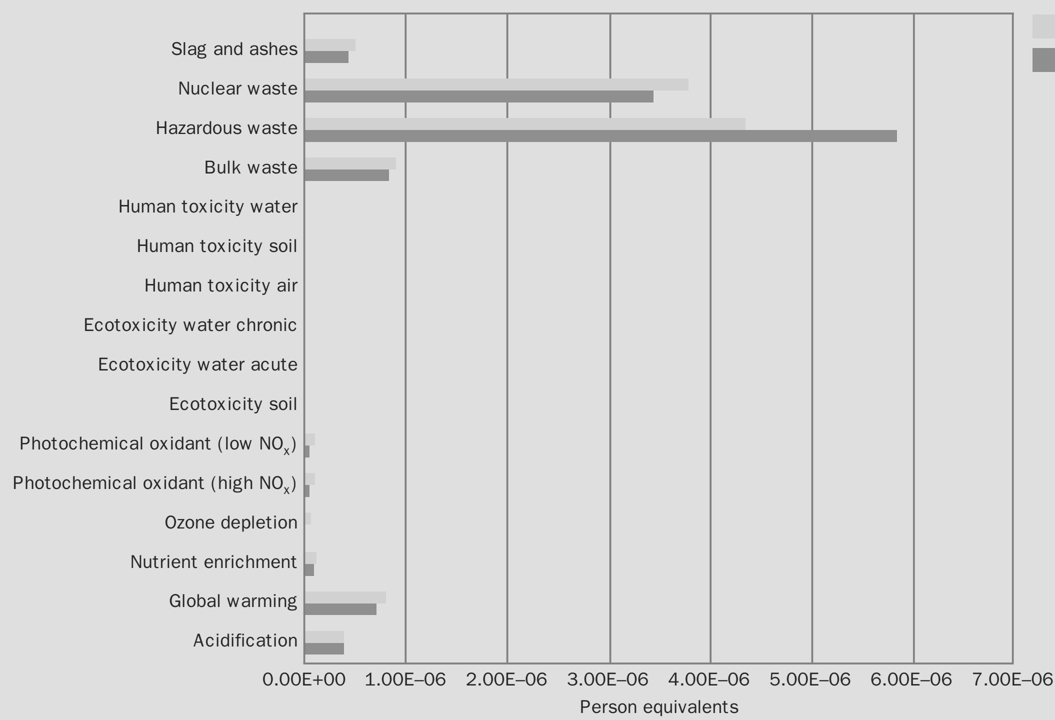
Environmental benefits of wind electricity can be assessed in terms of avoided emissions compared to other alternative electricity generation technologies.

LCI results for some relevant emissions from electricity production in a coal condensing power plant and in a natural gas combined cycle power plant are shown in Figure V.1.15, compared with the results obtained for onshore and offshore wind energy.

As observed in Figure V.1.15, emissions produced in the life cycle of wind farms are well below those produced in competing electricity generation technologies such as coal and gas. The only exception is the emissions of particles in the natural gas combined cycle (NGCC), which are of the same order of those from wind farms in the whole life cycle.

Emissions avoided using wind farms to produce electricity instead of coal or natural gas power plants are quantified in Tables V.1.2 and V.1.3.

Figure V.1.13: Onshore/offshore comparison of environmental impacts

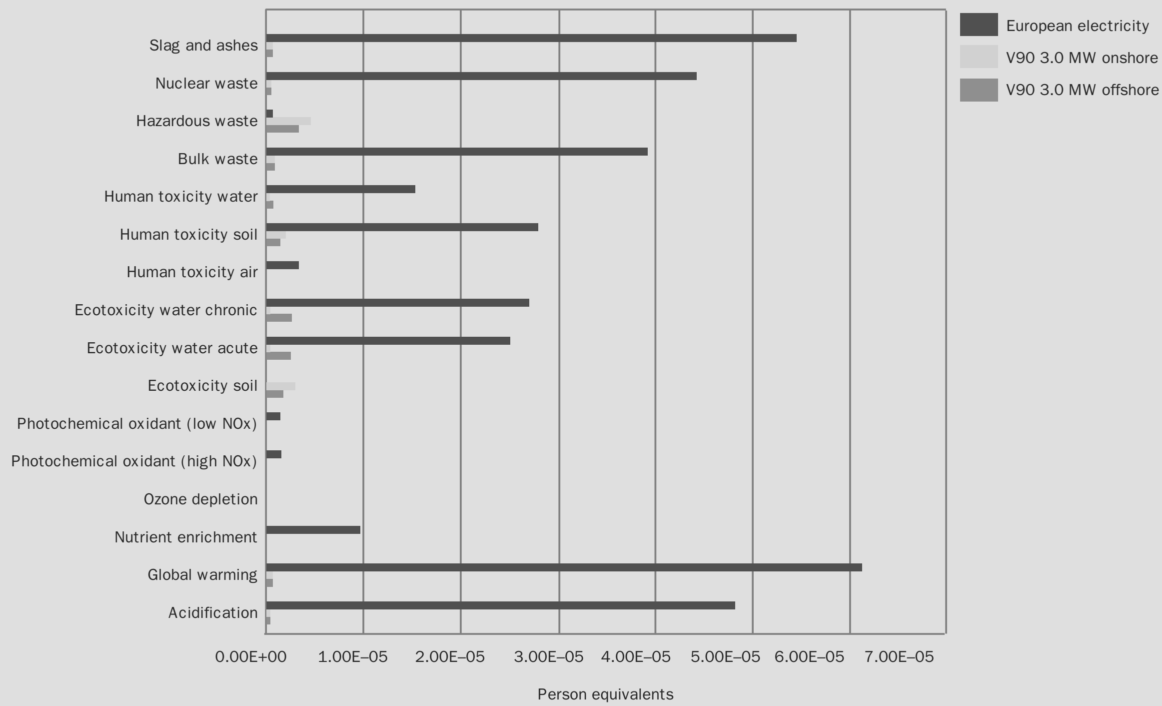


Source: Vestas Wind System A/S

Results show that as much as 828 g of CO_2 can be avoided per kWh produced by wind instead of coal, and 391 g of CO_2 per kWh in the case of natural gas. Quite significant nitrogen and sulphur oxides and NMVOC emission reductions can also be obtained by substituting coal or gas with wind energy.

As in the case of fossil energies, wind energy results show in general lower emissions of CO_2, methane, nitrogen and sulphur oxides, NMVOCs and particulates than other renewable sources. In this sense, it is possible to obtain avoided emissions, using wind (onshore and offshore) technologies in the power generation system.

Figure V.1.14: Onshore, offshore and electricity system comparison on environmental impacts



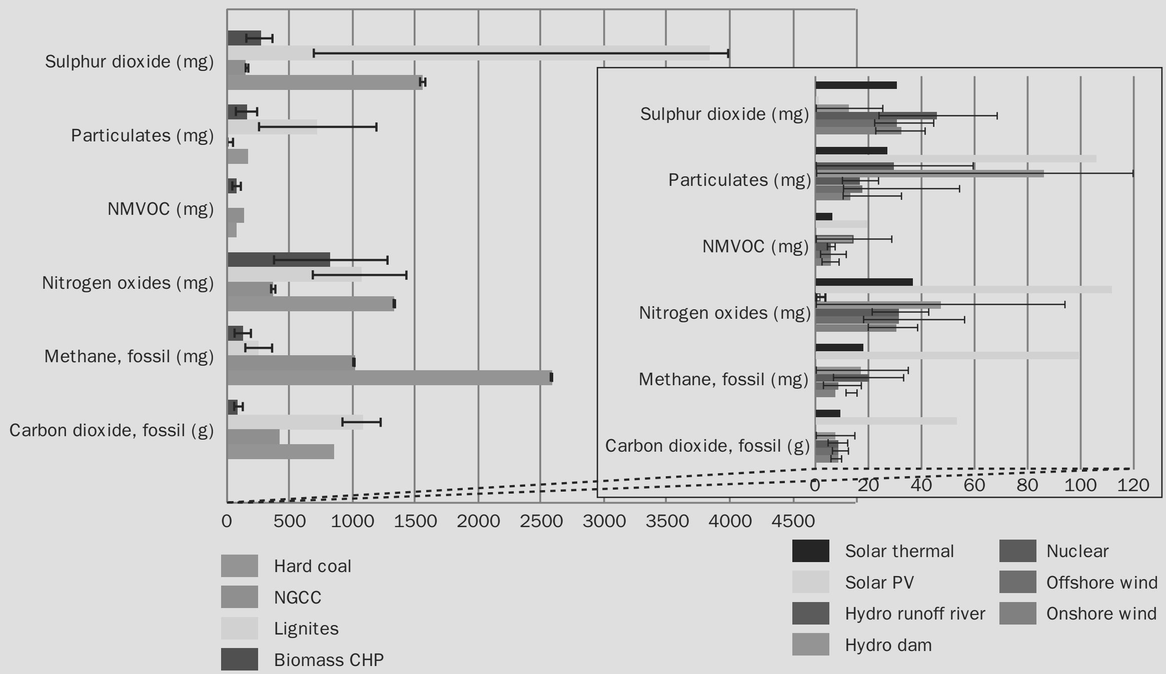
Source: Vestas Wind System A/S

Conclusions

LCA methodology provides an understandable and consistent tool to evaluate the environmental impact of the different phases of wind plant installations. LCA estimates the benefits of electricity from renewable energy sources compared to conventional technologies in a fully documented and transparent way.

The construction of the wind turbine is the most significant phase in terms of the environmental impacts produced by wind energy, both for offshore wind power plants and onshore wind power plants. Environmental

Figure V.1.15: Comparison of the emissions produced in the generation of 1 kWh in a coal and a natural gas combined cycle power plant and the emissions produced in an onshore and offshore wind farm



Source: Results from CASES, Ecoinvent and NEEDS for the coal and natural gas power plants

Table V.1.2: Emissions of relevant pollutants produced by wind electricity and coal and natural gas electricity in the whole life cycle, and benefits of wind versus coal and natural gas

	Emissions						Benefits		
	Onshore wind	**Offshore wind**	**Average wind**	**Hard coal**	**Lignite**	**NGCC**	**vs. coal**	**vs. Lignite**	**vs. NGCC**
Carbon dioxide, fossil (g)	8	8	8	836	1060	400	828	1051	391
Methane, fossil (mg)	8	8	8	2554	244	993	2546	236	984
Nitrogen oxides (mg)	31	31	31	1309	1041	353	1278	1010	322
NMVOC (mg)	6	5	6	71	8	129	65	3	123
Particulates (mg)	13	18	15	147	711	12	134	693	–6
Sulphur dioxide (mg)	32	31	32	1548	3808	149	1515	3777	118

Source: CIEMAT

Table V.1.3: Emissions and benefits of relevant pollutants produced by wind electricity and other renewable energies

	Emissions					Benefits			
	Average wind	Nuclear	Solar PV	Solar thermal	Biomass CHP	vs. Nuclear	vs. Solar PV	vs. Solar thermal	vs. Biomass CHP
Carbon dioxide, fossil (g)	8	8	53	9	83	0	45	1	75
Methane, fossil (mg)	8	20	100	18	119	12	92	10	111
Nitrogen oxides (mg)	31	32	112	37	814	1	81	6	784
NMVOC (mg)	6	6	20	6	66	0	14	1	60
Particulates (mg)	15	17	107	27	144	1	91	12	128
Sulphur dioxide (mg)	32	46	0	31	250	15	–31	–1	218

Source: CIEMAT

impacts generated in the transportation and operation phases cannot be considered significant in relation to the total environmental impacts of either offshore or onshore wind power plants. However, in offshore wind power plants, zinc is discharged from offshore cables during the operational stage.

The disposal scenario has great importance for the environmental profile of the electricity generated from wind power plants. Environmental impacts are directly dependent on the recycling level, with a higher amount of recycling resulting in a better environmental result.

The energy balance of wind energy is very positive. The energy consumed in the whole chain of wind plants is recovered in several average operational months. The comparison of wind energy with conventional technologies highlights the environmental advantages of wind energy. Quite significant emissions reductions can be obtained by producing electricity in wind farms instead of using conventional technologies such as coal and natural gas combined cycle power plants.

The significant benefits of wind energy should play an increasingly important role in deciding what kinds of new power plants will be built.

V.2 ENVIRONMENTAL IMPACTS

The energy supply is still dominated by fossil fuels, which contribute to the main environmental problems at the world level: climate change and air pollution. The use of renewable energies means lower greenhouse gas emissions and reduced air pollution, representing a key solution to reach a sustainable future.

Wind is clean, free, indigenous and inexhaustible. Wind turbines do not need any type of fuel, so there are no environmental risks or degradation from the exploration, extraction, transport, shipment, processing or disposal of fuel. Not only is generation produced with zero emissions of carbon dioxide (during the operational phase) but it also does not release toxic pollutants (for example mercury) or conventional air pollutants (for example smog-forming nitrogen dioxide and acid rain-forming sulphur dioxide). Furthermore, the adverse impacts caused by mountain-top mining and strip mining of coal, including acid mine drainage and land subsidence are avoided, and the negative effects of nuclear power, including radioactive waste disposal, security risks and nuclear proliferation risks, are not created. Finally, wind power can have a long-term positive impact on biodiversity by reducing the threat of climate change – the greatest threat to biodiversity.

At the same time, however, the construction and operation of both onshore and offshore wind turbines can result in negative local environmental impacts on birds and cetaceans, landscapes, sustainable land use (including protected areas), and the marine environment. The negative environmental impacts from wind energy installations are much lower in intensity than those produced by conventional energies, but they still have to assessed and mitigated when necessary.

EU Directive 85/337 defines environmental impact assessment (EIA) as the procedure which ensures that environmental consequences of projects are identified and assessed before authorisation is given. The main objective is to avoid or minimise negative effects from the beginning of a project rather than trying to counteract them later. Thus the best environmental policy consists of preventing pollution or nuisances at source so the environment is not damaged. The procedure requires the developer to compile an environmental statement (ES) describing the likely significant effects of the development on the environment and proposed mitigation measures. The ES must be circulated to statutory consultation bodies and made available to the public for comment. Its contents, together with any comments, must be taken into account by the competent authority (for example local planning authority) before it may grant consent.

A strategic environmental assessment (SEA) is the procedure used to evaluate the adverse impacts of any plans and programmes on the environment. National, regional and local governments must undertake SEAs of all wind energy plans and programmes that have the potential for significant environmental effects. Appropriate assessments (AAs) have to be carried out in accordance with the Habitats Directive to evaluate the effects on a Natura 2000 site. Where potential trans-boundary effects are foreseen, international cooperation with other governments should be sought. SEAs should be used to inform strategic site selection for renewable energy generation and identify the information requirements for individual EIAs.

Worldwide, biodiversity loss is in principle caused because of human activities on the environment (such as intensive production systems, construction and extractive industries), global climate change, invasions of alien species, pollution and over-exploitation of natural resources. In 2005 the transportation and energy (DG TREN) and environment (DG ENV) directorates at the European Commission created an ad hoc working group on wind energy and biodiversity. The group is composed of industry, governmental and non-governmental representatives. A draft guidance document is currently being debated and aims at facilitating the development of wind energy while preserving biodiversity.

Onshore

VISUAL IMPACT

The landscape is a very rich and complex concept. Defining landscape is not an easy task, as is made clear by the high number of definitions that exist. Landscape definitions can be found in different fields like art, geography, natural sciences, architecture or economics. According to the European Landscape Convention, landscape means an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors. Landscapes are not static. The landscape is changing over time according to human and ecological development.

Landscape perceptions and visual impacts are key environmental issues in determining wind farm applications related to wind energy development as landscape and visual impacts are by nature subjective and changing over time and location.

Wind turbines are man-made vertical structures with rotating blades, and thus have the potential of attracting people's attention. Typically wind farms with several wind turbines spread on the territory may become dominant points on the landscape.

The characteristics of wind developments may cause landscape and visual effects. These characteristics include the turbines (size, height, number, material and colour), access and site tracks, substation buildings, compounds, grid connection, anemometer masts, and transmission lines. Another characteristic of wind farms is that they are not permanent, so the area where the wind farm has been located can return to its original condition after the decommissioning phase.

Landscape and visual assessment is carried out differently in different countries. However, within the EU, most wind farms are required to carry out an EIA. The EIA shall identify, describe and assess the direct and indirect effects of the project on the landscape. Some of the techniques commonly used to inform the landscape and visual impact assessment are:

- zone of theoretical visibility (ZTV) maps define the areas from which a wind plant can be totally or partially seen as determined by topography; these areas represent the limits of visibility of the plant;
- photographs to record the baseline visual resource;
- diagrams to provide a technical indication of the scale, shape and positioning of the proposed wind development; and
- photomontages and video-montages to show the future picture with the wind farm installed.

Visual impact decreases with the distance. The ZTV zones can be defined as:

- Zone I – Visually dominant: the turbines are perceived as large scale and movement of blades is obvious. The immediate landscape is altered. Distance up to 2 km.
- Zone II – Visually intrusive: the turbines are important elements on the landscape and are clearly perceived. Blades movement is clearly visible and can attract the eye. Turbines not necessarily dominant points in the view. Distance between 1 and 4.5 km in good visibility conditions.
- Zone III – Noticeable: the turbines are clearly visible but not intrusive. The wind farm is noticeable as an element in the landscape. Movement of blades is visible in good visibility conditions but the turbines appear small in the overall view. Distance between 2 and 8 km depending on weather conditions.
- Zone IV – Element within distant landscape: the apparent size of the turbines is very small. Turbines are like any other element in the landscape. Movement of blades is generally indiscernible. Distance of over 7 km.

While visual impact is very specific to the site at a particular wind farm, several characteristics in the design and siting of wind farms have been identified to minimise their potential visual impact (Hecklau, 2005; Stanton, 2005; Tsoutsos et al., 2006):

- similar size and type of turbines on a wind farm or several adjacent wind farms;
- light grey, beige and white colours on turbines;
- three blades;
- blades rotating in the same direction;
- low number of large turbines is preferable to many smaller wind turbines; and
- flat landscapes fit well with turbine distribution in rows.

Mitigation measures to prevent and/or minimise visual impact from wind farms on landscape can be summarised as follows (Brusa and Lanfranconi, 2007):

- design of wind farm according to the peculiarities of the site and with sensitivity to the surrounding landscape;
- locate the wind farm at least a certain distance from dwellings;
- selection of wind turbine design (tower, colour) according to landscape characteristics;
- selection of neutral colour and anti-reflective paint for towers and blades;
- underground cables; and
- lights for low-altitude flight only for more exposed towers.

The effects of landscape and visual impact cannot be measured or calculated and mitigation measures are limited. However, experience gained recently suggests that opposition to wind farms is mainly encountered during the planning stage. After commissioning the acceptability is strong.

NOISE IMPACT

Noise from wind developments has been one of the most studied environmental impacts of this technology. Noise, compared to landscape and visual impacts, can be measured and predicted fairly easily.

Wind turbines produce two types of noise: mechanical noise from gearboxes and generators, and aerodynamic noise from blades. Modern wind turbines have virtually eliminated the mechanical noise through good insulation materials in the nacelle, so aerodynamic noise is the biggest contributor. The aerodynamic noise is produced by the rotation of the blades generating a broad-band swishing sound and it is a function of tip speed. Design of modern wind turbines has been optimised to reduce aerodynamic noise. This reduction can be obtained in two ways:

1. decreasing rotational speeds to under 65 m/s at the tip; and
2. using pitch control on upwind turbines, which permits the rotation of the blades along their long axis.

At any given location, the noise within or around a wind farm can vary considerably depending on a number of factors including the layout of the wind farm, the particular model of turbines installed, the topography or shape of the land, the speed and direction of the wind, and the background noise. The factors with the most influence on noise propagation are the distance between the observer and the source and the type of noise source.

The sound emissions of a wind turbine increase as the wind speed increases. However, the background noise will typically increase faster than the sound of the wind turbine, tending to mask the wind turbine noise in higher winds. Sound levels decrease as the distance from the wind turbines increases.

Noise levels can be measured and predicted, but public attitude towards noise depends heavily on perception. Sound emissions can be accurately measured using standardised acoustic equipment and methodologies (International Organization for Standardization – ISO Standards, International Electrotechnical Commission – IEC Standards, ETSU – Energy Technology Support Unit, UK Government and so on). Levels of sound are most commonly expressed in decibels (dB). The predictions of

Table V.2.1: Comparative noise for common activities

Source/activity	Indicative noise level (dB)
Threshold of hearing	0
Rural night-time background	20–40
Quiet bedroom	35
Wind farm at 350 m	35–45
Busy road at 5 km	35–45
Car at 65 km/h at 100 m	55
Busy general office	60
Conversation	60
Truck at 50 km/h at 100 m	65
City traffic	90
Pneumatic drill at 7 m	95
Jet aircraft at 250 m	105
Threshold of pain	140

Source: CIEMAT

sound levels in future wind farms are of the utmost importance in order to foresee the noise impact. Table V.2.1, based on data from the Scottish Government, compares noise generated by wind turbines with other everyday activities.

When there are people living near a wind farm, care must be taken to ensure that sound from wind turbines should be at a reasonable level in relation to the ambient sound level in the area. Rural areas are quieter than cities, so the background noise is usually lower. However, there are also noisy activities – agricultural, commercial, industrial and transportation. Wind farms are located in windy areas, where background noise is higher, and this background noise tends to mask the noise produced by the turbines. The final objective is to avoid annoyance or interference in the quality of life of the nearby residents.

Due to the wide variation in the levels of individual tolerance for noise, there is no completely satisfactory way to measure its subjective effects or the corresponding reactions of annoyance and dissatisfaction. The individual annoyance for noise is a very complex topic, but dose–response relationship studies have demonstrated a correlation between noise annoyance with visual interference and the presence of intrusive sound characteristics. In the same way, annoyance is higher in a rural area than in a suburban area and higher also in complex terrain (hilly or rocky) in comparison with a ground floor in a rural environment.

Low frequency noise (LFN), also known as infrasound, is used to describe sound energy in the region below about 200 Hz. LFN may cause distress and annoyance to sensitive people and has thus been widely analysed. The most important finding is that modern wind turbines with the rotor placed upwind produce very low levels of infrasound, typically below the threshold of perception. A survey of all known published measurement results of infrasound from wind turbines concludes that, with upwind turbines, infrasound can be neglected in evaluating environmental effects.

Experience acquired in developing wind farms suggests that noise from wind turbines is generally very low. The comparison between the number of noise complaints about wind farms and about other types of noise indicates that wind farm noise is a small-scale problem in absolute terms. Information from the US also suggests that complaints about noise from wind projects are rare and can usually be satisfactorily resolved.

LAND USE

National authorities consider the development of wind farms in their planning policies for wind energy projects. Decisions on siting should be made with consideration to other land users.

The administrative procedures needed to approve wind plants for each site have to be taken into account from the beginning of the project planning process. Regional and local land-use planners must decide whether a project is compatible with existing and planned adjacent uses, whether it will modify negatively the overall character of the surrounding area, whether it will disrupt established communities, and whether it will be integrated into the existing landscape. Developers, in the very early planning stage, should contact the most relevant authorities and stakeholders in the area: the Ministry of Defence, civil aviation authorities, radar and radio communication suppliers, the grid company, environmental protection authorities, the local population and relevant non-governmental associations, among others.

The authorities involved in reviewing and making land-use decisions on projects must coordinate and communicate with each other throughout the project. At the same time, local citizen participation as well as good communication with the main stakeholders (local authorities, developer, NGOs, landowners, etc.) would help to obtain a successful wind development.

Special attention must be paid to nature reserves, their surrounding zones and habitats of high value for nature conservation. There are additional obligations for assessment when Ramsar sites or Natura 2000 sites could be significantly affected by wind energy developments. The project or plan will only be approved if there is not an adverse effect on the integrity of the site. If it cannot be established that there will be no adverse effects, the project may only be carried out if there are no alternative solutions and if there are imperative reasons of public interest.

Recently, a new concern has been raised: wind farm installations over peatlands. Peatlands are natural carbon storage systems with a delicate equilibrium of waterlogging. According to the United Nations Environment Programme Division of Global Environment Facility Coordination (UNEP-GEF), peatlands cover only 3 per cent of the world's surface, but store the equivalent of 30 per cent of all global soil carbon, or the equivalent of 75 per cent of all atmospheric carbon. The impacts associated with drainage are carbon dioxide and methane emissions, erosion and mass movements, and dissolved organic carbon. The consequence is the loss of the land's capability of acting as a carbon sink. Moreover, the EU Habitats Directive has designated several grassland formations as special areas of conservation. In these areas, Member States have the responsibility to apply the necessary conservation measures for the maintenance or restoration of the natural habitats and/or the populations of the species for which they are designated. The Scottish Government (Nayak et al., 2008) has recently developed an approach to calculate the impact of wind energy on organic soils. This method permits the calculation of potential carbon losses and savings of wind farms, taking into account peat removal, drainage, habitat improvement and site restoration. The method proposes to integrate the carbon losses by peatland use in the overall life-cycle assessment (LCA) of the wind farms, computing the global carbon saving by the use of wind energy and subtracting the carbon losses associated with wind farm installations. The study also provides some recommendations for improving carbon savings of wind farm developments:

- peat restoration as soon as possible after disturbance;
- employing submerged foundation in deeper area of peat;
- maintenance of excavated C-layer as intact as possible until restoration;
- good track design according to geomorphologic characteristics;
- improving habitats through drain blocking and re-wetting of areas; and
- using floating roads when peat is deeper than 1 m.

Another issue is the interaction between tourism and wind energy developments. Many tourist areas are located in beautiful and/or peaceful landscapes. Wind power plants could reduce the attractiveness of the natural scenery. The most recent study, carried out by the Scottish Government (Scottish Government, 2008), has analysed the impacts of wind farms on the tourism industry and reviewed 40 studies from Europe, the US and Australia. The conclusions from the review can be summarised as follows:

- The strongest opposition occurs at the planning stage.
- A significant number of people think there is a loss of scenic value when a wind farm is installed; however, to other people, wind farms enhance the beauty of the area.
- Over time, wind farms are better accepted.
- In general terms, there is no evidence to suggest a serious negative impact on tourism.
- A tourist impact statement is suggested as part of the planning procedure to decrease the impact on tourism, including analysis of tourist flows on roads and number of beds located in dwellings in the visual zone of the wind farm.

IMPACTS ON BIRDS

Wind farms, as vertical structures with mobile elements, may represent a risk to birds, both as residents and migratory birds. However, it is difficult to reach a clear conclusion about the impacts of wind energy on birds for several reasons:

- Impacts are very site-dependent (depending on landscape topography, wind farm layout, season, types of resident and migratory birds in the area, and so on).
- Impacts vary among the different bird species.

The types of risks that may affect birds are:

- collision with turbines (blades and towers) causing death or injury;
- habitat disturbance: the presence of wind turbines and maintenance work can displace birds from preferred habitats and the breeding success rate may be reduced;
- interference with birds' movements between feeding, wintering, breeding and moulting habitats, which could result in additional flights consuming more energy; and
- reduction or loss of available habitat.

The main factors which determine the mortality of birds by collision in wind farms are landscape topography, direction and strength of local winds, turbine design characteristics, and the specific spatial distribution of turbines on the location (de Lucas et al., 2007). Specific locations should be evaluated a priori when a wind farm is planned. Every new wind farm project must include a detailed study of the interaction between birds' behaviour, wind and topography at the precise location. This analysis should provide information to define the best design of the wind farm to minimise collision with the turbines. Raptors present a higher mortality rate due to their dependence on thermals to gain altitude, to move between locations and to forage. Some of them are long-lived species with low reproductive rates and thus more vulnerable to loss of individuals by collisions.

The mortality caused by wind farms is very dependent on the season, specific site (for example offshore, mountain ridge or migration route), species (large and medium versus small, and migratory versus resident) and type of bird activity (for example nocturnal migrations and movements from and to feeding areas).

Bird mortality seems to be a sporadic event, correlated with adverse weather or poor visibility conditions. Results from Altamont Pass and Tarifa on raptors showed some of the highest levels of mortality; however, the average numbers of fatalities were low in both places, ranging from 0.02 to 0.15 collisions/turbine. In Altamont Pass the overall collision rate was high due to the large number of small, fast, rotating turbines installed in the area. In Tarifa, the two main reasons for collisions were that the wind farms were installed in topographical bottlenecks, where large numbers of migrating and local birds fly at the same time through mountain passes, and the use of wind by soaring birds to gain lift over ridges. In Navarra, studies of almost 1000 wind turbines and including all types of birds showed a mortality rate of between 0.1 and 0.6 collisions per turbine and year. Raptors were the bird group more affected (78.2 per cent) during spring, followed by migrant passerines during post-breeding migration time (September/October).

At the global level, it can be accepted that many wind farms show low rates of mortality by collision (Drewitt and Langston, 2006). However, even these low collision mortality rates for threatened or vulnerable species could be significant and make it harder for a particular species to survive.

A comparative study of bird mortality by anthropogenic causes was carried out by Erickson et al. (2005). Table V.2.2 gives the distribution by human activities.

A more recent study stated current wind energy developments are only responsible for 0.003 per cent of bird mortalities caused by human activities.

Concerning habitat disturbance, the construction and operation of wind farms could potentially disturb birds and displace them from around the wind farm site. The first step in analysing this disturbance is to define the size of the potential disturbance zone. Wind turbines can trigger flight reactions on birds displacing them out of the wind farm area. Potential disturbance distances have been studied by several authors, giving an average of 300 m during the breeding season and 800 m at other seasons of the year. Approximately 2 per cent of all flights at hub height showed a sudden change of direction in the proximity of wind farm.

Table V.2.2: Anthropogenic bird mortality

Causes	Annual mortality estimate
Buildings/windows	550 million
Cats	100 million
High tension lines	130 million
Vehicles	80 million
Pesticides	67 million
Communication towers	4.5 million
Airplanes	25 thousand
Wind turbines	28.5 thousand

Source: Erickson et al. (2005)

An indirect negative impact of wind farms is a possible reduction in the available area for nesting and feeding by birds avoiding wind farm installations.

During construction, species can be displaced from their original habitat, but in most cases they return during the operational phase. However, exclusions may occur for other species during the breeding period.

Mitigation measures to minimise impacts vary by site and by species, but common findings in the literature are as follows:

- important zones of conservation and sensitivity areas must be avoided;
- sensitive habitats have to be protected by implementing appropriate working practices;
- an environmental monitoring programme before, during and after construction will provide the needed information to evaluate the impact on birds;
- adequate design of wind farms: siting turbines close together and grouping turbines to avoid an alignment perpendicular to main flight paths;
- provide corridors between clusters of wind turbines when necessary;
- increase the visibility of rotor blades;
- underground transmission cables installation, especially in sensitive areas, where possible;
- make overhead cables more visible using deflectors and avoiding use in areas of high bird concentrations, especially of species vulnerable to collision;
- implement habitat enhancement for species using the site;
- adequate environmental training for site personnel;
- presence of biologist or ecologist during construction in sensitive locations;
- relocation of conflictive turbines;
- stop operation during peak migration periods; and
- rotor speed reduction in critical periods.

ELECTROMAGNETIC INTERFERENCE

Electromagnetic interference (EMI) is any type of interference that can potentially disrupt, degrade or interfere with the effective performance of an electronic device. Modern society is dependent on the use of devices that utilise electromagnetic energy, such as power and communication networks, electrified railways, and computer networks. During the generation, transmission and utilisation of electromagnetic energy, the devices generate electromagnetic disturbance that can interfere with the normal operation of other systems.

Wind turbines can potentially disrupt electromagnetic signals used in telecommunications, navigation and radar services. The degree and nature of the interference will depend on:

- the location of the wind turbine between receiver and transmitter;
- characteristics of the rotor blades;
- characteristics of the receiver;
- signal frequency; and
- the radio wave propagation in the local atmosphere.

Interference can be produced by three elements of a wind turbine: the tower, rotating blades and generator. The tower and blades may obstruct, reflect or refract the electromagnetic waves. However, modern blades are typically made of synthetic materials which have a minimal impact on the transmission of electromagnetic radiation. The electrical system is not usually a problem for telecommunications, because interference can be eliminated with proper nacelle insulation and good maintenance.

Interference to mobile radio services is usually negligible. Interference to TV signals has been minimised with the substitution of metal blades with synthetic materials. However, when turbines are installed very close to dwellings, interference has been proven difficult to rule out.

The interference area may be calculated using the Fresnel zone. This area is around and between the transmitter and receiver and depends on transmission frequency, distance between them and local atmospheric conditions.

Technical mitigation measures for TV interference can be applied during the planning stage, siting the turbine away from the line-of-sight of the broadcaster transmitter. Once the wind farm is in operation, there are also a set of measures to mitigate the interference:

- installation of higher-quality or directional antenna;
- direct the antenna toward an alternative broadcast transmitter;
- installation of an amplifier;
- relocate the antenna;
- installation of satellite or cable TV; and
- construction of a new repeater station if the area affected is very wide.

There is common agreement that adequate design and location can prevent or correct any possible interference problems at relatively low cost using simple technical measures, such as the installation of additional transmitter masts. Interference on communication systems is considered to be negligible because it can be avoided by careful wind farm design.

CONSTRAINTS ON NATURAL RESERVES AREAS

There is a rough consensus about which are the most important environmental threats and what are their general influences on biological diversity. The continuous deterioration of natural habitats and the increasing number of wild species which are seriously threatened has prompted governments to protect the environment.

There are many types of protected areas at national and regional levels. At the EU level, the Birds Directive (1979) and the Habitats Directive (1992) are the base of the nature conservation policy.

The Birds Directive is one of the most important tools to protect all wild bird species naturally living in or migrating through the EU. The directive recognises that habitat loss and degradation are the most serious threats to the conservation of wild birds. The Birds Directive has identified 194 species and sub-species (listed in Annex I) as particularly threatened and in need of special conservation measurements.

The aim of the Habitats Directive is to promote the maintenance of biodiversity by preserving natural habitats and wild species. Annex I includes a list of 189 habitats and Annex II lists 788 species to be protected by means of a network of high-value sites. Each Member State has to define a national list of sites for evaluation in order to form a European network of Sites of Community Importance (SCIs). Once adopted, SCIs are designated by Member States as Special Areas of Conservation (SACs), and, along with Special Protection Areas (SPAs) classified under the EC Birds Directive, form a network of protected areas known as Natura 2000.

The development of wind farms in natural reserves should be assessed on site-specific and species-specific criteria to determine whether the adverse impacts are compatible with the values for which the area was designated.

Of special importance is the requirement of the Habitats Directive to include indicative 'sensitivity' maps of bird populations, habitats, flyways and migration bottlenecks as well as an assessment of the plan's probable effects on these in the SEA and AA procedures. These maps should provide enough information about feeding, breeding, moulting, resting, non-breeding and migration routes to guarantee biodiversity conservation.

Offshore

Offshore wind energy is a renewable technology capable of supplying significant amounts of energy in a sustainable way. According to EWEA estimates, between 20 GW and 40 GW of offshore wind energy capacity will be operating in the EU by 2020. This capacity could meet more than 4 per cent of EU electricity consumption. The total offshore installed capacity in Europe at the end of 2007 was almost 1100 MW, distributed in the coastal waters of Denmark, Ireland, The Netherlands, Sweden and the UK, representing almost 2 per cent of the total wind energy (56,536 MW) in the EU.

Offshore wind projects are more complex than onshore ones. Offshore developments include platforms, turbines, cables, substations, grids, interconnection and shipping, dredging and associated construction activity. The operation and maintenance activities include the transport of employees by ship and helicopter and occasional hardware retrofits.

From an ecological point of view, shallow waters are usually places with high ecological value and are important habitats for breeding, resting and migratory seabirds. Close participation and good communication between the countries involved in the new developments is essential to reduce environmental impacts from several wind farms in the same area.

Most of the experience gained in offshore wind energy comes from several years of monitoring three wind farms in Denmark (Middelgrunden, Horns Rev and Nysted) installed between 2001 and 2003. Valuable analysis has also been carried out by the Federal Environment Ministry (BMU) of Germany through technical, environmental and nature conservation research about offshore wind energy foundations.

VISUAL IMPACT

Offshore wind farms usually have more and bigger turbines than onshore developments. However, visual impact is lower due to the greater distance from the coastline. Nevertheless, the coastal landscape is often unique and provides some of the most valued landscapes, thus special attention could be required.

The visual impact of offshore wind farms can affect three components of the seascape:

1. an area of sea;
2. a length of coastline; and
3. an area of land.

Figure V.2.1: Components of seascape

Source: Wratten et al. (2005)

Offshore wind farms involve several elements which influence the character of the produced visual impact (Wratten et al., 2005):

- the site and size of wind farm area;
- the wind turbines: size, materials and colours;
- the layout and spacing of wind farms and associated structures;
- location, dimensions and form of ancillary onshore (substation, pylons, overhead lines, underground cables) and offshore structures (substation and anemometer masts);
- navigational visibility, markings and lights;
- the transportation and maintenance boats;
- the pier, slipway or port to be used by boats; and
- proposed road or track access, and access requirements to the coast.

Just as for onshore developments, ZTV maps, photomontages and video-montages are tools used to predict the potential effects of new offshore wind developments.

The potential offshore visibility depends on topography, vegetation cover and artificial structures existing on the landscapes. The visibility assessment of offshore developments includes the extent of visibility over the main marine, coastline and land activities (recreational activities, coastal populations and main road, rail and footpath). The effects of the curvature of the Earth and lighting conditions are relevant in the visibility of offshore wind farms. Rainy and cloudy days result in less visibility. Experience to date on Horns Rev proves that a wind farm is much less visible than the 'worst-case' clear photomontage assessment, due to prevailing weather conditions and distance.

The magnitude of change in the seascape with the construction of a new offshore wind farm is dependent of several parameters, such as distance, number of turbines, the proportion of the turbine that is visible, weather conditions and the navigational lighting of turbines. The distance between observer and wind farm usually has the strongest influence on the visual impact perception. Nevertheless, changes in lighting and weather conditions vary considerably the visual effects at the same distance.

The indicative thresholds established for highly sensitive seascapes during the DTI study on three SEA areas in the UK are shown in Table V.2.3.

More recently, research on visual assessment by Bishop and Miller (2005) found that distance and contrast are very good predictors of perceived impact. The study, based on North Hoyle wind farm 7 km off the coast of Wales, showed that in all atmospheres and lighting conditions (except a stormy sky), visual impacts decreased with distance. However, visual impact increased with increasing contrast. Further research is needed to analyse the dependence of visual effects on turbine numbers, orientation and distribution.

Table V.2.3: Thresholds for seascapes

Thresholds
<13 km possible major visual effects
13–24 km possible moderate visual effects
>24 km possible minor visual effects

Source: Wratten et al. (2005)

Cumulative effects may occur when several wind farms are built in the same area. The degree of cumulative impact is a product of the number of wind farms and the distance between them, the siting and design of the wind farms, the inter-relationship between their ZTVs, and the overall character of the seascape and its sensitivity to wind farms.

The Danish Energy Agency (DEA) has reported an absence of negative press during the development of Nysted and Horns Rev offshore wind farms. Opinion polls showed better acceptance levels for the projects in the post-construction phase.

NOISE IMPACT

Offshore wind farms are located far away from human populations, which are thus not affected by the noise generated by the turbines. However, marine animals could be affected by the underwater noise generated during the construction and operation of wind turbines. Any effects of the noise will depend on the sensitivity of the species present and their ability to adjust to it.

The procedures to calculate the acoustic noise from offshore wind turbines should include the following:

- wind turbine parameters: rated power, rotor diameter and so on;
- type of foundation, material, pile depth and so on;
- effective pile driving and/or vibration energy;
- period of construction phase and blow or vibrator frequency; and
- depth of water at the site.

Construction and Decommissioning Noise

Construction and decommissioning noise comes from machines and vessels, pile-driving, explosions and installation of wind turbines. Measurements carried out by the German Federal Ministry of the Environment on two platforms reached peak levels of 193 dB at 400 m from the pile (North Sea) and 196 dB at 300 m (Baltic Sea). Nedwell reports peaks up to 260 dB in foundation construction and 178 dB in cable lying at 100 m from the sound source (Gill, 2005). These high sound levels may cause permanent or temporary damage to the acoustic systems of animals in the vicinity of the construction site. However, there is not enough scientific knowledge to determine the maximum thresholds permitted for certain effects. Close collaboration between physicists, engineers and biologists is necessary to get relevant information and obtain standardisation of the measurement procedures in offshore developments.

The measurements from FINO-1 at 400 m from source revealed peaks of 180 dB. The measurements carried out during construction of North Hoyle wind farm in the UK indicate that:

- The peak noise of pile hammering at 5 m depth was 260 dB and at 10 m depth was 262 dB.
- There were no preferential directions for propagation of noise.
- The behaviour of marine mammals and fish could be influenced several kilometres away from the turbine.

Table V.2.4 shows the avoidance reaction expected to occur due to pile-driving during the North Hoyle wind farm construction.

The behaviour of marine organisms may be modified by the noise, resulting in an avoidance of the area during construction. The possible effects on sealife will depend on the sensitivity of the species present in

Table V.2.4: Calculated ranges for avoidance distance for different marine species

Species	Distance
Salmon	1400 m
Cod	5500 m
Dab	100 m
Bottlenose dolphin	4600 m
Harbour porpoise	1400 m
Harbour seal	2000 m

Source: Nedwell et al. (2004)

the area and will be reduced when the noise decreases at the end of the construction (or decommissioning) phase.

Different working groups are currently discussing mitigation measures to reduce damage to sealife:

- soft start in the ramp-up procedure, slowly increasing the energy of the emitted sound;
- using an air-bubble curtain around the pile, which could result in a decrease of 10–20 dB;
- mantling of the ramming pile with acoustically insulated material such as plastic could result in a decrease of 5–25 dB in source level;
- extending the duration of the impact during pile-driving could result in a decrease of 10–15 dB in source level; and
- using acoustic devices which emitted sounds to keep away mammals during ramp-up procedure; several pingers might be necessary at different distances from the sound source.

Operational Noise

In the operation phase, the sound generated in the gearbox and the generator is transmitted by the tower wall, resulting in sound propagation underwater. Measurements of the noise emitted into the air from wind turbines and transformers have shown a negligible contribution to the underwater noise level. The underwater noise from wind turbines is not higher than the ambient noise level in the frequency range above approximately 1 kHz, but it is higher below approximately 1 kHz. The noise may have an impact on the benthic fauna, fish and marine mammals in the vicinity of wind turbine foundations (Greenpeace, 2005).

Operational noise from single turbines of maximum rated power of 1.5 MW was measured in Utgruden, Sweden, at 110 m distance by Thomsen et al. (2006). At moderate wind speeds of 12 m/s, the 1/3 octave sound pressure levels were between 90 and 115 dB.

This anthropogenic noise may have both behavioural and physiological impacts on sealife. Impacts on behaviour include:

- attraction to or avoidance of the area;
- panic; and
- increases in the intensity of vocal communication.

Reports about noise impact on fish have shown a range of effects, from avoidance behaviour to physiological impacts. Changes in behaviour could make fish vacate feeding and spawning areas and migration routes. Studies of noise impact on invertebrates and planktonic organisms have a general consensus of very few effects, unless the organisms are very close to the powerful noise source. Measurements from one 1500 kW wind turbine carried out by the German Federal Ministry of the Environment has found that operational noise emissions do not damage the hearing systems of sealife. Concerning behaviour, the same study stated that it is not clear whether noise from turbines has an influence on marine animals.

Ships are involved in the construction of wind parks and also during the operation phase for maintenance of wind turbines and platforms. The noise from ships depends on ship size and speed, although there are variations between boats of similar classes. Ships of medium size range produce sounds with a frequency mainly between 20 Hz and 10 kHz and levels between 130 and 160 dB at 1 m.

Standardised approaches to obtain noise certificates, similar to those existing onshore, are necessary.

Electromagnetic Fields and Marine Organisms

The electricity produced by offshore wind turbines is transmitted by cables over long distances. The electric current generated produces magnetic fields. Studies of possible effects of artificial static magnetic fields have been carried out on various species under various experimental conditions. Artificial electromagnetic fields could interact with marine organisms to produce detectable changes. Usually, however, only very slight differences in control groups have been recorded.

The magnetic field may affect molluscs, crustaceans, fish and marine mammals that use the Earth's magnetic field for orientation during navigation. But it is still unknown whether the magnetic fields associated with wind turbines influence marine organisms.

Elasmobranches, one of the more electro-sensitive species, are attracted by electrical fields in the range of 0.005–1 μVcm^{1} and avoid fields over 10 μVcm^{1}.

Electro-sensitive species could be attracted or repelled by the electrical fields generated by submarine cables. Special attention must be paid in areas of breeding, feeding or nursing because of the congregation or dispersion of sensitive individuals in the benthic community.

Experimental analysis on several benthic organisms exposed to static magnetic fields of 3.7 mT for several weeks have shown no differences in survival between experimental and control populations. Similarly, mussels living under these static magnetic field conditions for three months during the reproductive period do not present significant differences with the control group. The conclusions are that static magnetic fields of power cable transmissions don't seem to influence the orientation, movement or physiology of the tested benthic organisms.

The results from a study carried out at Nysted on the influence of electromagnetic fields on fish are not conclusive. Some impact on fish behaviour has been recorded, but it was not possible to establish any correlation. There is not enough knowledge about this topic and additional research is needed.

The magnetic fields of both types of cable (bipolar and concentric) used in marine wind farms are small or zero. The Greenpeace study mentioned earlier concludes that the electromagnetic fields of submarine cables have no significant impacts on the marine environment. Studies with a long-term perspective are necessary to confirm the negligible impact of electromagnetic fields of wind energy on marine ecosystems.

Impacts on Benthos

The benthos include the organisms that live on or in the sediment at the bottom of a sea, lake or deep river. The benthic community is complex and is composed of a wide range of plants, animals and bacteria from all levels of the food chain. It can be differentiated by habitat: *infauna* are animals and bacteria of any size that live in bottom sediments, such as worms and clams. They form their own community structures within the sediments, connected to the water by tubes and tunnels; *epifauna* are animals that live either attached to a hard surface (for example rocks or pilings) or move on the surface of the sediments. Epifauna include oysters, mussels, barnacles, snails, starfish, sponges and sea squirts.

These communities are highly dependent on some abiotic factors such as depth of water, temperature, turbidity and salt content. Fluctuations of any of those parameters result in changes in species composition and the numbers of individuals.

The introduction of hard bottom structures such as turbine foundations provides a new artificial substrate which helps to develop a new habitat for marine epifaunal organisms. These structures can attract specific benthos species, generating changes in the previous benthic associations by the colonization of these new substrates. The most susceptible groups are non-mobile (for example mussels, barnacles and sponges), hardly mobile species (snails, starfish) or sand-filtering species (oysters). Small fish species depredating over benthic animals and plants may also appear in the new area. Furthermore, larger benthic or pelagic fish as well as sea birds may be attracted from the surroundings areas. Therefore, the construction of offshore wind farms will modify the relationships of benthic communities, changing the existing biodiversity in the area and creating a new local ecosystem. (Köller et al., 2006).

The knowledge gained from Horns Rev monitoring shows that indigenous infauna habitats have been replaced by the epifauna community associated with hard bottom habitats with an estimated 60-fold increase in availability of food for fish and other organism in the wind farm area compared with the native infauna biomass. An increase of general biodiversity in the wind farm area and progress succession in the benthic community has been verified. The new hard bottom substrates have provided habitats as nursery grounds for larger and more mobile species like the edible crab *Cancer parugus*. The most noticeable news is the introduction of two new species: the ross worm *Sabellaria spinulos*a and the white weed *Sertularia cupressina* in the Horns Rev wind farm area, both considered as threatened or included on the Red List in the Wadden Sea area. The epifauna community in artificial underwater structures differs from the natural marine fauna in the vicinity of wind turbines not only in its species composition but also in the dynamics of its faunal succession.

The installation of steel structures in the western Baltic marine waters has also increased the diversity and abundance of benthic communities.

The construction work phase temporarily increased the water turbidity. This effect may have had a negative impact on vegetation, because of a decrease in the sunlight. However, this impact was transient so the habitat loss caused is expected to be negligible.

Impacts on Fish

The potential effects from offshore wind energy installations may be divided into:

- introduction of new artificial habitat;
- noise; and
- electromagnetic fields.

The construction phase probably disturbs many of the fish species. However, the underwater movements, noise and increased turbidity of the water associated with the works period disappear at the end of this stage.

The response from fish species to the introduction of wind turbine foundations is comparable with artificial reefs. Fish attraction behaviour to artificial reefs has been demonstrated in several European studies. It is expected that fish abundance and species diversity will be increased around the turbine foundations as the new habitat becomes more integrated with the marine environment.

The new artificial habitats created by the construction of Horns Rev and Nysted wind farms have had insignificant effects on fish. The species composition was similar inside and outside of the wind farm areas. Only sand eels show a different pattern, with the population increasing by about 300 per cent in the Horns Rev wind farm and decreasing by 20 per cent outside of it. More clear and definitive results will be obtained in the coming years, when the colonisation process becomes more mature.

Positive impacts from offshore wind energy are foreseen with the ban on fishing, especially demersal trawling, in the wind farm area resulting in more local fish. The increase of biomass in benthos communities as a result of the construction of new foundations would support this supposition.

The low frequency noise may be audible to many fish species. The frequency, intensity and duration of the noise will determine the grade of disturbance. Studies on goldfish, cod and Atlantic salmon have indicated that they can detect offshore turbines from 0.4 to 25 km at wind speeds of 8 to 13 m/s. The detection distance depends on the size and numbers of wind turbines, the hearing organs of the fish, the water depth and bottom substrate. The fish produce a variety of sound for communication that may be interfered with by the noise from turbines. This could decrease the effective range of communication by fish. However, the extent of this interference and its influence on the behaviour and fitness of fish is not known and additional studies are needed. There is no evidence that turbines damage the hearing of fish, even at low distances of a few metres. The avoidance distance is about 4 m, but only at high wind speeds of 13 m/s. The noise impact mainly masks communication and orientation signals, whereas it does not produce serious damage to hearing organs or strong avoidance reactions are produced.

Overall, the environmental monitoring in Horns Rev and Nysted shows that the effects of noise and vibrations from the wind farms on fish are negligible. However, the current knowledge about wind energy impacts on fish presents large uncertainties. Knowledge of the behavioural response of fish to noise and vibrations from offshore wind developments is still limited (Boesen and Kjaer, 2005; Thomsen et al., 2006). Future studies must gather better data on the nature of the acoustic field around wind turbines and the physiological and behavioural impacts on fish (Wahlberg and Westerberg, 2005; Thomsen et al., 2006).

Maintenance of wind farms needs more-or-less daily activity, with ships moving into the wind farm area. This associated noise should create more impacts than the operating turbines (Greenpeace, 2005).

Impacts on Marine Mammals

Offshore wind farms can negatively affect marine mammals during both construction and operation stages. The physical presence of turbines, the noise during construction, the underwater noise, and boat and helicopter traffic can disturb mammals, causing them to avoid wind farms.

Monitoring marine mammals living and moving below sea level is very difficult. Fortunately, the traditional visual surveys from ships and aircraft are being supplemented or replaced by new, more accurate technologies such as acoustic monitoring by stationary data loggers, remotely controlled video monitoring and tagging of individuals with satellite transmitters.

Mammals are very dependent on their hearing systems, which are used for several purposes: communication between individuals of the same species, orientation, finding prey and echolocation. The behavioural response by marine mammals to noise includes modification of normal behaviour, displacement from the noisy area, masking of other noises, and the impossibility of acoustically interpreting the environment. The consequences from this disturbance could cause problems of viability of individuals, increased vulnerability to disease, and increased potential for impacts due to cumulative effects from other impacts such as chemical pollution combined with stress induced by noise.

The noise measured by the German Federal Ministry of Environment doesn't seem to damage the hearing organs of marine animals, but it is not well known how it will affect their behaviour in the area surrounding the turbines. Although the sound level is moderate, it is permanent (until decommissioning), thus more research about its influence on marine animals behaviour is needed.

Horns Rev and Nysted wind farms in Denmark carried out a comprehensive environmental monitoring programme between 1999 and 2006, covering baseline analysis, construction and operation phases. The highlight of the study shows different reactions between seals and porpoises. Seals were only affected during the construction phase, due to the high sound levels in pile-driving operations. In the operation phase, it seems wind farms did not have any effect on seals. However, harbour porpoises' behaviour was dissimilar at the two offshore wind farms. In Horns Rev, the population decreased slightly during construction, but recovered to the baseline situation during operation. In Nysted, porpoise densities decreased significantly during construction and only after two years of operation did the population recover. The reason for this slow recovery is unknown.

Nysted wind farm is located 4 km away from the Rosland seal sanctuary. The presence of the wind farm had no measurable effects on the behaviour of seals on land.

The foundations of wind farms create new habitats, which are colonised by algae and benthic community. This further availability of food may attract new species of fish and subsequently mammals. This change could be neutral or even positive to mammals.

It is very difficult to assess the long-term impacts on reproduction and population status with the current state of knowledge. The possible behaviour modification of marine mammals due to the presence of wind turbines at sea is presumably a species-specific subject. Other factors which also require further research relate to oceanographic parameters (hydrography, bathymetry, salinity and so on) and the hearing systems of mammals.

Impacts on Sea Birds

The influence of offshore wind farms on birds can be summarised as follows:

- collision risk;
- short-term habitat loss during construction phase;
- long-term habitat loss due to disturbance from wind turbines installed and from ship traffic during maintenance;
- barriers to movement in migration routes; and
- disconnection of ecological units.

The methodology proposed by Fox et al. (2006) to support EIAs of the effects on birds of offshore wind farms reveals the great complexity of the analysis. The relationships between offshore wind farms and bird impacts must be analysed by gathering information about avoidance responses, energetic consequences of habitat modification and avoidance flight, and demographic sensitivity of key species.

Collisions have the most direct effect on bird populations. Collision rates for wintering waterfowl, gulls and passerines on coastal areas in northwest Europe range from 0.01 to 1.2 birds/turbine. No significant population decline has been detected. Direct observations from Blyth Harbour, UK, have demonstrated that collisions with rotor blades are rare events in this wind farm located within a Site of Special Scientific Interest and Special Protection Area, under the Birds Directive.

In poor visibility conditions, large numbers of terrestrial birds could collide with offshore wind farms, attracted by their illumination. However, this occurs only on a few nights. Passerines are the group mainly involved in these collisions. One of the most useful mitigation measures to avoid this type of impact is to replace the continuous light with an intermittent one.

Information about bird mortality at offshore wind farms is very scarce for two reasons: the difficulty of detecting collisions and the difficulty in recovering dead birds at sea. Further investigations on this topic are needed to get reliable knowledge.

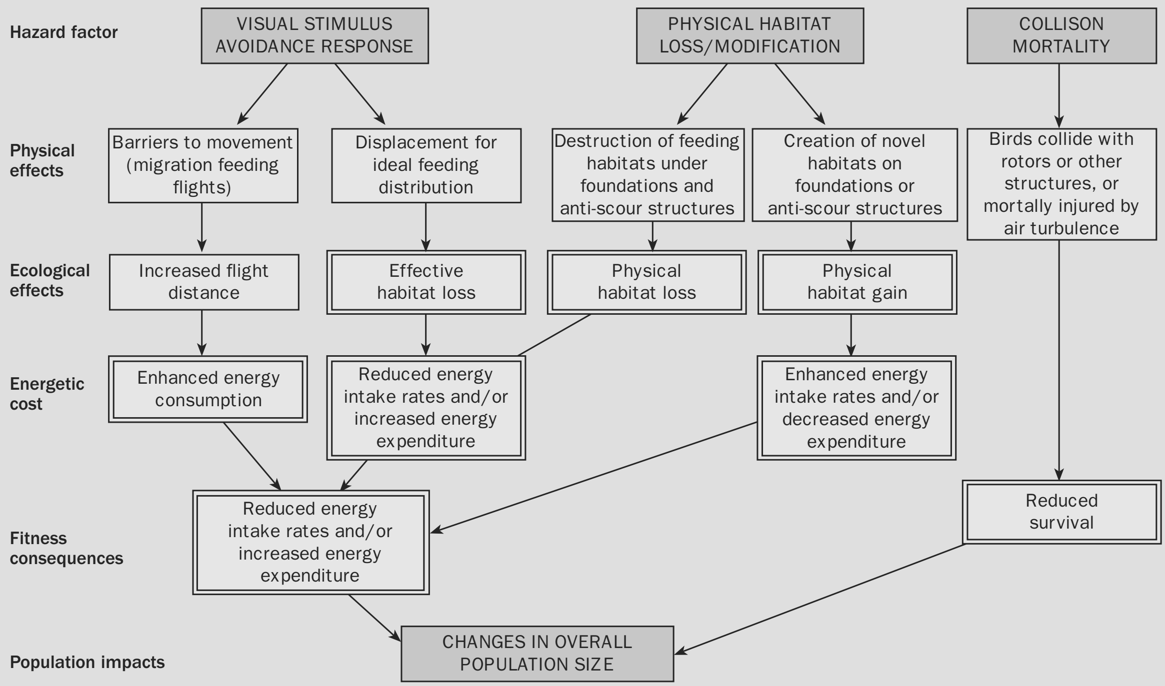
There is a lack of good data on migration routes and flight behaviour of many of the relevant marine bird species. But this data is essential for assessing the potential impacts of collisions and barriers to movements. The large scale of proposed offshore wind farms and the expected cumulative effects increase the need to fill in these gaps.

The degree of disturbance differs between different species. The disturbance may be determined by several factors such as availability of appropriate habitats, especially roosting and feeding areas, time of year, flock size and the layout of the wind farms.

Disturbances during construction are produced by ships and/or helicopter activities and noise generated by ramming piles. After that, in the operation stage, disturbances by boat traffic still have an impact on birds.

The impacts of marine wind farms are higher on sea birds (resident, coastal and migrant) than on onshore birds. The reasons for this higher impact at offshore developments are related to the larger height of marine wind turbines, the larger size of wind farms and

Figure V.2.2: Flow chart of hazards factors to birds by offshore developments



Source: Fox et al. (2006)

Note: Boxes with solid frame indicate measurable effects; boxes with double frame indicate processes that need to be modelled.

the higher abundance of large bird species, which are more sensitive to disturbance.

The most important findings after seven years of monitoring at Horns Rev and Nysted wind farms indicate negligible effects on overall bird populations. The majority of bird species showed avoidance of the wind farms. Although there was considerable movement of birds around wind farms, between 71 and 86 per cent of flocks avoided flying between the turbine rows of the wind farm. Changes in flying directions, for most of the species, were verified at 0.5 km from wind farms at night and at 1.5 km in the day. This avoidance represents an effective habitat loss, but the proportion of feeding area lost due to the presence of these two wind farms, in relation to the total feeding area, is relatively small and is considered of little biological importance.

Avoidance behaviour reduces the collision with turbines. The displacement of birds because of wind farm installations makes the collision risk at the two installations low. The predicted collision rates of common eiders at Nysted were around 0.02 per cent, which means 45 birds of a total of 235,000 passing each autumn in the area. Monitoring has also confirmed that waterbirds (mainly eider) reduce their flight altitude, to below rotor height, at the Nysted wind farm.

Avoidance observed in Nysted and Horns Rev affects flying, resting and foraging between turbines. New wind farm proposals in the same area have to be carefully analysed because they may cause important habitat loss for certain species.

EIAs on marine ecosystems must take into account the cumulative effects from all the wind farms in the surrounding area, including cable connections to the network on the mainland.

During the last several years, a lot of methodologies on collision risk models, baseline surveys using both ship and aerial techniques and post-construction monitoring have been developed. This data is needed to properly assess and predict the future impacts of proposed wind farms. Several sophisticated technologies, such as radar and infrared cameras, have helped to acquire a better understanding.

When there is not enough knowledge about specific species or taxonomic groups in unstudied habitats, the potential disturbance distances could be unknown. The most appropriate approach to define the disturbance distance may be to determine the bird numbers at different ranges of distances from wind farm, ensuring that all the affected area is covered in the study.

There is a common opinion on the need for more information about potential impacts of wind farms on birds. Further research is required on avian responses to wind farms, models to predict the future impacts of a new single wind farm installation and groups of wind farms on an area, the collection of information on bird movements to design marine sanctuaries, and data gathering standardisation methodologies.

Mitigation measures for onshore schemes are also applicable to offshore wind farms.

Ship Collisions

Ship collisions with the turbines are one of the potential risks associated with offshore wind energy development. Colliding with a wind turbine foundation could damage or possibly destroy a ship. The potential danger to the environment is the spillage of oil or chemicals from the ship into the water.

Evaluation of several collision scenarios between three different types of turbine foundations (monopile, jacket and tripod) and different ship types (single and double hull tankers, bulk carriers, and container ships) has been carried out in several locations in the North Sea and the Baltic Sea off Germany. The results have demonstrated two main results: the first is that monopile and jacket foundations are safer than tripod structures, and the second is related to the risk of collision, which can be reduced, but not totally avoided.

There are several safety approaches applicable to avoid or minimise this potential risk:

- redundant navigation and control systems such as radar and ships optimised to survive collisions;
- prohibition on navigation into the wind farm area for certain kinds of unsafe ships;
- introduction of traffic management systems;
- wind farm monitoring;
- availability of tug boats for emergencies; and
- crew training.

Radar and Radio Signals

The wind turbines may impact on aviation activity, both civil and military, due to interference with radars that manage aircraft operations. Radar is a system for detecting the presence or position or movement of objects by transmitting radio waves, which are reflected back to a receiver. The radio wave transmitted by radar can be interrupted by an object (also called a target), then part of the energy is reflected back (called echo or return) to a radio receiver located near the transmitter.

Wind turbines are vertical structures that can potentially interfere with certain electromagnetic transmissions. Mobile structures such as rotating blades may generate more interference on the radars than stationary structures. The effects depend on type of radar, specific characteristics of wind turbines and the distribution of wind turbines. Air traffic management is susceptible to being negatively affected by wind turbine installations. The systems managed by radars are air traffic control, military air defence and meteorological radars.

Table V.2.5 summarises the functions and the mitigation measures according to the different types of radar and wind turbine effects in the UK.

Table V.2.5: Effects and mitigation measures by radar types

Systems	Air traffic control		Meteorological control		Air defence	
Mission	Control of arrival, departure and transit in vicinity of airport and transit over the country		Weather forecasting; very important to aviation safety		Detect and identify aircraft approaching, leaving or flying over the territory of a country	
Types	Primary radar	Secondary surveillance radar	Weather radar	Wind profile radar	Ground based radars	Airborne radars
Wind turbines' effects	False radar responses or returns	Masking genuine aircraft returns; reflection from wind turbines could cause misidentification or mislocation of aircraft	Reflection	Reflection	Highly complex and not completely understood	Highly complex and not completely understood
Mitigation measures at the beginning of project planning	Ensuring location in area with low aircraft traffic; ensuring location not in line of sight of any aircraft radar	Avoiding close vicinity to radars; minimum safe distance between wind farms and these types of radars not defined	Avoiding wind farm installation at 10 km or less of radar facility		Minister of Defence of UK does not permit any wind farm located at less than 74 km from an air defence radar, unless developers can demonstrate no interferences with the defence radar	Moving the location of wind farm or adjusting the configuration of turbines to avoid interference; providing alternative site for the affected radar; contribute to investment in additional or improved radar system

Source: Based on DTI (2002)

The impacts associated with wind turbines are masking, returns/clutter and scattering.

MASKING

Radar systems work at high radio frequencies and therefore depend on a clear 'line of sight' to the target object for successful detection. When any structure or geographical feature is located between the radar and the target, it will cause a shadowing or masking effect. The interference varies according to turbine dimensions, type of radar and the aspect of the turbine relative to the radar. The masking of an aircraft can occur by reflecting or deflecting the returns when the aircraft is flying in the 'shadow' of wind turbines and thus it is not detected. Also the masking can occur when returns from the towers and blades of the wind turbines are so large that returns from aircraft are lost in the 'clutter' (radar returns from targets considered irrelevant to the purpose of the radar).

RETURNS/CLUTTER

Radar returns may be received from any radar-reflective surface. In certain geographical areas, or under particular meteorological conditions, radar performance may be adversely affected by unwanted returns, which may mask those of interest. Such unwanted returns are known as radar clutter. Clutter is displayed to a controller as 'interference' and is of concern primarily to air surveillance and control systems – ASACS and aerodrome radar operators, because it occurs more often at lower altitudes.

The combination of blades from different turbines at a wind farm can give the appearance of a moving object, which could be considered as an unidentified aircraft requiring controllers to take action to avoid a crash with another aircraft.

SCATTERING, REFRACTION AND/OR FALSE RETURNS

Scattering occurs when the rotating wind turbine blades reflect or refract radar waves in the atmosphere. The source radar system or another system can absorb the waves and provide false information to that system. This effect is not well known, but it has been reported in Copenhagen airport as a result of the Middelgrunden offshore wind farm.

The possible effects are:

- multiple, false radar returns such as blade reflections are displayed to the radar operator as false radar contacts;
- radar returns from genuine aircraft are recorded but in an incorrect location; and
- garbling or loss of information.

Marine radars and communication and navigation systems may suffer interference from nearby wind farms. However, Howard and Brown (2004) stated that most of the effects of Hoyle offshore wind farm do not significantly compromise marine navigation or safety. Mitigation measures in open water include the definition of vessel routes distant from wind farms, while in restricted areas the boundaries of wind farms must be kept at appropriate distances from navigation routes or port approaches.

V.3 POLICY MEASURES TO COMBAT CLIMATE CHANGE

The Kyoto Protocol

The Kyoto Protocol is an international treaty subsidiary to the United Nations Framework Convention on Climate Change (UNFCCC/1992). Negotiations for the Kyoto Protocol were initiated at the first Conference of the Parties (COP 1) of the UNFCCC in Berlin in 1995, in recognition that the voluntary measures included in the UNFCCC were ineffective. The major feature of the Kyoto Protocol is that it sets 'quantified emission limitation or reduction obligations' (QUELROs) – binding targets – for 38 industrialised countries and the European Community (Annex B countries)[6] for reducing greenhouse gas (GHG) emissions by an aggregate 5.2 per cent against 1990 levels over the five-year period 2008–2012, the so-called 'first commitment period'.

The Protocol was agreed in December 1997 at the third Conference of the Parties (COP 3) in Kyoto, Japan. After COP 7, in Marrakech in late 2001, the Protocol was considered ready for ratification, and over the course of the next three years sufficient countries ratified it for it to enter into force on 16 February 2005. Industrialised countries that ratify the Protocol commit to reducing their emissions of carbon dioxide and a basket of five other GHGs according to the schedule of emissions targets laid out in Annex B to the Protocol.

The Parties to the UNFCCC agreed that the effort to combat climate change should be governed by a number of principles, including the principle of 'common but differentiated responsibilities', in recognition that:

- the largest share of historical emissions of greenhouse gases originated in developed countries;
- per capita emissions in developing countries are still very low compared with those in industrialised countries; and
- in accordance with the principle of equity, the share of global emissions originating in developing countries will need to grow in order for them to meet their social and development needs.

As a result of this, most provisions of the Kyoto Protocol apply to developed countries, listed in Annex I to the UNFCCC. China, India and other developing countries have not been given any emission reduction commitments, in recognition of the principles of common but differentiated responsibilities and equity enumerated above. However, it was agreed that developing countries share the common responsibility of all countries in reducing emissions.

OBJECTIVES AND COMMITMENTS

The overall objective of the international climate regime, articulated in Article 2 of the UNFCCC, is to achieve 'stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic (human) interference with the climate system'.

The goal of the Kyoto Protocol is to reduce overall emissions of six GHGs – carbon dioxide, methane, nitrous oxide, sulphur hexafluoride, hydrofluorocarbons and perfluorocarbons – by an aggregate 5.2 per cent over the period 2008–2012, the first commitment period, which would then be followed by additional commitment periods with increasingly stringent emissions reduction obligations.

National emissions reduction obligations range from 8 per cent for the EU and some other countries to 7 per cent for the US, 6 per cent for Japan, 0 per cent for Russia, and permitted increases of 8 per cent for Australia and 10 per cent for Iceland. Emission figures exclude international aviation and shipping.

One of the most heavily contested issues in the Kyoto Protocol negotiations was the legally binding nature of the emissions reductions and the compliance regime. As the detailed architecture of the Protocol emerged in the period from 1997 to 2001, it became clear that for carbon markets to function effectively, the private sector needed to be able to 'bank' on the efficiency of the regime and the legality of the carbon credits.

What was agreed in the end was a compliance mechanism which held national governments accountable for their emissions reduction obligations, imposing a penalty of 30 per cent on countries for failing to meet their obligations by the end of the first commitment period (2012). Their obligation in the second commitment period, in addition to what was negotiated, would be increased by 1.3 tonnes for each tonne of shortfall in meeting their first commitment period obligation. Furthermore, if they were judged by the Protocol's Compliance Committee to be out compliance, then their right to use the flexible mechanisms would be suspended until they were brought back into compliance. Thus far, these legal arrangements have been sufficient to allow the functioning of the carbon markets, although the true test is yet to come.

STATUS OF RATIFICATION

As of May 2008, 182 parties have ratified the protocol. Out of these, 38 developed countries (plus the EU as a party in its own right) are required to reduce GHG emissions to the levels specified for each of them in the treaty. The protocol has been ratified by 145 developing countries, including Brazil, China and India. Their obligations focus on monitoring and reporting emissions, which also enable them to participate in the Clean Development Mechanism (CDM). To date, the US and Kazakhstan are the only signatory nations of the UNFCCC not to have ratified the protocol.

FLEXIBLE MECHANISMS

For combating climate change, it does not matter where emissions are reduced, as it is the overall global reduction that counts. As a result, the Kyoto Protocol has taken a strong market approach, recognising that it may be more cost-effective for industrialised (Annex I) parties to reduce emissions in other countries, whether also Annex I or developing. In order to achieve their targets set under the Kyoto Protocol, industrialised countries thus have the ability to apply three different mechanisms in which they can collaborate with other parties and thereby achieve an overall reduction in GHG emissions. These are:

1. Joint Implementation (JI);
2. the Clean Development Mechanism (CDM); and
3. emissions trading.

Joint Implementation

The Joint Implementation procedure is set out in Article 6 of the Kyoto Protocol. This stipulates that an Annex I country can invest in emissions reduction projects in any other Annex I country as an alternative to reducing emissions domestically. This allows countries to reduce emissions in the most economical way, and to apply the credit for those reductions towards their commitment goal. Most JI projects are expected to take place in so-called 'transition economies', as specified in Annex B of the Kyoto Protocol, mainly Russia, Ukraine and Central and East Europe (CEE) countries. Most of the CEE countries have since joined the EU or are in the process of doing so, thereby reducing the number of JI projects as the projects in these countries were brought under the European Union Emissions Trading Scheme (EU ETS) and its rules to avoid double counting. The JI development in Russia and Ukraine was relatively slow due to delays in developing the nations' domestic JI rules and procedures, although activity is now picking up.

The credits for JI emission reductions are awarded in the form of 'emission reduction units' (ERUs), with one ERU representing a reduction of one tonne of CO_2 equivalent. These ERUs come out of the host country's pool of assigned emissions credits, which ensures that the total amount of emissions credits among Annex I parties remains stable for the duration of the Kyoto Protocol's first commitment period.

ERUs will only be awarded for JI projects that produce emissions reductions that are 'additional to any that would otherwise occur' (the so-called 'additionality' requirement), which means that a project must prove that it would only be financially viable with the extra revenue of ERU credits. Moreover, Annex I parties may only rely on JI credits to meet their targets to the extent that they are 'supplemental to domestic actions'. The rationale behind these principles is to formally limit the use of the mechanism. However, since it is very hard to define which actions are 'supplemental' to what would have occurred domestically in any event, this clause is, sadly, largely meaningless in practice.

The Clean Development Mechanism

The Kyoto Protocol's Article 12 established the Clean Development Mechanism, whereby Annex I parties have the option to generate or purchase emissions reduction credits from projects undertaken by them in non-Annex I countries. In exchange, developing countries will have access to resources and technology to assist in development of their economies in a sustainable manner.

The credits earned from CDM projects are known as 'certified emissions reductions' (CERs). Like JI projects, CDM projects must meet the requirement of 'additionality', which means that only projects producing emissions reductions that are additional to any that would have occurred in the absence of the project will qualify for CERs. The CDM is supervised by an Executive Board, which is also responsible for issuance of the CERs. Other requirements, including compliance with the project and development criteria, the validation and project registration process, the monitoring requirements, and the verification and certification requirements, are done externally by a third party.

A wide variety of projects have been launched under the CDM, including renewable energy projects such as wind and hydroelectric; energy efficiency projects; fuel switching; capping landfill gases; better management of methane from animal waste; the control of coal mine methane; and controlling emissions of certain industrial gases, including HFCs and N_2O.

China has come to dominate the CDM market, and in 2007 expanded its market share of CDM transactions to 62 per cent. However, CDM projects have been registered in 45 countries and the UNFCCC points out that investment is now starting to flow into other parts of the world, such as Africa, Eastern Europe and Central Asia.

In 2007, the CDM accounted for transactions worth €12 billion (Point Carbon, 2008), mainly from private sector entities in the EU, EU governments and Japan.

The average issuance time for CDM projects is currently about one to two years from the moment that they enter the 'CDM pipeline', which counted over 3000 projects as of May 2008. Around 300 projects have received CERs to date, with over two-thirds of the issued CERs stemming from industrial gas projects, while energy efficiency and renewable energy projects seem to be taking longer to go through the approval process. However, there are now more than 100 approved methodologies and continuous improvement to the effective functioning of the Executive Board.

The rigorous CDM application procedure has been criticised for being too slow and cumbersome. The 'additionality' requirement has especially represented a stumbling block for some projects, since it is difficult to prove that a project would not be viable without the existence of CERs. The CDM also has the potential to create perverse incentives, in other words discouraging the implementation of rigorous national policies for fear of making the additionality argument more difficult.

There are many improvements yet to be made, and the additionality principle will be one of the many issues surrounding the flexible mechanisms to be discussed during the negotiations leading to a post-2012 climate agreement. The CDM, as a project-based market mechanism, is by definition going to be fundamentally limited in both scope and geographic application. A variety of options for sectoral approaches are under consideration for moving away from a project-based approach with its additionality requirements.

In addition, it has become very clear in retrospect that the large industrial gas projects which still count for a large share of the CERs on the market during this first period should in reality be dealt with legislatively rather than through the CDM.

Emissions Trading

Under the International Emissions Trading provisions, Annex I countries can trade so-called 'assigned amount units' (AAUs) among themselves, which are allocated to them at the beginning of each commitment period. The emissions trading scheme, which is established in Article 17 of the Kyoto Protocol, also foresees this to be 'supplemental to domestic actions' as a means of meeting the targets established for the Annex I parties. The total amount of allowable emissions for all Annex I countries (the 'cap') has been proposed under the Kyoto Protocol. The scheme then allocates an amount of these emissions as 'allowances' to each of the Annex I parties (the 'assigned amount'). The assigned amount for any Annex I country is based on its emissions reduction target specified under Annex B of the Kyoto Protocol. Those parties that reduce their emissions below the allowed level can then trade some part of their surplus allowances (AAUs) to other Annex parties.

The 'transition economies', such as Russia, Ukraine and CEE countries, have a huge quantity of surplus AAUs in the first commitment period, which is largely as a result of the collapse of the Warsaw Pact economies in the early 1990s. As these surplus AAUs were not created from active emissions reductions, the EU and Japanese buyers have vowed not to purchase them from the region unless the AAU revenue is associated with some 'greening' activities. The problem is partly being solved through the introduction of a new mechanism called the Green Investment Scheme (GIS), in which the sales revenue from AAUs are channelled to projects with climate and/or environment benefits. The surplus AAUs are now beginning to enter the market, with some CEE countries taking a lead in establishing the scheme. Various estimates suggest the total amount of AAUs entering the market through the GIS could be very large – much larger than the World Bank estimate of demand of between 400 million and 2 billion AAUs in the market (World Bank, 2008). The exact figure of the supply is hard to predict, however, as the biggest reserve of surplus AAU is in Russia, whose participation in the GIS is not yet clear.

Box V.3.1: The EU Emissions Trading System

HOW THE EU ETS WORKS

In order to tackle climate change and help EU Member States achieve compliance with their commitments under the Kyoto Protocol, the EU decided to set up an Emissions Trading System (ETS). Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003 established the EU ETS. On 1 January 2005 the EU ETS commenced operation. The system is being implemented in two trading periods. The first trading period ran from 2005 to 2007. The second trading period is set in parallel to the first commitment period of the Kyoto Protocol: it began on 1 January 2008 and runs until the end of 2012. A third trading period is expected to start in 2013 and to be implemented along with a reviewed ETS Directive.

The EU ETS is the first and largest international trading system for CO_2 emissions in the world (see following section, 'Carbon as a commodity'). Since January 2008 it has applied not only to the 27 EU Member States but also to the other three members of the European Economic Area – Norway, Iceland and Liechtenstein. It covers over 10,000 installations in the energy and industrial sectors, which are responsible for about 50 per cent of the EU's total CO_2 emissions and about 40 per cent of its total greenhouse gas emissions. The emission sources regulated under the system include combustion plants for power generation (capacities greater than 20 MW), oil refineries, coke ovens, iron and steel plants, and factories making cement, glass, lime, bricks, ceramics, pulp and paper. Discussions are under way on legislation to bring the aviation sector into the system from 2011 or 2012 (EC, 2006b).

The EU ETS is an emission allowance cap and trade system, that is to say it caps the overall level of emissions allowed but, within that limit, allows participants in the system to buy and sell allowances as they need. One allowance gives the holder the right to emit one tonne of CO_2.

Currently, for each trading period under the system, Member States draw up national allocation plans (NAPs), which determine their total level of ETS emissions and how many emission allowances each installation in their country receives. By allocating a limited number of allowances, below the current expected emissions level, Member States create scarcity in the market and generate a market value for the permits. A company that emits less than the level of their allowances can sell its surplus allowances. Those companies facing difficulties in keeping their emissions in line with their allowances have a choice between taking measures to reduce their own emissions or buying the extra allowances they need on the market.

The ETS Directive stipulates that at least 95 per cent of issued allowances should be given out for free by Member States for the period 2005–2007. For the second trading period (2008–2012), this value is 90 per cent. The remaining percentage can be charged for, for example in an auction. This process, referred to as 'allocation', has been carried out using what is known as a 'grandfathering' approach, which is based on historical data (emissions or production levels).

The scheme is linked to the Kyoto Protocol's flexible mechanisms through Directive 2004/101/EC. According to the 'Linking Directive', in addition to domestic action, Member States may also purchase a certain amount of credits from Kyoto flexible mechanisms projects (CDM and JI) to cover their emissions in the same way as ETS allowances.

PERFORMANCE OF THE EU ETS (2005–2007)

The EU ETS has so far failed to achieve some of its main objectives, notably encouraging investment in clean technologies and the use of CO_2 emissions reduction certificates as a market signal to regulate greenhouse gas emissions (Carbon Trust, 2007; Open Europe, 2007). This is due to a combination of adverse incentives associated with the EU ETS design:

- political national influence on the allocation process and over-allocation of permits;
- counterproductive allocation methods; and
- limited scope of the system.

Political national influence on the allocation process and over-allocation of permits

As previously explained, in order to make sure that real trading emerges, Member States must make sure that the total amount of allowances issued to installations is less than the amount that would have been emitted under a business-as-usual scenario.

Under the current system, where a significant degree of freedom over the elaboration of the NAPs is retained by Member States, decisions concerning allocation hinge upon emission projections, national interests and business efforts to increase the number of allowances (del Río González, 2006; Kruger et al., 2007; Blanco and Rodrigues, 2008).

Actual verified emissions in 2005 showed allowances had exceeded emissions by about 80 million tonnes of CO_2, equivalent to 4 per cent of the EU's intended maximum level (Ellerman and Buchner, 2007). This happened because government allocation had been based on over-inflated projections of economic growth and participants had a strong incentive to overestimate their needs (ENDS Europe Report, 2007 – http://www.endseurope.com).

The publication of those figures provoked the collapse of the CO_2 prices to less than €10/t in spring 2006. By the end of 2006 and into early 2007, the price of allowances for the first phase of the EU ETS fell below €1/tCO_2 (€0.08/tCO_2 in September 2007) (www.pointcarbon.com). The over-allocation of permits and the consequent collapse of CO_2 prices have hampered any initiative of clean technology investment, as it is clear that most companies regulated by the EU ETS didn't need to make any significant change to their production processes to meet the target they had been assigned (Blanco and Rodrigues, 2008).

Counterproductive allocation methods

The first phase of the EU ETS has shown that free allocation based on absolute historical emissions (grandfathering) causes serious distortions in competition by favouring de facto fossil fuel generation (EWEA, 2007).

A controversial feature of the system has been the ability of the electric power sector to pass along the the marginal cost of freely allocated emissions to the price of electricity and to make substantial profits. This happens because in competitive markets the power generation sector sets prices relative to marginal costs of production. These marginal costs include the opportunity costs of CO_2 allowances, even if allowances are received for free. As a consequence, fossil fuel power producers receive a higher price for each kWh they produce, even if the costs for emitting CO_2 only apply to a minor part of their merchandise. The effect is known as windfall profit.

In the first phase of the EU ETS, conventional power generators are believed to have made over €12.2 billion in windfall profits in the UK alone (Platts, 2008). There have been similar arguments over ETS windfall profits in other European countries, such as Germany and Spain (Platts, 2008). Carbon market experts see the situation as likely to arise again in the second trading period. According to a recent Point Carbon study of the UK, Germany, Spain, Italy and Poland, power companies could reap profits in excess of €71 billion over the next four years (Point Carbon, 2008).

Furthermore, as the economist Neuhoff remarks, any free allocation acts as a subsidy to the most polluting companies, which – in addition to not paying the environmental cost they entail – obtain substantial gains (Neuhoff et al., 2006). This is clearly in contradiction with the 'polluter pays principle' (established by Article 174 of the EC Treaty), which states that 'environmental damage should as a priority be rectified at source and that the polluter should pay'.

Grandfathering also penalises 'early action' and justifies 'non-action'. Since allowances are allocated as a function of emission levels, firms are clearly encouraged not to reduce their emissions, as this would result in fewer allowances in future phases (Neuhoff et al., 2006).

Limited scope of the ETS

About 55 per cent of the CO_2 emitted in the EU comes from sectors outside the EU ETS. In the same way, other more powerful greenhouse gases, such as nitrous oxide, sulphur hexafluoride and methane are excluded. The experience from recent years illustrates that it is in some of the sectors that have been left outside the ETS – notably transport – that the highest CO_2 emission growth rates have occurred (Eurostat, 2007).

PROPOSALS FOR THE POST-2012 PERIOD

As a preliminary step to design the third phase of the EU ETS (post-2012), the European Commission has embarked in a public consultation on what the new system should look like. The debate started in November 2006 with the publication of the Communication 'Building a global carbon market' (EC, 2006a). In the context of the European Climate Change Programme (ECCP), a Working Group on the review of the EU ETS was also set up to discuss the four categories of issues identified by the EC Communication (EC, 2006a):

1. scope of the scheme;
2. robust compliance and enforcement;
3. further harmonisation and increased predictability; and
4. participation of third countries.

As part of the Commission's climate change and energy package, and in the light of the European Council's 2020 commitments to reduce greenhouse gas emissions by 20 per cent compared to 1990 levels (30 per cent if other developed countries join the effort), a new proposal for reform of the EU ETS Directive was presented on 23 January 2008 (EC, 2008).

Although the proposal still needs to be approved by both the Council of the EU and the European Parliament, the main elements of the new system, which will enter into force in 2013 and run until 2020, seem to be the following:

- One EU-wide cap on the number of emission allowances. Allowances would be centrally allocated by the European Commission instead of through NAPs.
- Emissions from EU ETS installations would be capped at 21 per cent below 2005 levels by 2020 – thus a maximum of 1720 million allowances. The annual cap would fall linearly by 1.74 per cent annually as of 2013.
- 100 per cent auctioning for the power sector. For the other sectors covered by the ETS, a transitional system would be put in place, with free allocations being gradually phased out on an annual basis between 2013 and 2020.
- However, an exception could be made for installations in sectors judged to be 'at significant risk of carbon leakage', in other words relocation to third countries with less stringent climate protection laws. Sectors concerned by this measure are yet to be determined.
- At least 20 per cent of auction revenues would have to be ring-fenced to reduce emissions, to support climate adaptation and to fund renewable energy development.
- Extension of the system's scope to new sectors, including aluminium, ammonia and the petrochemicals sectors, as well as to two new gases, nitrous oxide and perfluorocarbons. Road transport and shipping would remain excluded, although the latter is likely to be included at a later stage.
- In the absence of an international climate agreement, the limit on the use of the CERs and ERUs is expected to be restricted to the unused portion of operators' phase two cap. This limit is to rise to 50 per cent of the reduction effort if a new international climate agreement is reached.

CARBON AS A COMMODITY

The Kyoto Protocol's efforts to mitigate climate change have resulted in an international carbon market that has grown tremendously since the entry into force of the Protocol in 2005. While previously, the relatively small market consisted mostly of pilot programmes operated either by the private sector or by international financial institutions such as the World Bank, it has experienced strong growth in the past two years, and was valued at €40 billion in 2007, 80 per cent more than the 2006 value. The total traded volume increased by 64 per cent from 1.6 $MtCO_2$ in 2006 to 2.7 Mt in 2007 (Figure V.3.1).

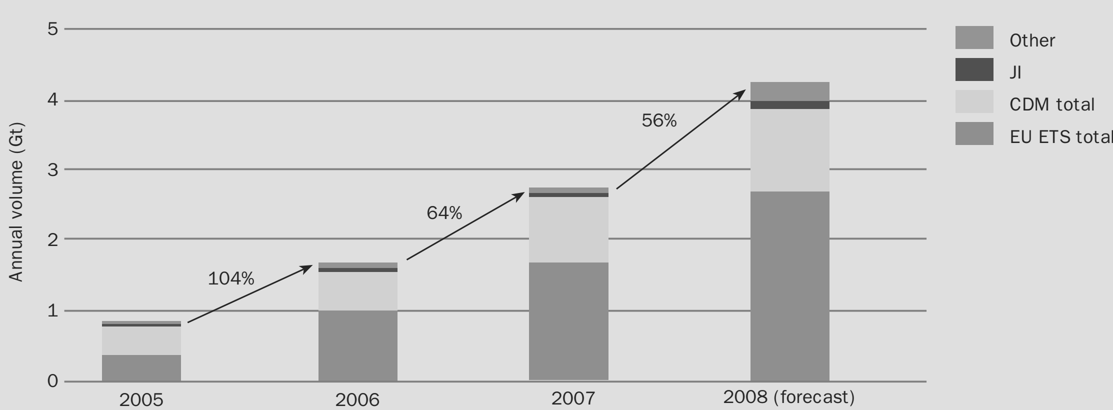
While the international carbon market has expanded to include a wide variety of project types and market participants, it has been dominated by two market-based mechanisms: the EU ETS and the CDM.

The EU ETS continues to be the largest carbon market, with a traded volume of 1.6 $MtCO_2$ and a value of €28 billion in 2007 (Point Carbon, 2008), which corresponds to nearly a doubling of both volume and value compared to the previous year. The EU ETS now contains more than 60 per cent of the physical global carbon market and 70 per cent of the financial market. The CDM market increased to 947 $MtCO_2$-equivalents and €12 billion in 2007. This is an increase of 68 per cent in volume terms and a staggering 200 per cent in value terms from 2006, and the CDM now constitutes 35 per cent of the physical market and 29 per cent of the financial market. The JI market, while still small, also finally started to take off in 2007, nearly doubling in volume to 38 $MtCO_2$ and more than tripling in value to €326 million.

However, experts predict that the potential for future market growth is much larger. Point Carbon forecasts 56 per cent market growth in 2008, increasing volumes to over 4 million tonnes of carbon, with a value of more than €60 billion, depending on prices. Current prices in the ETS hover around €25/tonne, and CDM prices range from anywhere between 9 and 17/tonne, depending on the type of project and its stage of development.

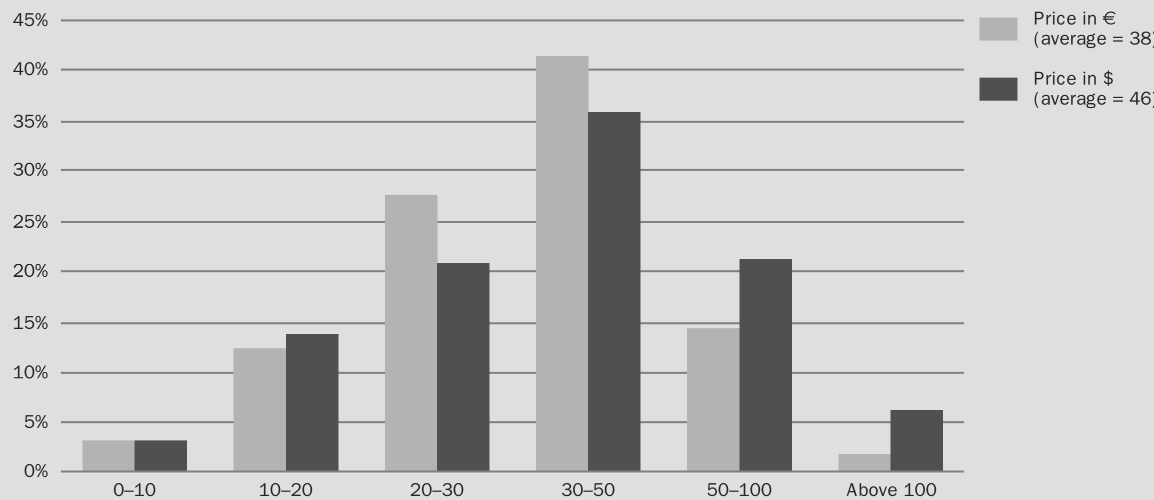
Providing that the price for carbon is high enough, the carbon market is a powerful tool for attracting investment, fostering cooperation between countries,

Figure V.3.1: Annual contract volumes, 2005–2008



Source: Point Carbon (2008)

Figure V.3.2: What will be the cost of carbon in 2020?



Currency of choice: N = 2591 (2157 responses in €; 967 in US$).

Source: Point Carbon (2008)

companies and individuals, and stimulating innovation and carbon abatement worldwide. In theory, at least, the price of carbon should more or less directly reflect the rigorousness of the economy-wide caps of the Annex B countries. The reality is of course more complicated, since there is only one real 'compliance market' at present, which is the EU ETS, and the CDM and JI markets are in reality just getting started. It is also not clear what role Canada, Japan and Australia will play in the carbon market during the first commitment period; and of course, the original conception and design of the carbon market was predicated on the fact that the US would be a large buyer, which has not turned out to be the case, again, for the first commitment period. Governments negotiating the post-2012 climate agreement seem committed to 'building carbon markets' and/or 'keeping the CDM', but there is very little detail to go on at present. The UNFCCC negotiations in June 2008 produced little more than a shopping list of issues to be addressed in the further development of carbon markets in general and the CDM in particular.

Point Carbon conducted a survey of carbon market practitioners at the end of 2007 and came up with the figures presented in Figure V.3.2. These give as good a prognostication as any as to the future price of carbon.

Wind Energy's Contribution to Emissions Reductions

EMISSIONS FROM THE POWER SECTOR

The power sector today accounts for 41 per cent of global CO_2 emissions (WEO, 2006), and continuing improvements of thermal power stations in terms of efficiency are offset by the strong growth in global power demand. The International Energy Agency (IEA, 2007a) estimates that by 2030, electricity production will account for over 17,000 $MtCO_2$, up from 10,500 $MtCO_2$ in 2004.

According to the IEA, electricity generation has had an average growth rate of 2.6 per cent since 1995 and is expected to continue growing at a rate of 2.1–3.3 per cent until 2030, which would result in a doubling of global electricity demand. The bulk of this growth is expected to occur in developing Asia, with India and China seeing the fastest growth in demand. World CO_2 emissions from power production are projected to increase by about 66 per cent over 2004–2030. China and India alone would account for 60 per cent of this increase.

These figures emphasise the strong responsibility and key role that the power sector has to play in reducing CO_2 emissions. According to the IEA, the power sector can be the most important contributor to global emission reductions, with potential CO_2 savings of 6–7 Gt by 2050 on the demand side and 14–18 Gt of CO_2 reductions on the supply side if the right policy choices are taken (IEA, 2008).

The carbon intensity of electricity production largely depends on a given country's generation mix. While inefficient coal steam turbines, which are still in use in many parts of the world, emit over 900 tCO_2/GWh (UNFCCC, 2006) and oil steam turbines around 800 tCO_2/GWh, modern combined cycle gas turbines only produce half these levels. China and India, which have a high share of coal in their power mix, see their electricity produced with over 900 tCO_2/GWh, while other countries, with a high share of renewable energy, such as Brazil, produce power with only 85 tCO_2/GWh. The global average for electricity production can be assumed to be at around 600 tCO_2/GWh, which is close to the OECD average.

WIND ENERGY'S POTENTIAL FOR EMISSIONS REDUCTIONS UP TO 2020

The Intergovernmental Panel on Climate Change (IPCC) released its Fourth Assessment Report in 2007. This left no doubt about climate change being real, serious and man-made. It warned that in order to avert the worst consequences of climate change, global emissions must peak and start to decline before the end of 2020. The potential of wind energy to curb global emissions within this timeframe is therefore key to the long-term sustainability of the power sector.

The benefit to be obtained from carbon dioxide reductions through wind energy again mainly depends on which other fuel, or combination of fuels, any increased wind power generation will replace, so this differs from country to country. For the purposes of this section, we assume a global average of 600 tCO_2/GWh.

Following the logic of the GWEC Wind Energy Scenarios (GWEC, 2008) presented in Part VI, global wind energy capacity could stand at more than 1000 GW by the end of 2020, producing 2,500,000 TWh annually. As a result, as much as 1500 $MtCO_2$ could be saved every year.

It is important to point out that modern wind energy technology has an extremely good energy balance. The CO_2 emissions related to the manufacture, installation and servicing over the average 20-year life cycle of a wind turbine are offset after a mere three to six months of operation, resulting in net CO_2 savings thereafter.

Wind Energy CDM Projects

The CDM has, to some extent, contributed to the deployment of wind energy globally. As of 1 September 2008, a total of 504 wind energy projects were in the 'CDM pipeline', totalling an installed capacity of 16,410 MW. This represents 13 per cent of the total number of projects introduced into the pipeline. Four million CERs have already been issued to wind projects, a number that will go up to 203 million by the end of the first commitment period in 2012.

The majority of these projects are located in China and India. In China, 90 per cent of wind energy projects have applied for CDM registration, and there are now 235 projects in the CDM pipeline, making up almost 11.93 GW of capacity. India now has 216 projects in the pipeline, totalling close to 4.24 GW.

The narrow focus of CDM-supported wind projects in a very few countries is unfortunate but is a reflection of the fact that while carbon finance is a *useful*, and in some cases *necessary* condition for the development of wind power, it is by no means *sufficient*. In the case of both India and China, carbon finance functions alongside a wide range of other measures necessary for countries to diversify and decarbonise their power supply sectors.

There are signs that some other countries may join the list of major host countries for wind power projects assisted by CDM carbon finance. However, it is clear that the ultimate responsibility for this lies with active government implementation of policies and measures

Table V.3.1: CDM projects in the pipeline

Type	Number	kCERs/yr	2012 kCERs	2020 kCERs
Afforestation	5	344	1864	7058
Agriculture	172	6570	43,494	77,570
Biogas	259	11,936	59,172	139,366
Biomass energy	582	33,850	184,661	427,249
Cement	38	6806	41,342	81,796
CO_2 capture	1	7	29	66
Coal bed/mine methane	55	23,597	121,634	301,687
Energy distribution	4	129	1053	1886
EE households	10	306	1504	3346
EE industry	168	6398	32,444	69,634
EE own generation	363	56,558	272,091	608,542
EE service	8	84	393	1034
EE supply side	36	8059	22,817	93,257
Fossil fuel switch	129	41,973	203,062	483,663
Fugitive	28	10,227	62,112	134,515
Geothermal	13	2457	13,775	32,443
HFCs	22	83,190	506,379	1,132,155
Hydro	1006	97,099	437,951	1,183,733
Landfill gas	290	45,793	253,685	559,304
N_2O	65	48,195	257,774	637,426
PFCs	8	1121	4785	11,806
Reforestation	22	1436	11,782	23,230
Solar	23	641	2816	7214
Tidal	1	315	1104	3631
Transport	7	711	3938	9451
Wind	504	40,801	203,081	496,050
Total	3819	528,602	2,744,744	6,527,113

Source: UNEP Risø DTU, CDM/JI Pipeline Analysis and Database, available at http://cdmpipeline.org/cdm-projects-type.htm

Table V.3.2: Wind CDM projects

JI projects in the pipeline (numbers, ERUs & issuance)	All JI projects		
Type	Projects	1000 ERUs	2012 kERUs
Afforestation	0	0	0
Agriculture	0	0	0
Biogas	3	351	1861
Biomass energy	22	1834	8960
Cement	1	306	1041
CO_2 capture	1	268	1071
Coal bed/mine methane	17	8758	43,790
Energy distribution	7	727	3636
EE households	0	0	0
EE industry	12	4870	22,807
EE own generation	1	1698	8491
EE service	0	0	0
EE supply side	15	3127	13,154
Fossil fuel switch	9	1965	9711
Fugitive	33	19,763	92,397
Geothermal	0	0	0
HFCs	3	1774	6579
Hydro	9	766	3295
Landfill gas	17	2436	11,758
N_2O	21	19,402	82,899
PFCs	1	233	1165
Reforestation	0	0	0
Solar	0	0	0
Tidal	0	0	0
Transport	0	0	0
Wind	18	1974	8610
Total	190	70,252	321,225

Source: http://cdmpipeline.org/cdm-projects-type.htm

to create the enabling environment within which carbon finance can play its role, in other words to be an important source to defray the marginal costs of wind power versus conventional fossil fuel plants. This is particularly the case in the absence of an economy-wide cap on carbon emissions.

While clarification and simplification of the carbon finance mechanisms can assist in the broadening and deepening participation of developing countries in the carbon finance market, the fundamental responsibility lies with the host governments, at least as far as wind power is concerned.

Wind Energy JI Projects

There are currently 18 wind energy projects in the JI pipeline (Table V.3.3), totalling an installed capacity of 961 MW. The biggest of these (300 MW) is located in Ukraine, in the autonomous Republic of Crimea. Other projects are based in Bulgaria, Poland, Lithuania and Estonia.

While the JI market is very small today in terms of traded volume, the mechanism could serve to incentivise large countries such as Russia and the Ukraine to tap into their important wind energy potential.

The Path to a Post-2012 Regime

The process to arrive at an international climate agreement for the period after 2012 has been long and arduous. As our understanding of the urgency of early action to avoid the worst dangers of climate change has increased, so has the political pressure on governments to conclude an effective agreement.

The Fourth Assessment Report of the IPCC, which shared the 2007 Nobel Peace Prize with former US Vice-President Al Gore, has promoted the powerful voice of the scientific community and led to a growing chorus of public support for this urgent call.

In addition, a number of independent studies, such as the report for the British Government by former World Bank Chief Economist Sir Nicholas Stern, have highlighted concerns that the economic and social costs associated with the increasing impacts of climate change will far outweigh the costs of effective mitigation of GHG emissions. In fact, the costs associated with mitigation of climate change seem relatively

Table V.3.3: JI projects in the pipeline

Type	Number	kERUs	2012 kERUs
Afforestation	0	0	0
Agriculture	0	0	0
Biogas	1	115	682
Biomass energy	16	1166	5618
Cement	1	306	1041
CO_2 capture	1	268	1071
Coal bed/mine methane	14	7418	37,088
Energy distribution	7	721	3401
EE households	0	0	0
EE industry	10	3207	15,252
EE own generation	1	1557	7787
EE service	0	0	0
EE supply side	13	2692	10,979
Fossil fuel switch	8	1912	9499
Fugitive	32	19,533	91,308
Geothermal	0	0	0
HFCs	2	1577	5789
Hydro	5	259	1325
Landfill gas	13	2088	10,226
N_2O	14	11,883	53,422
PFCs	1	233	1165
Reforestation	0	0	0
Solar	0	0	0
Tidal	0	0	0
Transport	0	0	0
Wind	10	1492	6314
Total	149	56,427	261,967

Source: UNEP Risø DTU, CDM/JI Pipeline Analysis and Database, available at http://cdmpipeline.org/cdm-projects-type.htm

small when viewed on a global basis over the next several decades, and in addition yield many potential economic, social and human health benefits.

However, despite the obvious conclusion that early action is required, questions of who does what, when and within what framework present political difficulties for government negotiators faced with the large task of, in effect, reshaping the global economy without either a clear mandate as to how that should be achieved or unambiguous backing by all governments involved.

In the autumn of 2005, anticipation grew over a ‘showdown’ in Montreal over the future of the Kyoto Protocol, which had just (finally) entered into force in February of that year. The future of the global regime, which was in large part designed around a US-driven demand for legally binding emissions reductions obligations driving a global carbon market, and which was in fact designed to accommodate the US as a large buyer of credits, was seriously jeopardized by a change in Bush Administration policy in early 2001 and its subsequent argument that a global regime, particularly a *binding* global regime, was neither necessary nor desirable. However, the intervening years saw an uneasy but effective alliance between the EU and key developing countries to get the regime established, ratified and finally operational for the first commitment period, 2008–2012.

Article 3.9 of the Kyoto Protocol states that:

> *commitments for subsequent periods for Parties included in Annex I shall be established in amendments to Annex B to this Protocol. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall initiate the consideration of such commitments at least seven years before the end of the first commitment period mentioned in Paragraph 7 above.*

As a result, just as the Protocol was becoming operational, countries had to establish a process for negotiating targets for the second commitment period, which would start following the expiration of the first commitment period in 2012.

Most countries and many experts entirely discounted the possibility that the Kyoto Protocol signatories would in fact agree to move forward with these negotiations. The US in particular was hostile to any such negotiations, stating over and over again that the Kyoto Protocol was 'fatally flawed'. However, thanks to both the resolve of the majority of countries to move forward with global climate protection and the resolve of US civil society and business organisations, as well as the skilful leadership of the Canadian Presidency, in December 2005 the Montreal COP agreed to move forward on negotiations for a second commitment period as specified in the treaty. The US delegation at first refused to participate in the talks, but at last came back to the table and agreed to proceed with negotiations. This major reversal marked the beginning of a new phase of the international climate negotiations.

Over the next two years, the negotiations proceeded on two parallel tracks: the Kyoto Protocol track mentioned above and the so-called 'dialogue' under the Convention, made up by a series of workshops covering a broad range of topics but with no formal relationship to the negotiations. In December 2007 at the 13th COP in Bali, countries achieved:

- an agreement to launch negotiations under the Convention to replace the 'dialogue';
- an agenda and process for conducting those negotiations; and
- an end date for the negotiations of COP 15 of December 2009 in Copenhagen.

The critical pieces of the negotiation process for the future regime will be conducted primarily under the following three processes:

1. The Ad Hoc Working Group on Long-Term Cooperative Action under the Convention (AWGLCAC – now shortened to AWG-LCA): this group was newly established at the COP in Bali, with the aim of creating a framework in which the US will negotiate until there is a new administration in place at the beginning of 2009; and in which China, India, Brazil and South Africa (and Japan to some extent) will negotiate until the US is fully engaged.
2. The Ad Hoc Working Group on Further Commitments for Annex I Parties under the Kyoto Protocol (AWG – now called the AWG-KP): this is the main ongoing working group of the Parties to the Kyoto Protocol to consider further commitments by Annex I Parties for the period beyond 2012. The aim is to ensure that no gap arises between the first and the second commitment periods. AWG-KP reports to the COP/MOP at each session on the progress of its work.

3. The Second Review of the Kyoto Protocol pursuant to its Article 9: the Article 9 review is where the formal consideration of the evaluation and potential improvements to the Kyoto Protocol takes place. This would be the major point of review for the entire climate regime if the US had ratified the Kyoto Protocol along with other countries, but in the current circumstances it has been difficult to get agreement on moving forward on this.

These bodies/processes will all feed into the formal COPs (at the end of each year), where all the final political decisions will be taken, either at the COP (Convention) or the COP/MOP (Kyoto Protocol) level, and this will be where all the pieces will have to be put together into a coherent whole.

For the wind sector, the outcomes of these negotiations are critical on a number of key points:

- the rigour of the emission reduction targets;
- the resultant future price of carbon;
- technology transfer agreements that actually work; and
- an expanded carbon market.

THE NEED FOR STRONG COMMITMENTS

The driver of the global climate regime must be rigorous, legally binding emission reduction targets for an increasing number of countries under the Kyoto Protocol or its successor agreement. Rigorous emission reduction targets for industrialised countries will send the most important political and market signal that governments are serious about creating a framework for moving towards a sustainable energy future. The indicative range of targets for Annex I countries agreed to by the Kyoto Protocol countries at Bali of CO_2 reductions of 25–40 per cent below 1990 levels by 2020 is a good starting point, although they would need to be closer to the upper end of that range to stay in line with the EU's stated policy objective of keeping global mean temperature rise to less than 2°C above pre-industrial levels.

CARBON PRICES

In addition to achieving climate protection goals, strong emission reduction targets are necessary to bolster the price of carbon on emerging carbon markets, and the regime needs to be broadened so that we move towards a single global carbon market, with the maximum amount of liquidity to achieve the maximum emission reductions at the least cost. While the EU ETS and the CDM are the two major segments of the market, and are growing enormously, they need to be broadened and deepened until they are truly global and the market is able to 'find' the right price for carbon. Achieving that objective must not be at the cost of the integrity of the system, and it will take significant experimentation and time; but it must be clear that that is the final objective, and that governments are agreed to sending the market a signal that the global economy needs to be largely decarbonised by 2050, and effectively completely decarbonised by the end of the century.

TECHNOLOGY TRANSFER

One of the fundamental building blocks of the UNFCCC when it was agreed in 1992 was the commitment by industrialised countries to provide for the development and transfer of climate-friendly technologies to developing countries. While a noble statement of intent at the time, when the world was contemplating how to spend the 'peace dividend' resulting from the end of the Cold War, reality has turned out somewhat differently. For the most part, governments do not own technology (other than military) and are therefore not in a position to 'transfer' it, even if they were in a financial position to do so, which most are not.

However, in the meantime, through economic globalisation, enormous quantities and varieties of technologies have been 'transferred' through direct and indirect foreign investment, world trade and a variety of means used by the private sector as the economy has become increasingly global. As a result, the abstract government and academic debate about technology transfer in its current form has at times become dated, as it no longer reflects the economic reality of today.

Having said that, the political and moral obligations on the part of industrialised countries to deliver on this promise do exist. Developing countries, rightly, are not slow to remind their industrialised country negotiating partners of that fact, nor that reaching some resolution of this subject will be a key part of a post-2012 agreement.

The development and dissemination of technology is a complex subject which varies widely from sector to sector and from country to country. In the first instance, it is useful to distinguish between three major categories in this discussion:

1. the dissemination of existing climate-friendly technology;
2. research and development and deployment of new technologies; and
3. the transfer, on a grant or concessional basis, of both mitigation and climate adaptation technologies to least developed countries and small island states.

Furthermore, it is necessary to define technology transfer activities under the UNFCCC framework and those which can be supported by public funds which would be established internationally as part of the post-2012 negotiation. From the wind industry perspective, category (1) above is most relevant, and the correct division of labours between government and the private sector in that area is of key importance. If these parameters were clear, it is possible that a useful role for the UN system on this subject might be devised.

EXPANDED CARBON MARKETS

The global climate regime can only be aided by the expansion and integration of the emerging carbon markets. Larger markets lead to more liquidity, which in turn results in more active markets and a greater likelihood of finding the 'right price' for carbon given the overall objectives to reduce emissions in the most cost-efficient fashion. However, markets are by definition imperfect, and require substantial and rigorous regulation to function effectively towards their stated goals.

In pursuit of the final objective of a global, seamless carbon market, there are a number of steps that can be taken. First and foremost, it is essential that the US, as the world's largest CO_2 polluter, joins the global carbon market, which was in fact designed largely at the instigation of the US and with the expectation that the US would be the major 'buyer' on the global market.

Second, the membership of Annex B needs to be expanded to include those countries which have recently joined the OECD and those whose economies have grown to reach or even exceed OECD or EU average income per capita. And third, there are many proposals under discussion for improving the scope and the effectiveness of the CDM in the period after 2012.

A SECTORAL APPROACH FOR THE POWER SECTOR

A sectoral approach has been proposed as one way to reform the CDM. A sectoral approach could also avoid the counterfactual and hypothetical questions of additionality at a project-by-project level. The concept was further developed into a broader discussion of using sectoral approaches to engage developing countries more fully in the post-2012 regime. The project-based approach does not satisfy the requirements for achieving rigorous measures to create the 'significant deviation' from baseline emissions growth in rapidly industrialising countries that models show are required to achieve an emissions pathway consistent with rigorous climate protection targets.

To ensure the maximum uptake of emissions-reducing technology for the power generation sector, the Global Wind Energy Council (GWEC) and others are exploring options for a voluntary electricity sector emissions reduction mechanism. The main characteristics of this proposal involve establishing a hypothetical baseline of future emissions in the electricity sector in an industrialising country, quantifying the effect of national policies and measures, and on that basis establishing a 'no regrets' target baseline for the entire electricity sector, which would usually mean a limitation in the growth of emissions in the sector. Reductions in emissions *below* that baseline in the electricity sector would then be eligible to be traded as credits on international carbon markets.

The advantages of this system over the current project-based CDM would be in terms of the simplicity and scope of its operation, encompassing both clean energy production as well as a built-in incentive for energy efficiency, while providing potentially very large sources of investment in the decarbonisation of the energy sector of a rapidly industrialising country. It would also be a good stepping stone between the current situations of non-Annex I countries and their eventual assumption of an economy-wide cap as the regime develops in the future.

V.4 EXTERNALITIES AND WIND COMPARED TO OTHER TECHOLOGIES

Introduction to Externalities

Analyses of the economics of wind energy have shown that it is increasingly competitive with conventional electricity generation technologies. However, in present market conditions the gap towards full competitiveness has to be covered by economic support instruments such as feed-in tariffs and tradable green certificates.

While wind energy and other renewable energy sources have environmental benefits compared with conventional electricity generation, these benefits may not be fully reflected in electricity market prices, despite a fledgling CO_2 Emission Trading Scheme. The question therefore is: 'Do present electricity market prices give an appropriate representation of the full costs to society of producing electricity?'. In other words, are externalities included in the price mechanisms?

The externalities of electricity generation deal with such questions in order to estimate the hidden benefit or damage of electricity generation not otherwise accounted for in the existing pricing system. The costs are real and 'external' because they are paid for by third parties and by future generations, and not directly by the generators or consumers. In order to establish a consistent and fair comparison of the different electricity generation technologies, all costs to society, both internal and external, need to be taken into account.

The following sections of Chapter V.4 explain the basic economic concept of external cost, the policy options to internalise external cost and the present knowledge of the external costs of different electricity generation technologies. Finally, empirical results on specific and total emissions, and on the external cost of fossil fuel-based electricity generation in the EU-27 are presented for the Member State level for 2005. Chapter V.5 continues with quantitative results on the environmental benefits of wind energy in terms of avoided emissions and external costs for different wind deployment scenarios in the EU-27 Member States up to 2020 and 2030.

The Economic Concept of External Effects

DEFINITION AND CLASSIFICATION

The different definitions and interpretations of external costs relate to the principles of welfare economics, which state that economic activities by any party or individual making use of scarce resources cannot be beneficial if they adversely affect the well-being of a third party or individual (see, for example, Jones, 2005).

From this, a generic definition of externalities is 'benefits and costs which arise when the social or economic activities of one group of people have an impact on another, and when the first group fails to fully account for their impacts' (European Commission, 1994).

By definition, externalities are not included in the market pricing calculations, and therefore it can be concluded that private calculations of benefits or costs may differ substantially from society's valuation if substantial external costs occur. Externalities can be classified according to their benefits or costs in two main categories:

1. **environmental and human health externalities:** these can additionally be classified as local, regional or global, referring to climate change caused by emissions of CO_2 or destruction of the ozone layer by emissions of CFCs or SF6; and
2. **non-environmental externalities**: hidden costs, such as those borne by taxpayers in the form of subsidies, research and development costs, or benefits like employment opportunities, although for the last it is debatable whether it constitutes an external benefit in the welfare economics sense.

If an external cost is recognised and charged to a producer, then it is said to have been 'internalised'.

IMPORTANCE OF EXTERNALITIES

By definition, markets do not include external effects or their costs. It is therefore important to identify the external effects of different energy systems and then to monetise the related external costs. It is then possible to compare the external costs with the internal costs of energy, and to compare competing energy systems, such as conventional electricity generation technologies and wind energy.

As markets do not intrinsically internalise external costs, internalisation has to be achieved by adequate policy measures, such as taxes or adjusted electricity rates. Before such measures can be taken, policymakers need to be informed about the existence and the extent of external costs of different energy systems. Analysing external costs is not an easy task. Science (to understand the nature of the impacts) and economics (to value the impacts) must work together to create analytical approaches and methodologies, producing results upon which policymakers can base their decisions for appropriate measures and policies.

Valuation procedures are needed, for example putting a value on a person becoming ill due to pollution, or on visual intrusion caused by a wind turbine, or on future climate change damage caused by a tonne of CO_2. Such evaluations of externalities have uncertainties due to assumptions, risks and moral dilemmas. This sometimes makes it difficult to fully implement the internalisation of externalities by policy measures and instruments (for example emission standards, tradable permits, subsidies, taxes, liability rules and voluntary schemes). Nevertheless, they offer a base for politicians to improve the allocation processes of the energy markets.

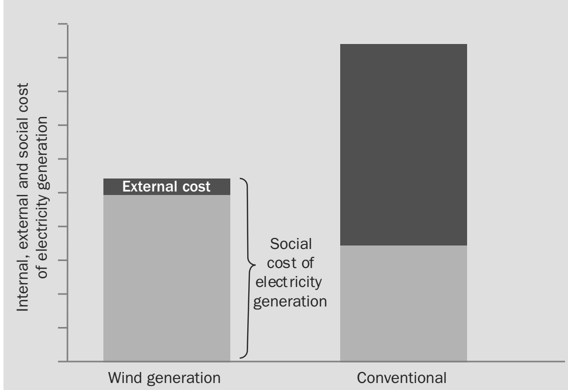
Subsequently, the question arises whether the internalisation of externalities in the pricing mechanism could impact on the competitive situation of different electricity generation technologies, fuels or energy sources. As Figure V.4.1 illustrates, a substantial difference in the external costs of two competing electricity generation technologies may result in a situation where the least-cost technology (where only internal costs are considered) may turn out to be the highest-cost solution to society if all costs (internal and external) are taken into account.

PRESENT STATE OF KNOWLEDGE

Serious study of external costs began in the late 1980s, when the first studies were published attempting to quantify and compare the external costs of electricity generation. The most important early studies are listed in the references. These studies seeded public interest in externalities, since they indicated that external costs could be of the same order of magnitude as the direct internal costs of generating electricity. Since that time more research and different approaches, better scientific information, and constant improvement of the analytical methodologies used have advanced the study of externalities, especially in Europe and the US.

This development has resulted in a convergence of methodologies, at least for calculating the external costs of fossil fuel-based electricity generation and

Figure V.4.1: Social cost of electricity generation



Source: Auer et al. (2007)

wind energy. Despite the uncertainties and debates about externalities, it can be stated that, with the exception of nuclear power and long-term impacts of GHGs on climate change, the results of the different research groups converge and can be used as a basis for developing policy measures aimed at a further internalisation of the different external costs of electricity generation.

Externalities of Different Types of Electricity Generation Technologies

PIONEERING STUDIES

The most noted project on determining the external cost of energy is the ExternE (Externalities of Energy) project, which attempted to develop a consistent methodology to assess the externalities of electricity generation technologies. Work and methodologies on the ExternE project are continuously updated (comprehensive details on ExternE are available at www.externe.info).

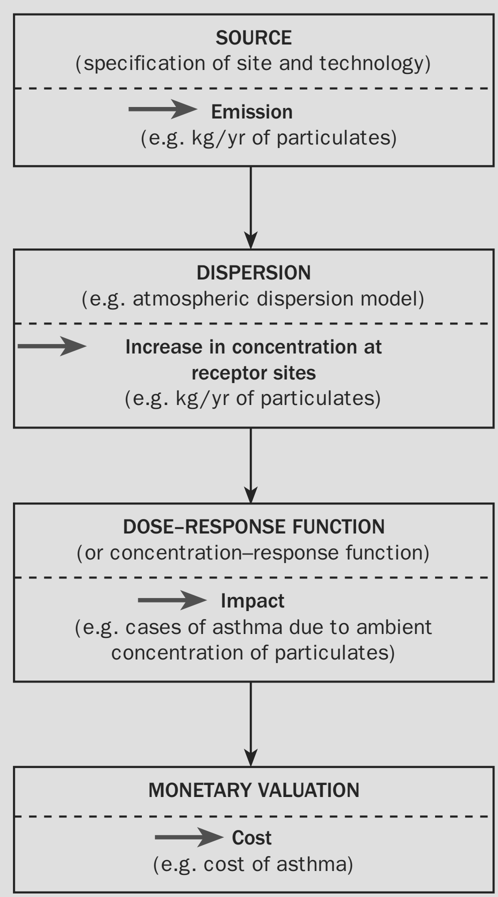
Prior to the ExternE project, studies were conducted in the late 1980s and beginning of the 1990s that gave an early insight into the importance of externalities for energy policy as a decision-making tool. An overview of the key aspects of these early studies is presented in Appendix I.

The ExternE methodology is a bottom-up approach which first characterises the stages of the fuel cycle of the electricity generation technology in question. Subsequently, the fuel chain burdens are identified. Burdens refer to anything that is, or could be, capable of causing an impact of whatever type. After having identified the burdens, an identification of the potential impacts is achieved, independent of their number, type or size. Every impact is then reported. This process just described for the fuel cycle is known as the 'accounting framework'. For the final analysis, the most significant impacts are selected and only their effects are calculated.

Afterwards, the 'impact pathway' approach developed by ExternE proceeds to establish the effects and spatial distribution of the burdens to see their final impact on health and the environment. Then, the 'economic valuation' assigns the respective costs of the damages induced by each given activity.

The methodology summarised above was implemented in the computer model EcoSense (also within the ExternE project). EcoSense is based on the impact pathway approach and is therefore widely used to assess environmental impacts and the resulting

Figure V.4.2: Impacts pathway approach



Source: European Commission (1994)

external costs of electricity generation technologies. Moreover, EcoSense provides the relevant data and models required for an integrated impact assessment related to airborne pollutants.

The modelling approach of EcoSense is briefly summarised in 'Methodology for the calculation of external costs of different electricity generation technologies based on the EcoSense Model' below, where the different steps for the determination of empirical results of external costs of electricity generation in the EU-27 Member States are presented. It is important to note that the EcoSense model not only includes the external costs caused by conventional electricity generation in its own country but also models the pathway of emissions from conventional power plants to the different receptors (humans, animals, plants, crops, materials and so on) all over Europe (in other words including those located thousands of kilometres outside an EU Member State). The aspect that emissions from one country pass to other countries, and, especially for climate change, to the whole world is essential to derive robust results. The objective of the EcoSense model, however, is to model cross-border effects in Europe only, and not on a global scale.

Because air pollutants can damage a number of different receptors (humans, animals, plants and so on), the task of analysing the impacts of any given emission is complex. Moreover, the final values of external effects and external costs vary between different countries and regions, since specific peculiarities from every country have an influence on the results due to a different range of technologies, fuels and pollution abatement options as well as locations.

In general, the fossil fuel cycle of electricity generation demonstrates the highest values on external effects and external cost (coal, lignite, peat, oil and gas), of which gas is the least damaging. In the ExternE studies, nuclear and renewable energy show the lowest externalities or damages.

FUEL CYCLE OF ELECTRICITY GENERATION TECHNOLOGY

In almost all studies to date, the fossil fuel cycles of electricity generation are associated with higher external costs than nuclear and renewable energies. An exception are the studies undertaken by Hohmeyer (1988) and Ottinger et al. (1990), which also show significant external costs of nuclear energy:

- For the *fossil fuel cycles*, earlier studies derived the impacts of emissions from regional and national statistics as a base for the economic valuation of the damage (top-down approach). In contrast, the more recent studies made use of the damage function approach, in which emissions of a pollutant are site-specifically quantified and their dispersion in the environment modelled to quantify the impact through dose–response functions. Finally, a monetary value is assigned to the impact (bottom-up approach). The emissions, concentrations and impacts of earlier studies are greater than those for recent studies, leading also to diverse results. For instance, atmospheric sulphur oxides (SO_x), nitrogen oxides (NO_x), total suspended particles (TSPs), and carbon dioxide (CO_2) are greater in earlier studies, thereby, results for associated health effects are larger.
- In the case of *nuclear power*, the assessment of severe accidents is the major focus of the analyses. Factors contributing to result variation are risk perception, resource depletion, and public spending on research and development. Hohmeyer (1998) and Ottinger et al. (1990), in contrast to the other studies, used data from the Chernobyl accident as the basis for their external cost analysis from severe reactor accidents. Generally, all studies conclude that the issue of the public's perception of the risks of nuclear power remains unresolved. In conclusion, the weakest points of externality studies of electricity generation so far have been that in almost all studies it is assumed that (i) in the nuclear cycle

waste and other hazardous impacts are well managed and (ii) the problem of accidents (for example severe core meltdown accidents with containment rupture) and their disastrous effects for society are not addressed accordingly and/or are completely neglected.

- For *renewable energies*, the external costs are usually lowest among all energy generation technologies. However, the use of hydro power can have significant external effects as it can impact high-value ecosystems and adjacent populations. External effects from wind energy, such as noise creation and visual impacts, can also be significant in certain areas (for a detailed discussion, see earlier chapters of this volume and 'Avoided emissions' below).

EMISSIONS OF FOSSIL FUEL-BASED ELECTRICITY GENERATION

The most important emissions concerning electricity generation are of CO_2, SO_2, NO_x and PM_{10} (particulate matter up to 10 micrometres in size). Emissions generally depend on the type of fuel used:

- CO_2 emissions are related to carbon content. There is no realistic opportunity of reducing such carbon dioxide emissions by using filters or scrubbers, although techniques such as burning fossil fuel with pure oxygen and capturing and storing the exhaust gas may reduce the carbon content of emissions. Carbon (dioxide) capture is the only possibility.
- For SO_2, the quantity of emissions per kWh electricity generated depends on the sulphur content of the input fuel. Furthermore, SO_2 emissions can be reduced by filtering the exhaust gases and converting SO_2 to gypsum or elementary sulphur. In general, the sulphur content of lignite is relatively high, fuel oil and hard coal have a medium sulphur content, and natural gas is nearly sulphur-free.
- In contrast, NO_x emissions are practically unrelated to input fuel. As NO_x gases are formed from the nitrogen in air during combustion, their formation depends mainly upon the combustion temperature. Thus NO_x emissions can be reduced by choosing a favourable (low) combustion temperature or by denitrifying the exhaust gases (by wet scrubbing).

Benefits of Wind Energy under the Consideration of External Cost

AVOIDED EMISSIONS

In general, the benefits of wind energy are avoided emissions and avoided external costs as compared with conventional, mainly fossil fuel-based, electricity generation. Figure V.4.1 (comparison of social costs of different electricity generation technologies) indicates that a kWh of wind energy (as for renewable energy in general) presents a negligible external cost in comparison with fossil fuel-based power systems. This fact illustrates the social and environmental advantages of wind energy and other renewables over conventional energy systems. Consequently, it is desirable to increase wind energy and other renewables in the electricity supply systems.

In recent years, the implementation of a variety of different renewable promotion instruments in Europe has resulted in significant amounts of renewable electricity generation, particularly wind generation. Without this, the corresponding amount of electricity generation would have been from conventional power plants. This means that renewable electricity generation has already displaced conventional electricity generation technologies and, subsequently, avoided significant amounts of emissions. Therefore, the external costs of total electricity generation have decreased as compared with the situation without any renewable electricity generation.

In the empirical analyses of avoided emissions and external costs in the EU-27 Member States (see 'The

EcoSense computer model' below), country-specific results are presented according to the quantity of external costs that have been already avoided due to wind generation in the different EU-27 Member States. In Chapter V.5, the avoided emissions and avoided external costs for different scenarios of wind deployment in the electricity systems of the EU-27 Member States up to 2020 and 2030 are presented.

EXTERNALITIES OF WIND ENERGY

Although wind energy is a clean technology, mainly due to the avoidance of air-pollutant emissions, it is not totally free of impacts on the environment and human health. However, wind energy has very few environmental impacts in its operation. The most commonly discussed impacts on people are acoustic noise and visual intrusion. Visual intrusion of the turbines and ancillary systems in the landscape and noise are considered as amenity impacts of the technology. Other impacts include indirect pollution from the production of components and construction of the turbine; the collision of birds in flight with turbines and bird behavioural disturbance from blade avoidance; the impacts of wind turbine construction on terrestrial ecosystems; and accidents affecting workers in manufacturing, construction and operation. A comprehensive overview and discussion of these kinds of wind energy externalities is conducted in previous sections of this Part.

Methodology for the Calculation of External Costs of Different Electricity Generation Technologies Based on the EcoSense Model

THE ECOSENSE COMPUTER MODEL

To calculate the external costs of a given conventional power plant portfolio as well as the avoided external costs of wind energy, it is necessary to model the pathway of emissions from conventional power plants to the different receptors, such as humans, animals, plants, crops and materials, which may be located thousands of kilometres away. As air pollutants can damage a number of different receptors, the task of analysing the impacts of any given emission is fairly complex. To allow such complex analysis of external costs, a tool has been developed during the last ten years in a major coordinated EU research effort, the EcoSense Model. The basics of the model are explained below, as used in the calculations of the external costs of electricity generation in the EU-27 Member States in Chapter V.5.

EcoSense is a computer model for assessing environmental impacts and the resulting external costs of electricity generation systems. The model is based on the impact pathway approach of the ExternE project (see www.externe.info as well as 'Pioneering studies' above) and provides the relevant data and models required for an integrated impact assessment related to airborne pollutants (see also European Commission, 1994).

EcoSense provides the wind-rose trajectory model for modelling the atmospheric dispersion of emissions, including the formation of secondary air pollutants. For any given point source of emissions (for example a coal-fired power plant), the resulting changes in the concentration and deposition of primary and secondary pollutants can be estimated on a Europe-wide scale with the help of this model. Developed in the UK by the Harwell Laboratory, it covers a range of several thousand kilometres. The reference environment database, which is included in EcoSense, provides receptor-specific data as well as meteorological information based on the Eurogrid coordinate system.

The impact pathway approach can be divided into four analytical steps (see, for example, Mora and Hohmeyer, 2005):

1. *Calculation of emissions*: the first step is to calculate emissions of CO_2, SO_2 and NO_x per kWh from a specific power plant.

2. *Dispersion modelling*: then air-pollutant dispersion around the site of the specific plant is modelled. Based on meteorological data, changes in the concentration levels of the different pollutants can be calculated across Europe.
3. *Impact analysis*: based on data for different receptors in the areas with significant concentration changes, the impacts of the additional emissions on these receptors can be calculated on the basis of so-called dose–response functions. Important data on receptors included in the model database are, for example, population density and land-use patterns.
4. *Monetisation of costs*: the last step is to monetise the impacts per kWh caused by the specific power plant. In this stage, the calculated physical damage to a receptor is valued on a monetary scale, based on the best available approaches for each type of damage.

INPUT DATA TO THE MODEL

Because the EcoSense model requires a specified site as a starting point for its pollutant dispersion modelling, one typical electricity generation site has been chosen for each country to assess the impacts and to calculate the costs caused by emissions from fossil fuel-fired power plants which may be replaced by wind energy. The coordinates at each site are chosen in order to locate the reference plants centrally in the electricity generating activities of each country. Thus it is assumed that the chosen site represents approximately the average location of electricity generating activities of each country that has been chosen.

To control for effects caused by this assumption and to prevent extreme data results, a sensitivity analysis was carried out by shifting the geographical location of the plant. This analysis showed a relatively high sensitivity of external costs to the location of the electricity generation facilities. This is due to the very heterogeneous distribution of the different receptors in different parts of a country.

In order to run the model, the capacity of the conventional power plant, its full load hours of operation and the volume stream of exhaust gas per hour are required. The assumptions made for the calculations are shown in Table V.4.1 for the different fossil fuels of conventional electricity generation.

For each country, calculations have been performed for a representative conventional power plant location based on the specific national emission data for each fuel and each pollutant.

The evaluation in the EcoSense Model includes damage from air-pollutant emissions like SO_2 and NO_x (PM_{10} is negligible compared to these) for the major receptors: humans, crops and materials. For each of the pollutants, high, medium and low specific external costs are derived per country.

The costs of the anthropogenic greenhouse effect resulting from CO_2 emissions are not modelled here in the EcoSense Model, but are based on estimates from Azar and Sterner (1996) and Watkiss et al. (2005).

Table V.4.1: Assumed data for the calculation of the reference fossil fuel-based power plant technology

Fuel type	Capacity (MW)	Full load hours per year	Volume stream per hour (m^3)
Hard coal	400	5000	1,500,000
Lignite	800	7000	3,000,000
Fuel oil	200	2000	750,000
Natural gas derived gas	200	2000	750,000
Mixed firing not specified	400	5000	1,500,000

Source: Auer et al. (2007)

Three different levels of specific external costs are implemented (high, medium and low) for the empirical calculation of CO_2-related external costs in the different EU Member States.

Summing up: to calculate the external costs of conventional electricity generation technologies and, subsequently, the avoided external costs by the use of wind energy, the external costs resulting from air pollutants such as SO_2 and NO_x (calculated by EcoSense) have to be added to the external costs of the anthropogenic greenhouse effect resulting from CO_2 emissions (not calculated by EcoSense).

DETERMINATION OF AIR-POLLUTING CONVENTIONAL POWER PLANTS AND REPLACEABLE SEGMENT OF CONVENTIONAL ELECTRICITY GENERATION BY WIND ENERGY

This section identifies, as a first step, the different types of conventional power plant responsible for air pollution (and, subsequently, for external costs caused by CO_2, SO_2 and NO_x). Then a methodology is derived for the determination of the replaceable segment of conventional electricity generation technologies by wind energy. Finally, empirical data on annual generation and specific emissions is presented for the portfolio of air-polluting conventional power plants in several of the EU-27 Member States.

Determination of Air-Polluting Conventional Power Plants

In general, the load duration curve of different types of conventional power plants is split into three different segments: base load, intermediate load and peak load. Typical examples of conventional power plants operating in the different load duration segments are:

- base load: nuclear power plants, large run-of-river hydropower plants, lignite power plants, hard coal power plants;
- intermediate load: hard coal power plants, fuel oil-fired power plants, combined cycle gas turbine plants; and
- peak load: pumped-storage hydropower plants, open cycle gas turbine plants.

With respect to above-mentioned air-polluting emissions (CO_2, SO_2 and NO_x), several different kinds of fossil fuel conventional power plants are candidates for further investigation.

Replaceable Segment of Conventional Electricity Generation by Wind Energy

Due to its inherent variability, wind power can at present only replace specific segments of the load duration curve of conventional electricity generation. More precisely, wind energy can replace conventional power plants at the intermediate rather than base-load or peak-load segment.

Keeping this in mind, a reference system can be defined whereby wind energy can be expected to replace conventional power plants:

- First, neither nuclear nor large hydropower plants are replaceable by wind energy, as both almost exclusively operate in the base load segment.
- As pump hydro storage power plants are used to cover very short load peaks, they cannot be replaced by wind energy either, due to the latter's variable nature.
- This leaves conventional electricity generation from the fossil fuels: lignite, hard coal, fuel oil and gas.

However, this assumption can lead to an overestimation of the share of the replaced electricity generation by lignite, as this is predominantly used in the base load segment as well, and to an underestimation of substituted electricity from gas, which, due to the dynamic characteristics of gas-fired power plants, lends itself perfectly to balance fluctuations in wind generation. As the current mode of operation of conventional power plants, the rules of their dispatch based on the so-called 'merit order' and the dynamic behaviour of the different types of conventional power plants is all well known, it can be safely assumed that a replacement of intermediate load by wind energy is the best description of the complexities of actual operation in the 'real world'.

For detailed empirical analyses, the contributions of the different fossil fuel-based power plant technologies to the intermediate load segment need to be specified. As the best statistics in this context available, data for the power plant in Germany (VDEW, 2000) are used as the basis for such analysis:

- The load curves for one typical load day are derived for each relevant type of fuel and are taken as the basis for the calculation of shares of intermediate load.
- In general, the highest load variations during one day are displayed by fuel oil and gas; hard coal shows some variation, while electricity generation based on lignite is almost constant.

Although the characteristics of the load curves are based on the German electricity generation structure, conventional power plants have common fuel-specific technical and economic characteristics. Therefore, load curves are assumed to have similar day-to-day variations in several other European countries. Based on these considerations, Table V.4.2 sets out assumptions for the intermediate load shares, with the percentage figures being based on the total amount of electricity generated for each fuel.

The assumptions for intermediate load shares replaceable by wind energy will remain the same for 2020 and 2030 for the fuel types lignite (10 per cent), hard coal (30 per cent), mixed firing (50 per cent) and fuel oil (100 per cent). For natural/derived gas the replaceable share will decrease from 100 per cent (2007) to 92.5 per cent (2020) and 85 per cent (2030) in those EU Member States with no other flexible power plant technologies like pumped hydro storage power plants. Due to significant shares of wind penetration in 2020 and 2030, a certain level of very flexible power plant types like combined cycle gas turbines (CCGTs) is absolutely necessary to balance the electricity systems (see, for example, Auer et al. 2007).

Table V.4.2: Share of intermediate load of different types of fossil fuel power plant

Fuel type	Share of intermediate load (%)
Lignite	10
Hard coal	30
Mixed firing	50
Fuel oil	100
Natural/derived gas	100

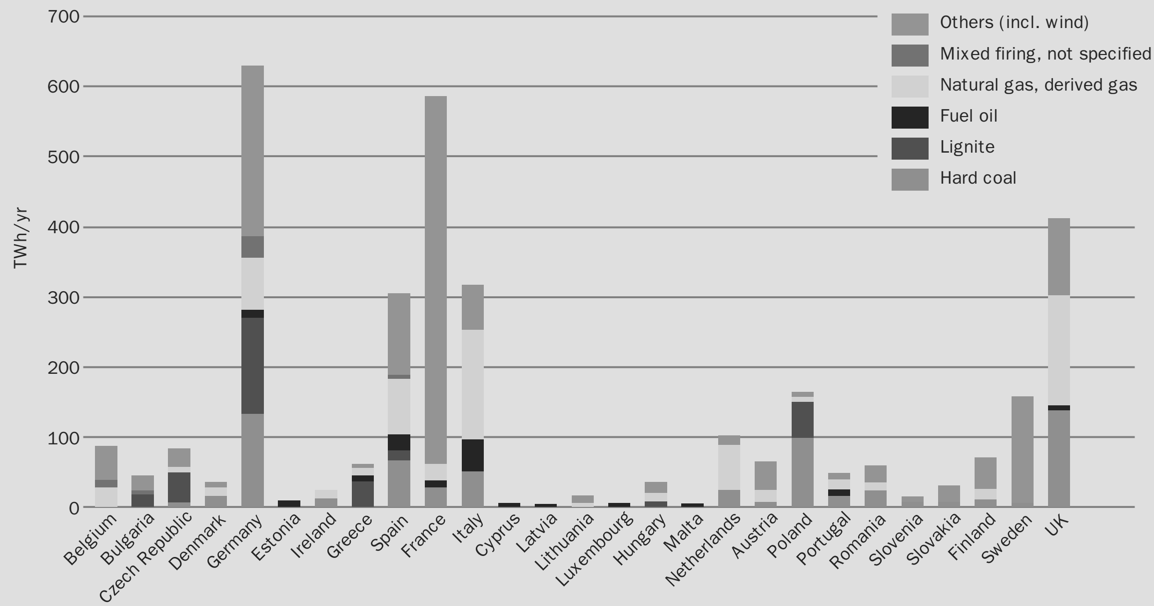
Source: Auer et al. (2007)

FOSSIL FUEL-BASED ELECTRICITY GENERATION AND ITS SPECIFIC EMISSIONS IN THE EU-27 IN 2007

The structure of total electricity generation (by fuel type) and the structure and fractions of fossil fuel-based electricity generation are presented at the EU-27 Member State level in Figures V.4.3 and V.4.4 respectively. The empirical data is mainly derived from the official 2006 Eurostat Statistics of the European Commission (*EU Energy in Figures – Pocket Book 2007/2008*) and updated for the reference year 2007 with the recent *Platts European Power Plant Data Base 2008*.

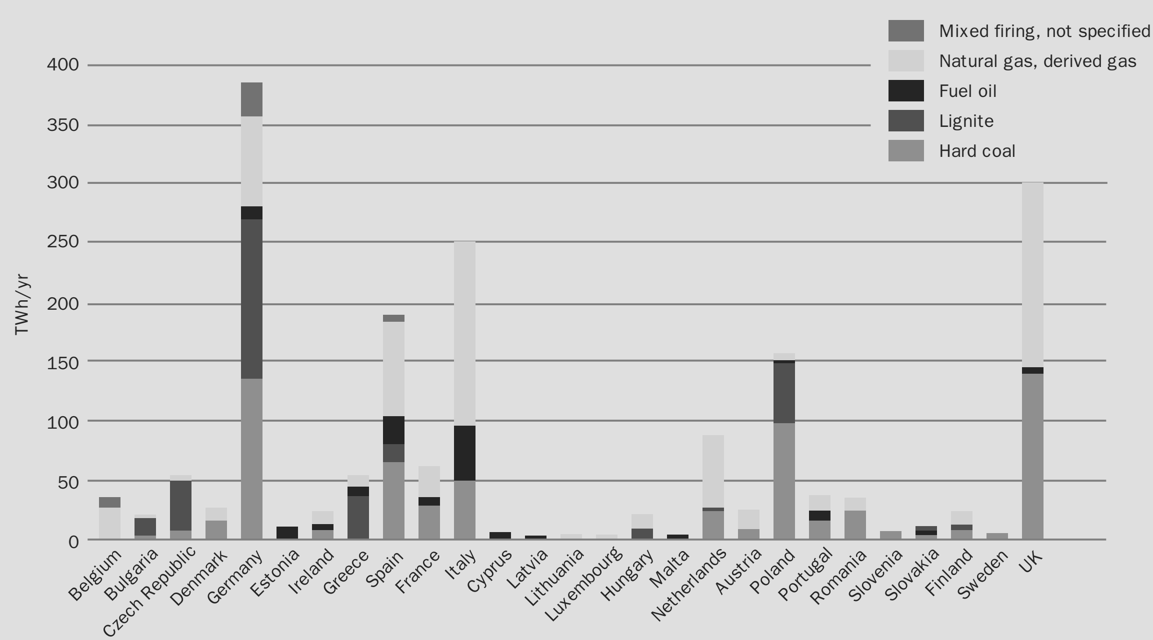
Figure V.4.3 indicates that the absolute levels and shares of input fuels for electricity generation vary greatly between the different EU-27 Member States. In particular, Figure V.4.3 indicates those fossil fuel-based electricity generation technologies that may well be replaced by wind energy and/or other renewable energy sources in the future. As already mentioned, neither base-load electricity generation technologies like nuclear and large hydro power nor peak-load technologies like pumped storage hydro

Figure V.4.3: Total electricity generation (by fuel type) in the different EU-27 Member States in 2007



Source: Auer et al. (2007)

Figure V.4.4: Fossil fuel-based electricity generation in the different EU-27 Member States in 2007



Source: Auer et al. (2007)

power plants are candidates to be replaced by wind energy. Also, several other kinds of renewable electricity generation technologies are incorporated into the category of 'others', since they are not of primary interest in further analyses when discussing fuel substitution by wind energy.

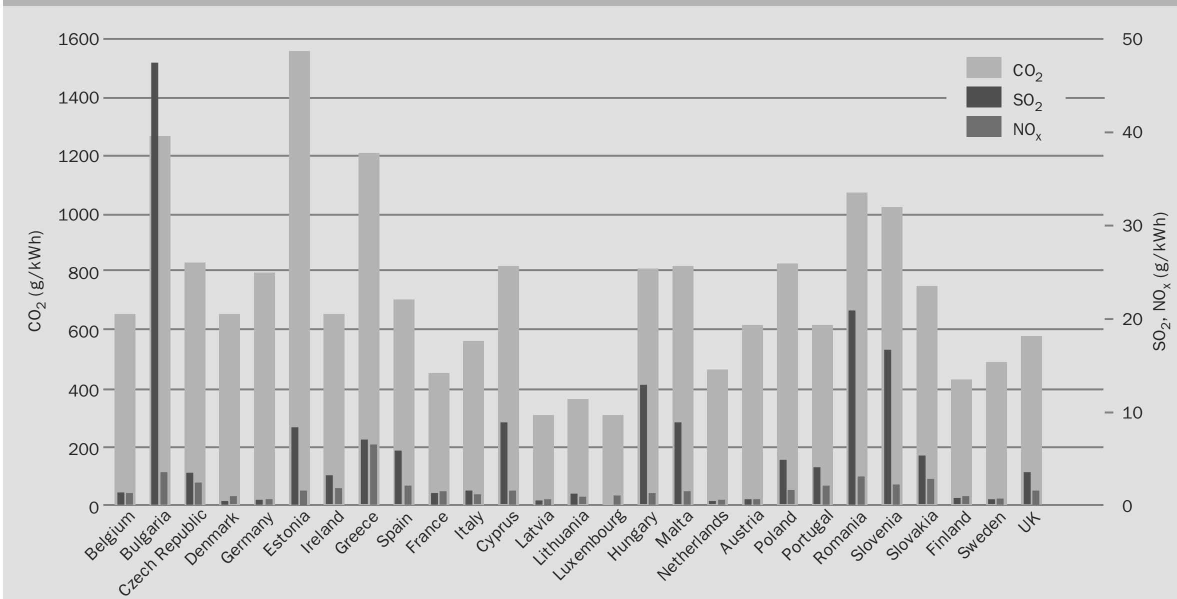
In Figure V.4.4, several fossil fuel-based electricity generation technologies at the EU-27 Member State level are presented in detail. The data presented here is the starting point for comprehensive in-depth analyses in subsequent sections.

Based on the portfolio of fossil fuel-based electricity generation in the different EU-27 Member States in 2007 presented in Figure V.4.4, the corresponding specific air-pollutant emissions (CO_2, SO_2, NO_x and PM_{10}) can be determined at the country level. The corresponding absolute air-pollutant emissions of fossil fuel-based electricity generation are derived from a variety of different Member States' statistics as well as from official documents of the European Commission.

In this context it is important to note that the corresponding national studies and statistics take into account a variety of country-specific and technology-specific characteristics, for example the age structure of the different power plants (and as a consequence also indirectly the primary fuel efficiency) in each of the EU-27 Member States.

Figure V.4.5 finally presents the results on the average specific CO_2, SO_2 and NO_x emissions from fossil fuel- based electricity generation at the Member State's level for 2007. In principle, the average specific emissions are less in the 'old' EU-15 Member States (except Greece) than in the 'new' EU-12 Member States. Bulgaria, Estonia, Greece, Romania and Slovenia are among the most air-polluting countries within the EU-27, at least in terms of CO_2 emissions.

Figure V.4.5: Specific average emissions (CO_2, SO_2, NO_x) from fossil fuel-based electricity generation in the different EU-27 Member States in 2007



Source: Auer et al. (2007)

Figure V.4.5 indicates that the difference in specific CO_2 emissions from fossil fuel generation is more than a factor of four between various EU-27 Member States. This is related to differences in the fuel mix and because some Member States still have power plants with very low efficiencies. The distribution of SO_2 emissions per kWh is also very different, as shown in Figure V.4.5. This is related to the very heterogeneous sulphur content of fuel and the use of desulphurisation in only the most advanced Member States. Finally, NO_x emissions differ between the countries according to the combustion process used, the combustion temperature, which is not optimal in all the Member States, and the scrubbing technologies employed.

The picture presented in Figure V.4.5 will be further elaborated in subsequent sections when discussing the replaceable/avoidable as well as already avoided shares of fossil fuel-based electricity generation by wind energy (and other non-fossil fuel-based generation technologies) for 2007, 2020 and 2030.

V.5 ENVIRONMENTAL BENEFITS OF WIND ENERGY IN COMPARISON TO REMAINING ELECTRICITY GENERATION TECHNOLOGIES

Electricity Generation, Emissions and External Cost in the EU-27 Countries in 2007

AMOUNT OF FOSSIL FUEL-BASED ELECTRICITY GENERATION AVOIDABLE/ REPLACEABLE BY WIND (AND OTHER RENEWABLE ELECTRICITY GENERATION TECHNOLOGIES) IN 2007

In general, the benefits of wind energy are the avoided emissions and external costs from fossil fuel-based electricity generation. The evaluation of external costs includes damage from:

- air-pollutant emissions;
- the anthropogenic greenhouse effect resulting from CO_2 and other emissions; and
- SO_2 and NO_x.

To analyse the environmental and health benefits of the use of wind energy, we need to know the specific emissions of fossil fuel-based electricity generation replaced thereby. These can be derived by dividing the absolute emissions produced by a type of fossil fuel in kilotonnes of CO_2 per year used for electricity generation in a country by the amount of electricity generated from this fuel in kWh per year.

In our model, wind energy only replaces intermediate load of conventional fossil fuel-based electricity generation. In general, the emissions avoided by wind energy depend on three factors:

1. the specific emissions from each type of fossil fuel-based electricity generation facility;
2. the fuel mix in each country; and
3. the percentage of each fuel replaced by wind energy.

Figure V.5.1 presents the absolute levels and shares of fossil fuel-based electricity generation replaceable/ avoidable by wind energy (and other renewable electricity generation technologies) in each of the EU-27 Member States according to the individual replaceable shares of fossil fuels in the intermediate load segment comprehensively discussed in the previous chapter (Table V.4.2).

Derived from Figure V.5.1, Figure V.5.2 presents the total emissions (CO_2, SO_2, NO_x) replaceable/ avoidable by wind (and other renewable electricity generation technologies) in the EU-27 Member States in 2007.

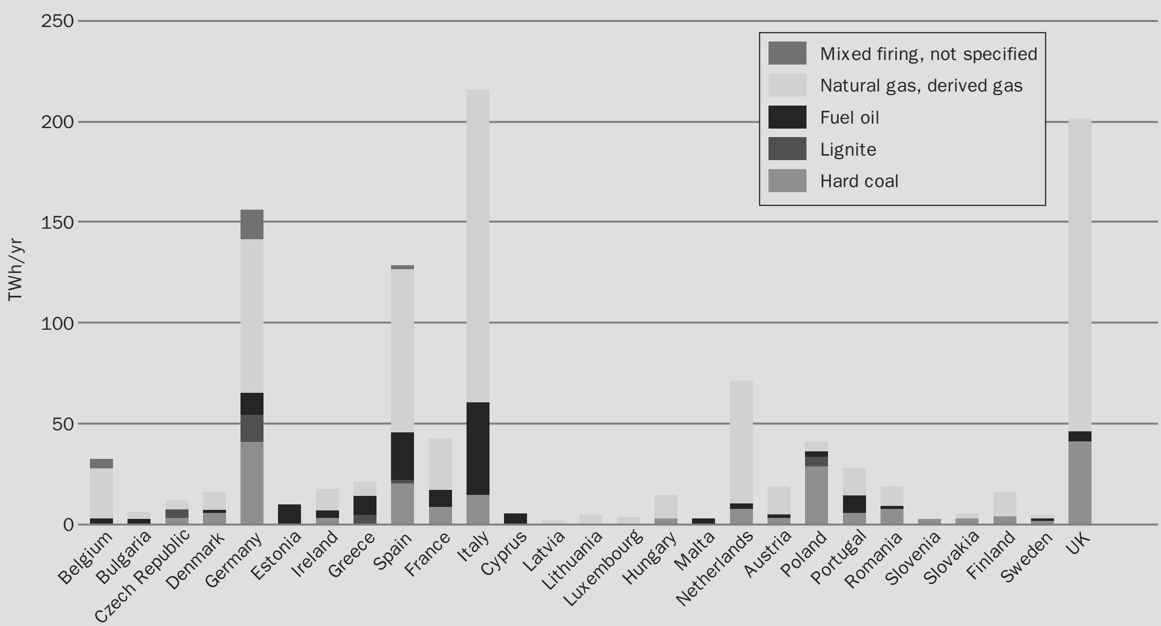
AMOUNT OF FOSSIL FUEL-BASED ELECTRICITY GENERATION REPLACED/ AVOIDED BY WIND IN 2007

The previous section presents the empirical data on the replaceable/avoidable amount of fossil fuel-based electricity generation. The following section shows the amount of already replaced/avoided fossil fuel-based electricity generation by wind energy in the EU-27 Member States in 2007. The annual wind generation in each of the EU-27 Member States in 2007 has to be studied first (see Figure V.5.3).

Figure V.5.3 clearly indicates that already a significant number of EU Member States have implemented a considerable amount of wind energy in 2007. On top of the list are Germany and Spain (around 39 TWh per year) annual wind generation each); Denmark (8 TWh per year) and the UK (6.3 TWh per year) are next; and other EU Member States like Portugal, Italy, The Netherlands, and France are aiming at the 5 TWh per year benchmark of annual wind generation very fast. However, there still existed many EU-27 Member States with negligible wind penetration in 2007.

The total CO_2, SO_2 and NO_x emissions from fossil fuel-based electricity generation having been already avoided by wind energy in the different EU-27 Member States in 2007 are presented in Figure V.5.4.

Figure V.5.1: Fossil fuel-based electricity generation replaceable/avoidable by wind (and other renewable electricity generation technologies) in the EU-27 Member States in 2007



Source: Auer et al. (2007)

The 2007 results in Figure V.5.4 take into account the individual characteristics of conventional electricity generation at the country level (for example age structure and efficiency of the fossil fuel power plants) in terms of the specific average emissions (CO_2, SO_2, NO_x) from fuel-based electricity generation on the one hand (see Figure V.4.5), and annual wind generation in 2007, on the other hand (see Figure V.5.3). Not surprisingly, the total avoided emissions in 2007 perfectly correlate with annual wind generation in the different EU-27 Member States.

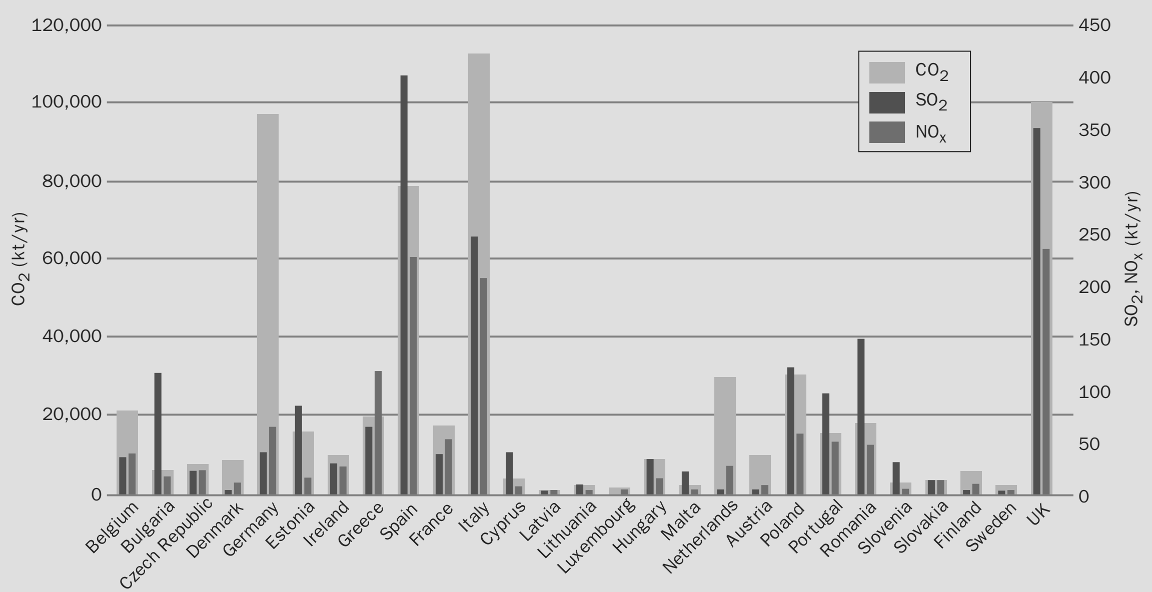
EXTERNAL COSTS OF FOSSIL FUEL-BASED ELECTRICITY GENERATION AND AVOIDED EXTERNAL COST BY WIND IN 2007

So far, empirical results have been presented for each of the EU-27 Member States on fossil fuel-based electricity generation replaceable/avoidable by wind energy (and other renewable generation technologies) in each of the EU-27 Member States in 2007. The factors involved are:

- average specific emissions (CO_2, SO_2, NO_x) from fossil fuel-based electricity generation in each of the EU-27 Member States in 2007;
- total wind generation in each of the EU-27 Member States in 2007; and
- total emissions (CO_2, SO_2, NO_x) already avoided from fossil fuel-based electricity generation in each of the EU-27 Member States in 2007.

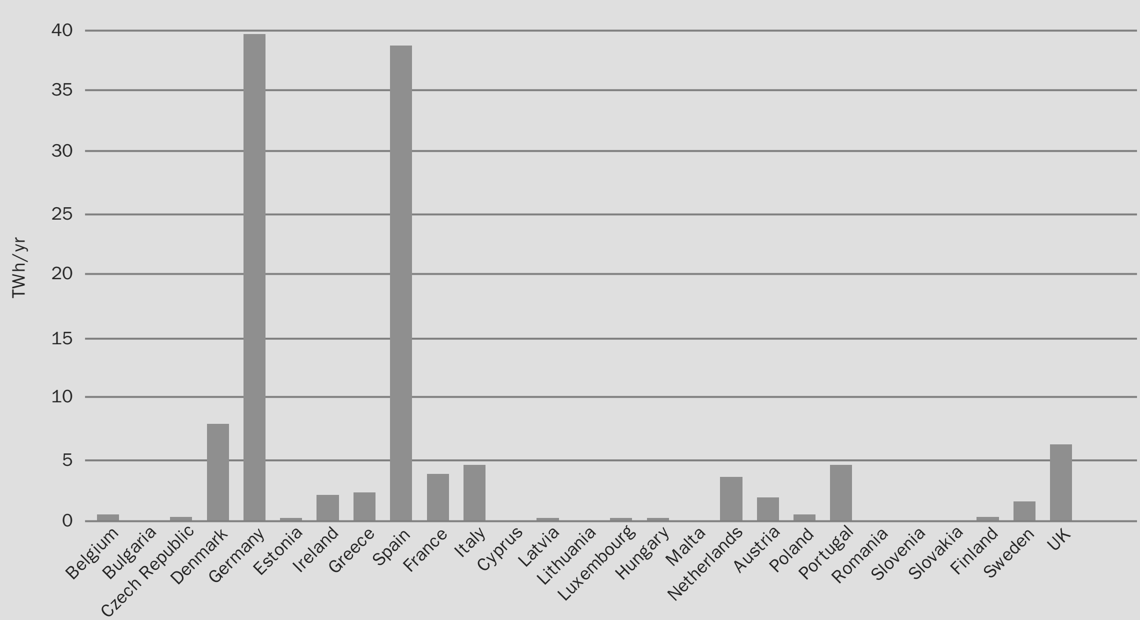
These analyses provide the basis for the final step to determine the external costs of fossil fuel-based electricity generation and the already avoided external costs from wind generation in the EU-27 Member States in 2007.

Figure V.5.2: Total emissions (CO_2, SO_2, NO_x) replaceable/avoidable by wind (and other renewable electricity generation technologies) in the EU-27 Member States in 2007



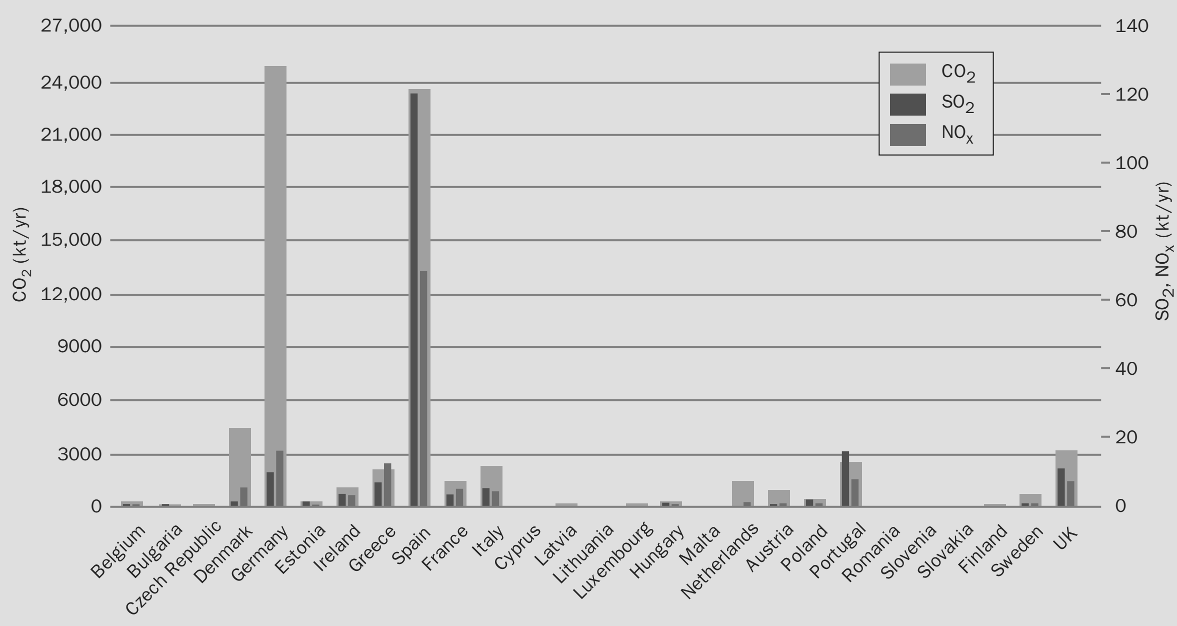
Source: Auer et al. (2007)

Figure V.5.3: Annual wind generation in the EU-27 Member States in 2007



Source: Auer et al. (2007)

Figure V.5.4: Total emissions (CO_2, SO_2, NO_x) from fossil fuel-based electricity generation already avoided by wind energy in the EU-27 Member States in 2007



Source: Auer et al. (2007)

The external costs resulting from air pollutants such as SO_2 and NO_x (calculated by EcoSense; see page 370) have to be added to the external costs of the anthropogenic greenhouse effect resulting from CO_2 emissions (not calculated by EcoSense, but based on estimates by Azar and Sterner, 1996, and Watkiss et al., 2005).

Because air pollutants can damage a large number of different receptors, calculations of external costs will generally include a large number of types of damage, which tend to be restricted to the most important impacts to allow a calculation of external costs with a limited resource input. At present, EcoSense includes the following receptors: humans (health), crops, materials (in buildings and so on), forests and ecosystems, with monetary valuation only included for human health, crops and materials. For each of these a bandwidth (high, medium and low values) is determined. There are two approaches to evaluating effects on human health: value of statistical life (VSL) and years of life lost (YOLL).

- The VSL approach measures a society's willingness to pay to avoid additional deaths.
- The YOLL approach takes human age into account. For each year of life lost approximately one-twentieth of the VSL value is used.

Unfortunately, outputs from the EcoSense Model used in this analysis do not provide a calculation based on the VSL approach. As pointed out above, VSL may lead to substantially larger external costs than the YOLL approach which is applied by the EcoSense Model. Results of former ExternE studies estimate external costs based on both approaches. These resulted in VSL results of approximately three times more than with YOLL. As the present version of

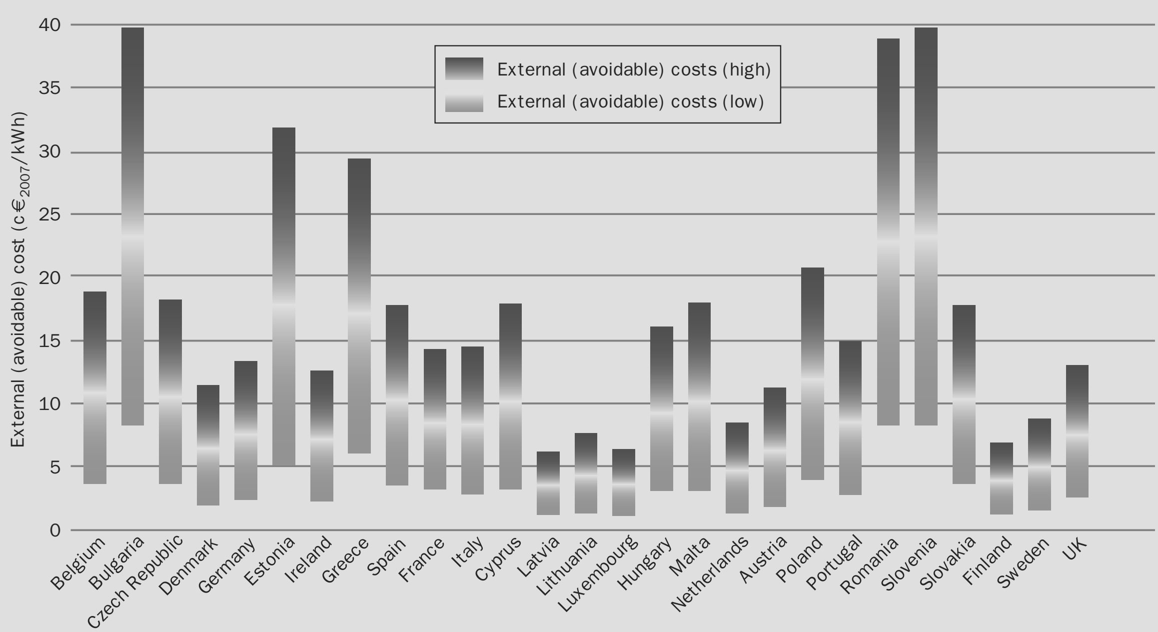
EcoSense does not calculate VSL values, the EcoSense results on human health effects based on the YOLL approach have been scaled. This has been done with a factor of one for low-damage cost estimates calculated for human health, a factor of two for medium cost estimates and a factor of three for high estimates.

Figure V.5.5 finally presents the results of the external costs of conventional fossil fuel-based electricity generation in each of the EU-27 Member States in 2007 (high/average/low values). Similar to the specific emissions of fossil fuel-based electricity generation presented in Figure V.4.5, there is a noticeable difference between external costs in different EU-27 Member States. Bulgaria, Romania and Slovenia are the Member States with the highest external costs of fossil fuel-based electricity generation (average values 20–25c€$_{2007}$/kWh), but Estonia and Greece also reach nearly 20c€$_{2007}$/kWh (average values for external costs). Latvia, Lithuania, Luxembourg, Finland, Sweden and The Netherlands are characterised by external costs of fossil fuel-based electricity generation below 5c€$_{2007}$/kWh (average values for external costs).

By combining the avoidable external costs of fossil fuel-based electricity generation with the amount of electricity produced by wind energy, the total amount of already-avoided external costs can be calculated for 2007. Figure V.5.6 presents the corresponding results of already-avoided external costs by wind generation in each of the EU-27 Member States.

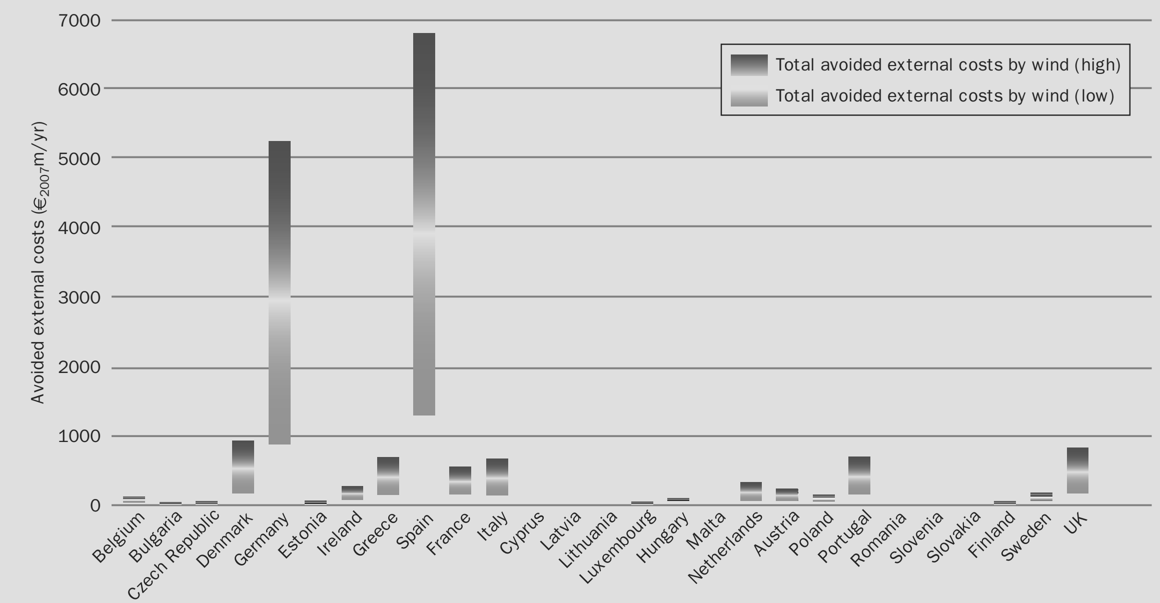
In 2007, in the EU-27 region around €$_{2007}$10.2 billion on external costs have been avoided by wind generation in total (summing up the average values in each of the EU-27 Member States shown in Figures V.5.6 and V.5.7).

Figure V.5.5: Bandwidth of specific external costs of fossil fuel-based electricity generation in the EU-27 Member States in 2007



Source: Auer et al. (2007)

Figure V.5.6: Bandwidth of avoided external costs of fossil fuel-based electricity generation in the EU-27 Member States in 2007



Source: Auer et al. (2007)

The following EU Member States are mainly responsible for the majority shares of this already impressive number: Spain (€$_{2007}$3.968 billion), Germany (€$_{2007}$3.027 billion), Denmark (€$_{2007}$0.518 billion), the UK (€$_{2007}$0.472 billion), Greece (€$_{2007}$0.400 billion), Portugal (€$_{2007}$0.388 billion) and Italy (€$_{2007}$0.377 billion).

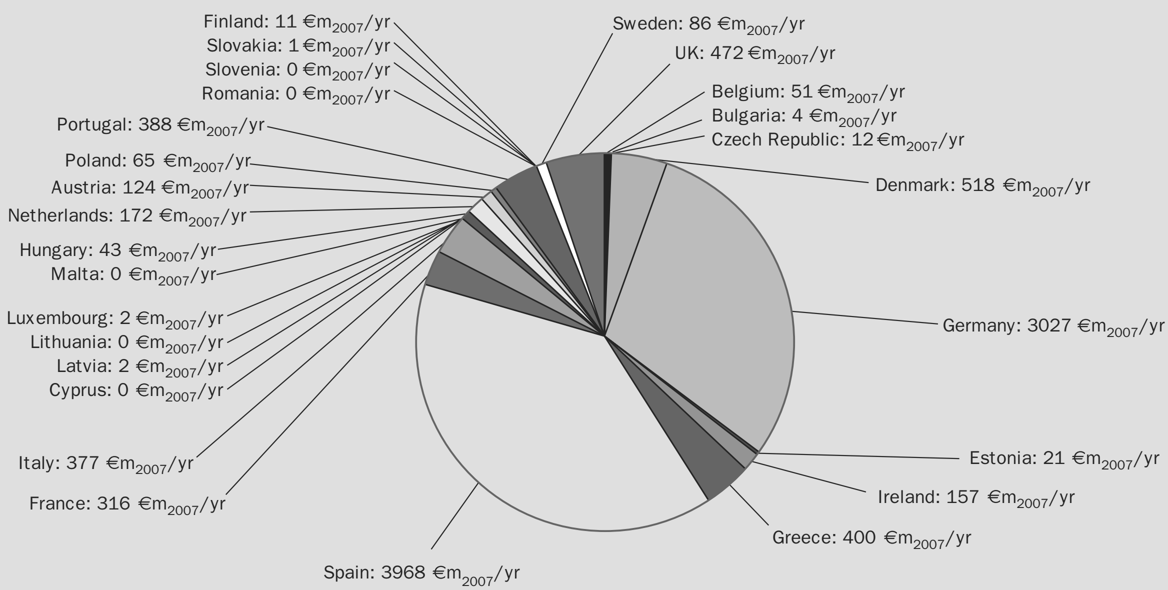
Figure V.5.7 finally presents the absolute values of already avoided external costs by wind generation in each of the EU-27 Member States in 2007.

Avoided Emissions and External Cost for Different Wind Deployment Scenarios in the EU-27 Member States in 2020

The previous section presented 'real' life in 2007. In the following section different scenarios on the portfolio of electricity generation in the EU-27 Member States in 2020 are discussed and, subsequently, the same analyses are conducted in terms of:

- determination of the share of fossil fuel-based electricity generation and corresponding emissions in each of the EU-27 Member States;
- determination of the amount of fossil fuel-based electricity generation and corresponding emissions replaceable/avoidable by wind (and other renewable technologies) in each of the EU-27 Member States;
- determination of the replaced/avoided emissions by wind energy in the three EWEA wind generation scenarios; and
- determination of the external costs of fossil fuel-based electricity generation and, subsequently, avoided external costs by wind generation in the three EWEA wind generation scenarios.

Figure V.5.7: Distribution of avoided external costs (average values) through wind generation in the EU-27 Member States in 2007



Source: Auer et al. (2007)

Before presenting the empirical results, there are at least the following three important points worth mentioning:

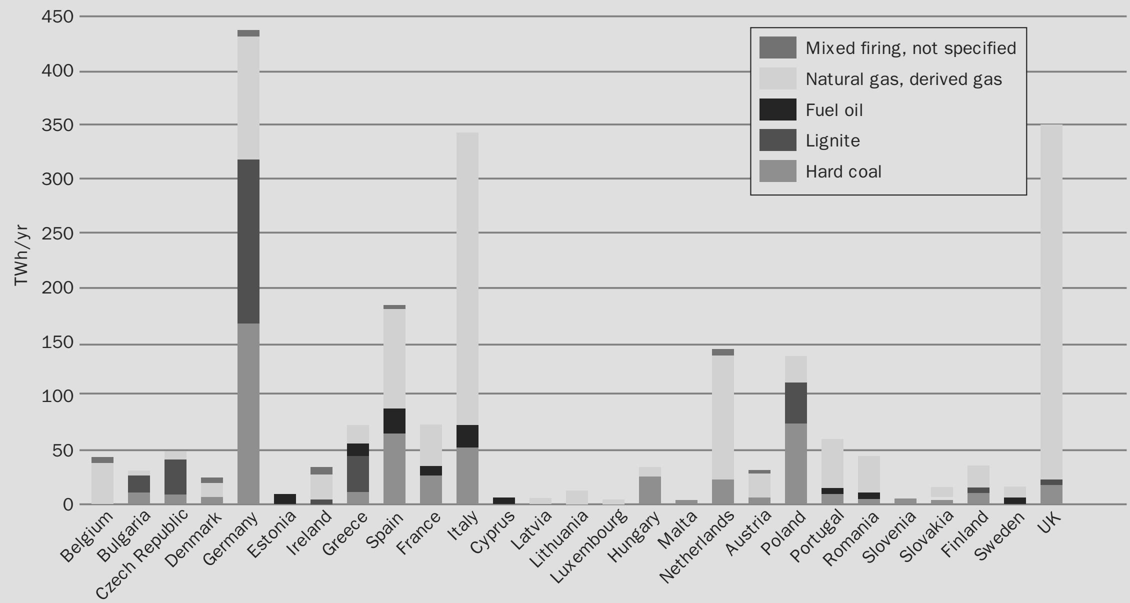
1. The business-as-usual scenarios in the portfolio of conventional electricity generation are based on the official documents of the European Commission (Eurelectric, 2006; Capros et al., 2008).
2. In general, the efficiency of new plants within each of the types of fossil fuel-based electricity generation technologies improves with time and, therefore, the specific emissions for 2020 decrease compared to 2007.
3. Due to expected electricity demand increase, the total amount of fossil fuel-based electricity generation in 2020 is supposed to be higher than in 2007 in almost all EU Member States (but specific emissions per power plant technology – see above – will be lower). However, the significant shares of wind generation in the different EWEA scenarios are expected to be even greater (see subsequent sections for details).

FOSSIL FUEL-BASED ELECTRICITY GENERATION AND EMISSIONS IN 2020

Figure V.5.8 presents fossil fuel-based electricity generation in the EU-27 Member States in 2020 and Figure V.5.9 the corresponding specific average emissions (CO_2, SO_2, NO_x).

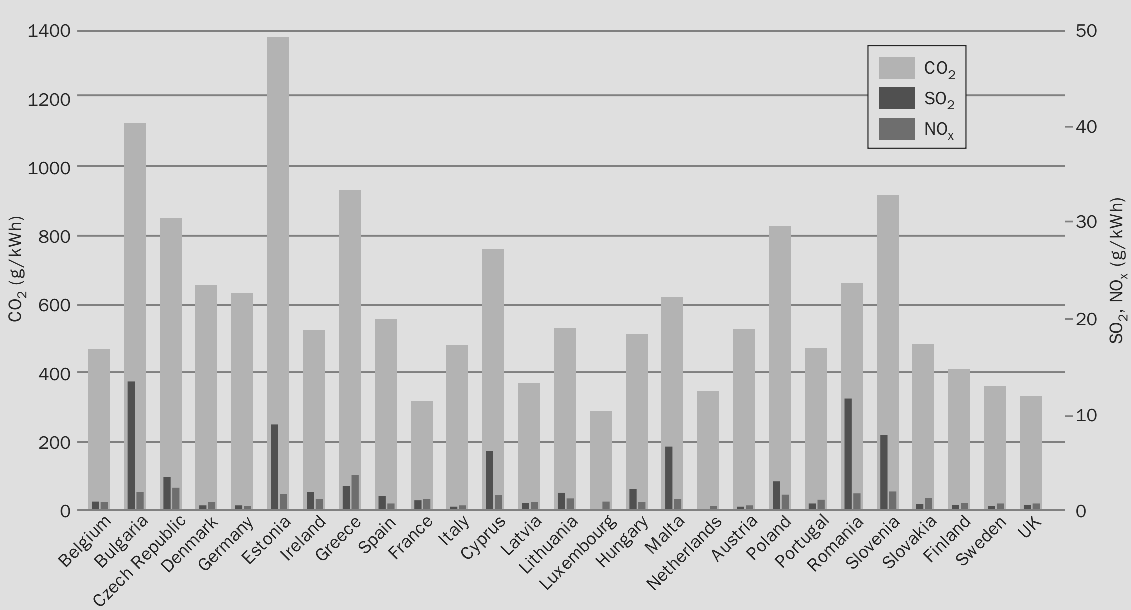
Figure V.5.10 presents the fossil fuel-based electricity generation replaceable/avoidable by wind (and other renewable electricity generation) in the EU27 Member States in 2020 and Figure V.5.11 the corresponding amount of total avoidable emissions (CO_2, SO_2, NO_x).

Figure V.5.8: Fossil fuel-based electricity generation in the EU-27 Member States in 2020



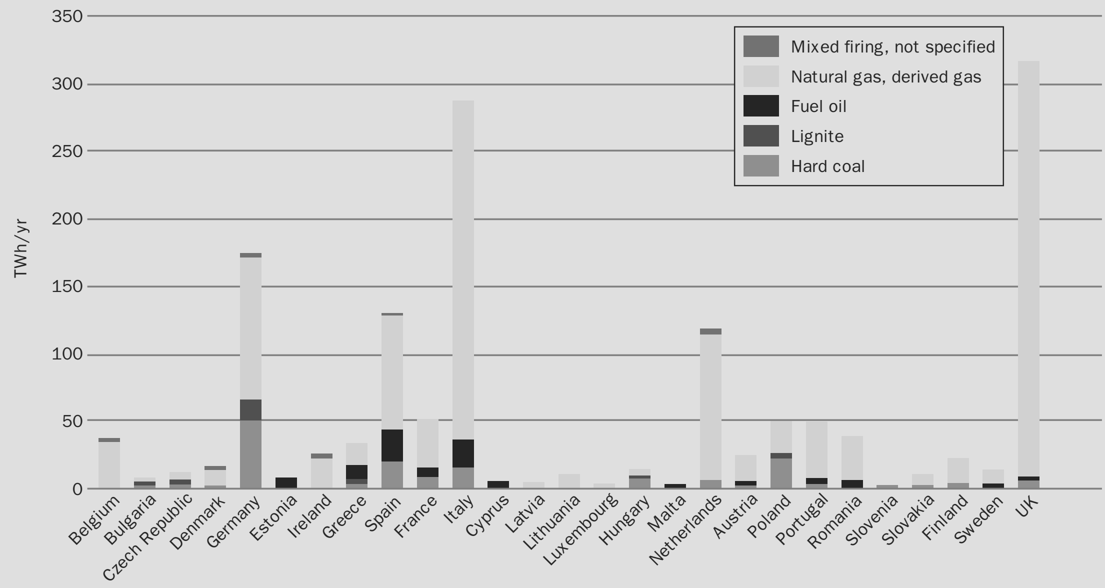
Source: Auer et al. (2007)

Figure V.5.9: Specific average emissions (CO_2, SO_2, NO_x) from fuel-based electricity generation in the EU-27 Member States in 2020



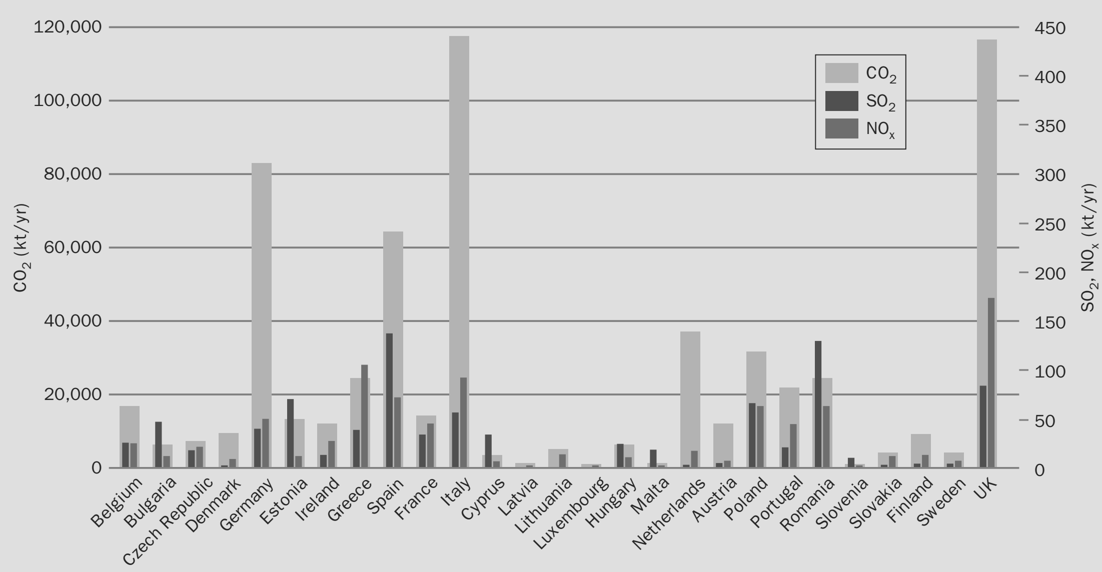
Source: Auer et al. (2007)

Figure V.5.10: Fossil fuel-based electricity generation replaceable/avoidable by wind (and other renewable electricity generation technologies) in the EU-27 Member States in 2020



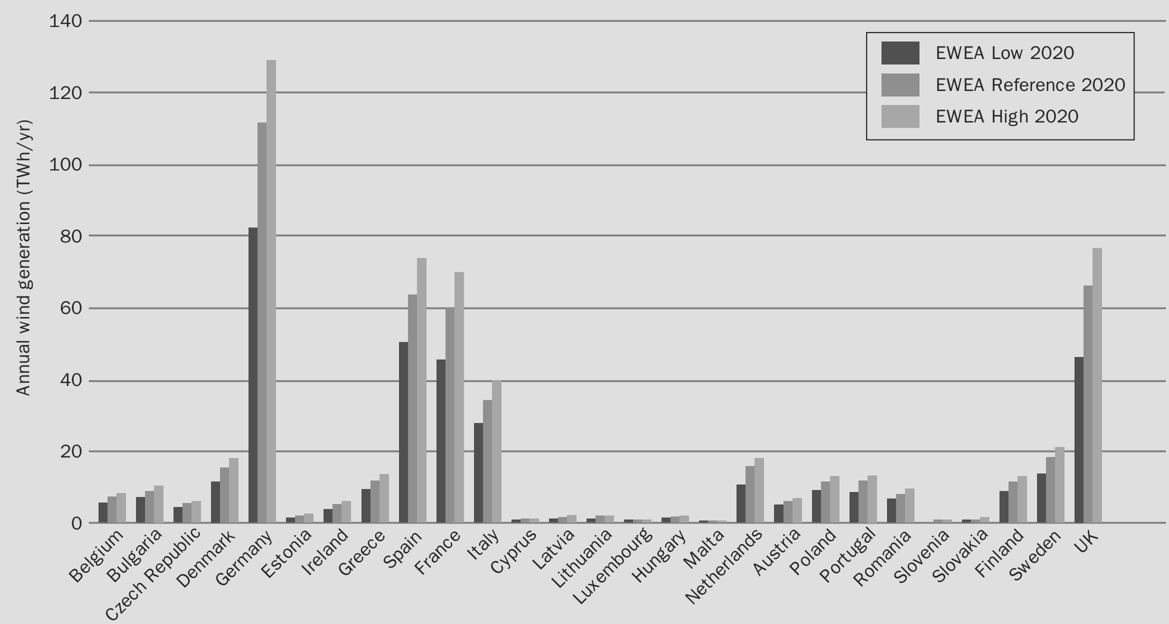
Source: Auer et al. (2007)

Figure V.5.11: Total emissions (CO_2, SO_2, NO_x) replaceable/avoidable by wind (and other renewable electricity generation technologies) in the EU-27 Member States in 2020



Source: Auer et al. (2007)

Figure V.5.12: Annual wind generation (TWh/yr) in each of the EU-27 Member States according to EWEA's three wind generation scenarios in 2020



Source: Auer et al. (2007)

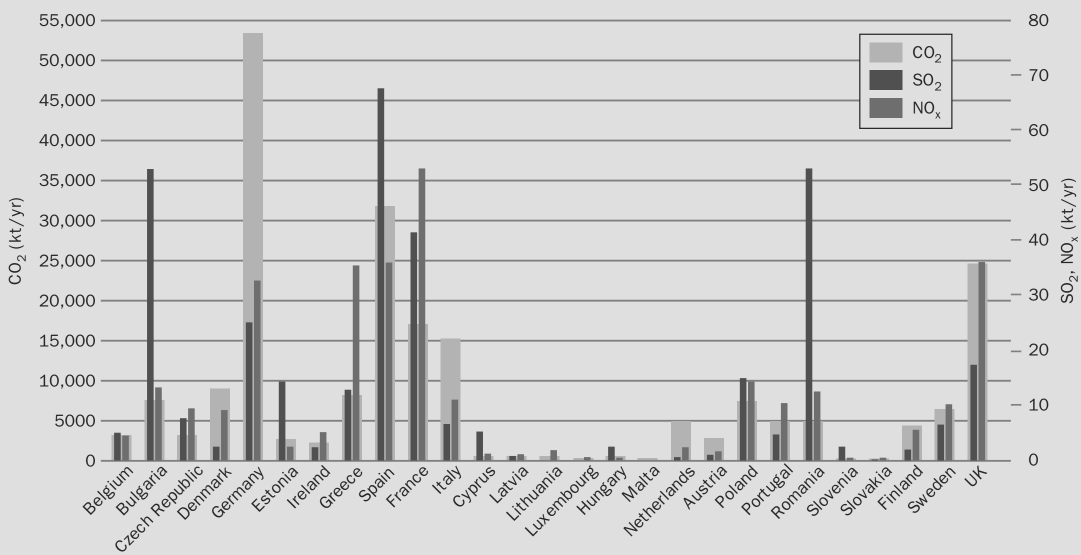
BREAKDOWN OF EWEA'S WIND GENERATION SCENARIOS FOR 2020 (BY EU MEMBER STATE)

In order to be able to calculate the amount of replaced/avoided fossil fuel-based electricity generation by wind energy in the EU-27 Member States in 2020, wind penetration scenarios for 2020 are necessary. Figure V.5.12 presents EWEA's three wind generation scenarios for the EU-27 on a separate – EU Member State – level. The breakdown of EWEA's three wind generation scenarios at the EU Member State level is mainly based on comprehensive modelling and sensitivity analyses with the simulation software model GreenNet-Europe (see www.greennet-europe.org). GreenNet-Europe models show cost deployment of renewable electricity generation technologies (wind in particular) at EU Member State level up to 2020 and 2030, taking into account several different country-specific potentials and cost of renewable (wind) generation, different renewable-promotion instruments, and a variety of other country-specific as well as general parameters and settings. The results of the breakdown of EWEA's three wind generation scenarios have also been cross-checked with other existing publications (for example, Resch et al., 2008, and Capros et al., 2008).

AVOIDED EMISSIONS (OF FOSSIL FUEL-BASED ELECTRICITY GENERATION) IN THE BREAKDOWN OF EWEA'S WIND GENERATION SCENARIOS FOR 2020

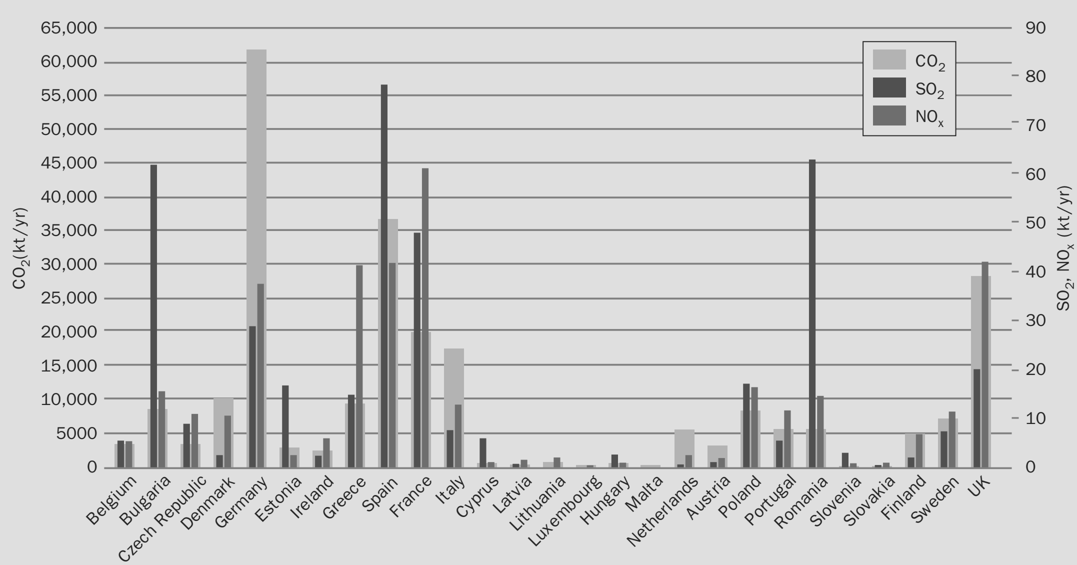
In Figures V.5.13–V.5.15, the total avoided emissions (CO_2, SO_2, NO_x) by wind generation are presented for EWEA's three wind generation scenarios in each of the EU-27 Member States in 2020.

Figure V.5.13: Total emissions (CO_2, SO_2, NO_x) from fossil fuel-based electricity generation avoided by wind energy according to EWEA's Reference Scenario in the EU-27 Member States in 2020



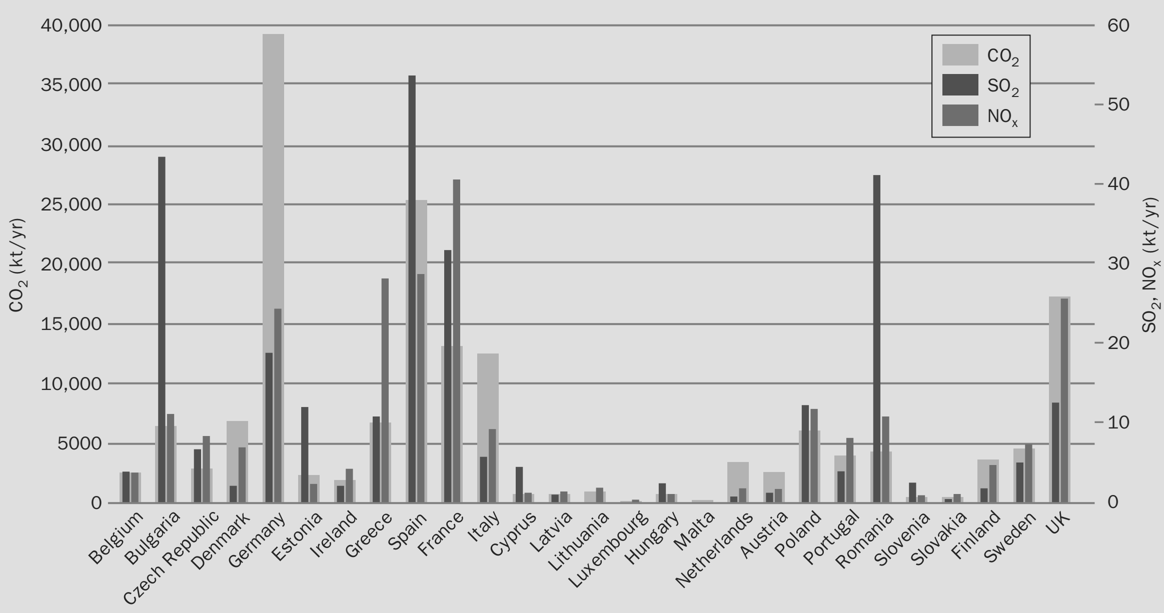
Source: Auer et al. (2007)

Figure V.5.14: Total emissions (CO_2, SO_2, NO_x) from fossil fuel-based electricity generation avoided by wind energy according to EWEA's High Scenario in the EU-27 Member States in 2020



Source: Auer et al. (2007)

Figure V.5.15: Total emissions (CO_2, SO_2, NO_x) from fossil fuel-based electricity generation avoided by wind energy according to EWEA's Low Wind Scenario in the EU-27 Member States in 2020



Source: Auer et al. (2007)

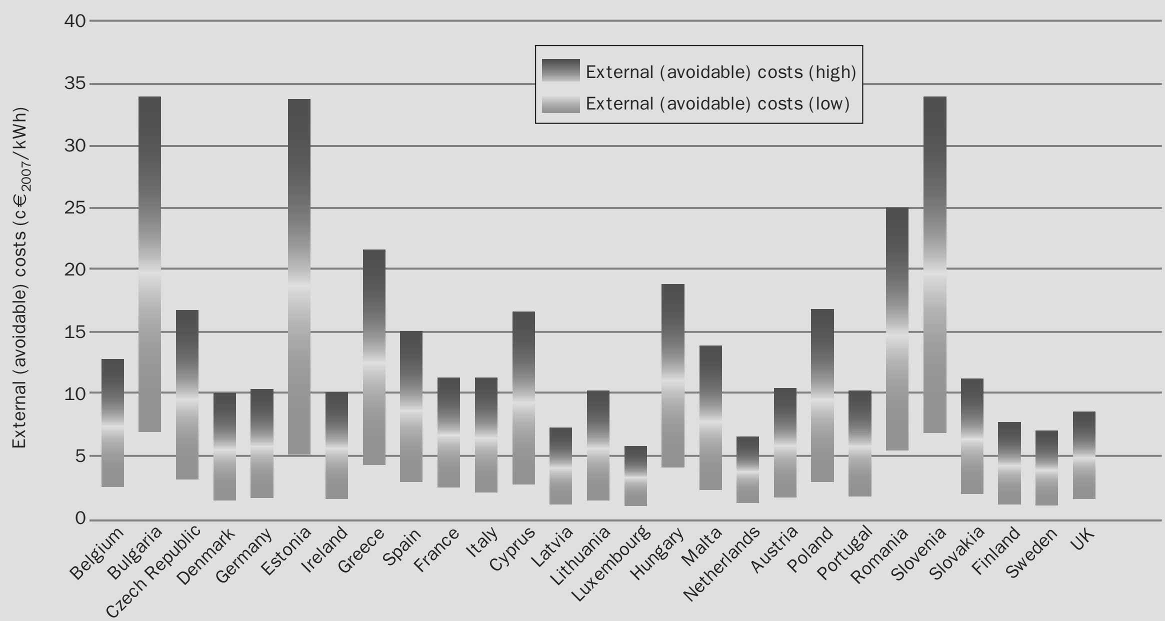
EXTERNAL COSTS OF FOSSIL FUEL-BASED ELECTRICITY GENERATION AND AVOIDED EXTERNAL COSTS IN THE BREAKDOWN OF EWEA'S WIND GENERATION SCENARIOS FOR 2020

Figure V.5.16 presents the results of the calculation of the external costs of conventional fossil fuel-based electricity generation in each of the EU-27 Member States in 2020 (high/average/low values), based on the same methodology used for 2007 (see Figure V.5.5). From this, we finally determine the avoided external costs of wind generation in 2020 in Figures 5.17–5.22 (according to EWEA's three wind generation scenarios).

It is important to note that the specific emissions of fossil fuel-based electricity generation technologies in 2020 are less than in 2007, and also the specific external costs in 2020 (Figure V.5.16) are, on average, less than in 2007 (see Figure V.5.5). In general, the picture for 2020 is similar to 2007 – in other words there is still a noticeable difference between the different EU-27 Member States. Bulgaria, Slovenia and Estonia are those Member States with the highest external costs of fossil fuel-based electricity generation (average values around 20c$€_{2007}$/kWh), but Romania and Greece reach nearly 15c$€_{2007}$/kWh (average values for external costs). On the other hand, there are also a significant number of EU Member States with external costs below 5c$€_{2007}$/kWh (average values of external costs).

By combining the avoidable external costs of fossil fuel-based electricity generation (Figure V.5.16) with the amount of electricity produced by wind energy (Figure V.5.12), the total amount of avoided external costs can be calculated for 2020. Subsequent figures

Figure V.5.16: Bandwidth of specific external costs of fossil fuel-based electricity generation in the EU-27 Member States in 2020



Source: Auer et al. (2007)

present the results of EWEA's three wind generation scenarios for each of the EU-27 Member States for 2020.

The corresponding total avoided external costs (using the values of the average specific external costs for each of the EU-27 Member States in Figure V.5.17) are presented in Figure V.5.18. At an aggregated EU-27 level, the total avoided external costs by wind generation in EWEA's reference scenario in 2020 is around €32 billion per year.

Avoided External Cost for Different Wind Deployment Scenarios in the EU-27 Member States in 2030

In this section, wind deployment scenarios for 2030 are addressed in the same way as for 2020. For clarity, empirical results are presented for EWEA's 2030 high scenario only, since this is the most optimistic assumption at present.

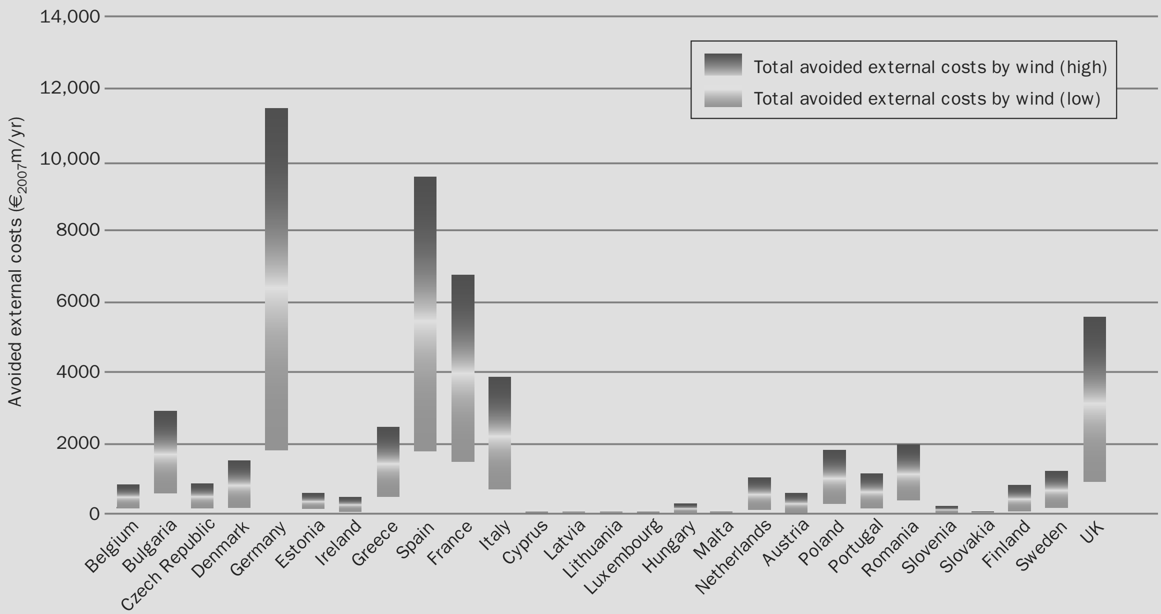
Before presenting the avoided external costs due to wind generation in EWEA's 2030 high scenario, annual wind generation of EWEA's three wind generation scenarios at EU Member State level in 2030 is shown in Figure V.5.23.

Figures V.5.24 and V.5.25 show €69 billion per year (in total) of avoided external costs in the EU-27 Member States by wind generation in EWEA's high wind penetration scenario at aggregated EU-27 level.

Environmental Benefits of Wind Energy – Concluding Remarks

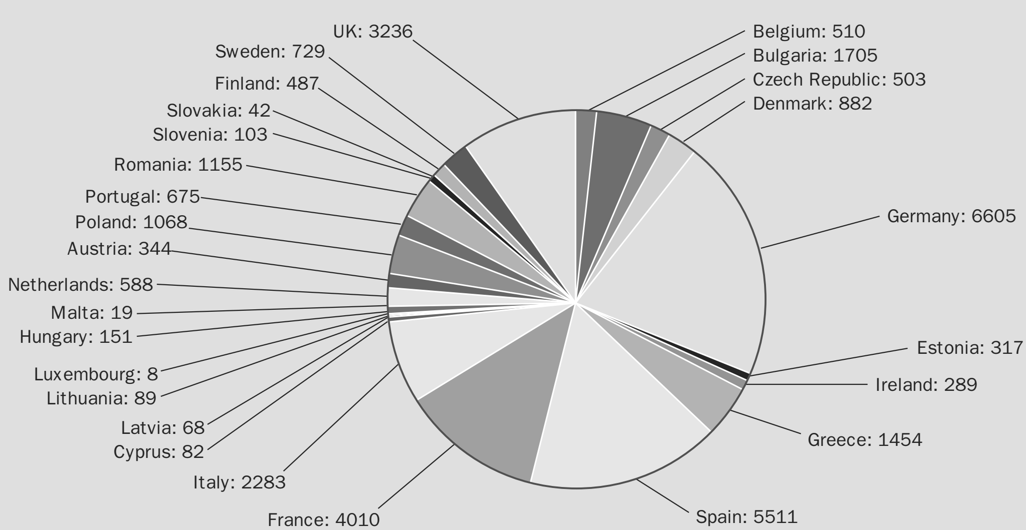
Empirical analyses in previous sections impressively demonstrate that there exist significant environmental benefits of wind generation compared to conventional electricity generation in the EU-27 Member States.

Figure V.5.17: Bandwidth of avoided external costs of fossil fuel-based electricity generation according to EWEA's Reference Scenario in the EU-27 Member States in 2020



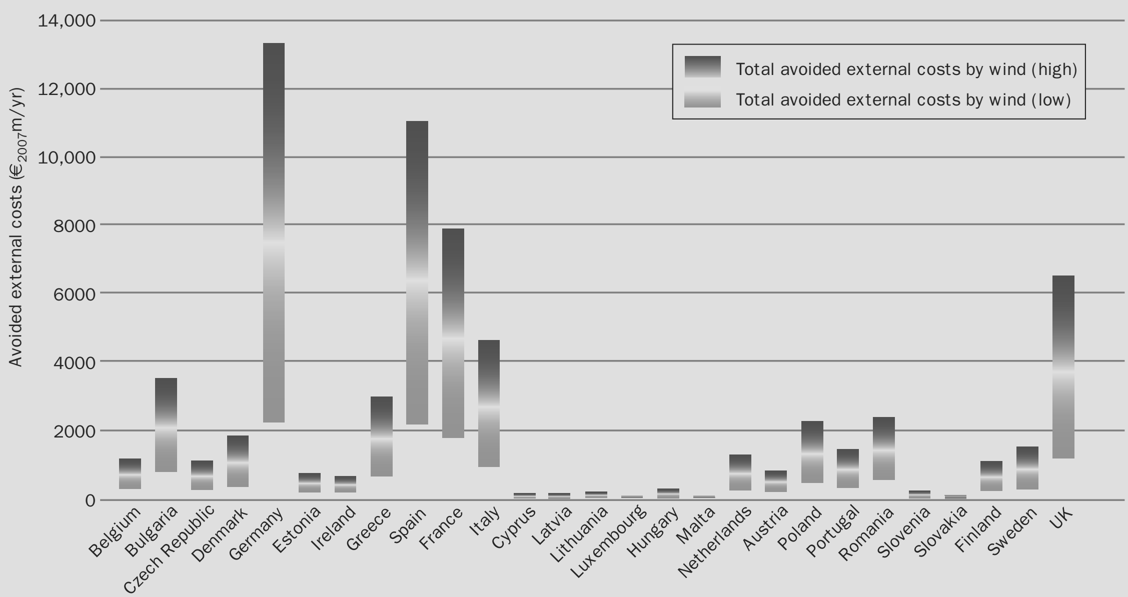
Source: Auer et al. (2007)

Figure V.5.18: Avoided external costs by wind generation according to EWEA's Reference Scenario in each of the EU-27 Member States in 2020 (a total of €32 billion per year)



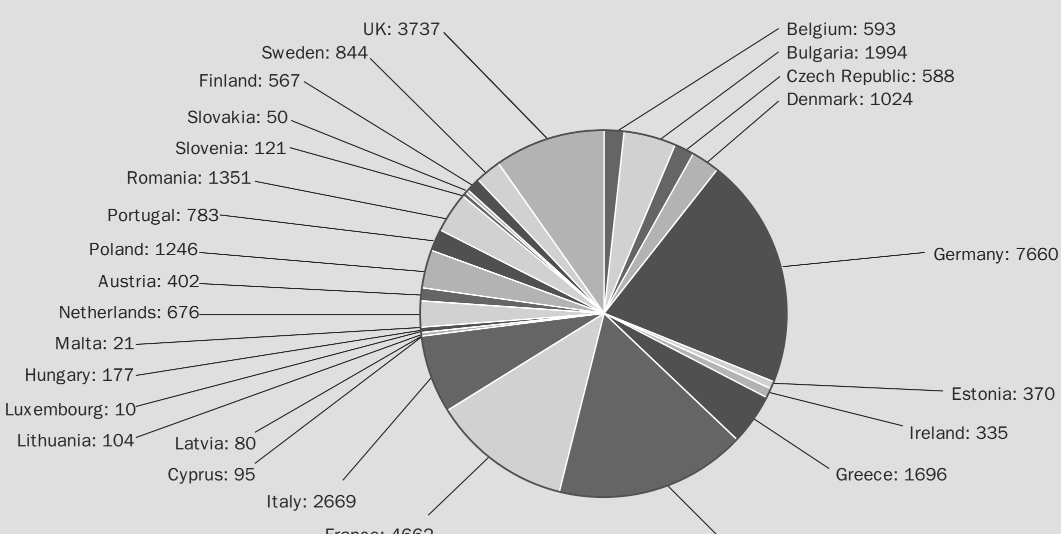
Source: Auer et al. (2007)

Figure V.5.19: Bandwidth of avoided external costs of fossil fuel-based electricity generation according to EWEA's High Scenario in the EU-27 Member States in 2020



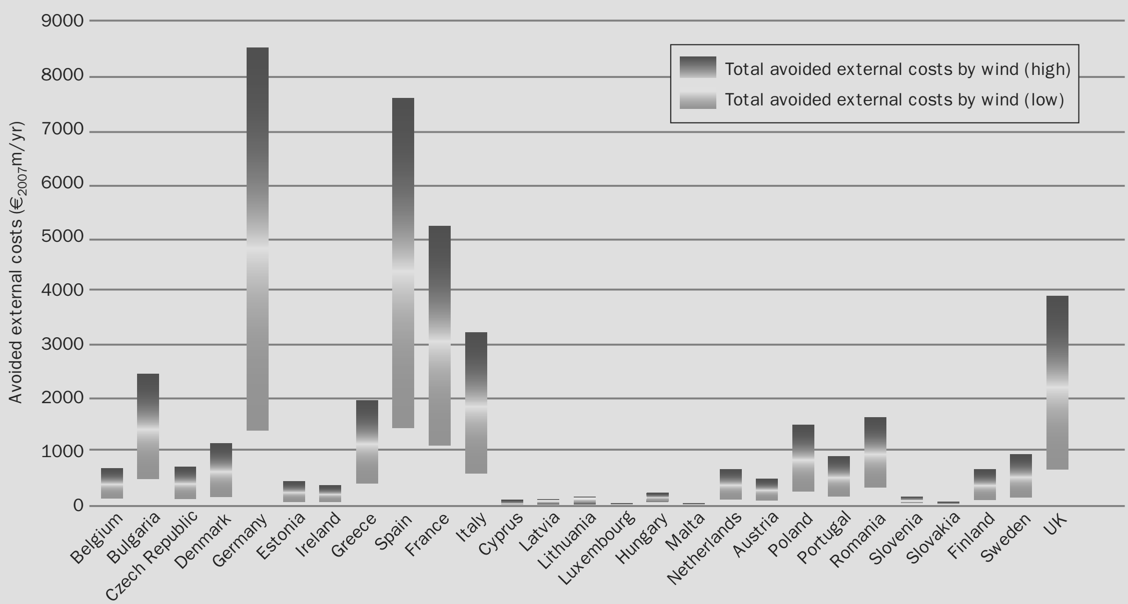
Source: Auer et al. (2007)

Figure V.5.20: Avoided external costs by wind generation according to EWEA's High Scenario in each of the EU-27 Member States in 2020 (a total of €39 billion per year)



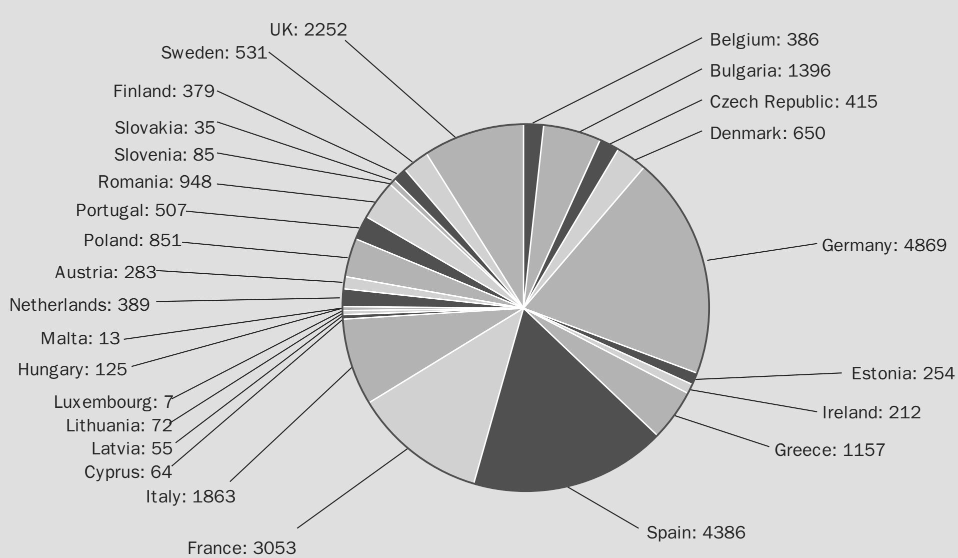
Source: Auer et al. (2007)

Figure V.5.21: Bandwidth of avoided external costs of fossil fuel-based electricity generation according to EWEA's Low Scenario in the EU-27 Member States in 2020



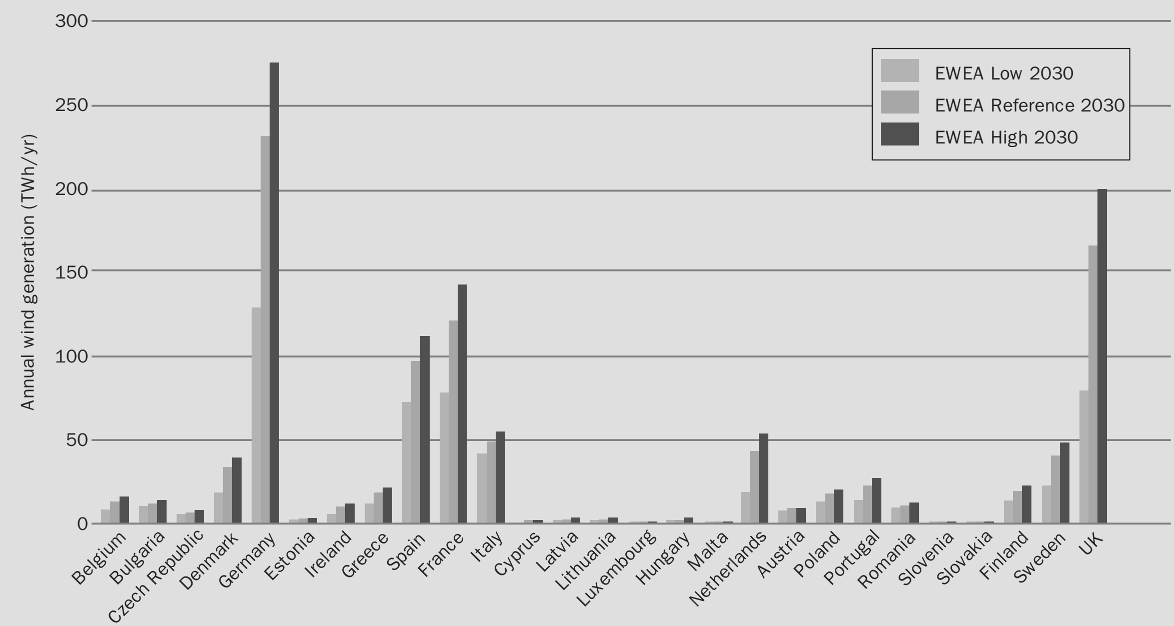
Source: Auer et al. (2007)

Figure V.5.22: Avoided external costs by wind generation according to EWEA's Low Scenario in each of the EU-27 Member States in 2020 (a total of €25 billion per year)



Source: Auer et al. (2007)

Figure V.5.23: Annual wind generation in each of the EU-27 Member States according to EWEA's three wind generation scenarios in 2030



Source: Auer et al. (2007)

In 2007, total annual wind generation of 118.7 TWh per year at EU-27 Member State level has already avoided 70,412 kt per year of CO_2, 183.7 kt per year of SO_2 and 135.3 kt per year of NO_x (see Table V.5.1). The countries mainly contributing to these 2007 results in the EU Member States are Germany, Spain, Denmark and the UK.

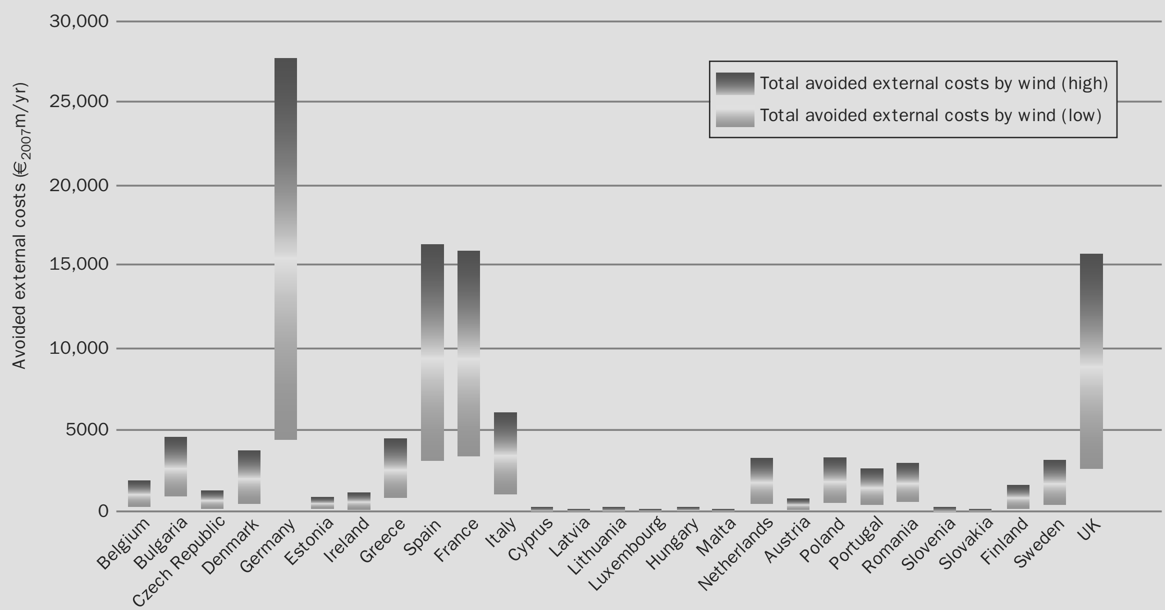
In the next decade the share of wind generation will increase considerably in the European power plant mix. Moreover, mainly due to offshore wind deployment (but also a continual increase of onshore wind), the amount of fossil fuel-based electricity generation replaced by wind generation will increase further in all of the three wind deployment scenarios analysed (see Figure V.5.2).

At aggregated EU-27 Member State level, the following amounts of emissions and external cost are avoided due to wind generation in the different wind deployment scenarios:

- reference scenario (477.4 TWh per year) – avoided emissions CO_2: 217,236 kt per year, SO_2: 379.1 kt per year, NO_x: 313.5 kt per year; avoided external cost €$_{2007}$32,913 million;
- high scenario (554.0 TWh per year) – avoided emissions CO_2: 252,550 kt per year, SO_2: 442.0 kt per year, NO_x: 364.8 kt per year; avoided external cost: €$_{2007}$38,284 million;
- low scenario (360.3 TWh per year) – avoided emissions: CO_2: 165,365 kt per year, SO_2: 299.7 kt per year, NO_x: 240.8 kt per year; avoided external cost: €$_{2007}$25,237 million.

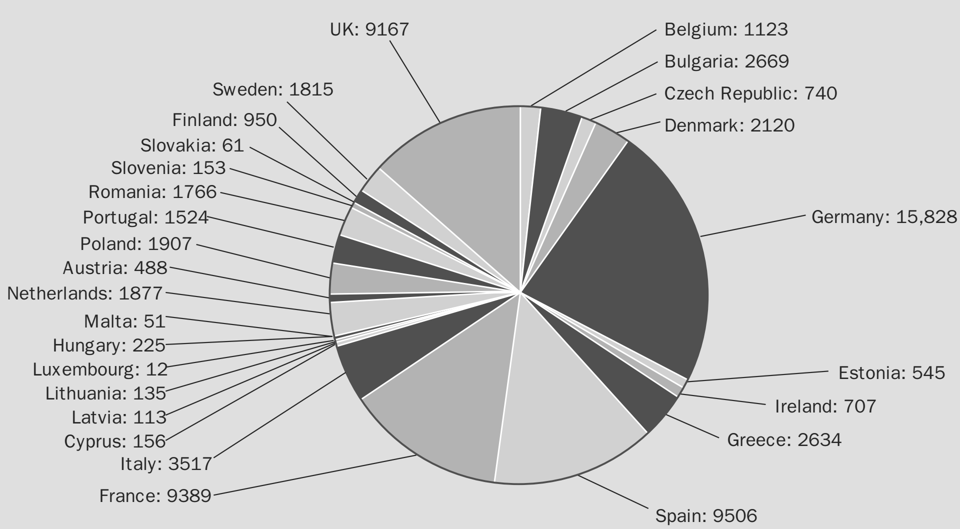
Finally, in the high scenario for 2030 (1103.8 TWh per year; see Table V.5.3), the estimates of the

Figure V.5.24: Bandwidth of avoided external costs of fossil fuel-based electricity generation according to EWEA's High Scenario in the EU-27 Member States in 2030



Source: Auer et al. (2007)

Figure V.5.25: Avoided external costs by wind generation according to EWEA's High Scenario in each of the EU-27 Member States in 2030 (a total of €69 billion per year)



Source: Auer et al. (2007)

Table V.5.1: Empirical results on avoided emissions and external cost due to wind generation in the EU-27 Member States in 2007

	Total emissions from fossil fuel-based electricity generation in 2007			Total emissions from fossil fuel-based electricity generation *avoidable* by wind (and other renewables) in 2007			Annual wind generation in 2007	Total emissions from fossil fuel-based electricity generation *avoided* by wind in 2007			***Specific*** external cost from fossil fuel-based electricity generation in 2007	***Total*** external cost from fossil fuel-based electricity generation ***avoided*** by wind in 2007
2007	CO_2 [kt/yr]	SO_2 [kt/yr]	NO_X [kt/yr]	CO_2 [kt/yr]	SO_2 [kt/yr]	NO_X [kt/yr]	[GWh/yr]	CO_2 [kt/yr]	SO_2 [kt/yr]	NO_X [kt/yr]	[$€_{2007}$/kWh]	[$€_{2007}$m]
Belgium	23,424	44	43	20,585	34	38	470	310	0.5	0.6	9.6	51
Bulgaria	26,508	994	72	5044	116	15	17	16	0.4	0.0	20.5	4
Czech Rep.	44,937	183	123	7231	20	21	110	70	0.2	0.2	9.3	12
Denmark	16,642	7	21	8353	2	10	7965	4486	1.3	5.4	5.7	518
Germany	305,795	155	196	97,131	39	64	39,446	24,796	9.9	16.2	6.8	3027
Estonia	15,763	83	15	15,753	83	15	118	184	1.0	0.2	16.1	21
Ireland	14,952	71	39	9345	27	25	2175	1224	3.6	3.2	6.4	157
Greece	63,885	366	334	19,340	62	116	2320	2138	6.9	12.8	15.3	400
Spain	132,708	1081	382	78,259	400	226	38,423	23,545	120.5	68.0	9.1	3968
France	27,447	73	86	16,855	37	52	3763	1502	3.3	4.6	7.4	316
Italy	136,248	333	253	112,504	245	206	4483	2336	5.1	4.3	7.4	377
Cyprus	3573	38	6	3573	38	6	0	0	0.0	0.0	9.0	0
Latvia	456	0	1	456	0	1	57	17	0.0	0.0	3.1	2
Lithuania	1454	5	3	1454	5	3	0	0	0.0	0.0	3.8	0
Luxembourg	949	0	3	949	0	3	64	20	0.0	0.1	3.2	2
Hungary	16,163	256	24	8273	32	13	460	276	1.1	0.4	8.2	43
Malta	1829	20	3	1829	20	3	0	0	0.0	0.0	9.0	0
Netherlands	40,402	12	37	29,262	4	25	3569	1477	0.2	1.3	4.3	172
Austria	14,435	11	11	9553	4	7	1919	1013	0.4	0.7	5.7	124
Poland	124,587	716	221	30,007	120	56	541	401	1.6	0.8	10.6	65
Portugal	23,090	150	74	15,295	95	48	4496	2550	15.9	8.0	7.6	388
Romania	36,059	697	99	17,162	147	46	0	0	0.0	0.0	20.2	0
Slovenia	5790	94	12	1908	29	4	0	0	0.0	0.0	24.8	0
Slovakia	6742	47	24	2707	9	10	8	5	0.0	0.0	9.1	1
Finland	10,217	14	19	5253	3	10	275	95	0.1	0.2	3.4	11
Sweden	1929	2	2	1503	2	2	1743	823	0.8	0.9	4.4	86
UK	172,260	1011	418	100,133	350	234	6278	3128	10.9	7.3	6.7	472
EU-27 TOTAL	1,268,247	6461	2520	619,719	1925	1258	118,700	70,412	183.7	135.3	9.1 (Average)	10,216

Source: Based on Auer et al. (2007)

Table V.5.2: Empirical results on avoided emissions and external cost due to wind generation in the different wind deployment scenarios in the EU-27 Member States in 2020

	Annual wind generation scenarios in 2020			Total emissions from fossil fuel-based electricity generation *avoided* by wind in the different scenarios in 2020									*Total* external cost (average values) from fossil fuel-based electricity generation *avoided* by wind in the different scenarios in 2020		
	Low Scenario	Ref. Scenario	High Scenario	Low Scenario			Reference Scenario			High Scenario			Low Scenario	Ref. Scenario	High Scenario
				CO_2	SO_2	NO_X	CO_2	SO_2	NO_X	CO_2	SO_2	NO_X			
2020	[TWh/yr]	[TWh/yr]	[TWh/yr]	[kt/yr]	[kt/yr]	[kt/yr]	[kt/yr]	[kt/yr]	[kt/yr]	[kt/yr]	[kt/yr]	[kt/yr]	[$€_{2007}$m]	[$€_{2007}$m]	[$€_{2007}$m]
Belgium	5.1	6.8	7.9	2386	3.8	3.6	3154	5.0	4.7	3665	5.8	5.5	386	510	593
Bulgaria	7.1	8.7	10.1	6216	43.3	11.0	7593	52.9	13.4	8878	61.8	15.7	1396	1705	1994
Czech Rep.	4.3	5.2	6.1	2640	6.4	7.8	3200	7.7	9.5	3744	9.0	11.1	415	503	588
Denmark	11.3	15.4	17.9	6659	1.8	6.8	9041	2.4	9.2	10,499	2.8	10.7	650	882	1024
Germany	82.1	111.4	129.2	39,181	18.4	24.0	53,158	25.0	32.6	61,645	29.0	37.8	4869	6605	7660
Estonia	1.3	1.6	1.9	2176	11.7	2.0	2718	14.6	2.5	3171	17.0	3.0	254	317	370
Ireland	3.6	5.0	5.7	1715	1.8	3.9	2340	2.4	5.4	2713	2.8	6.2	212	289	335
Greece	9.1	11.5	13.4	6577	10.3	28.1	8265	13.0	35.3	9641	15.1	41.2	1157	1454	1696
Spain	50.3	63.8	73.8	25,164	53.5	28.6	31,617	67.2	35.9	36,884	78.4	41.9	4386	5511	6429
France	45.7	60.0	69.7	12,975	31.4	40.2	17,042	41.2	52.8	19,811	47.9	61.4	3053	4010	4662
Italy	27.8	34.1	39.9	12,386	5.4	9.0	15,178	6.7	11.1	17,742	7.8	12.9	1863	2283	2669
Cyprus	0.7	0.9	1.0	507	4.1	1.0	645	5.3	1.2	752	6.1	1.4	64	82	95
Latvia	1.3	1.6	1.9	474	0.6	1.0	591	0.7	1.3	690	0.8	1.5	55	68	80
Lithuania	1.2	1.5	1.8	646	0.0	1.6	795	0.0	1.9	929	0.0	2.3	72	89	104
Luxembourg	0.2	0.3	0.3	58	0.0	0.2	71	0.0	0.2	82.6	0.0	0.2	7	8	10
Hungary	1.1	1.4	1.6	526	2.0	0.8	638	2.4	0.9	747	2.8	1.1	125	151	177
Malta	0.2	0.2	0.3	100	0.0	0.2	141	0.0	0.2	163	0.0	0.3	13	19	21
Netherlands	10.3	15.6	17.9	3301	0.3	1.6	4981	0.4	2.4	5733	0.5	2.8	389	588	676
Austria	4.7	5.7	6.7	2347	0.9	1.5	2844	1.1	1.8	3328	1.3	2.1	283	344	402
Poland	8.9	11.2	13.0	5878	11.9	11.5	7376	14.9	14.4	8605	17.4	16.8	851	1068	1246
Portugal	8.5	11.4	13.2	3763	3.6	7.8	5011	4.8	10.3	5819	5.5	12.0	507	675	783
Romania	6.4	7.8	9.2	4116	68.0	10.4	5017.9	82.9	12.7	5868	96.9	14.9	948	1155	1351
Slovenia	0.3	0.3	0.4	253	2.2	0.5	307	2.6	0.6	359	3.1	0.7	85	103	121
Slovakia	0.5	0.7	0.8	217	0.1	0.6	263	0.1	0.7	307	0.1	0.8	35	42	50
Finland	8.6	11.1	12.9	3408	1.4	4.6	4381	1.9	5.9	5102	2.2	6.8	379	487	567
Sweden	13.2	18.1	21.0	4629	4.7	7.4	6348.6	6.5	10.1	7356	7.5	11.7	531	729	844
UK	46.1	66.2	76.5	17,066	12.2	25.2	24,519	17.5	36.3	28,315	20.2	41.9	2252	3236	3737
EU-27 TOTAL	360.3	477.4	554.0	165,365	299.7	240.8	217,236	379.1	313.5	252,550	442.0	364.8	25,237	32,913	38,284

Source: Based on Auer et al. (2007)

Table V.5.3: Empirical results on avoided emissions and external cost due to wind generation in the High Scenario in the EU-27 Member States in 2030

	Annual wind generation in the *high* scenario in 2030	*Total emissions* from fossil fuel-based electricity generation *avoided* by wind in the *high* scenario in 2030			*Total external cost* (average values) from fossil fuel-based electricity generation *avoided* by wind in the *high* scenario in 2030
2030	**[TWh/yr]**	**CO_2 [kt/yr]**	**SO_2 [kt/yr]**	**NO_X [kt/yr]**	**[$€_{2007}$m]**
Belgium	15.7	6729	11.4	10.1	1123
Bulgaria	13.7	11,526	81.4	20.3	2669
Czech Rep.	7.8	4631	11.4	13.7	740
Denmark	39.4	21,751	6.0	22.2	2120
Germany	276.7	126,329	60.9	77.6	15,828
Estonia	2.9	4653	24.9	4.3	545
Ireland	12.8	5655	6.1	13.0	707
Greece	21.2	14,632	23.6	62.5	2634
Spain	111.9	52,999	116.6	60.4	9506
France	142.8	38,389	96.4	119.3	9389
Italy	55.0	22,807	10.6	16.7	3517
Cyprus	1.7	1220	10.0	2.3	156
Latvia	2.9	970	1.3	2.1	113
Lithuania	2.5	1204	0.0	2.9	135
Luxembourg	0.4	97	0.0	0.3	12
Hungary	2.1	919	3.5	1.3	225
Malta	0.7	388	0.0	0.7	51
Netherlands	53.2	15,796	1.4	7.6	1877
Austria	8.6	4006	1.7	2.5	488
Poland	20.5	12,967	26.8	25.3	1907
Portugal	27.0	11,121	11.2	23.0	1524
Romania	12.2	7305	127.9	18.6	1766
Slovenia	0.5	442	3.8	0.9	153
Slovakia	1.0	371	0.2	1.0	61
Finland	22.8	8525	3.8	11.4	950
Sweden	47.7	15,731	16.9	25.2	1815
UK	200.1	68,257	52.2	101.0	9167
EU-27 TOTAL	1103.8	459,422	709.8	646.4	69,180

Source: Based on Auer et al. (2007)

environmental benefits of wind generation (compared to fossil fuel-based electricity generation) are CO_2: 459,422 kt per year, SO_2: 709.8 kt per year and NO_x: 646.4 kt per year in terms of avoided emissions and $€_{2007}$69,180 million in terms of avoided external cost.

The analyses and results presented above impressively underline the importance of further significantly increasing the share of wind deployment (onshore and offshore) in the EU-27 Member States in the next decades. However, a precondition for the full implementation of the environmental benefits estimated here is both continuous adaption of financial support instruments and the removal of several barriers for market integration of wind energy.

Annex V.5

Table V.5.A briefly summarises the methodology for specific countries or regions of each of the 'early' studies on external costs in the late 1980s and the beginning of the 1990s.

Table V.5.A: Methodologies of external cost studies

Study	Methodology	Location
Hohmeyer (1988a)	Top-down apportioning of total environment damages in Germany to the fossil fuel sector	Germany; existing power plants
Ottinger et al. (1990)	Damage-based approach in which values were taken from a literature review or previous studies	US; existing power plants
Pearce (1992)	Literature survey to identify values used in a damage-based approach to calculate damages; in some respects an update of Ottinger et al. (1990) study from Pace University Center	Estimates for a new and old coal power plant in the UK
US Department of Energy ORNL/RFF (1994)	Damage function, or impact pathway, approach; detailed examination and use of scientific literature; emphasis on developing methodology, rather than on numerical results of specific examples	Estimates for new power plants in rural southwest and southeast US
RCG/Tellus (1994)	Damage function approach; developed EXMOD software	Sterling, rural area in New York state

Source: Lee (1996)

V.6 SOCIAL ACCEPTANCE OF WIND ENERGY AND WIND FARMS

The Social Acceptance of Wind Energy: An Introduction to the Concept

Wind energy, being a clean and renewable energy source in a global context of increasing social concerns about climate change and energy supply, is traditionally linked to very strong and stable levels of public support. The most recent empirical evidence on public opinion towards wind energy at both the EU and the country level fully supports such favourable perception of this energy source among European citizens. Nevertheless, experience in the implementation of wind projects shows that social acceptance is crucial for the successful development of specific wind energy projects. Thus we should look at the main singularities of the social acceptance of wind energy compared to the social acceptance of other energy technologies:

- the (very) high and stable levels of general public support: at an abstract level about 80 per cent of EU citizens support wind energy;
- the higher number of siting decisions to be made due to the current relatively small-scale nature of the energy source;
- the visibility of wind energy devices and the proximity to the everyday life of citizens (if compared with the 'subterranean' and distant character of conventional power generation and fossil fuels extraction); and
- the tensions between support and opposition concerning specific wind power developments at the local level: large majorities of people living near wind farm sites are in favour of their local wind farm (Warren el al. 2005), but wind planning and siting processes are facing significant challenges in some countries across Europe (Wolsink, 2007).

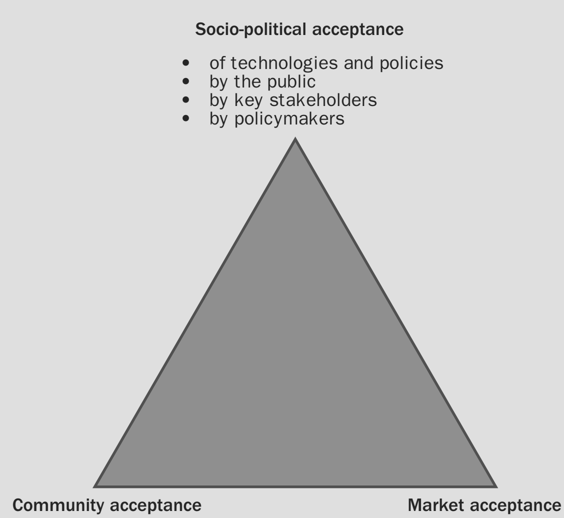
Consequently, the social acceptance of wind power entails both the general positive attitude towards the wind energy technology together with the increasing number of 'visible' siting decisions to be made at the local level. Importantly, it is at the local level where the 'technical' characteristics of wind energy interact with the everyday life of the individual, and the social and institutional environments of the communities hosting such developments. As we will see, the general positive attitudes towards wind power are not necessarily linked to the local acceptance of wind energy projects (Johansson and Laike, 2007).

This is the context in which we find the most recent formulation of the concept of 'social acceptance' linked to renewable energies (Wüstenhagen et al., 2007), the so-called 'triangle model', which distinguishes three key dimensions of social acceptance:

1. socio-political acceptance;
2. community acceptance; and
3. market acceptance.

- **Socio-political acceptance** refers to the acceptance of both technologies and policies at the most general level. Importantly, this general level of socio-political acceptance is not limited to the 'high and

Figure V.6.1: The triangle model of social acceptance



Source: Wüstenhagen et al. (2007)

stable' levels of acceptance by the general public, but includes acceptance by key stakeholders and policymakers. Stakeholders and policymakers involved in discussing 'renewable policies' become crucial when addressing planning issues or promoting local involvement initiatives. Thus the assessment of their levels of acceptance is an area of increasing interest for social researchers.
- **Community acceptance** refers to the acceptance of specific projects at the local level, including potentially affected populations, key local stakeholders and the local authorities. This is the area where social debate around renewables arises and develops, and the one that has attracted most of the social research traditionally carried out in the wind energy field.
- **Market acceptance** refers to the process by which market parties adopt and support (or otherwise) the energy innovation. Here we find processes such as green power marketing and willingness to pay for green power. Market acceptance is proposed in a wider sense, including not only consumers, but also investors and, very significant, intra-firm acceptance.

Interestingly, this 'triangle model' works well with the 'three discourses' scheme suggested by another recent conceptual approach to the social perception of energy technologies (Prades et al., 2008): the 'siting discourse' (where the technology is experienced in terms of a proposed construction of some facility in a given locality); the 'energy-innovation discourse' (where the technology is experienced as an innovation that may or may not fit in with preferred ways of life); and the 'investment discourse' (where the technology is experienced as an investment opportunity that is acceptable, or otherwise, in the light of the possible gains it will produce). Moreover, this 'triangle model' has been proposed as the conceptual framework in a recent task of the International Energy Agency – Wind (Implementing Agreement for Cooperation in the Research, Development and Deployment of Wind Energy Systems) dealing with the social acceptance of wind energy projects: 'Winning hearts and minds' (IEA Wind, 2007a).

The next sections will introduce the main findings of the social research with regards to socio-political acceptance (the acceptance of technologies and policies by both the general public and key stakeholders and policymakers) and community acceptance (the acceptance of specific projects at the local level).

The Social Research on Wind Energy Onshore

Social research on wind energy has primarily focused on three main areas:

1. **public acceptance**: the assessment (and corroboration) of the (high and stable) levels of public support (by means of opinion polls and attitude surveys);
2. **community acceptance**: the identification and understanding of the dimensions underlying social controversy at the local level (by means of single or multiple case studies, including surveys); and
3. **stakeholder acceptance**: social acceptance by key stakeholders and policymakers (by means of interviews and multiple case studies); recent approaches are paying increasing attention to this field.

The following section looks at what social research on wind energy tells us about the social acceptance of wind developments by such a wide range of social actors and levels.

PUBLIC ACCEPTANCE OF WIND ENERGY (SOCIO-POLITICAL ACCEPTANCE)

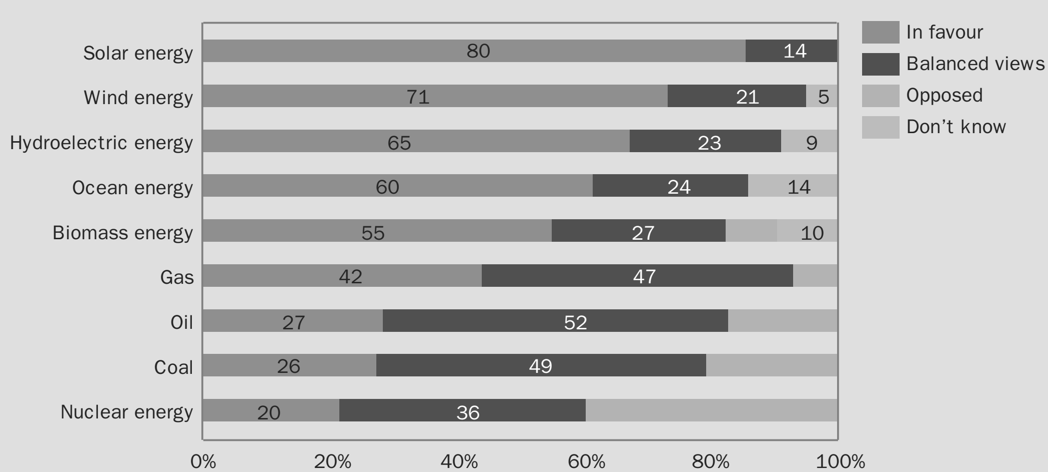
One of the traditional focuses of social research on wind energy has been the assessment of the levels of public support for wind energy by means of opinion polls and attitude surveys (Walker, 1995). Among opinion polls, the strongest indicator allowing comparisons of the level of support in different countries is the Eurobarometer Standard Survey (EB), carried out twice yearly and covering the population of the EU aged 15 and over. Over the 30 years that these surveys have been conducted, they have proved to be a helpful source of information for EU policymakers on a broad range of economic, social, environmental and other issues of importance to EU citizens. Recent EB data on public opinion (EC, 2006c and 2007c) confirm the strongly positive overall picture for renewable energies in general, and for wind energy in particular, at the EU level, and not only for the present but also for the future (see Figure V.6.2).

When EU citizens are asked about their preferences in terms of the use of different energy sources, renewable energies in general, and wind energy in particular, are rated highly positively (especially when compared with nuclear or fossil fuels). The highest support is for solar energy (80 per cent), closely followed by wind energy, with 71 per cent of EU citizens firmly in favour of the use of wind power in their countries, 21 per cent expressing a balanced view and only 5 per cent are opposed to it. After solar and wind, we find hydroelectric energy (65 per cent support), ocean energy (60 per cent) and biomass (55 per cent). According to this EB survey, only a marginal number of respondents opposed the use of renewable energy sources in their countries. As regards fossil fuels, 42 per cent of the EU citizens favoured the use of natural gas and about one-quarter accepted the use of oil (27 per cent) and coal (26 per cent). Nuclear power seems to divide opinions, with the highest rates of opposition (37 per cent) and balanced opinions (36 per cent) and the lowest rate of support.

Focusing on the use of wind energy, on a scale from 1 (strongly opposed) to 7 (strongly in favour), the EU average is 6.3. Even higher rates of support arose in some countries, for example Denmark (6.7), Greece (6.5), and Poland, Hungary and Malta (6.4). The UK shows the lowest support figure of the EU (5.7), closely followed by Finland and Germany (5.8).

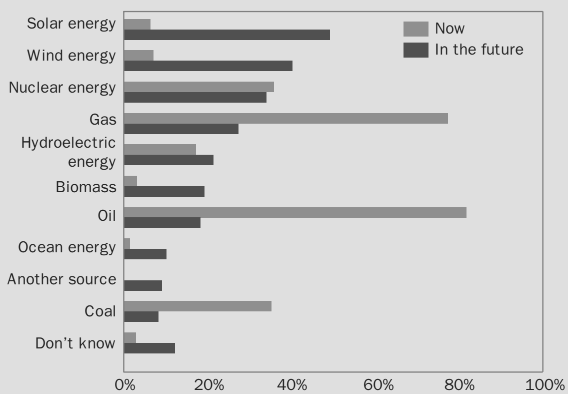
EU citizens also demonstrated a very positive view of renewable energy in general and of wind energy in

Figure V.6.2: General attitudes towards energy sources in the EU



Source: European Commission (2007c)

Figure V.6.3: General attitudes towards energy sources in the EU 30 years from now



Source: European Commission, 2007c

particular when asked about their expectations regarding the three most used energy sources 30 years from now. Results showed that wind energy is expected to be a key energy source in the future – just after solar. Respondents in all countries except the Czech Republic, Italy, Slovenia, Slovakia and Finland mentioned wind energy among the three energy sources most likely to be used in their countries 30 years from now. The expected increase in the use of wind energy from 2007 to 2037 is very important in all countries (that mentioned wind), with an average expected increase of 36.35 per cent.

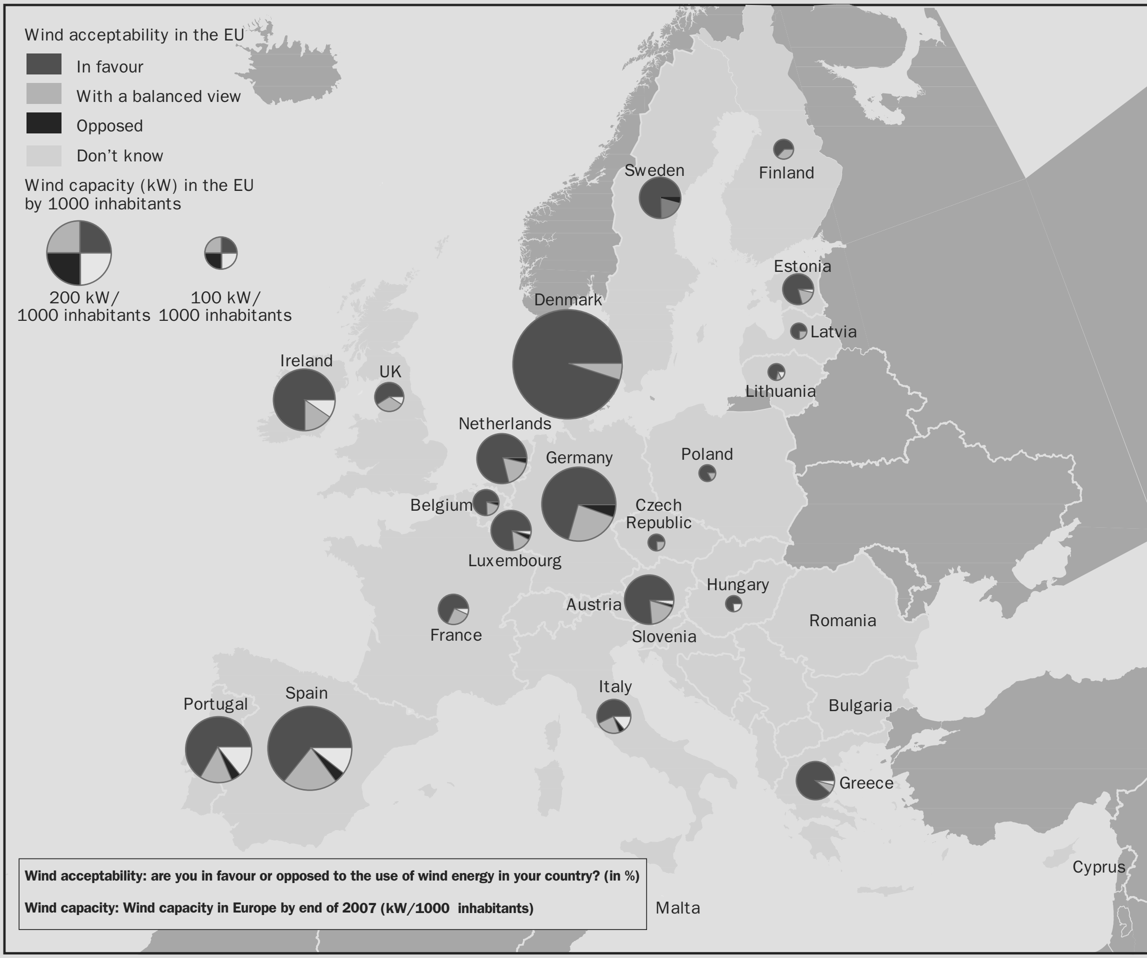
The latest EB on 'Attitudes towards energy' (EC, 2006c) further corroborates this positive picture of wind at the EU level. For EU citizens, the development of the use of wind energy was the third preferred option to reduce our energy dependence on foreign, expensive and highly polluting sources (31 per cent), after the increase in the use of solar energy (48 per cent) and the promotion of advance research on new energy technologies (41 per cent). Importantly, further evidence at the country level gathered by several national wind energy associations, such as the British Wind Energy Association, Associazione Nazionale Energia Del Vento (Italy) and or the Austrian Wind Energy Association, supports this positive overall scenario with regards to the use of wind energy, both at present and in the future.

One interesting question is the association between these high levels of general public support for wind energy and the actual implementation of wind power in each country. This could be analysed through the correlation of two variables: percentage of people strongly in favour of wind power, from the EB, and wind capacity in kW/1000 inhabitants (Figure V.6.4). The bivariate analysis shows a *low* and *not significant* linear correlation: the highest levels of public enthusiasm about wind power in our sample of countries were not associated with the highest levels of wind capacity per habitant. In line with the most recent formulation of the 'social acceptability' of wind farms, this result may indicate that the generally favourable public support for the technology of wind power does not seem to be directly related to the installed wind capacity (that is linked to positive social and institutional decision-making as will be seen later on). Thus it is very important to properly differentiate between the 'public acceptance' of wind energy and the 'community acceptance' (and stakeholders' acceptance) of specific wind developments.

Finally, from the methodological perspective, it should be noted that, despite a profusion of quantitative surveys, and with a few notable exceptions (Wolsink, 2000) there is still a lack of valid and reliable quantitative methodological tools for understanding general public perceptions of wind farms (Devine-Wright, 2005).

To conclude, the key messages regarding 'public acceptance' are the very high levels of public support for wind energy and the fact that this favourable general condition does not seem to be directly related to the installed wind capacity. Thus there is a need to also look at the perceptions of the other key actors involved in wind development: the local communities hosting the wind farms and the key stakeholders involved in such developments.

Figure V.6.4: Wind acceptability and wind capacity in the EU



Source: European Commission (2007c)

COMMUNITY ACCEPTANCE OF WIND ENERGY AND WIND FARMS

A wide variety of studies based on different approaches and methodologies have been carried out to identify the key elements involved in the interaction between wind energy developments and the communities hosting them. Importantly, these case studies have allowed a better understanding of the factors explaining success and failure of wind developments, and this may indeed provide useful insights to more evidence-based decision-making in the future.

Recent research into how wind projects interact with the local community questions the traditional explanation of local rejection to technological projects based on the NIMBY acronym (Not In My Back Yard), as this term may give an incorrect or only partial explanation of all the variables involved in the planning process

(Krohn and Damborg, 1999; Wolsink, 2000, 2007). According to the NIMBY idea, resistance is explained in terms of motives of local citizens, but the latest findings suggest that such an interpretation would be too simplistic considering the number of views and circumstances involved in the local planning of wind projects (Warren et al., 2005). The NIMBY label 'leaves the cause of opposition unexplained' (Kempton et al., 2005) and consequently it lacks explanatory value. One of the key messages from social research points out that how wind farms are developed and how people make sense of the impact of wind farms upon the places in which they live may be more important in shaping pubic reactions to new projects than the purely physical or technical factors. As Wolsink (2000) suggests, local opposition is often based on distrust, negative reactions to the actors (developers, authorities and energy companies) trying to build the turbines, and the way projects are planned and managed, and not to wind turbines themselves.

Thus, according to the social sciences literature, when trying to understand the community acceptance of wind farms, there are some potential errors that could lead to misunderstandings. One type of error, as stated in the previous section, is not considering *community acceptance* as a social phenomenon with a *different dynamic* than *public acceptance* of wind power as a reliable source of energy. Another potential error is interpreting public attitudes towards wind farms as merely influenced by the characteristics of the technology, without properly considering how the implementation of the technology is part of a socio-technical system that interacts with the local community, the local environment, the key stakeholders and the project developers.

Three categories have been established that help explain the social response to wind energy (see Prades and González Reyes, 1995). First, we consider those physical, technical and environmental characteristics of the technology that affect how the public perceives wind farms. Second, we analyse the different individual and psycho-social factors of those living in the hosting communities, such as knowledge, general attitudes or familiarity, which might shape views of wind farms. And third, we consider the social and institutional elements governing the interaction between the technology and the hosting community, such as planning characteristics or level of engagement, and how they might influence public attitudes towards, and acceptance of, wind farm projects.

Table V.6.1: Factors affecting public perceptions of wind farms and other energy innovations

Perceptions of physical and environmental factors	Psycho-social factors	Social and institutional factors
Visual impact: • Landscape characteristics • Turbine colour • Turbine and farm size • Unity of the environment (as designed by the authors) • Wind farm design • Turbine noise • Distance to turbines • Ecological site characteristics (birds and other wildlife)	• Familiarity • Knowledge • General attitudes • Perceived benefits and costs • Socio-demographics • Social network influences	• Participatory planning • Public engagement • Justice and fairness issues • Local ownership • Policy frameworks • Centralisation/decentralisation • Campaigns by action groups

Source: CIEMAT

Physical, Environmental and Technical Attributes of Wind Farms

As with any other technological development, the specific physical and technical attributes of the implementation of the technology itself are significant predictors of public attitudes. Consequently, social research on wind farm projects has attempted to identify how such wind power attributes are perceived by the public. One of the most relevant early research findings (Thayer and Freeman, 1987; Wolsink, 1988 and 1989) in this regard was the identification of visual impacts and noise as important issues in the social response to wind energy (Devine-Wright, 2005).

Visual impact has been considered the main influence on public attitudes towards wind farms, as 'aesthetic perceptions, both positive and negative, are the strongest single influence on public attitudes' (Wolsink, 2000). The perceived impact on landscape seems to be the crucial factor in this regard, and opposition to the visual despoliation of valued landscapes has been analysed as the key motivation to opposition to wind farms (Warren et al., 2005). A study on how perceptual factors influence public intention to oppose local wind turbines (Johansson and Laike, 2007) found that 'perceived unity' of (or harmony with), the environment is the most important perceptual dimension. Those who perceived the turbines to have a high degree of unity with the landscape express a low degree of opposition. With regard to colour, a higher level of public support seems to exist for turbines that are painted neutral colours. In relation to size, studies in the UK, Denmark, The Netherlands and Ireland found a systematic preference for smaller groups of turbines over large-scale installations (Devine-Wright, 2005).

Visual intrusion and noise were the key anticipated problems by respondents in a survey carried out in Ireland (Warren et al., 2005). However, the same study found that noise pollution and visual impacts were less important to the public than anticipated before the project construction, concluding that respondents' fears had not been realised. The limited effect of noise disturbance on acceptance levels has also been found in other contexts (Krohn and Damborg, 1999). On a more detailed level, Pedersen and Waye (2007) found, in different areas in Sweden, that the visual factor of the fit of the turbines to the landscape has a stronger impact than the sound levels.

Danger to birds and other wildlife is considered to be one of the more important environmental impacts of wind energy developments. As stated in Chapter V.2 ('Environmental impacts'), bird mortality caused by wind farms seems to be a sporadic event and dependent on different elements such as the season, the specific site, the species and the type of bird activity. Studies on community acceptance (Wolsink, 2000; Simon, 1996) have shown that the concern about hazards to birds, when present, has only a small impact on individuals' perceptions of wind farms. However, in ecological areas with threatened or vulnerable species, impacts from wind farms on birds and habitats might generate opposition from environmental and other public interest groups, media attention and increase local concern.

Another element investigated by the empirical research has been the effect of distance to the wind farms on perceptions. In Denmark, different studies, to some surprise, have found that people living closer to wind farms tend to be more positive about wind turbines than people living farther away (Scottish Executive Central Research Unit, 2000). As we will see, familiarity with wind farms could be one possible explanation of this phenomenon.

To conclude, research has shown that the physical, environmental and technical attributes of wind farms and the selected site are significant predictors of public attitudes and, consequently, issues such as harmony with the landscape and turbine/wind farm size and colour should be carefully considered when planning wind energy developments. Nevertheless, social acceptance of wind farms is not merely influenced by the characteristics of the technology: more important are the implementation of the technology and how it interacts with the local community, the key stakeholders and the project developers.

Psycho-social Factors

Psycho-social factors have become crucial dimensions to explain how local communities interact with, and react to, new wind farm developments. Familiarity with the technology is a significant element widely explored by social research. The familiarity hypothesis refers to the fact that those who experience wind farms generally become more positive towards them (Wolsink, 1994; Krohn and Damborg, 1999). This phenomenon has been represented as the 'U-shape curve' (Wolsink, 1994). Based on empirical data, this model states that public attitudes change from very positive, before the announcement of the project, to negative when the project is announced, to positive again after the construction. This important result shows the dynamic nature of public attitudes. Opinions on technological developments may change as citizens are confronted with specific developments. However, as has been documented (Wolsink, 2007), the improvement of attitudes after a facility has been constructed is not guaranteed.

Separate to the familiarity dimension is the degree of knowledge about wind energy and its effects on individuals' perceptions of wind farms. Although some studies have found a positive relation between knowledge and attitude (Krohn and Damborg, 1999), there is little evidence of a significant correlation between level of knowledge of wind power and its acceptance (Wolsink, 2007; Ellis et al., 2007). This does not mean, however, that providing clear and honest information about the technology and the project does not play an important role in increasing public understanding: it is essential in the process of creating trust between developers, authorities and local communities.

General attitudes towards wind energy are another key element influencing public perceptions of wind farms. As seen in the previous section, general attitudes towards wind power are very positive. A recent study by Johansson and Laike (2007) found that the general attitude towards wind power was one of the most significant predictors in the response to a local project, with those more positive about wind power more in favour of the specific project. Pedersen and Waye (2008) have also revealed that people with anti-wind-energy views perceive wind turbines to be much noisier and more visually intrusive than those who are optimistic about wind power.

The effects of socio-demographic variables on individuals' views of wind farms have also been studied. Age, gender, experience with wind farms, and use of the land and/or beach were found to be slightly correlated with the attitudes towards wind power in a Danish study dealing with public perceptions of on-land or offshore wind turbines (Ladenburg, 2008).

Devine-Wright (2005) has pointed out other psycho-social factors less explored by social research on public reactions to wind farms, such as the role of social networks in 'how people come to hear about proposed wind farm developments and whom they trust, as well as the eventual perceptions that they choose to adopt' (Devine-Wright, 2005, p136). In this framework, social trust, considered as the level of trust individuals have with organizations and authorities managing technological projects, is increasingly regarded as a significant element in social reactions to technological developments (Poortinga and Pidgeon, 2006). In the wind power context, Eltham et al. (2008) have documented, through the study of public opinions of a local population living near a wind farm, how suspicion of the developers' motives by the public, distrust of the developers and disbelief in the planning system may impede the success of wind farm projects. Trust can be created in careful, sophisticated decision-making processes that take time, but it can be destroyed in an instant by processes that are perceived as unfair (Slovic, 1993; Poortinga and Pidgeon, 2004). Trust is an interpersonal and social variable, linking attitudinal processes with institutional practices.

To conclude, psycho-social factors such as familiarity (or otherwise) with wind technology, general attitudes towards the 'energy problem' and/or socio-demographic variables do play a role in the shaping of wind energy acceptance and should properly be considered when planning wind energy developments.

Social and Institutional Factors

The notion of 'citizen engagement' has become a central motif in public policy discourse within many democratic countries, as engagement – 'being responsive to lay views and actively seeking the involvement of the lay public in policymaking and decision-making' (Horlick-Jones et al., 2007) – is acknowledged as an important component of good governance (National Research Council, 1996). Consequently, the analysis of the social acceptance of technologies is increasingly recognising the importance of the 'institutional arrangements', in other words the relationships between the technology, its promoters and the community (Rogers, 1998; Kunreuther et al., 1996). This is precisely the focus of the most recent investigations on the sources of success or failure of wind farms projects: the relationship between local resistance and levels of community engagement, fairness and compensation (Loring 2007; Wolsink, 2007).

One of the most substantive questions in this regard is whether local involvement and participatory planning in wind farms increases local support. Recent studies agree that successful wind farm developments are linked to the nature of the planning and development process, and that public support tends to increase when the process is open and participatory (Warren et al., 2005; Wolsink, 2007; Loring, 2007). It is also suggested that collaborative approaches to decision-making in wind power implementation will be more effective than top-down imposed decision-making (Wolsink, 2007) and that public engagement may serve to reduce opposition and to increase levels of 'conditional supporters' to wind power developments (Eltham et al., 2008). As Wolsink (2007, p1204) states, 'the best way to facilitate the development of wind projects is to build institutional capital (knowledge resources, relational resources and the capacity for mobilisation) through collaborative approaches to planning'.

There is little doubt that fairness issues may shape a local community's reactions to wind developments in siting contexts. Findings from research indicate that perceptions of fairness influence how people perceive the legitimacy of the outcome (Gross, 2007). It is assumed that a fairer process helps the creation of mutual trust, and hence it will increase acceptance of the outcome. As has been stated by other authors, the underlying reason for NIMBY attitudes is not selfishness, but a decision-making process perceived to be unfair (Wolsink, 2007).

In the review of factors shaping public attitudes towards wind farms, it has been emphasised (Devine-Wright, 2005; Krohn and Damborg, 1999) that there exists a significant relationship between share ownership and perceptions. Individuals who own shares in a turbine have a more positive attitude towards wind energy than those with no economic interest. Although limited to the Danish context, it has been found that in some communities, members of wind cooperatives are more willing to accept more turbines in their locality in comparison with non-members.

The influence of policy frameworks on the social acceptance of wind energy has also been analysed through case studies (Jobert et al., 2007). Results from German and French cases underline the relevance of factors directly linked with the implementation of the project: local integration of the project developer, creation of a network of support and access to ownership. According to the authors, the French policy framework makes developers more dependent on community acceptance, and therefore the French case studies show much more conflict resolution and networking among key local actors than in the German one. The planning problem and the role of national and local policies are also being analysed as key dimensions in the social acceptance of wind power in Scotland and Wales (Cowell, 2007).

The role of action groups in a wind farm planning decision (Parkhill 2007) is also receiving quite a lot of attention from social research, as evidence is showing their substantial influence on wind farm planning decisions at the sub-national level (Bell et al., 2005; Toke, 2005; Boström, 2003). The strength of local opposition groups has been considered as an important social and institutional factor causing distrust during the planning and siting stages (Eltham et al., 2008).

To conclude, social research is highlighting the complexity and multidimensionality of the factors underlying community acceptance of wind energy projects. Recent evidence is increasingly demonstrating that 'how' wind farms are developed may be more important in shaping pubic reactions to new projects than the purely physical or technical factors.

STAKEHOLDERS' AND POLICYMAKERS' ACCEPTANCE (SOCIO-POLITICAL ACCEPTANCE)

As most social research on wind energy developments has focused either on 'public acceptance' or 'community acceptance', the first issue to be highlighted is that exploring the acceptance of wind energy by key stakeholders and policymakers (at all levels: EU, national and local) clearly requires further efforts. Nevertheless, the available evidence on stakeholders' and policymakers' acceptance does provide essential insights. The very first investigation on stakeholders' acceptance was carried out in the 1980s, when it was first acknowledged that 'the siting of wind turbines is also a matter of ... political and regulatory acceptance' (Carlman, 1984) and the need to analyse the views of politicians and decision-makers was recognised. The pioneer study on 'institutional frameworks' is from the mid-1990s, when energy policy, policy performance and policy choices related to wind energy in the Dutch context were first analysed (Wolsink, 1996).

The most recent research on stakeholders' acceptance is paying special attention to the so-called 'institutional landscapes' and how diverse types of such landscapes are related to different levels of wind implementation (and ways of achieving it) at the EU level. With this aim, how key stakeholders in the energy field perceive issues such as political commitment (and the perceived 'urgency' of energy-related matters), financial incentives (models of local financial participation) and planning systems (patterns of early local involvement in the decision-making process) have been analysed in multiple cases studies from several EU countries (The Netherlands, the UK, and the German state of North Rhine Westphalia) from the 1970s to 2004 (Breukers and Wolsink, 2007). A very similar approach was proposed by Toke et al.(2008) to understand the different outcomes of implementation of wind power deployment in five EU countries: Denmark, Spain, Scotland, The Netherlands and the UK). Different national traditions related to four key institutional variables (planning systems; financial support mechanisms; presence and roles of landscape protection organisations; and patterns of local ownership) were examined to identify and understand their inter-relations and how they might be related to the different levels of wind power implementation between countries. This recent research on stakeholders' and policymakers' acceptance has allowed the identification of two crucial factors for the successful implementation of wind energy: the financial incentives and the planning systems. With regard to financial incentives, evidence shows that participation or co-ownership is crucial in successful developments (the feed-in system in combination with support programmes promoting the involvement of a diversity of actors has proved to be the most efficient policy) (Breukers and Wolsink, 2007). As far as the planning system is concerned, evidence shows that planning regimes supporting collaborative practices of decision-making increase the correspondence between policy intentions and the outcome of the process (bottom-up developments have also proved to be the most successful ones) (Toke et al., 2008). Results of an extensive stakeholder consultation carried out on behalf of the European Commission to identify, among other things, the main 'institutional' barriers to exploiting renewable energy sources for electricity production

(Coenraads et al., 2006; see also Chapter IV.5 of this volume) fully supports this picture, as the 'administrative' and 'regulatory' barriers were perceived to be the most severe.

Consequently, and in line with the latest findings of the social research on community acceptance, a key message can be drawn from the most recent analysis on stakeholders' and policymakers' acceptance: facilitating local ownership and institutionalising participation in project planning could allow a better recognition and involvement of the compound interests (environmental, economic and landscape) that are relevant for the implantation of wind energy.

The Social Research on Wind Energy Offshore

In recent years, there has been a growing interest in the analysis of the public reactions to offshore wind power. Although the available empirical evidence is much more limited than that available for onshore wind development, studies from different countries have explored the main factors shaping public attitudes towards offshore projects as well as whether public acceptance differs between offshore and onshore.

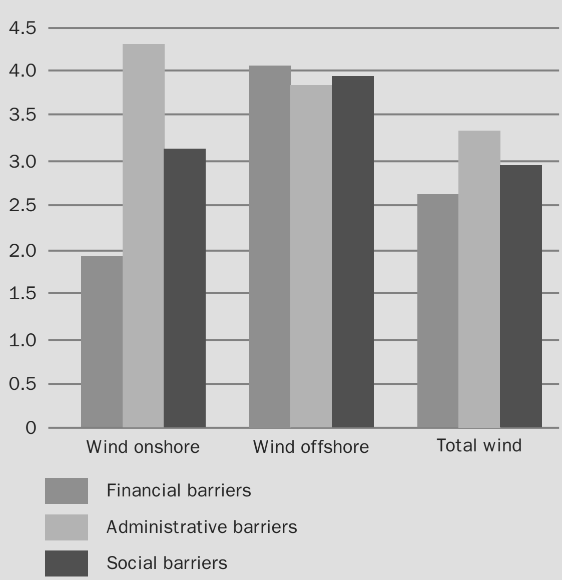
As was the case with wind onshore, at the first stages of the technological development the physical and environmental attributes are the ones attracting more attention from social researchers. Offshore projects could also face negative reactions and promoters should be aware that 'coastal communities are just as sensitive to threats to seascapes as rural society is to visual disturbance in highland areas' (Ellis et al., 2007, p536). A study of residents near a proposed development near Cape Cod in the US (Firestone and Kempton, 2007) found that the main factors affecting individuals' reaction to the offshore project were damage to marine life and the environment. The next most frequently mentioned effects were aesthetics, impacts on fishing or boating, and electricity rates. The majority of participants expected negative impacts from the project. However, the project was more supported if turbines were located further offshore. Bishop and Miller (2007), by means of a survey using offshore wind farm simulations in Wales, found less negative response, in terms of perceived visual impact, to moving than to static turbines and to distant than to near turbines.

The available evidence on the psycho-social, social and institutional factors underlying the acceptance of wind offshore in the EU is to be found in Denmark, the country with the longest experience with offshore developments. A longitudinal study using qualitative techniques compared the reactions to Horns Rev and Nysted offshore wind farms (Kuehn, 2005; Ladenburg, in press). The authors found that at both sites, support for the project was linked to environmental attitudes, in a context of climate change and commitments to reduce CO_2 emissions. Another key argument for support was the expected occupational impact at the local level, in other words the expected number of jobs to be generated by the wind development. On the other hand, negative attitudes were based on concerns about visibility and negative impacts on the horizon. At Horns Rev opposition centred on business interests and tourism, while at Nysted the crucial issue was the need to not interfere with nature and preserve it as it was ('intact'). Regarding the planning process, most interviewees showed a feeling of being ignored in the decision-making process, as the decision on the wind park had already been taken by central authorities. Supporters tended to be active in the local debates. A recent study in Denmark (Ladenburg, 2008) has compared local attitudes towards offshore and onshore projects. The study finds that respondents tend to prefer offshore to onshore. Even if onshore wind power is perceived as an acceptable solution to the Danish public (only 25 per cent were opposed to an increase in the number of turbines onshore), respondents were more positive to more offshore wind turbines (only 5 per cent of respondents were opposed).

As far as key stakeholders in the development of renewable energies are concerned, as mentioned in the previous section, the OPTRES study demonstrates that the administrative and regulatory barriers are perceived to be the most severe to the development of wind offshore.

Even though, as the Figure V.6.5 illustrates, the importance attributed to the different barriers varies substantially from onshore to offshore. The accumulated experience in onshore and the lack of it in offshore may be a relevant factor in this regard, together with the management of the interaction between the technology and the community. Consequently, another important message can be drawn from this extensive stakeholder consultation: offshore and onshore wind seem to present relevant differences in the relative perceived importance of the barriers to their development.

Figure V.6.5: Stakeholders' perception of the barriers to wind development in the EU



Source: Coenraads et al. (2006)

Conclusions

As shown in this chapter, social research linked to wind energy developments has increased in the last few years, and such efforts have allowed a better understanding of the complexity and multidimensionality underlying the social acceptance of wind energy. Thus social research in the wind energy field has allowed the characterisation of factors explaining success or failure of wind developments. A general typology of factors involved has been proposed:

- factors related to the technical characteristics of the technology (physical and environmental characteristics of the site and technical attributes of wind energy);
- factors related to the individual and collective profile of the community hosting such technology (psycho-social factors); and
- factors related to the interaction between technology and society (social and institutional factors).

In this sense, and in order to capture the wide range of factors involved in the development of wind energy, we have provided a more complete formulation of the concept of 'social acceptance'. Three key dimensions have been identified: community acceptance ('the siting discourse'), market acceptance ('the investment discourse') and socio-political acceptance ('the energy-innovation discourse'). Future research needs to focus on these different dimensions as well as how they interact. In terms of socio-political acceptance, special attention should be paid to the development and implementation of suitable financial instruments and fair planning policies. In terms of community acceptance, proper institutional arrangements (including a comprehensive consideration of landscape issues) that could support trust-building processes also require further efforts. Methodological and conceptual improvements, integrated frameworks, and the evaluation of a citizen engagement process will be key elements in the social research on wind energy in the coming years.

A proper consideration of this wide range of issues may provide significant insights to a more evidence-based decision-making process on wind energy developments. There are no recipes to manage social acceptance on technological issues, but more precise knowledge may help promoters and authorities learn from past experiences and find mechanisms to improve citizen engagement with wind energy development.

Part V Notes

1 For more information on the ECLIPSE project, visit http://88.149.192.110/eclipse_eu/index.html

2 More information on the EC project NEEDS is available at www.needs-project.org/.

3 For more information on the EC project CASES, see www.feem-project.net/cases/.

4 The Ecoinvent data v2.0 contains international industrial life-cycle inventory data on energy supply, resource extraction, material supply, chemicals, metals, agriculture, waste management services, and transport services. More information on the Ecoinvent database is accessible at http://www.ecoinvent.org/

5 Life Cycle Assessments, 2005 Report, Vestas Wind Systems A/S, available at http://www.vestas.com/en/about-vestas/sustainability/wind-turbines-and-the-environment/life-cycle-assessment-(lca).aspx.

6 There is often confusion between 'Annex I' (to the UNFCCC) and 'Annex B' (to the Kyoto Protocol). The list of 'industrialised countries' in each is the same, except that Turkey and Belarus are in Annex I but not Annex B. Belarus applied to join Annex B at COP 12 and has been submitted to the Parties for ratification of the amendment to Annex B. Turkey has recently decided to ratify Kyoto, and may apply to join Annex B. Liechtenstein, Slovenia, Slovakia, Croatia and the Czech Republic are in Annex B but not in Annex I.