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A system-based approach to assessing the value of wind for society

Report based on an experts' workshop, which took place in Petten, the Netherlands, on 13 and 14 November 2013

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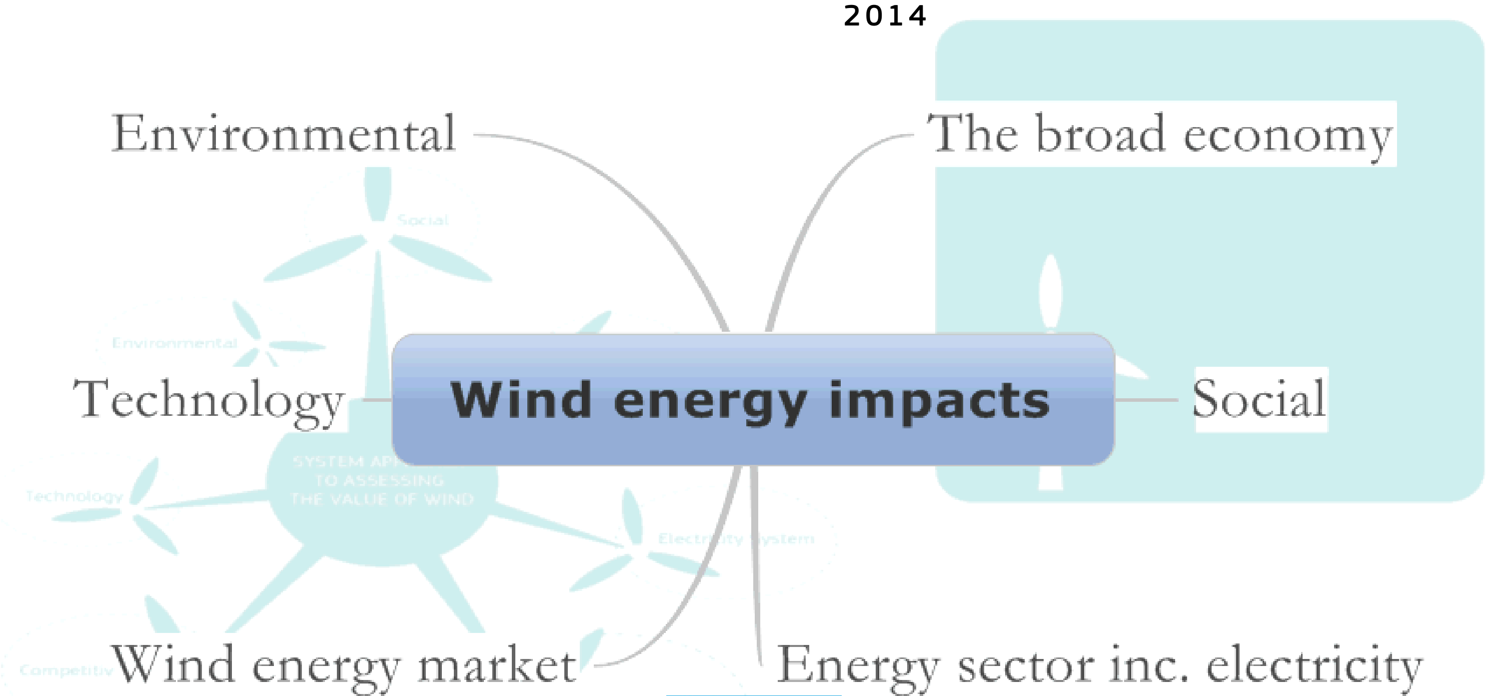
2014



Joint
Research
Centre

Report EUR 26740 EN

European Commission:
Joint Research Centre
Institute for Energy and Transport

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https://ec.europa.eu/jrc

JRC89902

EUR 26740 EN

ISBN 978-92-79-39414-0

ISSN 1831-9424

doi:10.2790/33776

Luxembourg: Publications Office of the European Union, 2014

Abstract

A system-based approach to assessing the value of wind is based on the definition of the subsystems that lie inside the system boundary, then the categories in each subsystem, and finally the elements that compose those categories.

The subsystems that were identified as affecting the value of wind are:

- technology, including research, development and demonstration (RD&D), technology spillover and materials;
- the energy sector, including the electricity market and electricity system categories, the security and economic aspects of security of supply and the wider non-electricity energy market;
- the wind energy market, including industrial activities and the cost of wind energy and its support, for example, in the form of subsidies, grants, taxes, fees and levies, and by the financial sector;
- the broader economy, including electricity generation technology investment, government actions and industrial competitiveness;
- social, covering employment, the impact on land or the sea, social acceptance, non-economic costs of administration, anti-wind campaigns, health and safety issues;
- environmental categories, including life-cycle greenhouse gas emissions, air pollution, water use and land and water surface.

The result is a guide that could be used by analysts and practitioners of policy-support theory and practice to define which subsystems, categories and/or elements they decide to include in a prospective analysis of the value (and the impact) of wind for society.

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Report based on an experts' workshop, which took place in Petten, the Netherlands, on 13 and 14 November 2013

by

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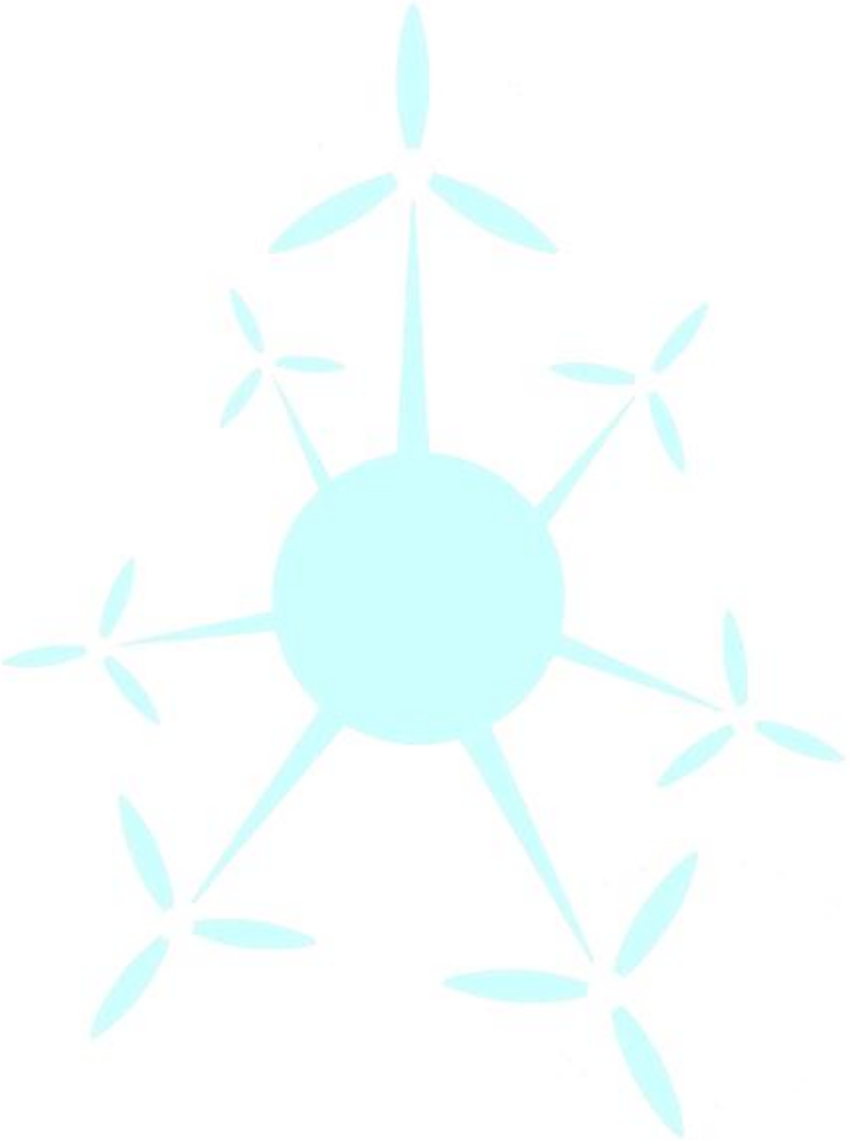

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ACKNOWLEDGEMENTS

The authors would like to thank first and foremost the experts who kindly took part in the workshop organised by the Joint Research Centre (JRC) and Task 26 of the International Energy Agency (IEA) Implementing Agreement for Co-operation in the Research, Development, and Deployment of Wind Energy Systems (IEA Wind/Task 26), in Petten, The Netherlands, on 13th and 14th of November 2013. The list of participating experts is included in section 11 below.

Most of the content of this report was generated during the breakout groups and the plenary debate, described below. This is the reason for the different levels of detail in different subsystems. This "raw" content was later clarified and supplemented, during the drafting of this report, with other sources cited in each case.

The authors would also like to express their appreciation to the reviewers of this report, in particular, María del Mar Pérez-Fortes, Ryan Wiser, Hannele Holttinen, Thomas Jenkin, Aisma Vitina and Jean Welstead, and to the linguistic editor PWT Communications.

Citation:

Please refer to this report as: Lacal-Arántegui, R.; Radu, D.; Magagna, D. and Hand, M. (2014). *A System-based Approach to Assessing the Value of Wind for Society*. Joint Research Centre of the European Commission. ISBN 978-92-79-39414-0, doi:10.2790/33776.

ABBREVIATIONS AND ACRONYMS

This report uses two-letter country codes per the International Organization for Standardization: http://www.iso.org/iso/country_names_and_code_elements. Other abbreviations and acronyms are:

CapEx	capital expenditure or capital cost
CEM	Clean Energy Ministerial
CO_2	carbon dioxide
CO_2-eq	emissions equivalent to a carbon dioxide unit
DSM	demand-side management
Dy	dysprosium
ETS	European emissions trading scheme
EU	European Union
FiT	feed-in tariff (see Wikipedia)
GHG	greenhouse gas(es)
HVDC	high-voltage, direct current
IEA	International Energy Agency
IEA Wind	IEA Implementing Agreement for Co-operation in the Research, Development, and Deployment of Wind Energy Systems
IPCC	International Panel on Climate Change
IRENA	International Renewable Energy Agency
JRC	Joint Research Centre, a directorate general of the European Commission
kWh	kilowatt-hour (= 1 000 watt-hours)
LCoE	levelised cost of energy
lidar	light radar (see Wikipedia)
LVRT	low-voltage ride-through
MW	megawatt (= 1 000 000 watts)
Nd	neodymium
NEEDS	New Energy Externalities Development for Sustainability project
NREL	National Renewable Energy Laboratory
OEM	original equipment manufacturer, in the context of this report OEM is the wind turbine manufacturer
OpEx	operational expenditure or O&M cost
O&M	operations and maintenance
PHS	pumped hydropower storage
PM2.5, 10	particulate matter with diameter of less than 2.5 or 10 μm
PPA	power purchase agreement (see Wikipedia)
RD&D	research, development and demonstration
R&D	research and development
Tb	terbium
VAT	value-added tax
VRE	variable renewable electricity
WACC	weighted average cost of capital

EXECUTIVE SUMMARY

This document reports on an experts' workshop held in Petten, the Netherlands, on 13 and 14 November 2013, aimed at exploring the value of wind energy for society, grouped into three main themes: social, environmental and economic.

The preparation of the workshop, the course of it and later work all addressed identifying and following a system-based approach: first the system boundary and subsystems that could be included in any analysis of the value of wind for society, then the categories in each subsystem and finally the elements that compose those categories. During the drafting of this report, it became clear that it was not possible to include all the elements in the short time available, thus only some examples are included below.

The subsystems identified as affecting the value of wind are:

- technology, including research, development and demonstration (RD&D), technology spillover and materials;
- the energy sector, including the categories of electricity market and electricity system, the security and economic sides of security of supply and the wider non-electricity energy market;
- the wind energy market, including industrial activities, the cost of wind energy and its support, for example, in the form of subsidies, grants, taxes, fees and levies, and by the financial sector;
- the broader economy, including electricity generation technology investment, government actions and industrial competitiveness;
- social, covering employment, the impact on land or the sea, social acceptance, non-economic costs of administration, anti-wind campaigns, health and safety issues;
- environmental, including life-cycle greenhouse gas emissions, air pollution, water use and land and water surface categories.

The result is a guide that could be used by analysts and practitioners of policy support theory and practice to define which subsystems, categories and/or elements they decide to include in a prospective analysis of the value (or the impact) of wind for society.

This report is accompanied by a web application with examples of analyses that will allow expanding the work into new elements.

1 Introduction

This section describes how to make the best use of this report, some background information on the value of wind, and the topics in each section of the document.

1.1 How to use this report

This report is intended for use as a reference for the study and analysis of the various elements that constitute the value of wind for society resulting from all the impacts that wind energy may have in the society where it is deployed.

The reader may follow the report sequentially for a comprehensive approach to the value of wind, or access a specific section of interest on one of the aspects of the value of wind, e.g. technology, energy system, energy market, electricity system or social aspects.

1.2 Background

The concept of ***value of wind*** (energy) is based on the idea that the impact of wind energy generation on society is very broad, and it must include all impacts, whether positive or negative, in order to assess its real and complete value to society. These include economic, social, environmental, technological and energy-system impacts at a minimum.

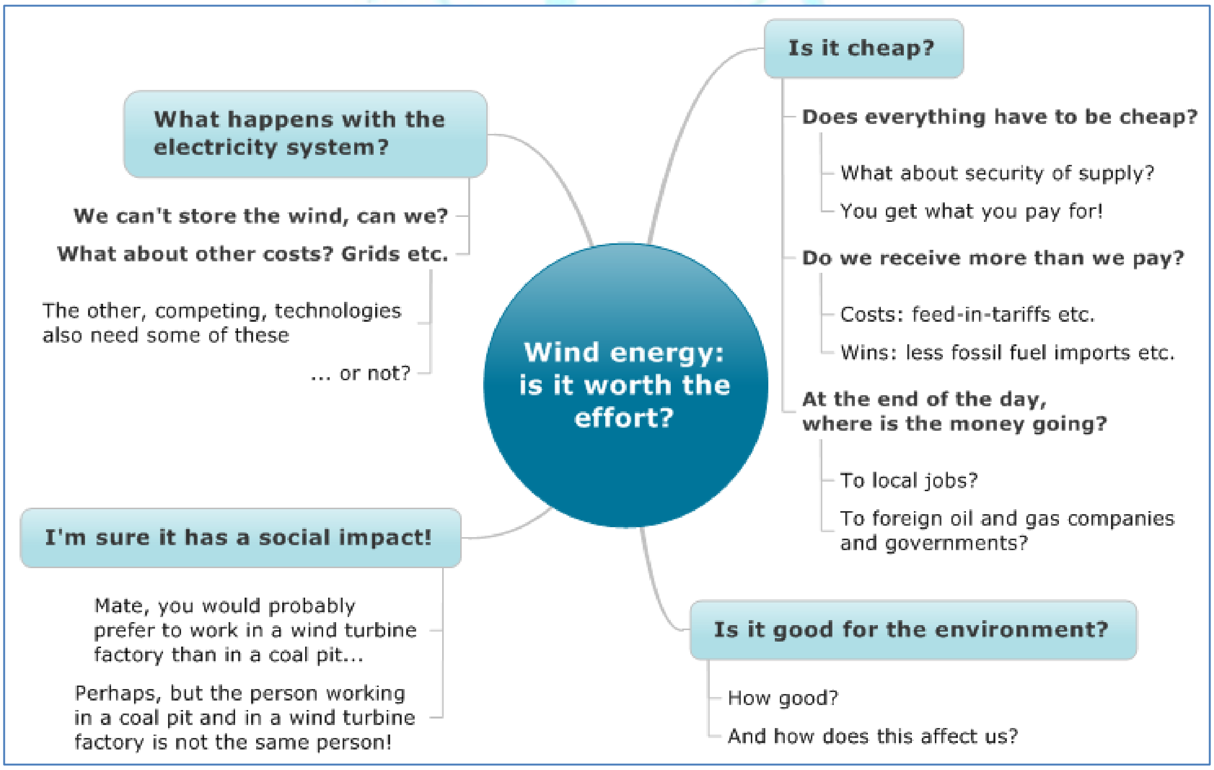

Figure 1: Some of the questions (and attitudes) that policy makers and the public at large might pose (and take) in the debate about wind energy

In the aftermath of the financial and economic crisis that hit the world, in particular Europe, from 2008 onwards, governments have streamlined their expenditures and diminished or even cancelled their support for wind energy, claiming it is more expensive than conventional electricity generation. Various interest and social groups expressed their disappointment and disapproval of these political decisions. Their main argument was that the benefits of wind energy go beyond the simple economics of its support system; therefore, it would be narrow-minded to limit the debate to its burden to the rate- or tax-payer. Figure 1 indicates some of the issues that policy makers and the general public alike put forward at the discussion table.

This debate is similar for other renewable energies confronted with the same kinds of challenges. Groups of international experts under the International Energy Agency (IEA) Implementing Agreements for other technologies,[1] the International Renewable Energy Agency (IRENA) and other fora have discussed and proposed different approaches to identify and assess the value of renewable energies. See, for example, IRENA and Clean Energy Ministerial (IRENA and CEM, 2014).

Which elements should be included when assessing the value of renewables to society? It seems clear that the benefits or costs of renewables include social, environmental and economic themes, each including many elements (see below) that can be grouped into categories. However, it is uncertain which specific elements should be included in each category.

Given this background, in participation and cooperation with IEA Wind and with the support of Operating Agent, Dr Maureen Hand, and the participating parties in Task 26,[2] the Joint Research Centre of the European Commission organised a workshop of multi-disciplinary experts to answer the question of which elements should be considered when defining the value of wind energy.

1.3 Organisation of this document

Throughout the document, reference to the ***societal*** value refers to the value of wind in the broadest or most complete sense and includes purely social aspects along with environmental ones, in addition to traditional economic considerations.

Section 2 of this document describes the objectives of the workshop and its course. Section 3 presents the initial definition of the system considered. Section 4 highlights the important effect of the context on the impact of wind, e.g. the same effect — say, contribution to system stability — has a very different impact when the share of wind generation is 2 %, than when it is more than 50 % of the electricity mix.[3] The following six sections address each of the subsystems: technology, energy sector, wind energy market, economic, social and environmental. Sections 11 and 12 list the workshop participants and references, respectively.

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[1] For example, Photovoltaic Power Systems and Renewable Energy Technology Deployment.

[2] The scope of IEA Wind Task 26 is to assemble and analyse estimates of past, present and future wind energy costs using transparent, consistent methodologies. Participating parties currently include Germany, Norway, Denmark, Ireland, the Netherlands, the United States and the European Commission.

[3] It is important to distinguish share of wind generation vs capacity because the share of capacity (MW) is generally higher when, as is usually the case currently, the overall average system utilization is higher than the capacity factor of wind. On the other hand, the share of wind generation is only approximate given natural year-to-year variation in the wind capacity factor for turbines or wind farms at any given location.

2 The workshop

The scope of the workshop was ***to create and enhance a comprehensive list of social, environmental and economic elements, which should or could be included in any analysis of the value of wind energy to society,*** depending on the purpose of each individual analysis.

The workshop background included the identification of elements or successful analytic results of previous studies (e.g. gross employment, net employment or other employment metrics) that explored the value of wind energy. The workshop then focused on identifying gaps in these analyses and additional aspects that should be addressed to allow for comprehensive analysis.

Participating experts were briefed on the policy demands, stemming from society and conveyed through policy makers that led the European Commission to support a study on the value of wind. Next, they were briefed on three recent studies on the value of wind. Before the workshop participants split into subgroups, they were presented with the elements used for the new assessment of a 20 % wind contribution to the US electricity mix by 2030.

2.1 Desired outcomes

In order of priority the desired outcomes of the workshop included:

1) An agreed upon list of all the elements that should, could or should not be included in ***a system approach*** to assessing ***the societal value of wind energy***;
2) identified appropriate system boundaries;
3) a set of explanations of why the elements in the agreed upon list should be included or excluded;
4) the detailed data needed for every element and the more common gaps.

This report was created to present the conclusions of the workshop to policy makers, analysts, scientists, policy-support practitioners, etc.

2.2 Thematic areas of expertise

The experts were selected according to their areas of expertise in order to cover the following topics:

- experience with similar studies
- economics (macro and micro), including modelling
- systems approaches
- cost–benefit and other impact assessment tools
- energy systems, including wind energy and integration
- environmental aspects
- social aspects.

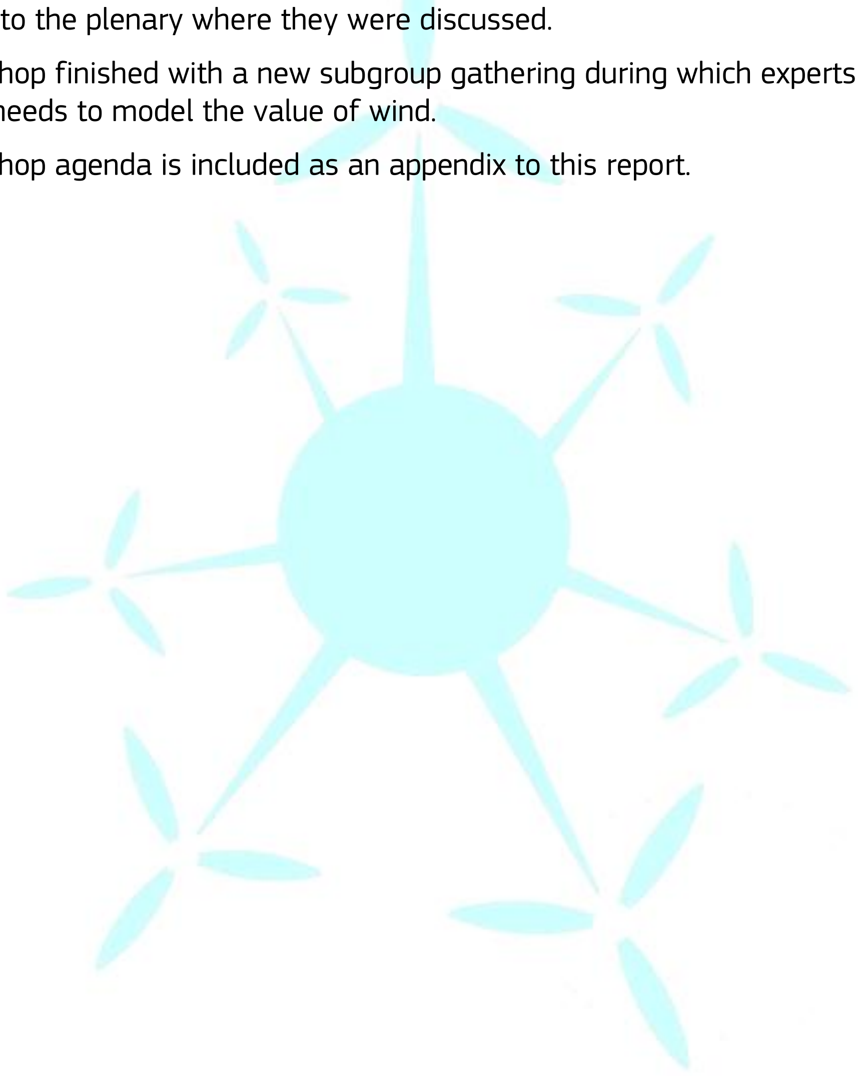
2.3 Workshop structure

The group was split into four subgroups of six to nine people, each of them focused on four groups of aspects broadly corresponding to environmental, social, macro-economic, and electricity system and market. Experts, other than subgroup chairs, were asked to first join a subgroup that did not correspond to their main area of expertise (the "non-expert" subgroups) in order to reinforce creative thinking and provide out-of-the-box input to the debate.

The experts were then asked to move to the subgroup of their main area of expertise, the "expert" subgroups. The chairs were responsible for carrying over "non-expert" proposals to the "expert" subgroups for further discussion. Chairs were then asked to present subgroup proposals to the plenary where they were discussed.

The workshop finished with a new subgroup gathering during which experts discussed gaps and data needs to model the value of wind.

The workshop agenda is included as an appendix to this report.



3 System definition

In this context, we define the ***value of wind system*** as a group or combination of interrelated, interdependent or interacting elements, such as wind technology exports or taxes paid by wind workers, which are affected by the introduction or presence of wind energy technology and/or the electricity it generates. This system forms a collective entity; a methodical, coordinated assemblage of parts, facts, concepts, etc.

The system discussed in the workshop included a flexible boundary delimiting the elements that should be taken into account when defining the societal value of wind. This system does not contain figures but rather it defines the variables that should be included and identifies the data required to estimate values.

The workshop began with the definition of a system containing the elements impacted by wind energy generation, with a system boundary separating them from elements not influenced by wind energy or with minimal influence. Figure 2 shows examples of elements that could be included and excluded in this system. Taxes that do not differentiate the fuel origins of generated electricity, such as value-added tax (VAT) on electricity, are left out of the system. However, taxes and fees, which are specific to wind energy or to any of the competing technologies (e.g. a carbon emissions-related tax), are inside the system.

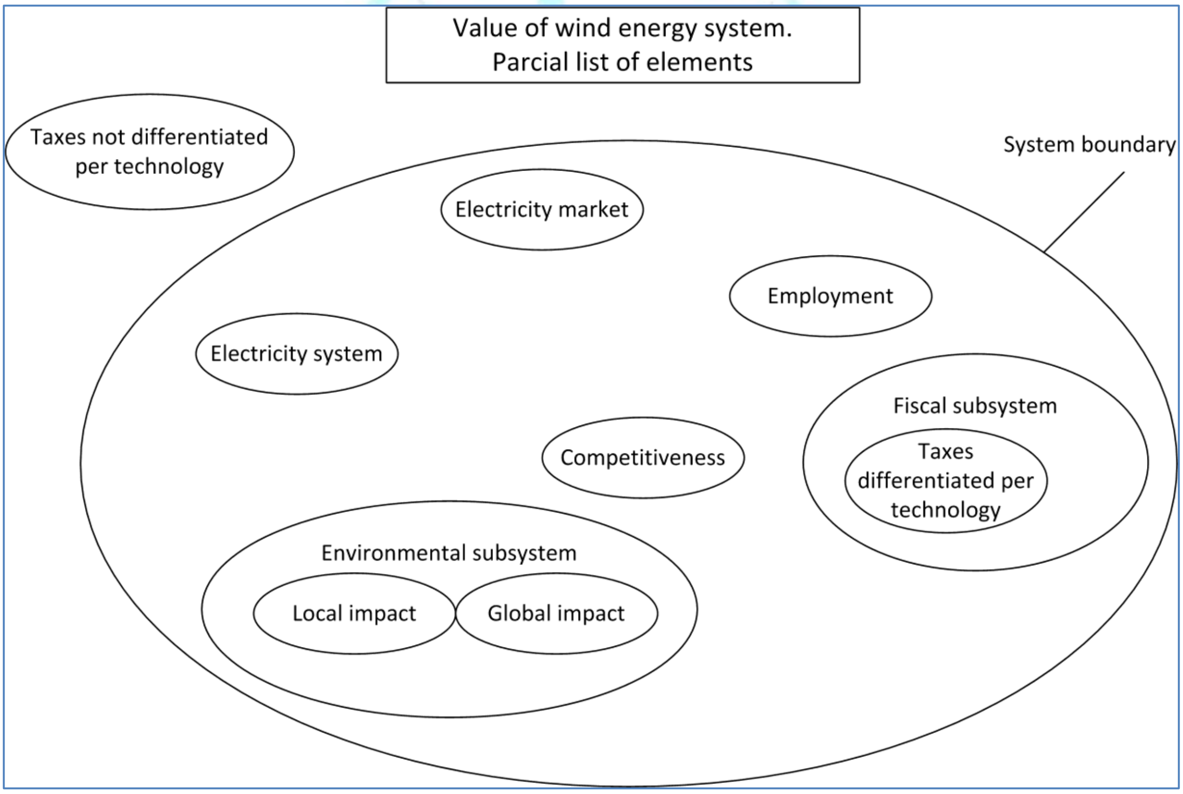


Figure 2: Basic value of wind system and subsystem structure with some examples of elements inside and outside the system

Considering a system approach to assessing the value of wind is quite challenging because of the broad application of topics, the analytic approaches and the data being utilised today, and the type and magnitude of impacts being assessed. The system boundary definition is critical because it affects the analytic approach as well as the results.

Some elements associated with the value of wind energy are quantifiable with the models and data available today. Other elements require improved data or analytic tools for assessment; some aspects may never be fully quantified. Many impacts are largely localised around the vicinity of a wind plant, while the societal benefits are more broadly distributed. By identifying the elements associated with assessing the value of wind energy, an initial framework for understanding the interactions, boundaries, and extent of analysis could be developed.

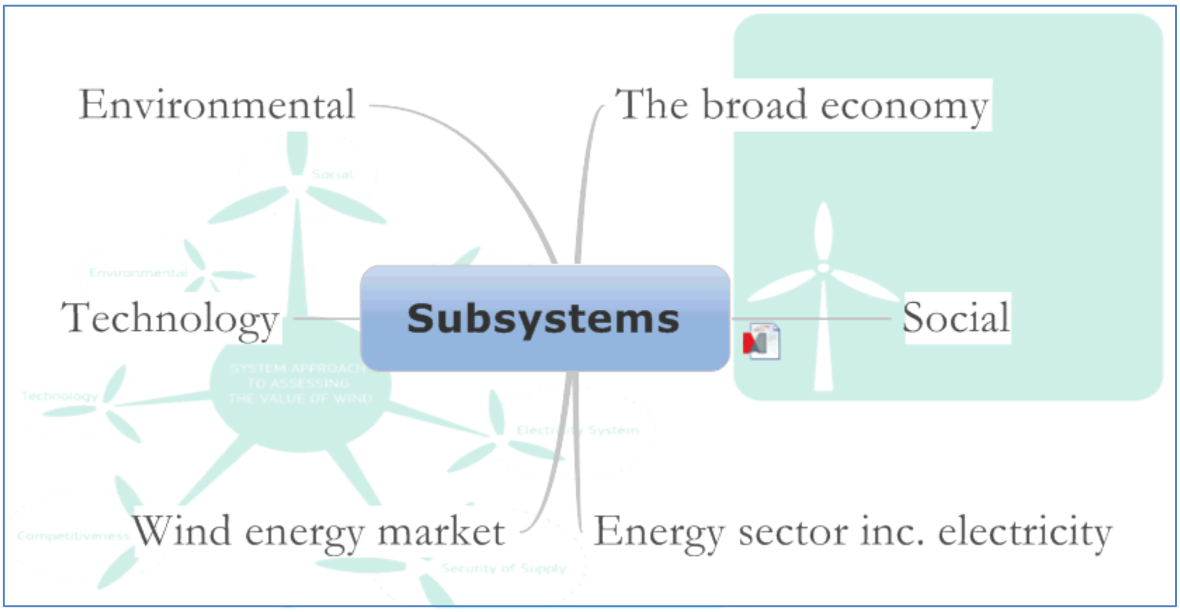


Figure 3: The six subsystems considered

4 The effect of context

The actual impact of wind is determined by the context in which it is deployed. For example, a given element has very different impacts in an electricity system with a 22.5 % penetration of wind electricity generation (Iberian Peninsula in 2013[4]) than in an electricity system with a 3 % wind penetration (China, also in 2013). Context affects competing generation technologies similarly to how it affects wind.

4.1 Elements of the context

Context includes the following partial list of elements:

- level of penetration;
- size of the electricity system and market;
- wind farm geographical distribution;
- portfolio of generation technologies, in particular the flexibility of each generator;
- availability of electricity storage;
- availability and structure of demand-side management (DSM).

The list is considerable; its items are embedded in the subsystems below. Future deployment scenarios would be needed to construct further, forward-looking analysis.

The regulatory framework is one of the key elements of the context for setting up a system for value-of-wind analysis, as it determines the expected cash flow from revenue to cost, the risk and uncertainty of this cash flow, and all the related economic elements impacting the profitability and risks of a wind energy project.

The time line of the analysis is also part of the context. For example, different greenhouse gases (GHG) have different levels of global warming potential, depending on the time line used to assess this potential. In another example, the investment recovery period determines the investment recovery rate and thus the expected internal rate of return (IRR) of projects, with direct impact on the cost of energy. The benefits associated with avoided greenhouse gases will also depend on the anticipated lifetime of the wind asset, changes in demand and generation mix over time, including the retirement of fossil plants.

4.2 Other contextual issues

When planning a study, analysis or assessment on the value of wind, we recommend that the authors discuss their possible biases, interests and emotional status, and reflect them as a disclaimer at the introduction of the assessment; for example, as answers to the following partial list of questions:

- have I received funding from an organisation for/against wind;
- do I receive regular/irregular income from pro-/anti-wind entities;
- do I have an economic interest in wind/fossil fuel/nuclear generation;
- do I believe that the threat posed by climate change to humankind is/is not real;
- do I like/dislike wind turbines;
- do I think wind energy is too expensive?

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[4] Portugal: 11.76 TWh produced from wind for a 49.15 TWh total demand; Spanish peninsular wind production of 53.93 TWh for a total demand of 246.17 TWh. Source: JRC based on system operators reports

5 Technology subsystem

The technology subsystem is mainly composed of research and technology development, including both products and manufacturing processes. It has an impact on a number of other technological fields and on new-materials manufacture and demand.

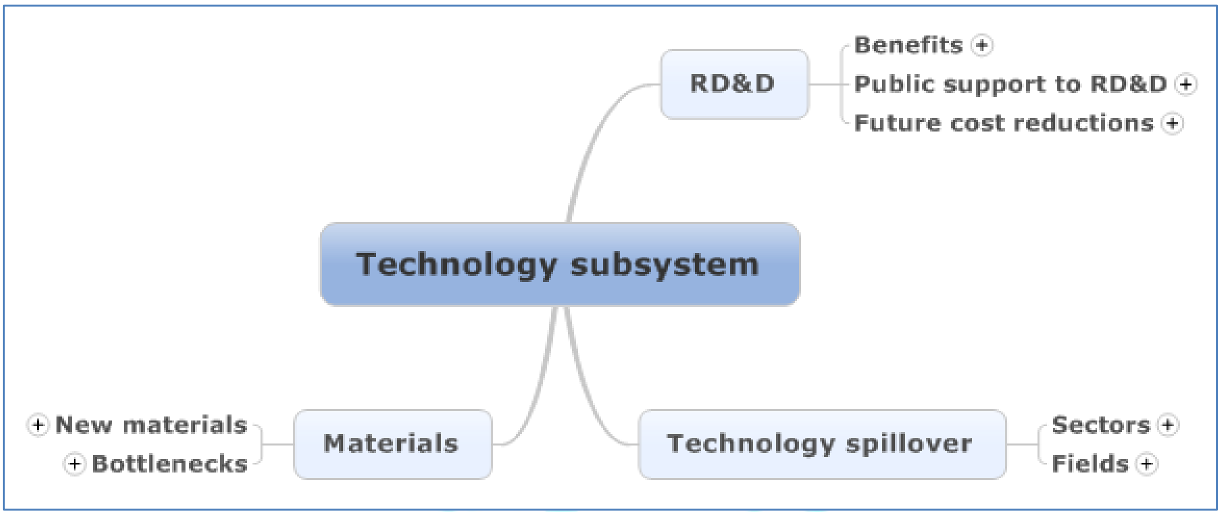

Figure 4: Diagram of the technology subsystem

5.1 Research, development and demonstration

RD&D categories relate to the knowledge gained, the cost of RD&D, and the prospects for future cost reductions resulting from the application of newly gained knowledge.

5.1.1 Benefits of the knowledge gained

The following list includes some of the benefits of RD&D knowledge:

- increased industrial production, jobs, related taxes, etc.
- revenues from licensing the technology
- patents
- increased scientific knowledge that can spill over into other industrial sectors.

5.1.2 Public support for RD&D

Direct public support takes the form of grants. Indirect public support can be tax deductions or the financing of RD&D loans (e.g. by the European Investment Bank).

5.1.3 RD&D leads to future cost reductions

RD&D is the basis of future cost reductions:

- better wind production forecasting will reduce balancing costs;
- development of storage technologies will increase the share of renewables, and may reduce overall costs;
- improved high-voltage, direct current (HVDC) and cabling technologies will reduce the cost of new transmission lines;
- new mining processes will reduce the cost of mining raw materials, e.g. rare earths;

- new processing techniques, e.g. for chemical, will reduce the cost of transforming raw materials;
- new manufacturing technologies and processes for the main turbine components will reduce the cost of components and turbines;
- new turbine and component designs will increase the amount of energy captured.

A comprehensive analysis of possible cost reductions from individual innovations was carried out for the offshore wind sector by BVG Associates. See, for example, Table B.1 in Crown Estate (2012) and Figure 0.2 in KIC InnoEnergy (2014).

5.2 Technology spillover

Patents, licences and intellectual property development cause further development of a knowledge-based society.

Technologies developed to reduce the cost of wind energy or improve the specifications of wind components may be used for similar objectives in other industrial sectors. Examples include:

- power electronics, permanent-magnet electricity generators and the like for the power and traction (e.g. for vessels) industries;
- new lightweight materials for blades in other sectors using composites, including tidal turbines.

Innovations in wind turbine materials, technology, manufacturing and installation processes may spill over to the following fields:

- aerodynamics
- recycling
- remote-control surveillance
- sensors for meteorology (LIDAR etc.)
- meteorological forecasting
- offshore logistics; foundation design and installation
- high-temperature superconductors
- HVDC components and system design
- tidal/current turbines.

5.3 Materials

New materials, with better specifications, developed as a result of wind energy RD&D, will become available for other applications and sectors.

High demand by the wind sector may cause bottlenecks in materials and the supply chain. Materials are not necessarily produced in the countries where wind energy is deployed, which may result in a net transfer of wealth to the exporting countries.

6 Energy sector subsystem

The energy sector subsystem comprises the electricity market and system, both security and economic security of supply and the non-electricity energy market.

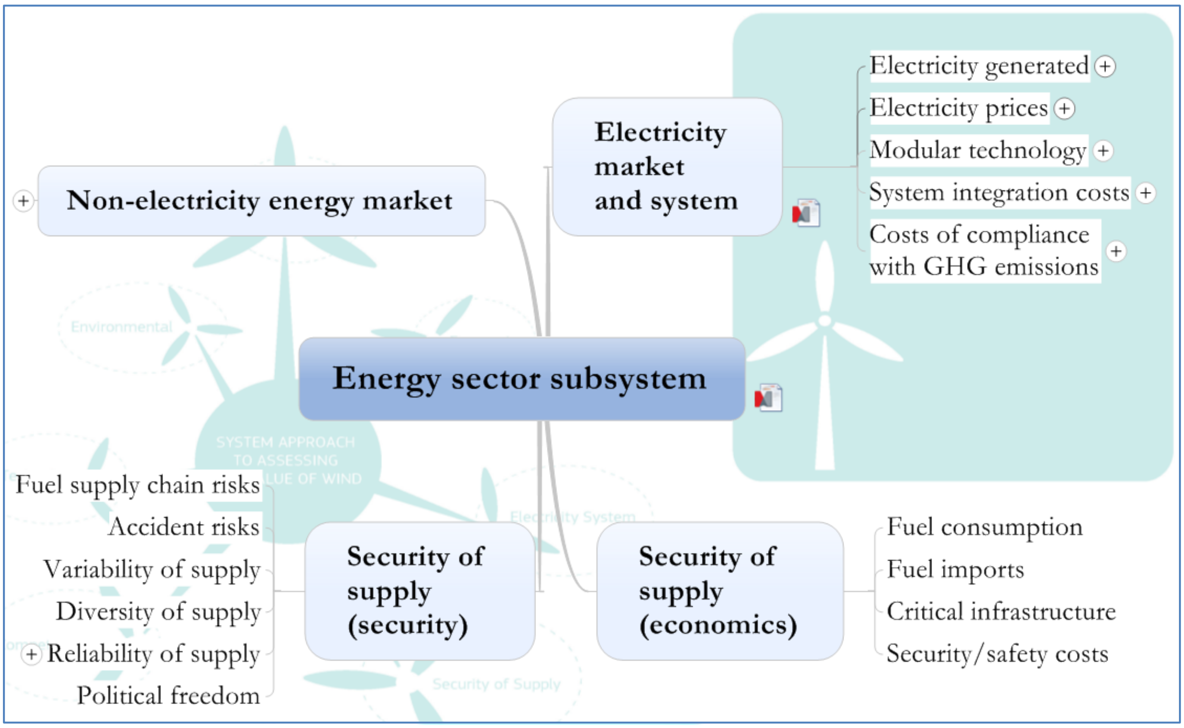

Figure 5: Basic energy sector subsystem including some of the categories considered

6.1 Electricity market and electricity system

The most significant components of the energy sector subsystem, from the point of view of wind energy, are the electricity system and the electricity market. Because of their extremely interwoven nature, these components are treated here as a single subsystem. Figure 5 shows the broad categories that form the energy sector subsystem. Figure 6 shows the wind energy impacts with regard to the electricity market and system.

Because of the interactions that the economic and technological aspects of the energy system have with end users and other sectors, wind energy may also have an impact on the transport and heating sectors (e.g. through the electrification of transport, and heat storage of excess electricity, respectively).

6.1.1 Electricity generated

The product of wind energy is the electricity generated by wind turbines, which displaces electricity from competing technologies in existing power plants. In the long term and with high shares of wind power, wind generation capacity will displace other technologies as the operating times of existing power plants are reduced to a level too low for economic use, aging power plants need to be replaced or new plants are built to cover future demand increases. The most affected generation technologies are fossil-fuel-based (natural gas, coal, lignite, and fuel oil (diesel)) and nuclear, but other renewables are also affected.

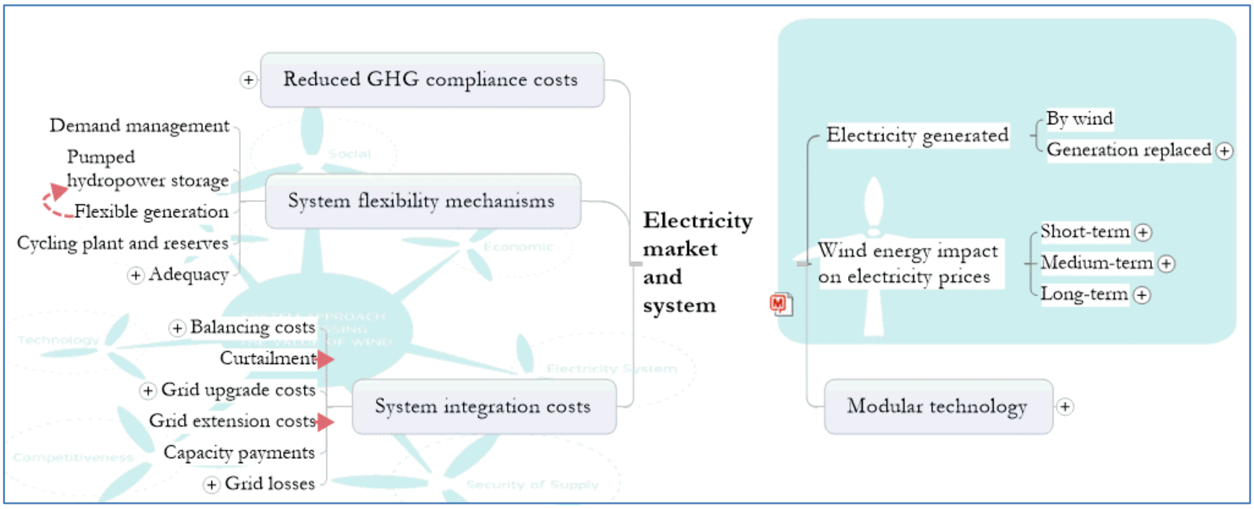

Figure 6: Summary of the electricity market and system part of the energy sector subsystem

6.1.2 Wind energy impact on electricity prices

The impact of wind energy on electricity prices has short-, medium- and long-term effects, such as:

- short-term effects (e.g. up to a year): lower marginal cost;
- medium-term effects (e.g. two to six years): retirement of the most inefficient fossil-fuel plant;
- long-term effects (e.g. beyond six years): changes in the portfolio of generation equipment.

Wind might trigger other changes to the functioning of the electricity system and market, which would impact wholesale and final prices; for example, new capacity payments for firm capacity to backup non-dispatchable renewables.

The design of the wholesale and balancing markets determines or strongly influences the impact of wind. One example is gate closure times in both day-ahead and intra-day markets; by allowing shorter gate closure times, wind forecast errors are reduced, which reduces the impact of uncertainty to the system.

6.1.3 Modularity

Unlike large nuclear or coal power stations, onshore wind offers the possibility of relatively small, “modular” step-by-step capacity addition, which can impact financing needs in a positive manner. The flexibility to add 100 MW or less capacity for wind farms (rather than being limited to additions of 500 MW or more for some fossil and nuclear plants) has value and reduces the risks and costs associated with supply and demand imbalances created by larger, more “lumpy” investments. Individual wind turbines constitute distributed generation that can be closer to the demand in rural areas, and are connected to the distribution network; both of which reduce losses, allowing for even more granular scalability.

In contrast to onshore wind, these scale- and flexibility-related benefits are less likely to apply to new offshore wind farms, which are typically less scalable, as they require large capital investments (of up to EUR 2.8 billion[5]) in part to support the infrastructure needed to bring the power to shore.

6.1.4 System integration costs

System integration costs can be part of the electricity market or the electricity system. They can be borne by the wind farm operator, in which case they constitute CapEx or OpEx and should not be considered here, or by the system operator, in which case they are shared by all electricity users and thus constitute a system cost (although allocation mechanisms are important).

System integration costs may include:

- increased balancing costs due to wind electricity — depending on the legal framework, this may be borne by the wind farm operator;
- curtailment — depending on the legal framework these costs may be borne by the wind farm operator;
- grid upgrade or extension costs that are exclusively due to a new wind plant, or its share thereof;
- increased grid losses when a wind power plant is built far away from the load.

Making capacity payments to dispatchable plants is a mechanism that was being used in some markets before the arrival of wind power. Only a part of it can be considered as an integration cost for wind.

Additional grid investment may be needed for:

- transporting wind electricity from remote sites to demand centres;
- allowing a better flow of renewable electricity between countries; in Europe, this goal would also support the development of the single electricity market;
- increased grid congestion or constraints on transmission lines caused by wind power triggering grid upgrades.

System integration costs can be reduced by:

- improved technology, e.g. developments allowing better wind production forecasting;
- market designs more appropriate for the variable renewables, e.g. shorter gate-closure times;
- higher capacity factors, e.g. from large rotors; in this case the cost reduction is per unit of electricity generated (e.g. MWh), as overall capital costs might still rise;
- system flexibility mechanisms (see inset).

A high presence of variable renewable electricity (VRE) promotes system flexibility mechanisms. These mechanisms include:

- demand-side management (DSM) — Wind makes DSM more attractive if it is adapted to a high-wind scenario in which demand is stimulated when there is a high level of VRE in the system;
- pumped hydropower storage (PHS) — PHS can effectively make wind generation more dispatchable, e.g. by storing wind energy generated at night when demand is low (via pumped hydro) and discharging (generating) during the day at times of higher demand. The business case for PHS can be reinforced or diminished by VRE depending on the legal, contractual and market framework.
- Cycling plant and reserves. Flexible generation such as hydropower and fast-acting gas plant help accommodate VRE.

Allowing wind power to bid into balancing markets creates the possibility of using wind

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[5] The Gemini offshore wind farm in the Netherlands reached financial close in May 2014 at EUR 2.8 billion.

power for supporting the frequency and voltage of the power system during hours of high shares of wind, and of reducing curtailment needs.

6.1.5 Reduced cost of compliance with GHG emissions limits

A higher share of renewable electricity in the electricity mix involves less greenhouse gas emissions, resulting in higher availability of GHG allowances in GHG market schemes, such as the European Emissions Trading Scheme (ETS) and similar schemes in other countries. This leads to the subsequent reduction in the cost of allowances and thus a lower cost of compliance with GHG reduction requirements. This would be a positive result in a scenario of rising prices of GHG allowances. However, if the related policies do not work in unison, the reduced prices could reduce the stimuli for companies to be more efficient in their use of energy and their processes.

6.2 Security of supply — economic aspects

Security of supply has several aspects which can be assessed in economic terms, normally as avoided costs. They include reduced:

- fuel consumption
- imported fuel
- critical infrastructure
- security expenditures (e.g. for protecting critical infrastructure)
- safety expenditures (e.g. for population preparedness in case of nuclear accident).

Calculating the fuel that is not consumed as a result of wind power generation and its impact in economic terms is relatively straightforward but one must be careful not to make assumptions. Section 8.2 discusses this element.

Increased local supply reduces the need for certain infrastructure which can be critical in an energy system. Examples include natural gas regasification terminals,[6] liquefied natural gas (LNG) carriers and pipelines, fuel tankers and other infrastructure.

After the earthquake and tsunami in Fukushima, wind turbines continued generating electricity and thus supporting the grid. Similarly, given the small size of wind turbines and their dispersed nature, the addition of wind energy does not typically increase the need for reserves kept for contingency events or to provide protection against large generators tripping offline (though it may increase the need for some other reserves such as load following and ramping).

6.3 Security of supply — security aspects

The security aspects of security of supply in this subsystem are less clearly translated into costs or cost savings.

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[6] The transport of natural gas by means other than pipelines takes place by liquefying the gas at low temperatures in a liquefaction plant, then shipping it in a LNG carrier, and finally converting it back to gas in a regasification plant.

6.3.1 Fuel supply chain risks

The supply chain for fuels such as coal, natural gas, oil and uranium can be troublesome, e.g. vessels subject to attacks by pirates or gas/oil pipelines subject to threat in a transit country. The degree of risk for various fossil and nuclear fuel sources is country-specific and may also depend on a country's own resources and location, nearest neighbours, access to the sea and so on.

The country of origin of the fuels might also be the source of the risk if it is subject to political and social instability or if it uses its fuel exports to support political objectives.

Natural gas, as an alternative for electricity generation, involves an additional delivery risk in that there may be pipeline constraints at the times of highest demand.

6.3.2 Reduced risk of accidents

Less nuclear energy results in a lower risk of nuclear accidents; less fuel-oil transport by bunkers reduces the risk of bunker accidents, an event which also has very serious environmental consequences.

6.3.3 Reduced variability of energy supply

Because energy from renewables is indigenous, governments and companies do not have to find fuel, nor are they subject to the vagaries of the fuel markets. Volatility of fuel prices is considered an economic issue dealt with in section 8.2.

6.3.4 Reliability of supply

Because wind is a local energy resource, wind electricity supply often does not depend on long transmission lines with their potential for associated supply constraints. However, at least four other elements refer to reliability of supply:

- Adequacy is a positive impact, but it is lower in the case of wind than for conventional generation;
- Wind may impact grid stability but low-voltage ride-through (LVRT), inertia and other of the technical capabilities of turbines or substations can also support the grid;
- Voltage control by wind turbines may also support weak distribution lines when installed at the end of the line;
- Conventional energy sources depend on the input of large amounts of water at the right temperature, e.g. for cooling. If there is a drought or a heat wave these plants may be forced to shut down, as it already happened for nuclear power stations.

6.3.5 Diversity of supply

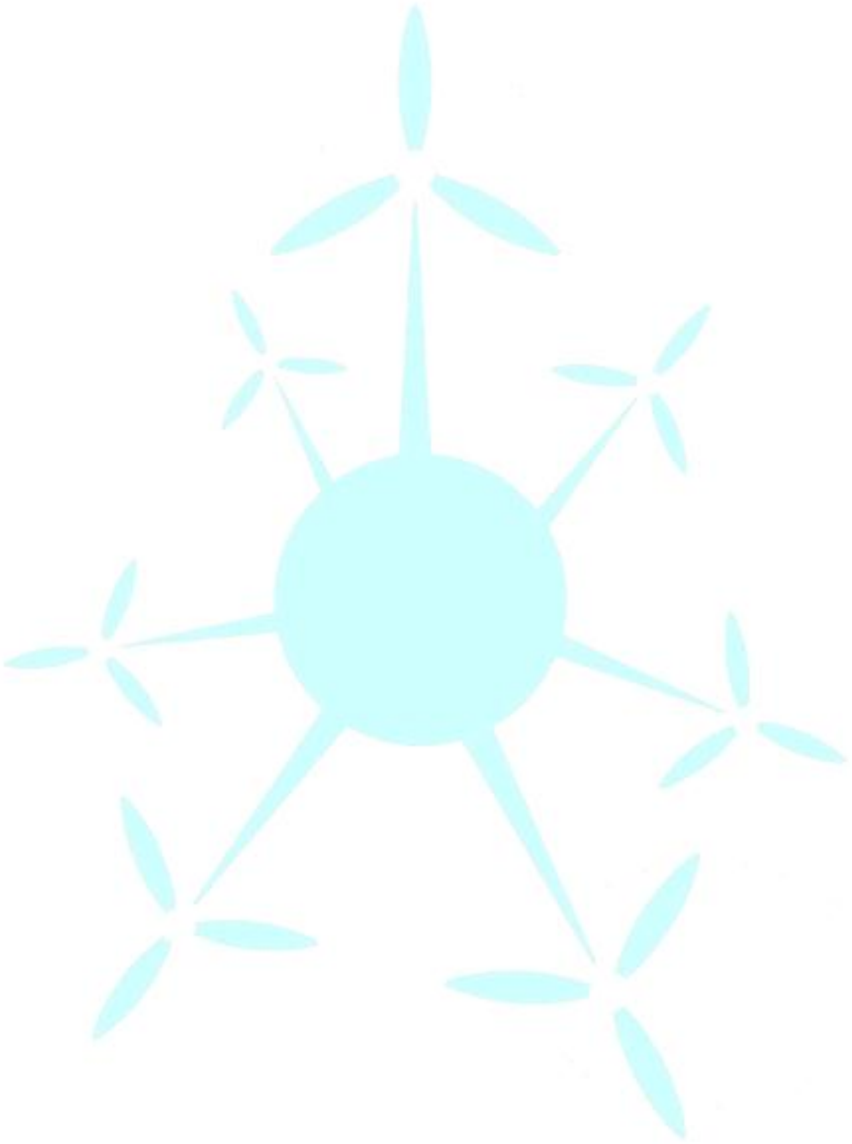
Issues related to the diversity of supply refer, or are specific, to the fuel mix, the world region and even time factors. Renewable energy can add diversity to the supply mix; and reduce the price, reliability and delivery risks associated with over-dependence on too few energy sources.

6.3.6 Political freedom

Locally produced electricity provides independence from trade agreements that may be influenced by political situations.

6.4 Non-electricity energy market

Fuels not used for electricity generation have other fuel and non-fuel uses (e.g. as chemical raw materials). Reduced use of these fuels for electricity generation has physical and economic impacts, e.g. increased availability and potential price reductions.



7 Wind energy market subsystem

The wind energy market subsystem comprises the development of the industrial sector (turbine and component manufacture, balance of plant (BoP), developers and consultants, and development of the necessary materials, but not mining), the cost of energy from wind installations, how wind energy is supported, its contribution to the treasury (taxes, levies, etc.), and the related financial aspects. Some of these aspects could also be dealt with in the economic subsystem. It was suggested that the broader economic implications (e.g. trade) would fit better in the economic subsystem, whereas impacts directly related to the development of wind energy are included in this subsystem.

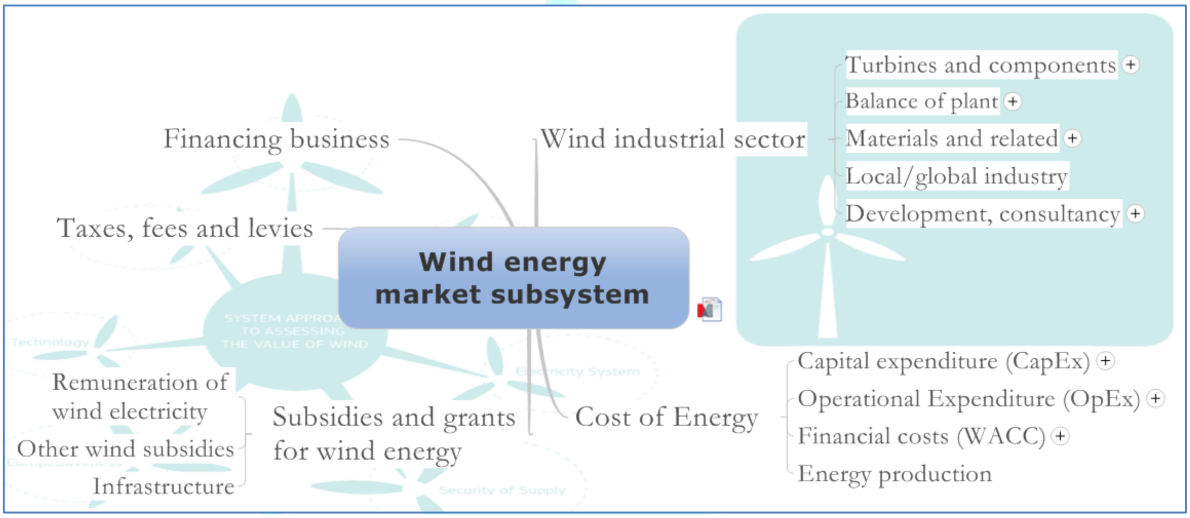


Figure 7: Categories and some subcategories included in the wind energy market subsystem

7.1 The wind industrial sector

An important impact of wind deployment is the creation of industrial activity in the country concerned. The extent of the impact is affected by international trade, in that the national/local activities may be increased (pre-eminence of exports) or decreased (no local/national manufacture of turbines or components).

Secondary impacts include:

- education and training, e.g. of technicians and researchers;
- research and development activity, perhaps with the creation of new research centres;
- intellectual property development, which provides long-term revenue.

Industrial development can lead to specialisation in the different manufacturing and management areas (e.g. wind farm development, component manufacturing and RD&D), and the creation of dedicated industrial clusters, for example, harbours for offshore wind. Large deployment levels bring about economies of scale, a high level of specialisation and increased efficiency.

The following elements form part of the wind energy industrial sector.

7.1.1 Wind turbine

Wind turbines contribute to the wind energy industrial sector through the:

- design and assembly of nacelles and other assemblies (towers, hubs, electrical systems and drive trains);
- design and manufacture of subassemblies and components: blades, electricity generators, power converters, gearboxes, yaw systems, pitch systems, transformers, etc.;
- transport and installation of nacelles, assemblies and components.

7.1.2 Balance of plant

Balance of plant contribution includes:

- design and construction of wind farm substations (onshore/offshore) and collection systems;
- design, manufacture and installation of wind farm measurement equipment;
- design, manufacture and construction (onshore)/installation (offshore) of foundations;
- construction and improvement of access and internal roads to/at the wind farm.

7.1.3 Materials and miscellaneous

Other contributions to the industrial sector are:

- mining and transformation of raw materials: copper, iron/steel, aluminium, glass fibre, resins, rare earth elements, cement, etc.;
- the electricity and electronics components subsectors;
- wind project development and related consultancy services.

7.1.4 Local versus global industry development

The development of local industry sets the competitive advantage for building wind farms.

The value of wind, in terms of competitiveness, can be experienced in the development of various industries:

- the manufacturing industry in countries with technology know-how;
- a supply chain industry in countries with industrial capabilities;
- the wind sector in countries with no supply chain or manufacturing industry, but with wind resources;
- creation of economies of scale.

Technology transfer potential exists for export/import of technology, based on the potential/development level of local industry and RD&D. This leads to changes in trade flows, energy fuel mix and power sales.

7.2 The cost of wind energy

The cost of wind energy is composed of investment costs, operational costs, taxes, financing costs (i.e. debt), developer profits (e.g. as represented by the internal rate of return indicator) and occasionally grid connection costs beyond the wind farm substation. The corresponding flow of revenue embraces many parts of our economic system.

7.2.1 Investment costs or capital expenditure (CapEx)

The deployment of a large wind farm project requires the involvement of many highly specialised professions, bringing about a varied group of costs, such as procurement mechanisms, contract structures, environmental assessment, etc. Therefore, capital costs spill into many industrial and non-industrial subsectors as shown in Figure 8 for onshore projects.

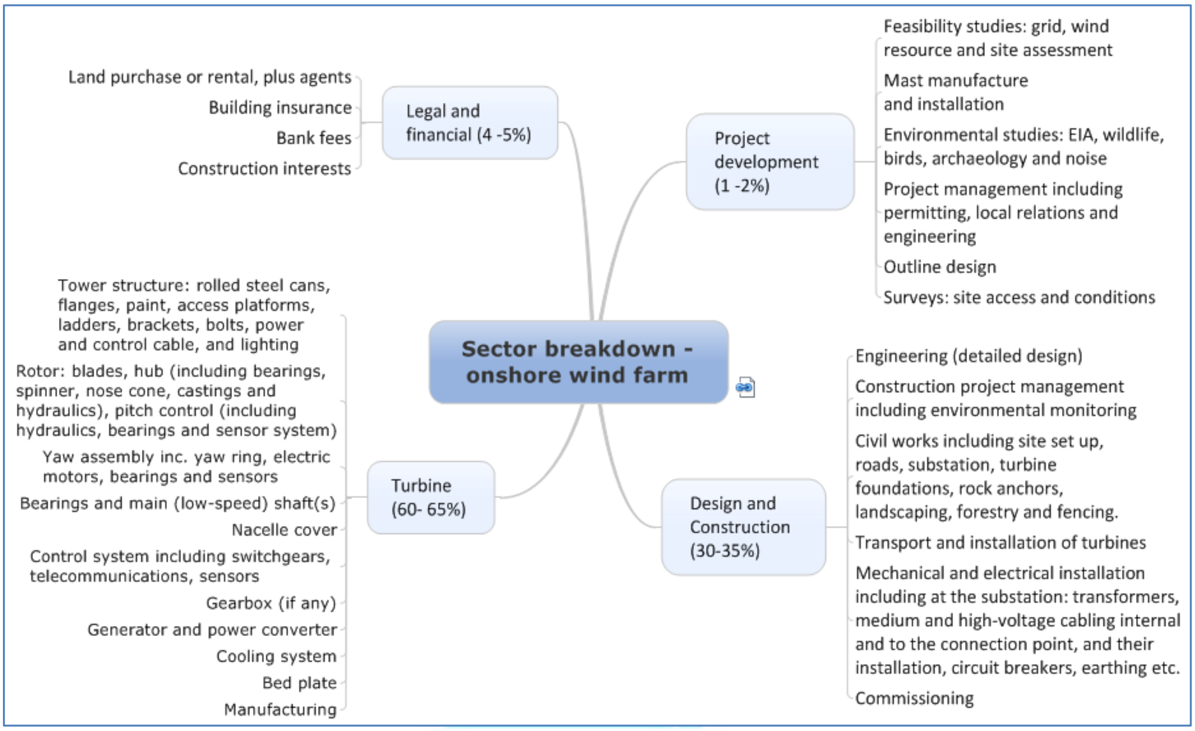


Figure 8: Onshore wind farm capital costs (CapEx) spill into many industrial and non-industrial sectors (Source: JRC based on (O'Herlihy & Co. Ltd, 2006) and others)

7.2.2 Operational expenditure (OpEx)

The basic breakdown of OpEx is between operations and maintenance (O&M) costs and other operational costs. O&M costs include turbine scheduled O&M, unscheduled turbine repairs, BoP maintenance, performance monitoring, condition monitoring and predictive maintenance systems.

Other operational costs are utilities (mostly electricity), project administrative/management fees, wind integration charges (e.g. balancing), land or seabed lease/royalties, compensation to third parties (e.g. fishermen and farmers), insurance, property tax, business rates, local or regional taxes, outside service and other general and administrative costs (GL-Garrad Hassan, 2012).

Operational grid integration costs are detailed in section 6.1.4

O&M is carried out mostly by highly specialised personnel, which entails above-average salaries (i.e. high employment costs), the need for training and the resulting costs. Other O&M costs are for materials, replaced components and devices used for maintenance-related work (e.g. cranes for exchanging large components) and transport of staff and components.

7.2.3 Cost of finance

Financing a wind farm involves different ratios of equity and debt. The indicator used to measure financing cost is often the weighted-average cost of capital (WACC), the share of equity return and debt interest rate multiplied by their respective weights.

Financing is needed during construction and operation, and sometimes it is derived from different financing instruments.

Elements that influence the expected equity return and the interest rate offered by debt providers (banks, insurance companies or other financial institutions, or non-financial players such as pension funds) include:

- risk perception about the technology and the regulatory framework;
- political support;
- the contract structure (e.g. power-purchase agreement (PPA), feed-in tariff (FiT), cost plus or wholesale market price (merchant));
- expected level of income and associated risks, including the attractiveness and variability of the wind resource.

Contract structures in particular can be important — the decision to build a large offshore wind farm, often dependent on offtake agreements, can significantly reduce the financial risk to the owner — which in turn can impact WACC and the cost of energy.

7.3 Supporting wind energy: subsidies and grants

All sources of energy receive or have received subsidies in diverse forms, e.g. tax relief (for exploration, exploitation, generation, RD&D, etc.), RD&D grants and loans, investment grants and loans, job creation grants, etc.

7.3.1 Remuneration of wind electricity

For wind, support may come in the following forms:

- subsidy-based: feed-in tariffs, feed-in premium, etc.;
- built-market-based: renewables obligations, certificates, etc.;
- competitive tender-based tariffs.

See reference RES Legal project

7.3.2 Other energy-related subsidies

Assessing the subsidies received by wind energy involves a comparison with those received by other energy and non-energy technologies including:

- fossil fuels — coal subsidies in Europe, subsidies for oil exploration;
- nuclear energy — decommissioning costs, waste-treatment costs, the implicit potential cost of government providing “backstop” insurance in case of a severe accident;
- other renewables — support for new or close-to-market technologies;
- demand-management — pilot deployment of smart grids.

7.3.3 Infrastructure

The building and operation of infrastructure, including the electricity grid, the natural gas network and district heating networks, may be affected by wind and/or other competing generation technologies.

7.4 Taxes, fees and levies

This section describes taxes, fees and levies on electricity production, as well as other taxes.

Taxes on electricity production can be broadly distinguished in two categories: those that impact electricity equally and independently from the source of energy, and those that tax different electricity sources differently. The former group should not be considered in analyses comparing the value of different electricity sources; an example of these taxes is (end-use) value-added tax.

The latter group is made of regional and local taxes, property tax, business rates, etc., and generally entails the transfer of a part of the wind farm revenue to the local council. Community funds and similar welfare-transfer measures exhibit a similar behaviour to these taxes, so they are included in this section.

Figure 9 shows a summary of the impact of wind on what the state "gives" (i.e. support) and what it "obtains" (i.e. taxes, levies, etc.) from wind. All other energy sources receive support and are taxed as well.

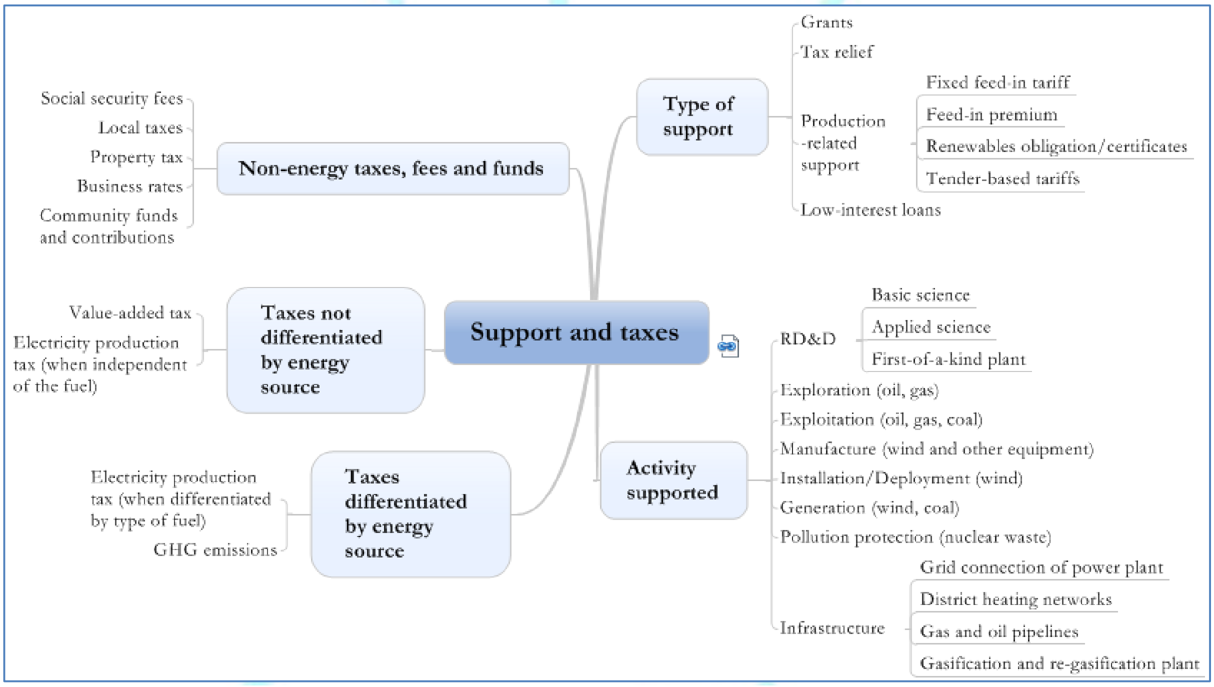


Figure 9: Support to wind and other energy sources and taxes, levies, etc.

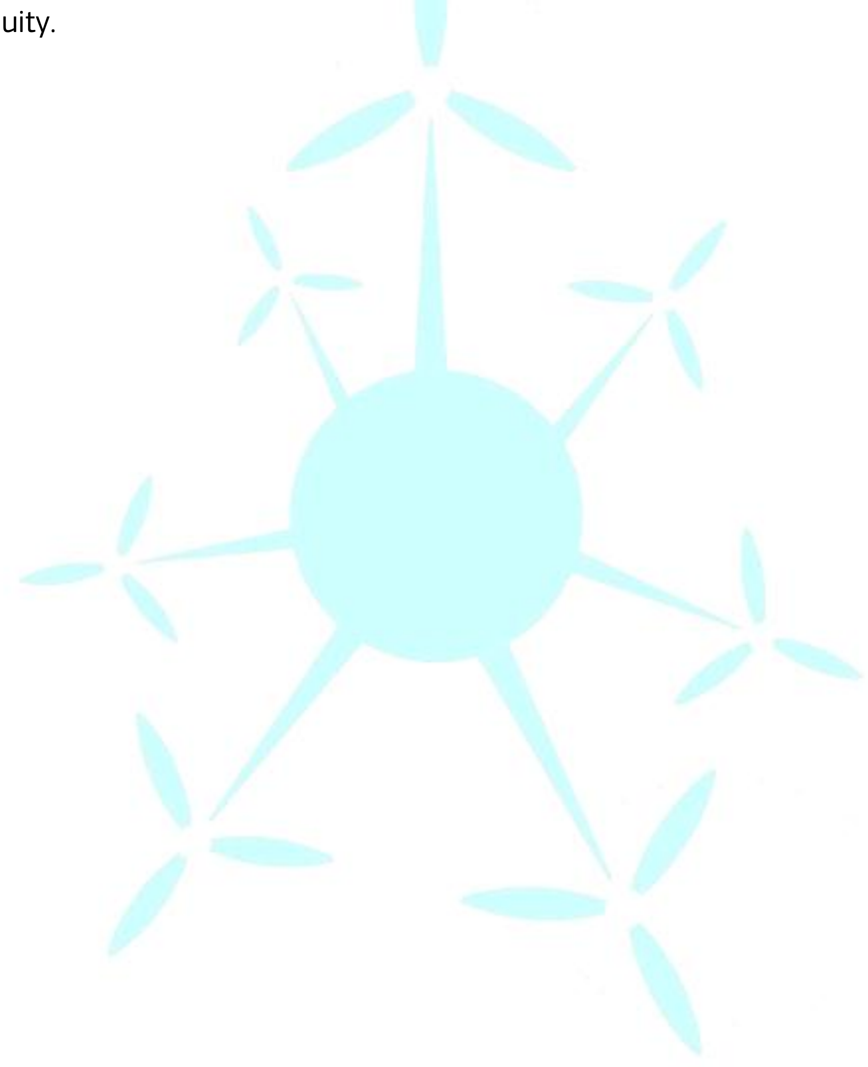
Taxes that have a different impact depending on the electricity generation technology and fuel used sometimes do so because of the different weights of taxable capital in each generation technology:

- overall income tax from employees is higher for labour-intensive technologies such as biomass;
- corporate tax from companies is higher for high-margin technologies;
- social (security) taxes and charges are, again, higher for labour-intensive technologies;
- regional and local taxes are higher for distributed technologies such as wind;
- fees (e.g. for road construction).

Last but not least, tax avoidance is likely to be higher in the largest corporations, which, in the energy sector, tends to coincide with conventional technologies (e.g. oil and gas conglomerates) because they have higher (e.g. intellectual) resources to seek transferring taxes to fiscal paradises and other means of tax avoidance.

7.5 Financial sector for wind deployment

The financial sector is influenced by wind energy deployment in that wind creates a business opportunity (and the linked jobs) and has become a client sector. Financial sector players include banks, export-credit agencies, institutions (e.g. pension funds and sovereign funds), private companies, individual investors, etc. Financial players can contribute debt and/or equity.



8 Economic subsystem

Nearly every single impact of wind energy has an economic aspect. However, the need to analyse the different impacts imposes a differentiation and, in this context, the economic subsystem contains broader economic aspects including fuel costs, electricity generation technology investments, government actions, and industrial competitiveness.

The economic impacts on the land and sea are discussed in section 9.2.

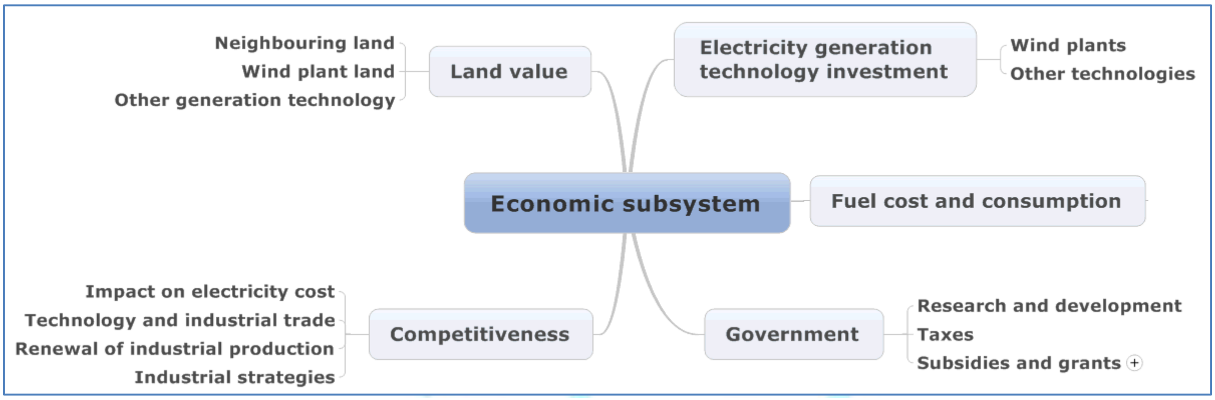


Figure 10: Snapshot of the economic subsystem

8.1 Electricity generation technology investment

Private sector investment in electricity generation technology is necessary to meet electricity sector demand. There are many options from which to choose, and each electricity generation technology has a cost, as well as additional impacts. Wind plant cost elements are discussed in section 7.2.

It is necessary to understand and, if appropriate, to take into account, similar aspects (including capital investment, operating costs, energy production, and financing costs) for all generation technology options both in the present and the future. Monetary costs associated with changing land or water surface value should be represented in the capital investment or operating costs for generation technologies.

8.2 Fuel costs and consumption

Traditional fossil-fuel and nuclear-powered electricity generators consume fuel to produce electricity, which requires infrastructure to produce, transport and store the fuel. Reserves of these fuels vary in extent, but are finite. Wind power does not require any fuel during plant operation. To the extent that wind plant generation offsets fuel requirements for traditional electricity generation sources; reserves and infrastructure requirements (along with the associated environmental impact of producing, transporting and storing fuels) are affected, thus reducing the cost of fuels for the industrial sectors.

When these fuels are not produced locally, a significant second impact is the reduction of fuel imports which, in many cases, weigh heavily in a country's balance of payments.

Although the cost of (fuel) price volatility is difficult to assess in economic terms, it does exist and is reduced following the introduction of wind energy. In effect, wind resources are free; and if they contribute a large share of the electricity mix a smaller part of that mix is subject to the volatility of the fuel markets. Because this volatility may have a high impact in wholesale markets when fuel technologies set the marginal price, wind energy provides a natural hedge against the subsequent risk of electricity price volatility.

8.3 Government actions

Governments take various actions to achieve public outcomes related to electricity generation. Actions include tax structures, subsidies and grants, as well as support for RD&D. The aspects of tax structure are discussed in section 7.4. Subsidies and grants are discussed in section 7.3. RD&D is discussed in section 5.1.

8.4 Industrial competitiveness

The categories of industrial competitiveness considered here include the impact of wind on electricity costs, as a trigger for renewal of old manufacturing plants.

8.4.1 Wind impact on industrial electricity cost

This category is based on, and a consequence of, the impact of wind on electricity prices (see section 6.1.2).

The study of the impact of wind on the competitiveness of the economy tends to focus on how the addition of wind energy to the grid can impact the cost of electricity for the final industrial user.

The subsidies paid to wind power may increase the final cost of electricity if charged to the rate-payer. This cost can initially be defined as the revenue (based on feed-in tariffs or alternatives) paid to wind producers minus the actual wholesale cost of that electricity. It is normally assessed per hour of production. However, it is more accurate to calculate this cost (or benefit) as the difference between the revenue paid to wind energy generation and the revenue which otherwise would have been paid for the same electricity in the absence of wind electricity in the market, i.e. at a higher marginal price.

As discussed in section 6.1.2, in the short term, the reduction of the marginal price brought about by the introduction of wind into a wholesale market is ***applicable to all electricity***. Thus it significantly reduces the average cost of electricity. However, the long-term impact of large amounts of wind in electricity markets is likely to involve a significant change to the market and system structure, which was originally created for dispatchable sources of electricity generation.

8.4.2 Trade: the impact of global technology leadership on exports and imports

Section 7.1 discussed the impact of (potential) exports including: manufactured goods (turbines, components), licences and other revenue-raising forms (e.g. engineering and consultancy services).

Potential exports/imports of technology, based on the potential/development level of local industry and on RD&D investment, could trigger changes in trade flows, the energy fuel mix and power sales.

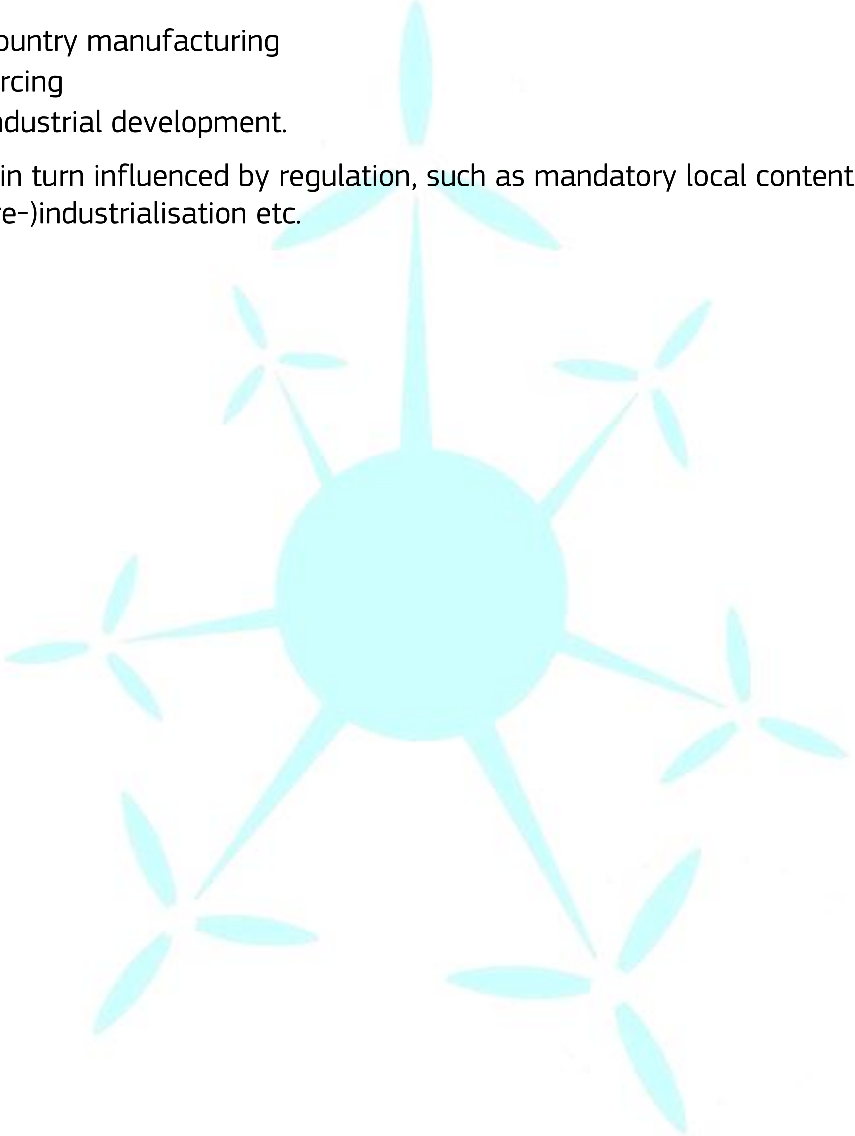
An important gap in assessing this impact is the lack of wind-related data/statistics provided by companies or associations. It is not normally possible to know the intra-company trade flow, e.g. for wind turbine components. When the wind manufacturer belongs to a larger conglomerate, even public figures on RD&D might not disaggregate the wind portion. When the company is not quoted in stock markets, the reporting obligations are minimal, and even global RD&D figures are impossible to find.

8.4.3 Industrial strategies

The industrial strategies of original equipment manufacturers (OEM) and their main component suppliers can have an impact on trade:

- local/country manufacturing
- outsourcing
- local industrial development.

These are in turn influenced by regulation, such as mandatory local content, by subsidies to promote (re-)industrialisation etc.



9 Social subsystem

In order to consider the social component of the value of wind, it is necessary to understand who is impacted and how.

Many of the elements of the social subsystem refer to changes in welfare, and may cause distributional effects on: employment, land use, planning and overall social cohesion. Distributional effects play a role at different levels and scales, from individual to global. The chosen scale determines the way social impacts are understood and how they affect the evaluation of the value of wind. Figure 11 summarises the social categories of impacts.

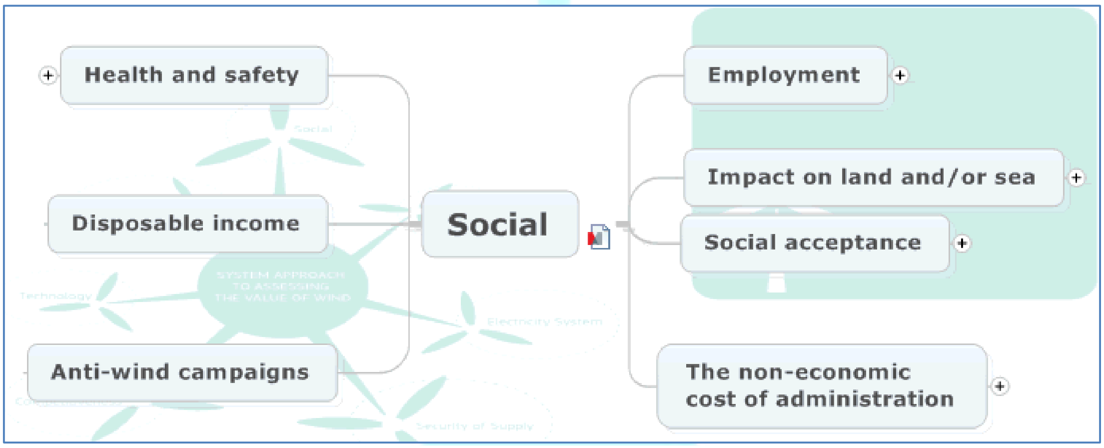


Figure 11: Summary of social categories

An important part of the social subsystem is made of perceived, rather than measurable, effects on people and the environment. These, at times, correspond to human emotional response and include, for example, certain health issues. In some cases, science has demonstrated that either the perception does not correspond to the reality or it is generated by a different cause.

9.1 Employment

Employment effects include the quantity, quality and spatial distribution of jobs created by wind energy deployment, whether direct, indirect or induced:

- direct job creation corresponds to domestic jobs in manufacturing and services, both for capital expenditure and for operations;
- indirect job creation is made of domestic jobs in the supply chain;
- induced job creation corresponds to domestic jobs in the rest of the economy due to the additional welfare generated in the entire supply chain.

Any analysis should compare these with similar effects from the competing electricity generation technologies, e.g. natural gas, including the displacement of existing jobs or lack of future jobs in those subsectors. This is called net job creation.

Overall, the wind sector creates jobs in the following sectors:

- research and academic institutions for RD&D and education/training;
- manufacture of wind turbines and their components, including the corresponding part of mineral extraction and processing of the corresponding materials — these jobs are rarely local but can be national, depending on the historical development of the wind sector and on national energy and economic policies, e.g. local content requirements;
- development, legal and consultant companies — these jobs are rarely local but tend to be regional or national;
- administration at local and national government agencies;
- operations and maintenance — these jobs are most often local or entail technicians moving into the wind farm area to reside locally, which impacts the local economy.

Fuel costs form a large part of the overall cost of competing electricity generation technologies and often, particularly in Europe, fuel is imported. Therefore, extraction and processing jobs for fuel are often exported to the fuel-rich countries.

Job quality tends to be high in the wind sector given its high technological component, involving researchers, engineers, environmental and other consultants, etc. Job quality in materials mining for wind energy can be assimilated to the competing technology or to similar activities for other industrial sectors.

Salary levels should be compared to those in the competing technologies as well.

9.2 Impact on land or the sea

Wind impacts land in three main aspects: change of its use, economic value (increase or reduction) and creation and/or improvement of infrastructure.

9.2.1 Changes in the use of land and sea

The main impact on land use relates to the infrastructure created to access the construction site and maintain the wind farm, and the land occupied by the wind turbines and ancillary services (e.g. cables in trenches and substation) themselves. These new uses account for one to two per cent of the wind farm area, while the rest remains available for the former or any other use.

There may be an impact of offshore wind farms on shipping lanes, fishing areas and other users of the sea.

The installation of wind farms can open the door to, or support, uses leading to new business or increasing/reducing their significance. Examples include the creation or increase in availability of certain commercial fisheries (e.g. some varieties of shellfish) linked to the foundations of the offshore wind farms, as they act as artificial reefs.

Wind farms, and in particular large wind farms, can stimulate tourism therefore helping to provide diversified revenue to rural areas, which not only has positive economic impact but also plays the important social role of helping the local population to stay in place. Examples include: vessels that take tourists to visit offshore wind farms and new hiking and mountain-bike trails within the wind farm, e.g. Wild Horse Wind Farm, Washington, US, which also allows hunting, and Whitelee in Scotland, UK, with 130 km of hiking and mountain-bike trails.

Therefore a new wind farm may bring about new amenity possibilities including, but not limited to:

- cycling and hiking trails or lanes
- services (libraries or educational centres).

9.2.2 Impact on land economic value

There may be different kinds of impacts on the economic value of land:

- the land where the wind turbines are installed receives a new revenue stream from the wind farm income, either in the form of a rent or shares;
- the value of neighbouring land may increase because of new business opportunities, e.g. in tourism, or it might decrease if the owners or prospective buyers consider the new environment less agreeable;
- land owners and/or the local community can be compensated in different ways by the wind farm owner as a result of agreements during the permitting process.

Evidence from the US suggests that wind farms do not have a negative impact on (neighbouring) land value, see e.g. Hoen et al. (2013).

In some regulatory schemes, e.g. in Denmark, neighbours are legally entitled to invest in wind farms and obtain an additional income option.

The other energy technologies also have an impact on the land and sea, which can be taken into account, e.g. mining coal, nuclear and fossil fuel electricity plants, etc.

A note on missing data: data must include both distributional (local and individual) and absolute impacts. The same effect could be positive or negative, depending on the scale of deployment.

9.2.3 Improving current infrastructure

In addition to the new roads needed for access to the wind farm, which now allow better access in general, e.g. to more remote farming areas, the following infrastructure may be affected by new wind farms:

- medical infrastructure (new and upgraded)
- social housing and housing development (opportunity for building more housing)
- bus/tram routes, roads
- water distribution and treatment.

9.3 Social acceptance

One of the major points of social acceptance is a sense of belonging; people belonging to the community and the community belonging to the land and heritage. This subsection also considers the geopolitical impact of wind. The following elements could be taken into account.

9.3.1 Community sustainability

The wind industry contributes to community sustainability in the following areas:

- acceptance of the new character of the community where the new activity (wind energy generation) impacts it. This is linked to 9.3.3.
- social cohesion

- demographics[7]
- diversification.

9.3.2 Impact on local communities

Impacts of wind plants on local communities include:

- migration patterns (workers and residents)
- changes in local speech/dialects[8]
- local employment rate and quality.

9.3.3 Public acceptance of wind energy in general

The public learns to accept wind energy in relation to:

- number of new businesses opening and old businesses closing
- local opinion may change
- the feeling of having a new low-carbon life
- empowerment of community in decision-making
- adaptation to this impact
- belief or non-belief in climate change science — emotional response, see section 9.5.

9.3.4 Heritage and belonging

The wind industry can contribute to a community's heritage and sense of belonging:

- legacy (what is left for future generations)
- pride
- education
- diversification
- morals — adaptation to decentralised and low-carbon life style.

9.4 The non-economic cost of administration

Administrative staff (e.g. at local councils) needs to be trained about wind farms and their environmental impact in order to review planning applications.

There is a social cost to changing legislation, which results in the need for all stakeholders to adapt. Experience has shown that these changes, if not done properly, can increase the administrative workload for both public and private entities, thus diverting resources from productive activities, resulting in an overall reduction of national productivity.

Procedures for consent that are cumbersome and difficult to implement increase the cost of energy.

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[7] With the provision of local jobs and business opportunities, residents are more likely to stay in the remote areas of the country thus preventing depopulation.

[8] Perhaps from exposure to non-local workers involved in the installation and maintenance of the wind farm, in particular for large projects, or to visitors in case of increasing tourism.

9.5 Anti-wind campaigns

Some people reject either wind (or renewable) energy or the presence of wind farms in either the vicinity of their dwellings or in the countryside that they occasionally visit. There are different motivations behind this rejection, see for example Barnard (2014). Investigating these motivations can shed light on additional areas where wind energy deployment creates social impacts.

9.6 Disposable income

The local community is subject to variations in disposable income, which may affect their response to a new wind farm:

- increased salaries versus an increased cost of living in the area;
- low earners and their impact in the community;
- fuel poverty.

9.7 Health and safety issues

An issue common to all human activity is the potential for accidents during construction and operation, which affects wind facilities as well as conventional technologies and, in both cases, the support systems (e.g. substation and transmission infrastructure).

During operation, one real, but limited, risk is ice thrown from iced blades. There are also claims that wind turbines cause specific health problems:

- physical and mental illnesses related to wind and changes
- shadow flicker
- ultrasound and infrasound.

Some of these claims have been traced to a "nocebo effect" caused by anti-wind campaigns (Chapman, 2013), i.e. it is the campaigns themselves that cause people to believe that wind turbines produce a harmful effect.

In some cases, health effects were caused by old wind technology, particularly noise impact during turbine operation, which no longer occurs when good practices are followed. Noise can also be considered an economic impact in that there are ways to insulate housing against noise, reduce operational noise, or even replace a turbine component with a less noisy one.

Quantification

Quantifying social (and environmental) impacts can be very difficult. In general, one can estimate the costs of mitigation measures or the costs of the resulting impacts. For example, with respect to wind plant noise and vibration, one can value the impact of noise by estimating the cost of producing low-noise turbines. Or one could estimate the value of the noise impact by estimating costs associated with remuneration for people directly affected by noise. The latter is difficult to quantify. The former is easier to quantify, but is, at best, only a proxy for the value of the impact.

10 Environmental subsystem

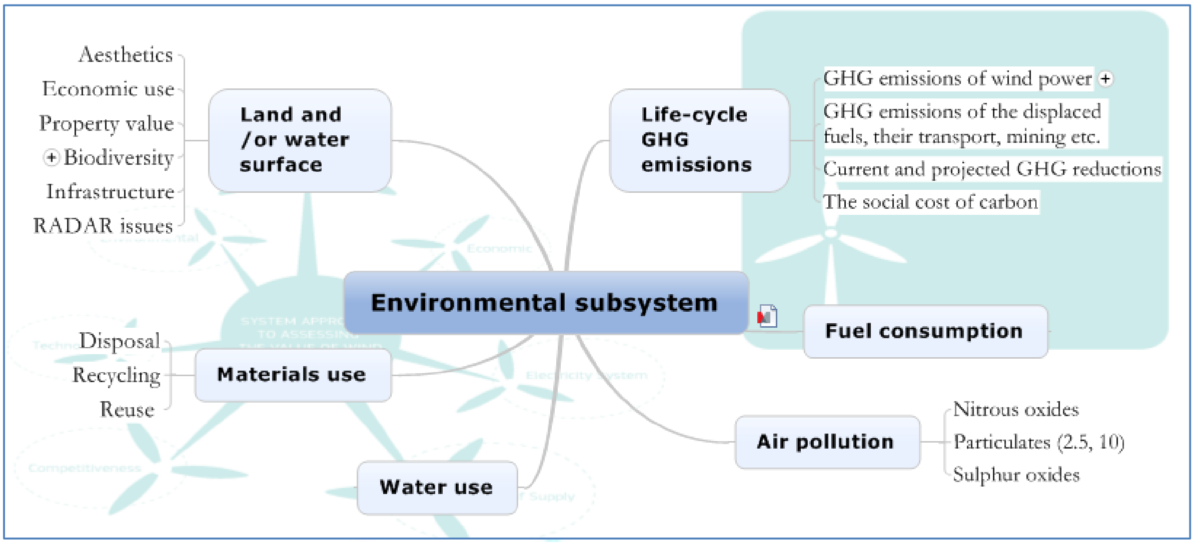


Figure 12: A snapshot of environmental aspects related to wind energy

The environmental subsystem includes all impacts on the environment related to wind energy and the competing sources of energy. Impacts on human health are treated in section 9.7 of the social subsystem.

Some environmental impacts are global, e.g. reduction of greenhouse gas emissions resulting in climate change mitigation, or regional, e.g. reduction of sulphur and nitrous oxides, and particulate ($PM_{2.5}$, PM_{10}) emissions from coal-fired power plants. Other environmental impacts are quite local to the vicinity of wind plants, e.g. habitat disruption for certain species residing where a wind plant is constructed.

Impacts of wind plants can be offset by the corresponding impacts of competing electricity generation that is avoided by using wind generated electricity. However, it is recommended that the discussion also include the impacts of any possible backup/reserve generation.

10.1 Life-cycle greenhouse gas emissions

Greenhouse gas emissions contribute to global climate change. Although greenhouse gases are emitted during the manufacture and installation of wind plants, the emissions during operation are very low. Traditional fossil-fuel based generation emits much more greenhouse gas over the life-cycle of the plant than wind plants (IPCC, 2011; NEEDS, 2009). Since fossil-fuel generators are typically the first plants to reduce generation when wind electricity is introduced, the addition of wind electricity reduces overall GHG emissions from electricity generation.

10.1.1 Reduction in greenhouse gas emissions from electricity generation

Because wind electricity generates much less GHG emissions than fossil-fuel generation, and because fossil-fuel generation technologies are displaced by wind electricity, the addition of wind electricity reduces overall GHG emissions from electricity generation.

10.1.2 GHG emissions from wind power

The New Energy Externalities Development for Sustainability (NEEDS) study suggested that offshore wind emits 7.64 g CO_2/kWh and roughly 8 g CO_2-eq/kWh based on life-cycle assessments compared to 398 g CO_2/kWh from a modern gas combined cycle power plant (NEEDS, 2009).

Most of the emissions from wind projects originate in the construction phase and none occur during operations. A figure of 10 g CO_2-eq/kWh in total for onshore wind seems reasonable.

10.1.3 The environmental cost of GHG emissions

GHG emissions and the resulting climate change have well-documented risks. An analysis of the value of wind should take into account the possible cost of these risks, as well as the cost of alternative means of climate change mitigation, e.g. by using other energy technologies, tree plantations etc.

10.2 Air pollution

Other emissions in the air from wind energy and competing generation technologies follow a similar pattern as GHG except when the other technology is nuclear energy (in this case the pollution avoided is nuclear waste). These pollutants include at least particulates ($PM_{2.5}$, PM_{10}), nitrous oxides and sulphur oxides from burning fossil fuels. An example of environmental effects by these pollutants is ecosystem disruption due to acid rain. These emissions should not only take into account the combustion of the displaced fuels, but also their transport, mining, etc.

10.3 Water use

Water withdrawal and consumption can affect river basin systems, resulting in competition among municipal, agricultural, industrial and environmental uses. Water temperature alterations due to thermal generation plants can affect species and local ecosystems.

Wind plants do not require water supplies during operation (other than small amounts of water for cleaning blades periodically), thereby minimizing these environmental impacts and releasing water for other uses.

10.4 Land and water surface

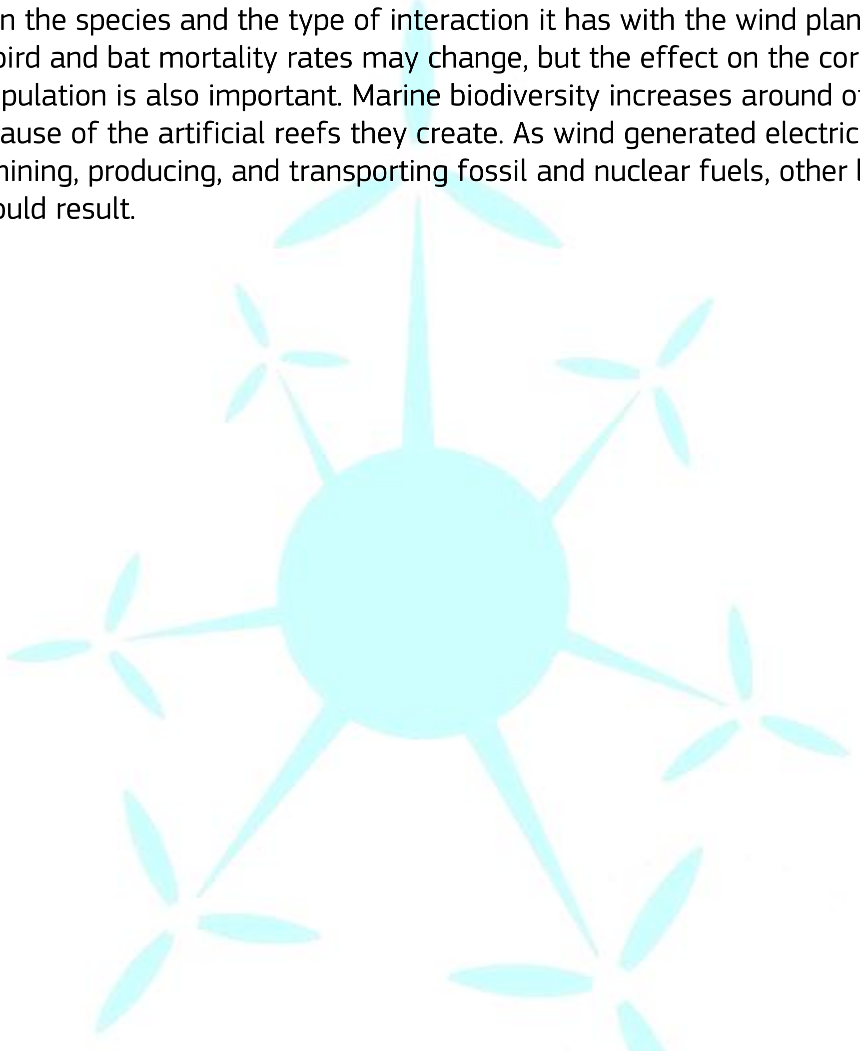
Wind plants impact the land where they are installed, and both the sea bed and the water surface are impacted around offshore wind plants. While pre-existing uses of land and water can often continue, some adjustment to the use is typically required. Land or water surface impacts for competing electricity generation technologies must be compared in order to assess the net impact of wind plants.

Aesthetic impacts include visual and aural impacts to humans and animals in the vicinity. Disruption of viewsheds may be perceived differently by residents and visitors. Noise from operating wind plants or construction activities can be disruptive to humans and animals, particularly marine mammals. Historic preservation may also be impacted by wind plant siting.

Wind turbines may create false images on aviation radars, both civilian and military. This can be solved sometimes through redesigning the wind farm layout or, more often, by installing new radar systems — but this comes at a cost.

There may be impacts linked to the use of materials including rare earths (Nd, Dy, and Tb), copper, aluminium, iron and steel, carbon and glass fibres, balsa wood, resins, etc. The impact depends on whether materials are disposed of, recycled or reused (e.g. turbines may be exported after a certain age is reached). Nuclear generation technologies have unique disposal requirements associated with waste.

Introduction of wind plants alters habitat and migratory patterns. The extent of disruption depends on the species and the type of interaction it has with the wind plant location. For example, bird and bat mortality rates may change, but the effect on the corresponding species population is also important. Marine biodiversity increases around offshore wind plants because of the artificial reefs they create. As wind generated electricity offsets the need for mining, producing, and transporting fossil and nuclear fuels, other biodiversity impacts could result.



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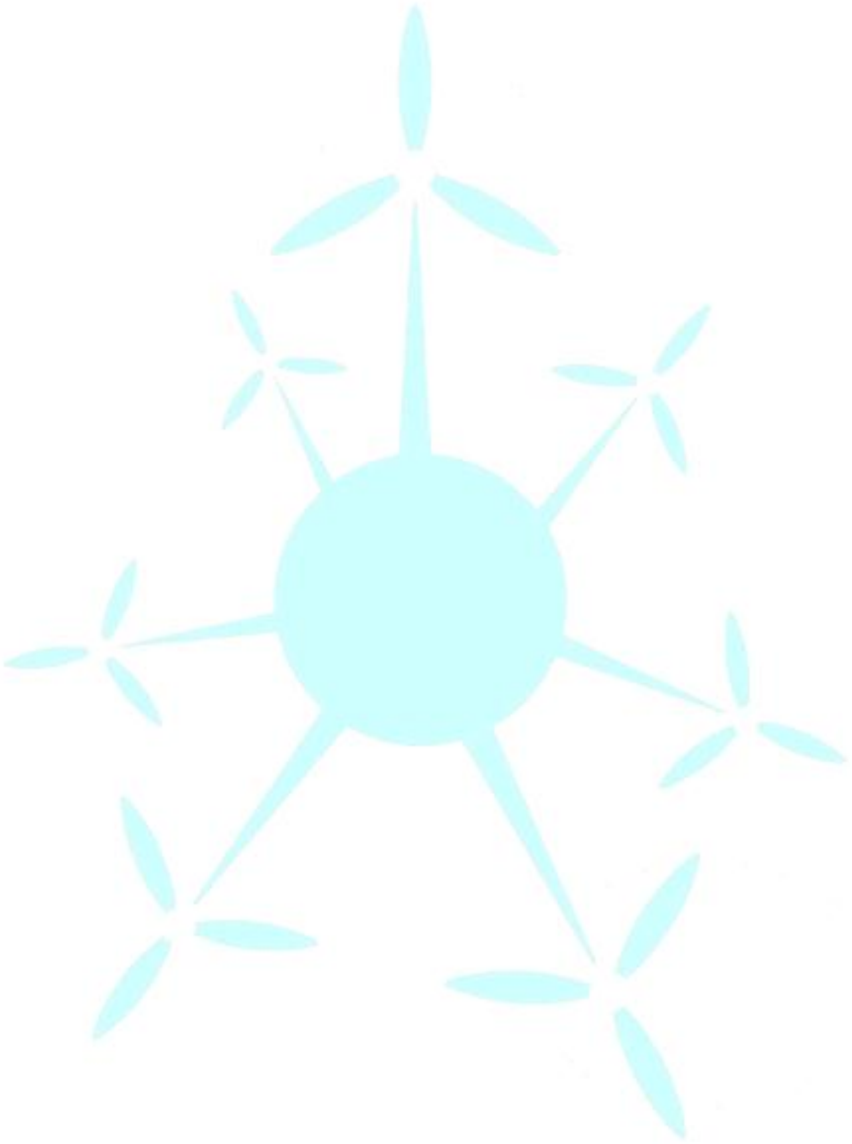

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Appendix: Workshop agenda

The workshop started at noon on 13 November 2013 and finished in the late afternoon of the next day. The agenda was as follows:

13 November:

13:00 Presentation of the workshop and participants. Organisation of the workshop, choice of chairs, and discussion of the elements of the subsystems.

13:30 Presentation: a policy brief for an analysis of the value of wind by the European Commission.

14:00 Presentation of three recent studies from a systems perspective: what they took into account, what they did not and for which reasons.

14:50 Presentation of the update of the assessment of US 20 % wind share by 2030.

15:10 Coffee break

15:20 Subgroups round 1 "non-expert"

16:50 Subgroups round 2 "expert"

14 November:

09:00 Subgroup discussion continues.

10:00 Coffee break

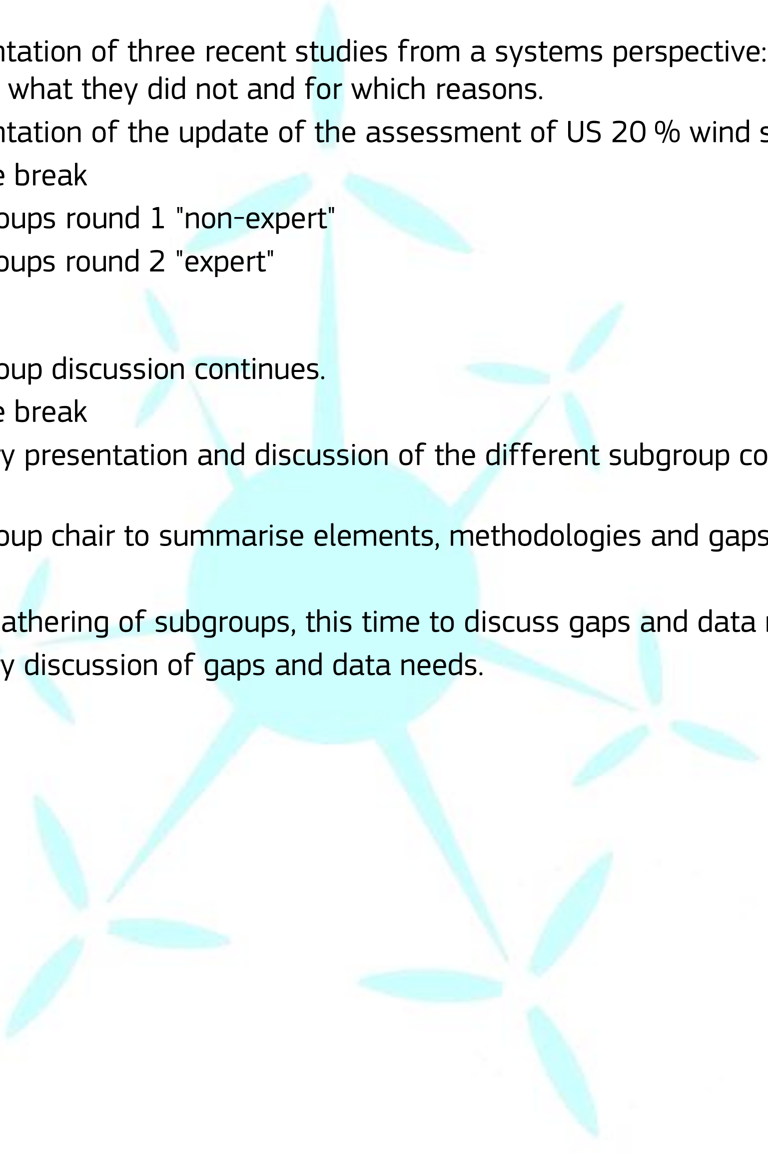
10:20 Plenary presentation and discussion of the different subgroup conclusions and debate.

12:30 Subgroup chair to summarise elements, methodologies and gaps.

13:00 Lunch

14:00 New gathering of subgroups, this time to discuss gaps and data needs.

15:00 Plenary discussion of gaps and data needs.



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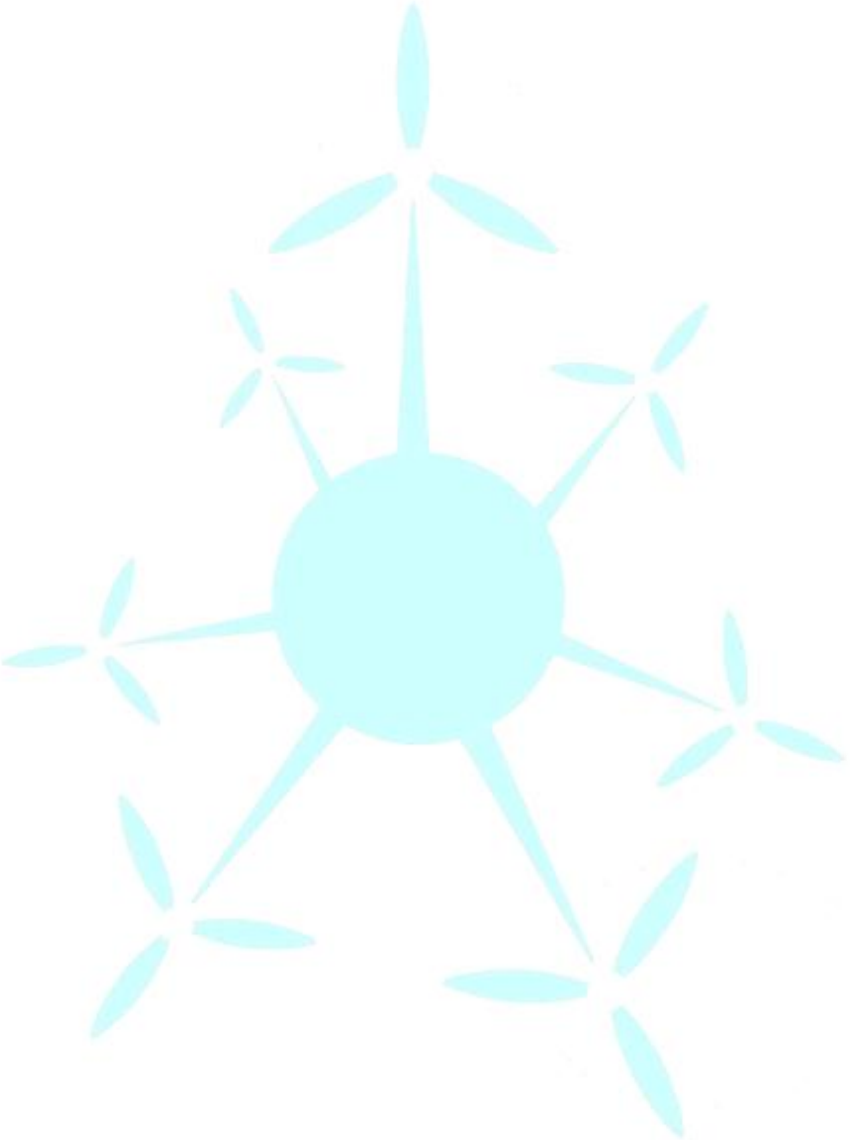

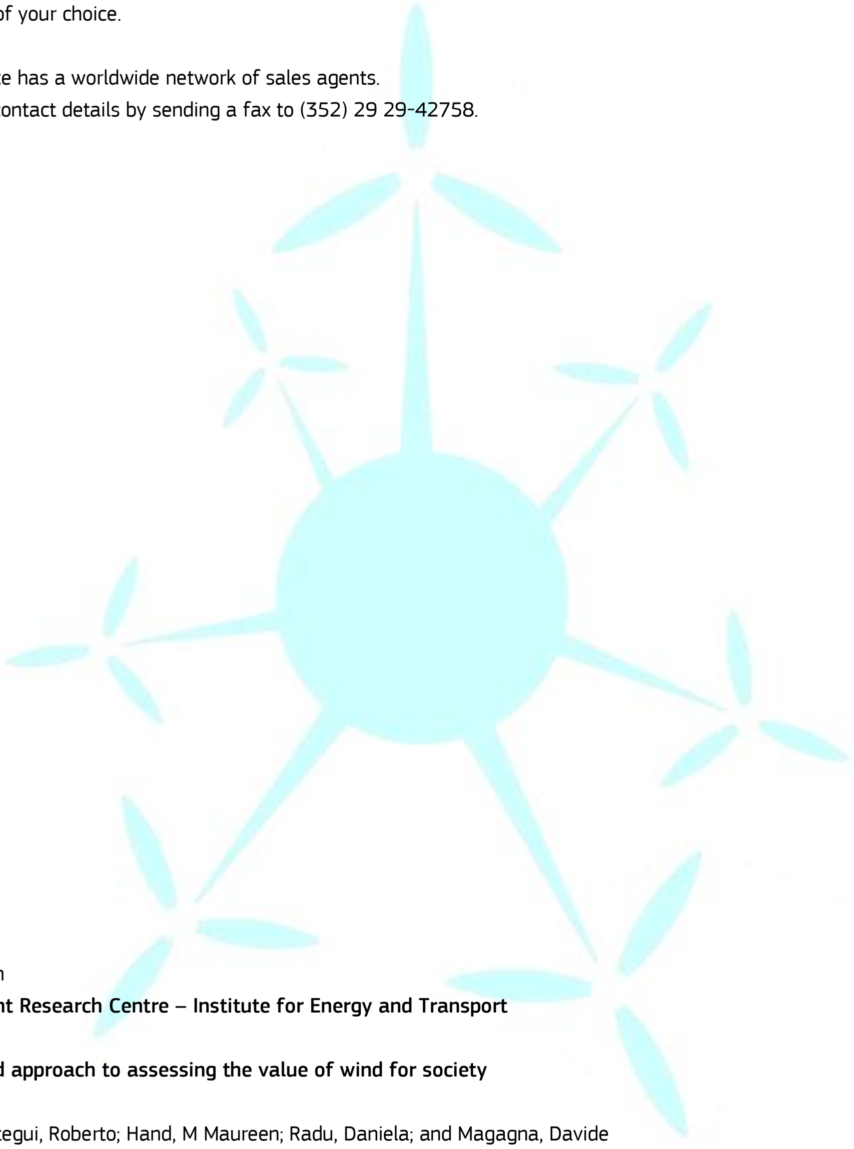

European Commission
EUR 26740 EN – Joint Research Centre – Institute for Energy and Transport

Title: **A system-based approach to assessing the value of wind for society**

Author(s): Lacal-Arántegui, Roberto; Hand, M Maureen; Radu, Daniela; and Magagna, Davide

Luxembourg: Publications Office of the European Union

2014 – 48 pp. – 21.0 x 29.7 cm

EUR – Scientific and Technical Research series – ISSN 1831-9424

ISBN 978-92-79-39414-0

doi:10.2790/33776

LD-NA-26740-EN-N

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doi:10.2790/33776

ISBN 978-92-79-39414-0

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