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Greenhouse gas emissions from electricity generated by offshore wind farms

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ABSTRACT

For wind power generation offshore sites offer significantly better wind conditions compared to onshore. At the same time, the demand for raw materials and therefore the related environmental impacts increase due to technically more demanding wind energy converters and additional components (e.g. substructure) for the balance of plant. Additionally, due to environmental concerns offshore wind farms will be sited farshore (i.e. in deep water) in the future having a significant impact on the operation and maintenance efforts (O&M). Against this background the goal of this analysis is an assessment of the specific GHG (greenhouse gas) emissions as a function of the site conditions, the wind mill technology and the O&M necessities. Therefore, a representative offshore wind farm is defined and subjected to a detailed LCA (life cycle assessment). Based on parameter variations and modifications within the technical and logistical system, promising configurations regarding GHG emissions are determined for different site conditions. Results show, that all parameters related to the energy yield have a distinctive impact on the specific GHG emissions, whereas the distance to shore and the water depth affect the results marginally. By utilizing the given improvement potentials GHG emissions of electricity from offshore wind farms are comparable to those achieved onshore.

1. Introduction

Globally the use of wind energy for power generation gains importance due to environmental benefits and the possible contribution to a domestic – and thus safe – energy provision. Today onshore wind power generation can be seen as a mature technology and its installed capacity increases steadily all over the world. By the end of 2012 globally roughly 280 GW with a potential electricity generation of 422 und 703 TWh have been operated [1]. The commercial use of offshore wind energy began in the year 2000 and since then develops mostly in the Northern part of Europe and in China [2].

For offshore application the initially installed wind energy converters have been commonly used onshore converters with a rated power output of 2–3 MW [3], which were located in shallow waters with a maximum distance to shore of roughly 20 km (nearshore; Fig. 1). To exploit economic benefits the technology evolved to more powerful wind energy converters with a rated electrical power between 3.6 and 6 MW. Announced and recently built prototypes have even higher capacities of up to 8 MW [3]. For this development the towers get larger and the substructures become more massive [4]. And to fulfil further growth targets and to face the given environmental restrictions (e.g. nature conservation areas), wind farms will be located farshore in distances to shore up to 150 or even 200 km in the future [5]. The water depth increases approximately proportional with the greater distance to shore [6] and therefore the substructures need to be adjusted; and the grid connection becomes more demanding. Likewise, these larger distances to shore have a significant impact on the operational phase of the wind mills, as the travel time to the wind energy converter for maintenance will accrue unacceptably long and consequently new O&M concepts for farshore projects need to be developed [7].

This on-going development is thus characterized by a strong increase in material demands and logistic efforts on the one hand side and a higher electricity generation on the other due to higher wind speeds farshore. Thus the question arises if such a development supports the reduction of GHG emissions throughout the overall life cycle.

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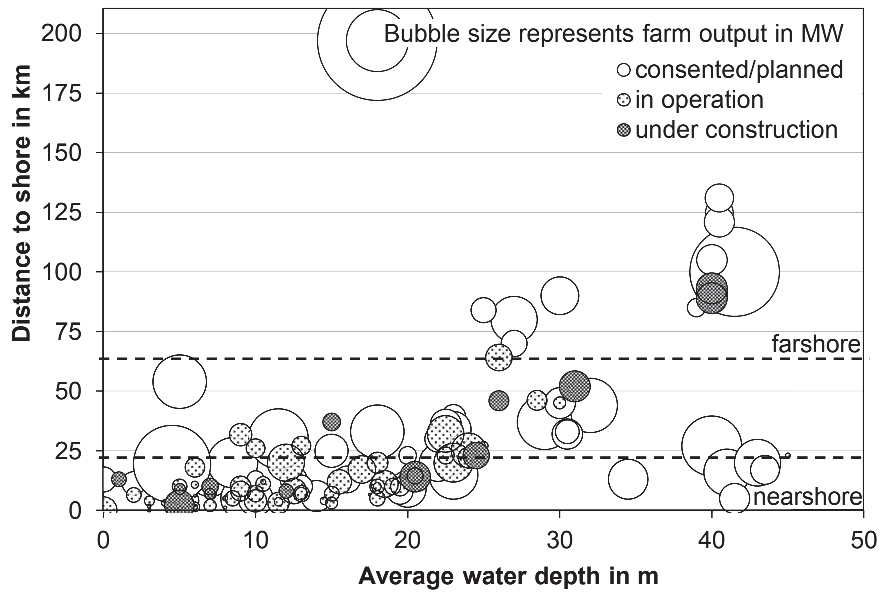

Fig. 1. Classification of existing and planned offshore wind farms in terms of distance to shore and average water depth (according to [8] and [9]).

Against this background the goal of this paper is to model an offshore wind farm overall life cycle phases and to carry out a LCA to assess the GHG emissions throughout the complete life cycle. A special focus is put on the interdependencies of the components and logistics to the different constraints of the sites such as water depth and distance to shore as well as on different logistic concepts for the operational phase. Additionally within different scenarios the influence of the higher resource requirements vs. the increased energy production with an increasing distance from shore will be investigated. The same is true for new O&M concepts compared to the port based maintenance.

2. Methodology

The methodological approach underlying a LCA consists of four steps according to the given standards ISO 14040 [10] and 14044 [11]. Firstly, the goal of the LCA and the boundaries of the analysed system need to be specified. Then all relevant energy, material and emission flows are collected or calculated to build up the inventory analysis. Within the subsequent impact assessment, the considered impact categories are defined and the results of the inventory analysis are calculated. In the last step, the results are interpreted and conclusions are drawn. The adaptation of these four steps to this investigation is discussed below.

2.1. Goal and scope definition

The objective of this investigation is to determine the GHG emissions of the utilization of offshore wind energy for electricity generation on a cradle to grave approach. In particular, the influence of different sites with varying spatial and naturally given constrains and the correspondingly adjusted wind energy converter technology and logistics are assessed related to the GHG emissions. Finally, the results are compared to an onshore wind power generation.

According to the LCA approach, the entire life cycle, starting with the raw material extraction and ending with the decommissioning, of all wind farm components (wind energy converter and balance of plant) is considered. This life cycle is subdivided into manufacturing of the wind energy converters and the grid connection including the raw material extraction, the installation of all components, the operation of the wind farm, and decommissioning including the disposal of all components on site. The system boundary shown in Fig. 2 includes in particular a detailed assessment of the operational phase with a focus on means of transport and required spare parts.

Thus the investigated system includes all components in the field as well as the cable to transport the electricity onshore. The system boundary is the interface where the energy is fed into the onshore substation. The assessed raw materials and respective masses of the components are calculated according to data from manufacturers and/or based on own assumptions. Also the subsequent manufacturing processes including transport duties between different manufacturing facilities and the delivery to the port are taken into consideration. For the installation phase, the transport from the port to the wind farm site and the energy demand of the installation vessels based on the installation time and the capacity of the vessels are calculated separately for the substructure, the wind energy converter and the grid connection.

The modelling of the operational phase is based on average annual maintenance and repair efforts for a single wind energy converter. Based on this wind mill the required amount of visits, lubricants and spare parts can be determined for the whole wind farm on a yearly basis depending on the O&M concept (incl. the transit time from port). With the required operating hours of the individually used transport facilities the overall fuel consumption per year is calculated. The required numbers of different means of transport are estimated according to their utilization related to the wind farm.

The dismantling of the wind farm components is comprised similar to the installation. The energy consumption of the vessels for dismantling and transport are calculated and included. The disposal process is represented by standard processes for each material group. The recycling of the various materials is not considered.

The functional unit is defined as 1 kWh electricity generated by the wind farm fed into the onshore substation. Thus all losses are included.

2.2. Inventory analysis

Several parameters are analysed influencing the constructional design and the energy yield of the offshore wind farm. The input and output variables set out in the goal and scope definition are