Environmental Impacts of Renewable Energy: Gone with the Wind?

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Abstract Wind energy is constantly gaining ground, especially in the UK, helping to tackle climate change and support energy security as the country wants to become less dependent to imported fossil fuels like coal and gas. Nevertheless, wind farm life cycle environmental impacts are not negligible and the construction and operation of wind turbine generators can cause several environmental impacts to the area where they have been sited. Therefore, it is reasonable to question, (a) whether there are "hidden" environmental impacts from the use of renewable energy technologies, and (b) whether supporting wind energy in order to displace fossil fuels just substitutes one environmental problem with another one (or more). This chapter uses UK as a case-study to describe thorough processes of environmental assessment and the environmental impacts related to wind energy. This lecture creates a pallet of potential issues that should be taken into account with regards to implementing environmental energy governance practices. The two methods used here, are (a) the Environmental Impact Assessment approach (used to identify on-site impacts that wind farms have on the environment) and (b) the Life Cycle Assessment (LCA) approach, which connects the energy, material, wastes and emissions with a wide range of environmental impact categories. The findings could change the way we think about wind energy and might make it easy to understand why there are still people who are opposed to the development of wind farms.

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E. Michalena and J. M. Hills (eds.), *Renewable Energy Governance*,
Lecture Notes in Energy 23, DOI: 10.1007/978-1-4471-5595-9_12,

1 Introduction

The main drivers for the development of renewable energy sources have been the challenges of climate change and energy security. The reason is that fossil fuels that dominate our energy mix have two main disadvantages: their combustion emit greenhouse gases that contribute to global warming and their reserves are diminishing, threatening the security of supply. Therefore, renewable energy's advantage is that can be utilised inside a country's territory according to the government's will and contributing to tackling climate change, which is the main environmental problem of our times. Nevertheless, their development so far has highlighted that they can be restricted by their associated resulting environmental impacts. Wind power has been the renewable energy that is increasingly gaining ground, especially in the UK, where its contribution to the electricity production mix has gone up from 2.5 to 4 % approximately within the last 2 years, contributing to the reduction of CO_2 emissions by 6 million tonnes annually. Since both onshore and offshore farms have been used for adequate years to allow the technology to come to maturity, the question that has arisen is the following: Which are their adverse environmental impacts of using renewable energy technologies and how can we maximise the wind energy contribution without harming the environment?

The development of Wind power in the UK can be examined better by distinguishing onshore from offshore wind farms. The reasons for doing that, is the fact that although they may use the same wind turbine generators they require different supportive infrastructure as well as different design, construction operation and maintenance. Moreover, the development of onshore wind started earlier and that led to reaching an early technological and institutional maturity level providing more secure choices with regards to the specific technology that can be used. This has resulted in the creation of more complete policies and regulations, streamlined investment processes, better awareness and education of the relevant stakeholders, etc. On the other hand, that means that the market is not virgin anymore and it is more difficult to develop additional wind power schemes restricting the availability of land and capital. In other words, there are *little or no low hanging fruits for the development of onshore wind farms, unless a new breakthrough in their technologies allows a new "renaissance" especially if this coincides with the retrofitting of older wind farms.* From an environmental point of view, the different terrain of onshore and offshore wind farms together with the different accompanying infrastructure result in different type or magnitude of impacts.

These differences are mentioned here so as to set a technological and policy framework through which the environmental impact section should be looked at (EWEA 2009). In the next paragraphs, two approaches will be followed to study the case of the UK wind power environmental impacts in order to answer this question.

2 Some Interesting Methods to Assess Environmental Impacts

With regards to the method, we have used two methodological approaches to identify the environmental impacts of wind farms, throughout the whole life cycle of the projects. So first it is useful to distinguish the environmental impacts according to the different phases of their development. The on-site activities which include installation and operation and maintenance phases can be studied separately than the rest (construction, transportation, disposal and recycling) as their main characteristic is the interaction with the public and the environment they are located, rather than the material and energy use or their waste and emissions. Of course, during installation, operation and maintenance, materials and energy resources are required but their impacts are much lower and less noticeable or disturbing than the activities taking place on the particular site, such as the traffic of vehicles, the explosions for the excavations and the utilisation of heavy machinery. For example, the greenhouse gas emissions emitted during the operational phase for the production of electricity are less disturbing than the noise and the potential negative effects on the biodiversity (e.g. birds). Therefore, it is useful to study the environmental impacts of wind power in two different ways.

2.1 On Site Environmental Impact Assessment

The first way is to follow an approach similar to an Environmental Impact Assessment process which is mainly required for large projects, but also for even smaller projects if there is a strong probability that they will have significant effects on the environment and that depends on the nature, size and location of the specific project. According to the European Union, Environmental impact assessment is a procedure for the environmental implications of decisions to ensure that plans, programmes and projects likely to have significant effects on the environment are made subject to an environmental assessment, prior to their approval or authorisation (European Commission 2011).

Apart from assessing the environmental impacts that arise from the production of the wind turbines and the other wind farm components which is an approach more or less product oriented, there are also other important environmental impacts that come as a result of placing and operating the wind farms in a specific location. These impacts resemble the ones that a common building/industrial infrastructure would have to an area like noise, land use change, impacts on birds and visual aesthetics, while others are more specialised and relevant to the operation of the turbines like impacts from electromagnetic fields as well as impacts to the anthropogenic environment, like problems to radars and ship collisions.

As already mentioned before the offshore wind farms are more complex as the whole infrastructure has to be placed and interact with the sea elements and therefore need additional components and work like platforms, underwater cabling, interconnectors and substations, dredging, underwater construction and explosions. Even the operation and maintenance is more complex as the structures and the wind turbines have to be protected against corrosion and the inspection has to utilise boats or helicopters for the transportation of the personnel.

2.2 Life Cycle Assessment of Environmental Impacts

Therefore, the second way is to follow a Life Cycle Assessment (LCA) which is a structured and standardised method that takes into account all the phases of a product or service from the raw materials extraction, production, transportation, operation and maintenance to the end of life treatment (disassembly, disposal and/or recycling) and provides a systematic view for the flow of materials, energy, waste and emissions. This approach provides a transparent and objective way to map the inputs of material and energy and outputs of emissions and wastes with regards to the product or service under study. The LCA methodology according to the ISO 14040 standard includes four stages, as explained below (ISO 2006).

In the first stage, at the *Goal and Scope definition*, we define the aim and set the boundaries of the product/service that we want to study. For example, our goal can be to assess the environmental impacts that come from the electricity of 1 kWh generated from a wind farm, to these that come from a coal fired power station. Our boundaries could include the wind turbines, the substations and exclude the connection to the national grid. Later on, based on the study requirements and on more information about the breadth and depth as well as data availability, we may need to redefine these boundaries. For example, if we cannot find enough data for the substation, we should restrict our study to the wind turbine.

In the next stage, the *Life Cycle Inventory analysis*, we analyse the product to its components and map the necessary materials, energy and processes used during all the phases of the product/service. For example, we would break the wind turbine down to its components (tower, foundations, nacelle, blades etc.) and these into the materials and processes they need. So for the wind turbine's tower we would take into account the amount of steel required the galvanisation process it has to go through the fact that it will be transported from the factory which could be in Germany, Denmark (if we are talking about a Siemens or a Vestas wind generator) and so on. In that way we compile and quantify the inputs and outputs against the functional unit, which in simpler words shows what is the need that our product or service covers. This analysis ideally leads to basic flows of material/energy.

Then we proceed to the next stage, the *Life Cycle Impact Assessment*, where knowing the inputs and outputs we can match them with their associated environmental impacts and evaluate the overall impact of the product/service.

Let us consider a very simplified case where we know that the carbon dioxide emissions for the transportation of 1 kg for 1 km by boat would be 10 g and by truck 130 g. Then we could add the carbon dioxide emissions for the transport of the 200 ts wind turbine from a Chinese port 17,900 km away (by boat) and to the place where it will be sited 100 km away (by truck) and find out that the total carbon dioxide emissions from that would be 38.35 ts which will contribute to the global warming potential by 38.35 ts CO_2 eq. On that point, we should mention that it is not only the Global Warming Potential (GWP) that we are interested in, but also other environmental impact categories like Ozone Depletion potential or Human toxicity potential.

Finally, in the *Interpretation* stage, we check the results and understand what they mean with regards to the original aim of the study. We could see which part of our product contributes more to the environmental impacts and analyse different scenarios for the use of alternative materials and process which would make our product or service more environmental friendly.

The Houses of Parliament in the UK, through the Parliamentary Office of Science and Technology (POST), published two reports on Carbon footprint of electricity generation (POST 2006, 2011). The latest results show that the life cycle GWP of the electricity coming from coal ranges between 786 and 990 gCO_2 eq/kWh and from gas between 365 and 488 gCO_2 eq/kWh, while for onshore and offshore wind the ranges are 38–96 and 5.2–13 gCO_2 eq/kWh, respectively. This is not bad if we take into account that the variety of the low carbon energy sources could achieve almost zero emissions or do not usually exceed 150 gCO_2 eq/kWh. Of course, the results vary among the different literature sources and that depends on the exact characteristics of the power station or wind farm under study, but even these estimations highlight the dramatic decrease in the environmental impacts that an increase of wind power contribution to the UK electricity mix would have.

3 Turning Theory into Practice: Case Studies from UK

3.1 Environmental Impact Assessment Case Studies

Before a wind farm project proposal gets consent in the UK an Environmental Impact Assessment should take place and therefore many documents can be found for cases from small/medium wind farms to large ones. Through studying these documents someone can get information about the potential impacts of a wind farm project, but the easiest way to find the cases of rejected wind farm proposals can be found in newspapers, especially in the local ones as it is the local councils that mainly reject the projects after the intervention of the people who are/will be affected. Those people can be affected in a number of ways:

3.1.1 Noise Impacts

Usually, a wind farm during its operation produces low to moderate noise ranging from 35 to 45 dB, where 35 is the noise similar to that of a library and 45 to that of an open plan office and this can be either because of the mechanical noise that comes from the generators and the gear boxes or the aerodynamic noise from the blades. Noise, is affected by the turbine characteristics, the landscape, the layout of the farm, the topography and of course the wind's speed and direction. In depth research has been undertaken from the especially set up Working Group on Noise from Wind Turbines whose findings are depicted in the ETSU-R-97 report (Department of Trade and Industry 1996) and which are taken into account into the guidelines for national planning of renewable energy. Nevertheless, in 2011 a Lincolnshire couple sued locals, on whose land some of the turbines have been sited, as well as the companies which own and operate the 2 MW wind turbines as written in the BusinessGreen (Shankleman 2011).

Apart from the easily perceived noise that humans can hear wind turbines also produce infrasound which is low frequency noise at a range below 200 Hz, inaudible to humans and which allegedly could cause symptoms ranging from irritability and sleep disturbance to anxiety and memory disturbances (Berglund et al. 1999). The UK Health Protection Agency acknowledges the lack of evidence supporting wind turbine generated infrasound as a health risk and more research is necessary (Centre for Sustainable Energy 2011).

3.1.2 Land Use

Like every construction project, wind farms change the use of the land and this may have important environmental impacts. Equally important environmental burden can be placed on peatlands and natural reserve areas, which are included in the surroundings and in general natural habitats that should be conserved which are included in the Ramsar and Natura 2000 sites.

Peatlands in particular are very important and if the main driver towards developing wind farms is global warming mitigation then they should be a place to avoid. Plans to build one of Europe's largest onshore wind farms in the Outer Hebrides were formally rejected in April 2008 after Scottish ministers ruled the £500 m scheme would devastate a globally significant peatland. A Scottish MEP claimed that Scotland's 1.9 m hectares of peat and bog were part of the planet's "airconditioning system" and this coincides with the scientific review which states that peatlands could be the most important terrestrial carbon store which has the ability to store so much carbon that could offset the annual UK carbon dioxide emissions many times (Worral et al. 2010).

3.1.3 Impacts on Birds and Bats

The Royal Society for the Protection of Birds (RSPB) takes into account the impacts of wind farms on birds and classifies them in the following four types: collision, disturbance displacement, barrier effects and direct habitat loss (Langston and Pullan 2003). The two most important effects are collision and disturbance displacement, which may also include the barrier effect. These are quite intuitive as such vertical structures with moving parts could easily be resembled to giant scarecrows that keep the birds away reducing the availability of flight paths for resident species and disrupting the paths of migratory birds. Also intuitive is the fact that birds may collide on a height structure as it usually happens with big buildings. The direct habitat loss could also be very important though, in the cases that very rare species are affected and of course attention should be given to placing a lot of wind farms in a small area. In the case of the £1.5 billion project of a wind farm scheme near Norfolk which was scrapped over fears that it could kill 90 birds a year as written in the Guardian (Macalister 2012) the RSPB admitted it had opposed that wind farm but supported other schemes in the area.

Additionally, for the offshore wind farms the disturbance from ships and the adverse impacts to the shallow water ecological areas (which host the habitats for breeding, resting and migratory seabirds) has to be taken into account, too. Furthermore, offshore wind farms use higher wind turbines and cover greater surface and include higher abundance of sensitive large bird species, in their area. As observed in Blyth Harbour, bird collisions with rotor blades are rare events even despite the wind farm is located within a Site of Special Scientific Interest and Special Protection Area, under the Birds Directive.

Similarly to birds also bats are affected by wind farms, and several mortality cases have been reported, especially since their migratory paths are not well known like birds and more research would be needed but since bats are protected species, there are certain policies in place and specific guidance is provided by Natural England (2012). Based on such policies, as broadcasted from BBC the District Council rejected the scheme near North Devon because of the impact on bats (BBC 2008).

3.1.4 Impacts on the Anthropogenic Environment

Visual impacts subsequently affect both the landscape and sea scape as the introduction of a manmade tall structure in the environment is not aesthetically welcomed by some people especially when this is placed in areas famous for their beautiful surroundings like touristic areas, archaeological sites, or in general areas of outstanding natural beauty. As mentioned in the Courier (Reoch 2013) in the case of a wind farm, the Scottish Natural Heritage consider it to be inappropriate, and the Council's development quality manager, recommended refusal of the plan, based partly on the "siting, size of turbines, prominence and visual association" with existing and approved wind farms having a major "adverse" cumulative impact on the existing landscape and visual amenity. On the other hand, offshore wind farms may have taller structures but they are usually far from human vicinity and therefore they are not so disturbing.

Another adverse effect that may take place, is the phenomenon known as 'shadow flicker' which is observed easier during sunny days and has to do with the shadow that the blades are casting on a specific area when they hide the sun during their rotation. This can be annoying but according to research there is no sound evidence supporting that this causes seizures to photo epileptic people (Smedley et al. 2010).

The presence of high vertical metal structures like the wind turbine towers as well as their blades may cause false radar responses or mask the genuine aircraft returns and cause misidentification or miscalculation of the location of the aircrafts, posing potential threats to aviation safety as well as the national security (DTI 2002). The case of Hoyle offshore 60 MW wind farm though which has been the UK's first major offshore renewable power project and which covers an area of 10 square kilometres, started its operation in 2003 and has shown (Howard and Brown 2004) that it does not significantly compromise marine navigation or safety.

3.2 Life Cycle Assessment of Wind Farm Environmental Impacts

Although Environmental Impact Assessments (EIA) are mandatory for the development of wind farm projects of significant size, a LCA is not legally required for the development of any product or service in the UK. This fact, together with the time and money required for an LCA, has restricted the existence of these studies only within the scientific community and the manufacturers of wind turbines. Moreover, the external validation and the interpretation of the results can increase the complexity and discourage the use of this method.

Nevertheless, in Denmark where the offshore wind has been developed earlier than the UK, a couple of LCA case studies exist (Vestas 2006) and provide us with interesting findings. In addition, LCA studies and reports for the wind power can be found in various sources. There are European and nationally funded projects reports, like the ones from ECLIPSE, the NEEDS, the CASES and the SPRIng (Azapagic et al. 2011) or Environmental Product Declarations from wind turbine suppliers like Vestas and Siemens. Scientific journals like the Journal of Cleaner production, the International Journal of Life Cycle Assessment and the Journal of Industrial Ecology have published interesting articles relevant to LCA of wind power too. Last but not least, professional databases like the Ecoinvent and the ELCD provide very useful material (SCLCI 1998), which can also be used for modelling and which allows further incorporation of the specific characteristics of each wind farm.

According to those references, the phases that are usually covered during the whole life cycle of a wind farm are described as follows. Firstly, *the construction of the different components* of the wind turbines like the tower, the nacelle and hub, the blades, the foundations and the grid connection cables and substations. This takes into account the extraction of the raw materials and manufacturing of these components or building of the specific structures. It has to be noted that the wind turbines might be the same for both onshore and offshore farms but offshore wind farms require usually larger wind turbines and more sophisticated foundation and transmission infrastructure and that increases the total environmental impacts.

Then, comes the *installation phase* where the components of the wind turbine are assembled. In some cases this may include the on-site building works like the foundations and substations mentioned in the construction phase, especially important for the offshore wind where boats, drilling and dredging might be included.

The *transportation phase* includes a wide range of activities like the transport of the raw materials to the manufactures, the transport of the different components among the suppliers and to the assembly place, the transportation of the technicians required for the operation and maintenance and finally the transport of the different parts after the end of life for disposal or recycling. The operation and maintenance phase may include the technical inspection and fixing/replacing of parts, cleaning and the lubrication and that might include the use of trucks, cars, boats and sometimes even helicopters. Finally, the end of life or decommissioning phase includes the dismantling of the wind turbines, disposal for landfill or incineration and recycling of the different parts.

As described in the previous paragraphs the wind energy is "doing well" with regards to their life cycle impact assessment comparing to coal, gas and falls near the mean value of the rest renewables. Nevertheless, these results can be very generic and may be restricted in terms of the breadth and depth of the LCA and they may not express the environmental impacts in more categories other than the Global warming potential.

So, the following question arises: *If we exclude the Global Warming potential, is wind power better than fossil fuel generated electricity for the rest of the environmental impacts?*

Based on LCA modelling of the UK Electricity mix that was performed using GaBi software and Ecoinvent database, at the Life Cycle Assessment Research Hub of the University of Cumbria, wind power electricity generation seems to have less impact on the Acidification, Eutrophication and Ozone Layer and Photochemical Depletion, Freshwater and Marine Aquatic Potential *but it seems to have more impacts on and Terrestrial Ecotoxicity as well as Abiotic depletion potential*. This practically means that we have to pay attention and address specific areas that could create problems in the future and they have to do mainly with the materials for the following reasons: The toxicity issues are a result of the use of materials like zinc, tin, etc. that can be toxic and which are mainly used for the anti-corrosion treatment of the metal parts which is necessary for the increase of the wind turbine's life time. The abiotic depletion potential has to do with the fragile abundance of materials like steel which is the main material used (the tower itself may contain 200 ts of steel) as well as with the scarcity of special materials called rare earths (like neodymium and dysprosium) which are used in the magnets of the generators.

The next question that can be answered through the LCA study is which phases during the whole life cycle pollute more. It seems that the construction phase accounts for the majority (around 80 %) of the impacts. The transportation usually accounts for the least and the rest 20 % is divided between operation and maintenance and end of life phases and this depends on the disposal and recycling options used. Nevertheless, it has to be noted again that these results are site specific but a general suggestion can be drawn that it might be appropriate to focus on the improvement of the construction phase.

4 Discussion and Concluding Remarks

Following both approaches (EIA and LCA) for the evaluation of the environmental impacts of the wind farms, a lot of issues are highlighted that may put pressure on the actors involved. Hopefully, scientific progress and policy development might alter the existing technical and institutional framework by providing mitigation or adaptation opportunities that will facilitate the renewable energy governance.

A lesson that can be derived from the case studies of the rejected wind farm proposals as well as the LCA modelling, is that renewable energy may be the solution to climate change and fossil fuel reserves depletion but a *successful governance* should also include the aspects of a good design and intense development effort, so as to minimise the potential adverse effects that might come up.

Tackling the adverse environmental impacts of wind farms can be more complex and less uniformly since they are very much site specific. Nevertheless, the following generic suggestions could be adopted. With regards to the noise, this can be mitigated by insulating the nacelle that contains the mechanical parts and by setting the wind farms at a certain distance away from residential areas. For the land use issues, abiding the guidelines and policies and including the local stakeholders early in the wind farm project development can be really helpful. Aviation species issues can be more complex and the need of experts such as ornithologists should be sought as the mitigation measures vary by sites and species but as a rule of thumb important zones of conservation and sensitivity areas must be avoided.

Concerning the anthropogenic environment impacts, proper siting of wind farms could also help again interference with radars and communication signals. Thus, national and local authorities should include a various range of stakeholders like the Environment Agency, the National Grid, the Ministry of Defense, the Civil Aviation Authority and of course representatives of the local citizens and non-governmental associations during planning.

For both the natural and anthropogenic impact, proper design and location can help to avoid any potential problems, but if the "perfect place" cannot be found or issues are realised after the wind farms have been installed, there is a variety of solutions that could be applied but these should always be balanced against cost implications. To this point, early stakeholder involvement can be the key as the cost of retrofitting gets higher the closer the project comes to an end. So although the Government has all the infrastructure in place to protect local habitants of an area, it seems that it lacks insights and link with local communities, highlighting the gap between national and local planning and implementation. But EIA is not enough, because there are "hidden" environmental impacts from using wind power, which can only be demonstrated through new scientific methods, such as LCA. The majority of the environmental impacts identified from the LCA approach could probably be mitigated by using alternative materials so as to avoid the ones that are or will become scarce. For example, very strong, low cost, environmental friendly, permanent magnets could be manufactured by iron nitride $Fe_{16}Ni_2$, alleviating the need for rare earth inputs, such as neodymium (University of Minnesota 2010). For more common but high demand materials, like steel, apart from their substitution by other materials, a more efficient manufacturing design can be developed, minimising the material inputs requirements to the production system (Allwood and Cullen 2012).

Nevertheless, the wind farm development boom is happening **now** and the toxicity brings up the concern whether *we create one problem* (*water poisoning and ecosystem deterioration*) *in our effort to solve another one* (*climate change*). The scarcity of materials on the other hand is connected with economic problems, security of supply and potential increase of greenhouse gas emissions due to the increased transportation and raw material acquisition processes that have to be implemented to make up for the demand.

Therefore, the issues highlighted by studying the development of wind energy farms should be taken into account and involvement of all the relevant actors should be sought at first place. Furthermore, the planners and developers should always keep themselves updated for the solutions that science and engineering advances offer and use their imagination for developing the answers to the questions that will arise. For example, what will happen if climate change is dethroned from the top of the environmental challenges agenda?

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