Web tool for energy policy decision-making through geo-localized LCA models: A focus on offshore wind farms in Northern Europe

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Isabelle BLANC[1], Catherine GUERMONT[1], Benoît GSCHWIND[1], Lionel MENARD[1], Charles CALKOEN[2], Hein ZELLE[2]

Abstract

Environmental performances of electricity generation, expressed as environmental impacts per kWh of electricity produced, depend strongly on technical, methodological and geographical parameters. When considering the global environmental performances of renewable energies, a geo-dependent life cycle assessment (LCA) taking into account geographical issues is of high interest.

To illustrate this issue, a web map service enabling "geolocalized life cycle assessment" of offshore wind farms for different configurations has been developed. Based on a modular LCA model and on collaborative works made within the framework of the FP7 co-funded project EnerGEO, the developed tool should help decision makers in assessing the global environmental impacts caused by an offshore wind farm in Northern Europe.

1. Introduction

In order to face to climate change and decrease its dependence to energy, the EU has implemented three targets to be met by 2020 (EC, 2007). These so-called "20-20-20" targets aim at reducing the EU greenhouse gas emissions by at least 20% (below 1990 levels), increasing its average renewable energy share to 20% by 2020, and reducing its primary energy use by 20% compared to projected level for 2020. To achieve these objectives, it is necessary for energy policy makers to have a full understanding of the global environmental impacts caused by energy generation in Europe. Indeed, all energy generating systems are not neutral for the environment: they require primary energy and materials to manufacture operate and maintain their components. Moreover, the environmental performances of electricity generation (environmental impacts per amount of electricity produced) depend strongly on technical, methodological and geographical parameters (IPCC, 2011), (Padey/Blanc/Le Boulch/Zhao, 2012). That is why it is necessary to adopt a geo-dependent life cycle assessment (LCA) taking into account geographical and technical issues when assessing the global environmental performances caused by electricity generation (Menard et al., 2011). The FP7 co-funded project EnerGEO[3] has been launched in this perspective. Organized according to different pilots dealing with fossil fuel, biomass, solar energy and wind energy, EnerGEO aims at developing a global observation strategy to monitor and forecast the environmental impacts generated by energy resources exploitations.

This paper reports the outcomes of the EnerGEO wind pilot whose main objective is to support environmental policy regarding wind energy. As a renewable energy source, wind energy has a major role to play in realizing the "20-20-20" targets. Indeed, projected technical potential for wind energy development in Europe within 2020 reaches 70,000 TWh (EEA, 2009), and wind turbines are identified as a very low CO_2 equivalent emission technology (Weisser, 2007). Focusing on offshore wind energy, this pilot aims at giv-

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[3] http://www.energeo-project.eu

ing an easy and free access to potential environmental impacts caused by electricity generation from a wide range of configurations and locations of offshore wind farms. A special interest is given to Northern Europe as offshore wind energy is expected to be widespread in this area in coming years (EEA, 2009).

The organization of this paper follows the elaboration of the pilot providing environmental performances maps through three significant steps : 1- The development of an algorithm processing geo-dependent data and life cycle assessment (LCA) results coming from an offshore wind farm modular model; 2- The algorithm implementation to Northern Europe; 3- A web map service development and results dissemination.

2. Development of a geo-dependent environmental performances algorithm based on modular LCA

2.1 Defining wind farm geo-dependent environmental performances

The environmental performances of an offshore wind farm over its lifetime (WF Perf) are given as follows:

WF Perf = Environmental impacts / Electricity generated [1]

- where the "Electricity generated" is the total amount of electricity generated by the wind farm over its life time (expressed in kWh).
- where "Environmental Impacts" is the sum of all the environmental impacts caused by the processes involved in the life cycle of the wind farm on a selected damage category (known as "life cycle analysis", LCA). The unit of the resulting impacts depends on the impact category which is focused on. It may be for example grams of CO_2 equivalent or Primary MJ.

When assessing site-specific "WF Perf" it is necessary to consider geo-dependent key parameters having an influence on the environmental impacts and on electricity generated potentials. The "Electricity generated" potential at a specific site is quite easy to assess compared to "Environmental impacts" assessment which requires LCA algorithm reprocessing. The LCA Standard ISO 14040 (ISO, 2006a), (ISO, 2006b) distinguishes four phases in a LCA study: the goal and scope definition, the life cycle inventory calculation, the life cycle impact assessment and the interpretation. Through the definition of the goal and scope step, a site-specific LCA is defined by default. In our case, we need to produce a series of geo-dependant environmental performances to allow comparison between different locations for a same wind farm. Since LCA algorithms are not yet flexible enough to consider geo-dependent parameters, our objective is to integrate this geo-localized constraint to compute geo-dependent impacts.

That is why we propose to firstly develop a modular LCA model of a typical offshore wind farm enabling the assessment of geo-dependent environmental impacts then, to develop an algorithm combining these modular LCA results with site-specific parameters.

2.2 Including geo-dependent parameters into the LCA of wind farm's components

The different key components and processes characterizing an offshore wind farm have been identified. They include wind turbines (moving parts and fixed parts), transmission cables (used for the high voltage substation connection to shore), collection cables (used for turbines connection to offshore high voltage substation) and maintenance scheme (which depends on distance between the farm and the nearest relevant harbor) (See Figure 1). To make our wind farm LCA model geo-dependent, we have considered all the farm's site-sensitive components and processes such as:

- The length of sub-marine cabling, which is influenced by the distance of the farm to the coast
- The marine transport scheme, which depends on distance to the relevant nearest harbor
- The foundation choice (floating vs. fixed), which depends on water depth

As a consequence, the wind farm's components that depend on these geo-dependent parameters have been modeled as a function of them. For example, the LCA of the transmission cables used to connect the high voltage transformer to coasts has been performed for one km; resulting impacts have then been combined with our variable representing distance to coast. Each identified geo-dependent parameter has been defined as a variable of our algorithm to be combined with the farm's components LCA results.

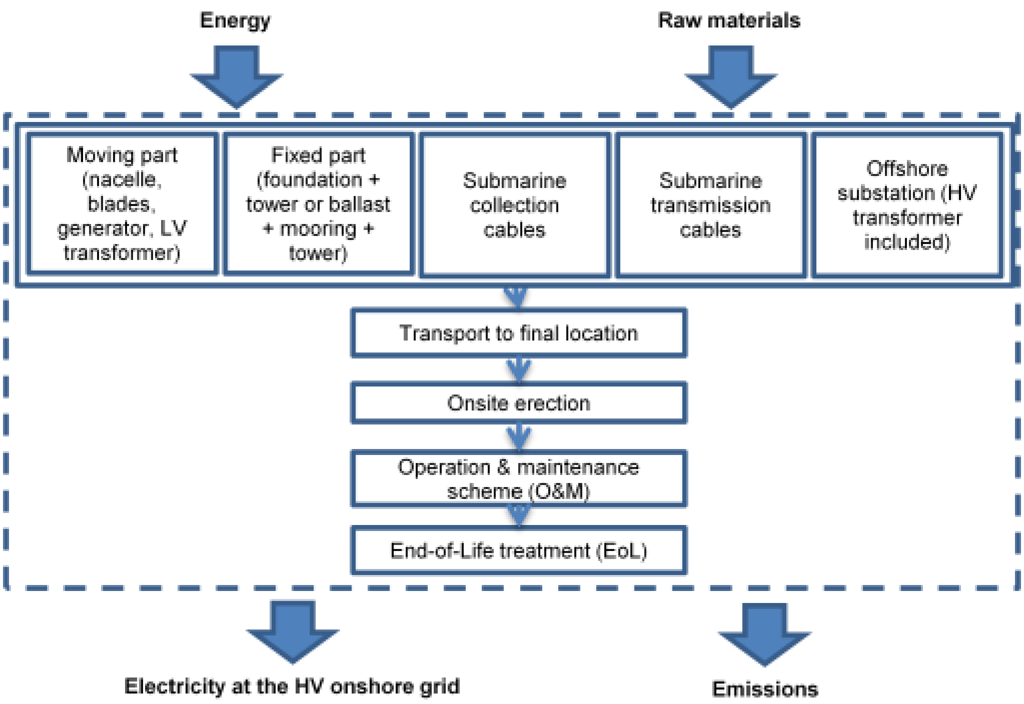

Figure 1: Components considered for the offshore modular LCA model

2.3 Configurations implementation

Taking advantage of this modular offshore wind farm model, additional parameters have been included in order to build different realistic configurations:

- The number of wind turbines per farm
- The life time of wind farm

- The type of maintenance scheme
- The failure rate level

The number of wind turbines is an integer limited by the physical capacity of the different components (cables, transformer, turbine…), the life time of wind farm is expressed in years, and the maintenance scheme and the failure rate are defined according to a range of realistic scenarios.

2.4 Environmental performances assessment

To get the geo-dependent environmental performance, we need the geo-dependant impact issued from the new LCA algorithm and the corresponding electricity production (Equation 1). The generated electricity potentials have been assessed from the selected turbine power curve and the wind speed distribution at the hub height. The electricity production is accounting for the load factor, i.e. the ratio of the electricity produced over a period of time to the amount that would have been produced if the turbine has run at full power for that period, and the average downtime per wind turbine failure.

3. Application of the new geo-localized LCA algorithm to Northern Europe

We now implement our algorithm for a set of geo-localized data available in order to generate maps. We chose Northern Europe area in our case of study and collect all data needed.

High-resolution Weather Research and Forecasting (WRF) models driven by the NCEP Final Analysis data of the *National Center for Environmental Prediction*[4] given on a one-degree grid over 11 years[5] have been used for wind speed distribution assessment before being linearly extrapolated at the rotor height.

Our wind pilot is based on different wind farm configurations depending on geographical variables but based on a similar generator in order to use the same wind power curve for electricity potential assessment. We reviewed different studies dealing with current and future offshore wind technologies (Andersen/Bjerregaard 2001) (Larsen/Petersen 2002) (NEED 2008) (NREL 2007) (UpWind 2011) (Vestas 2005) (Weinzettel/Reenaas/Solli/Hertwich 2009). A selection of materials and energy life cycle inventories of an offshore wind turbine have been identified. Two types of 5 MW wind turbines have been selected: a fixed one with a tripod foundation, and a floating one settable in deeper water (over 30 meters) and likely to be widespread in coming years (both structures have the same generator so are assumed to produce the same amount of electricity when the rotor is set at the same place). Weinzettel et al. (2009) publication dealing with a 5 MW floating offshore turbine has been used as a reference for our LCA data sourcing. Impacts of each component of our modular wind farm have been assessed from the LCA software Simapro by using the ecoinvent database for background data. The IMPACT2002+ LCA methodology (Jolliet et al, 2003) has been selected. It allows impacts assessment for the following four damage categories: human health expressed in Disability Adjusted Life Years (DALY), climate change expressed in g CO_2 eq, resources expressed in Primary MJ, and ecosystem quality expressed in Potentially Disappeared Fraction square meter year (PDF m_2 year).
Figure 2 represents the environmental performance map resulting from the implementation of one specific scenario for the damage category “climate change” (see details in Table 1).

[4] http://dss.ucar.edu/datasets/ds083.2/

[5] From January 2000 to January 2011

Table 1 Scenario description

Scenario description	- Floating turbines are assumed to be settled when depth > 30m, fixed structures else - WT lifetime is assumed to be 15 years - There are 30 turbines per farm (capacity max[6]) - A high failure rate is assumed: 2.33 failures per year, Down Time = 195 hours - A high maintenance scheme is assumed: 1050 hours of transport by helicopter per year + 150 landing and take-offs per year + 1 return to shore for complete inspection during the turbine's lifetime + 7.5 % of additional manufacturing in case of turbine breakdowns - Electrical losses are assumed to represent: 4% - Wake losses are assumed to represent 10%

Figure 2 Impact on climate change per kWh generated at the high voltage grid

Figure 2 shows that environmental performances range from 13 to 23 g CO_2 eq/kWh of electricity produced at the high-voltage grid. These values confirm the overall good performances of offshore wind farms in North Sea. The high performances observed far from the European coasts highlight the advantage of wind farms development where wind distribution are more favorable. Irregularities in the costal performances come from two phenomenon: 1- wind distributions at hub height could be locally less favorable to electricity generation; 2- the environmental impact of the selected fixed wind turbines, which is assumed to be settled near to coasts, are bigger than those of the floating structures (mainly because of steel required for the foundation)..

[6] The capacity of the high voltage transformer selected is 250 MVA.

4. Web client: tool for decision makers

Our maps which focus on the Northern European area have been published into a web map service (WMS) to ease their dissemination[7]. In the line of previous works (Ménard et al, 2011) on the interoperability between GEOSS (Global Earth Observation System of Systems) and environmental models for the impacts assessment of photovoltaic systems, our web service has been implemented through a recognized international standard namely the OGC (Open Geospatial Consortium) Web Map Service.

A screen shot of the developed web map service for EnerGEO is shown on Figure 3. To run the wind pilot the user must select the following parameters:

- the number of turbines per farm: 30, 40 or 50
- the life time of wind farm: 15, 20 or 25 years
- the level of maintenance: low or high schemes
- the failure occurrence rate: low or high occurrences
- the foundation type: only floating or fixed when possible
- The damage category within the four proposed in IMPACT2002+ method

Once these parameters are selected, a resulting map is displayed with a legend corresponding to the impact category chosen. Any user can therefore compare the environmental performances of different configurations by changing the input key parameters. When clicking on a specific site of the map, the numerical value of the resulting environmental performance appears.

Figure 3
Screenshot of the developed web map service for EnerGEO
Source: http://viewer.webservice-energy.org/energeo_wind_pilot/index.htm

[7] Available at http://viewer.webservice-energy.org/energeo_wind_pilot/index.htm

5. Conclusion and perspective

The developed map service is a concrete illustration of how a web-service greatly eases LCA results dissemination to non LCA experts. This service is easily accessible from the Internet and can be used by a wide range of users: energy operators, energy policy decision-makers as well as offshore wind parks developers. Running our web service highlights the importance to consider geo-dependent life cycle approach when assessing the global environmental performances caused by electricity production from offshore wind turbines. Based on specific technical characteristics, the tool enables to generate different potential scenarios based on variable failure rates, O&M schemes, turbine lifetime, potential losses, and technical choices. Other parameters such as local environmental impacts, soil characteristics, protected zones and maritime routes localizations may be also considered to enlarge multi-criteria analyses.

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