



Life Cycle Assessment of a multi-use offshore platform: Combining wind and wave energy production



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ABSTRACT

Due to increasing demand in the use of ocean space for energy and food production, multi-purpose use of marine areas is under concern. Here, a novel semi-submersible floating platform, which unites wave and wind energy converters, is investigated in terms of environmental sustainability. LCA is a methodology, to assess environmental burdens of a product/function including all the phases it experiences, which makes it a perfect tool to determine environmental burdens of renewable energy systems due to their considerably lower impacts during operation. In this study, LCA of an energy farm, constituted of multi-use offshore platforms was executed. Results showed manufacturing of the platform is the main source of pollution. In the manufacturing phase; fixed, moving and mooring parts are the main contributors and the WECs make a minor contribution. Material consumption is the main source for burdens during the life cycle of the system hence recycling ratios considered at the end of life scenarios affect the overall results. Implementation of multi-use floating concept to different locations gives various results changing with the capacity factor and the distances. The comparison between semi-submersible system and the spar platform ended up with comparable results both in terms of environmental burdens and material consumption.

1. Introduction

Multi-use offshore platforms are novel structures which are still at design stage. As indicated by the outlined literature survey, outputs obtained on environmental impacts are affected from quite a lot of factors. Such a picture emphasizes the importance of case by case evaluation for offshore energy structures.

It is a well-known fact that energy generation from renewable energy resources instead of fossil fuels is preferred due to their lower environmental burdens, and also low carbon policies lead governments to increase the ratio of energy generation from renewable sources. According to IPCC (2011) 20% of the world's energy need might be generated from wind energy by the year 2050. Wind energy is converted into electricity by means of turning the rotor by wind power. Wind energy systems are well established technologies where mainly horizontal axis turbines are used although vertical axis turbines also exist. The use of offshore areas for energy generation from renewables has increased in the last decades. In 2014, 2 488 wind turbines with 8 045.3 MW installed capacity in 74 offshore wind farms are operated through Europe. In an average wind year, 29.6 TWh energy is generated in these offshore wind farms which

supplies 1% of the total energy in European Union (EWEA, 2015). Offshore areas are preferred due to absence of obstruction and also high wind speeds. Hence while the turbine parts do not change according to the onshore or offshore area, type of the foundation (gravity, monopile, tripod, and steel jacket) varies due to water depth on offshore wind farms. In deeper offshore areas, floating wind turbines are also installed.

Wave energy converters (WEC) are another way of producing renewable energy using marine space generating electricity by using the energy of gravity waves. Total wave energy potential on Earth is calculated to be 8 000–80 000 TWh per year (Soerensen and Weinstein, 2008) and this high potential results in design and installation of a variety of WEC prototypes since 1970s. First commercial WEC, LIMPET 500, which generates electricity with Oscillating Water Column (OWC) principle, has been operating in Britain since 2000. Air is compressed in OWC type WECs due to wave motion and this compressed air forces the turning movement of the turbine. There are more than hundreds types of WECs which can be classified in several ways regarding different criteria such as device location vs. shoreline (shoreline, inshore, offshore), device location vs. wave direction (point absorber, attenuator, terminator) and conversion principle (OWC, Overtopping Devices, Wave Activated

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Bodies) (Koca et al., 2013).

Use of coastal and ocean areas to produce energy has a tendency of increase, also the rise of human population elevates demand for more aquaculture production and transportation. This results in competitive usage of marine areas. Thus, integration possibilities of different usages in offshore structures or using same sea area for several purposes, so called multi-use concept, is emerged. There are studies related to various aspects of multi-use of marine space combining different methods of marine renewable energy production (Astariz et al., 2015; Michailides et al., 2016; Castro-Santos et al., 2016; etc.) as well as combining marine renewables and aquaculture (Michler-Cieluch and Krause, 2008; Buck et al., 2010; Hooper and Austen, 2014; etc.). Multi-use of ocean space is also encouraged by European Commission with project calls in Framework 7 and Horizon 2020. Feasibility of different design concepts bringing together combination of several usages are examined in the context of funded projects (Url-1, Url-2, Url-3).

Life Cycle Assessment (LCA) has been widely used for assessing environmental burdens of renewable energy systems. Due to its quantitative nature, it eases comparison of environmental consequences arising from different energy generation systems. Besides it points out the optimal environmental outputs within a chosen mode of energy generation.

There are various LCA studies which are carried out for existing or planned wind farms and the results of these studies vary despite handling wind turbines with similar technologies and structures (Lenzen and Munksgaard, 2002). The possible causes of these diverse results are outlined as the materials used in the turbines, the ratio of different metals adopted as materials, lifetime of the turbine parts (Raadal et al., 2014), capacity factor (Raadal et al., 2011), wind park location (Guezuraga et al., 2012; Raadal et al., 2014; Tsai et al., 2016), energy mix ratios in the region (Oebels and Pacca, 2013), foundation type (Raadal et al., 2014), O&M activities, etc. (Tremeac and Meunier, 2009; Guezuraga et al., 2012; Raadal et al., 2014).

The review of studies related to LCA of wind energy systems by Arvesen and Hertwich (2012) shows that the biggest amount of the emissions is generated from production of turbine parts. Foundation also takes an important part for offshore wind turbines (OWTs), during the life cycle of the wind turbine. Greenhouse Gas (GHG) emissions per 1 kWh energy production are 20 ± 14 and 16 ± 9.6 gCO₂-equivalents for onshore and offshore wind turbines respectively (Arvesen and Hertwich, 2012). Kaldellis and Apostolou (2017) focuses on comparison of carbon footprint and energy payback time (EPBT) values of onshore and offshore wind turbines. Regarding higher amount and different material demand for construction and installation of offshore wind turbines which withstand harsh environmental conditions, carbon footprint values of mentioned structures are clearly higher than the onshore ones. However, offshore wind turbines have higher energy performance with shorter EPBT values due to greater offshore wind resource. For both offshore and onshore wind turbines, construction phase contributes ~80 to 90% and O&M has ~5 to 20% share in the total environmental impact (Kaldellis and Apostolou, 2017). Offshore wind turbines need more source; however, their emission amounts are close to onshore turbines due to high capacity factors offshore. According to Arvesen and Hertwich (2012) capacity factors are estimated more optimistic than reality which decreases environmental impacts per 1 kWh electricity generation and different estimations on material ratios used in turbine part production cause difference in the LCA results and also End of Life (EoL) scenarios varies in a wide range. Davidsson et al. (2012) also points out that estimated design capacity factors and recycle ratios are higher compared to actual situation in the review study they completed. Cumulative energy demand (CED) and energy return on investment (EROI) are the other parameters in addition to EPBT that defines energy performance of a wind turbine. These parameters highly affected by applied recycling ratios during EoL phase of a wind turbine (Huang et al., 2017).

Human toxicity and impacts from respiratory inorganics were found to be the significant environmental impact categories besides climate

change for onshore and offshore wind turbines analysed (Bonou et al., 2016). Kouloumpis et al. (2013) states that acidification, eutrophication, ozone layer depletion, freshwater and marine aquatic potential are less affected by energy production from wind energy and on the contrary terrestrial ecotoxicity and abiotic depletion potential are affected more due to resource use. Kouloumpis et al. (2013) also draw attention to the fact that we must be careful not to increase water toxicity while trying to prevent from climate change.

WECs are still emerging technologies, therefore there are a few studies on LCA of WECs. Soerensen et al. (2006) carried out an LCA study on a WEC called Wave Dragon which showed that this type of devices produces 20 times more energy than the energy used for it during its life cycle. Dahlsten (2009) conducted LCA of a WEC and claimed that most of the impacts are related to the material used besides installation, maintenance and decommissioning cannot be disregarded. Thomson et al. (2011) revealed that Pelamis WEC emits 24–30 gCO₂-eq/kWh and EPBT is 21–25 months as results of an LCA study. Collins (2014) used LCA to choose the material to be used in the design of Delos-Reyes Morrow pressure gadget, creating three scenarios for use of different materials in part production. Walker and Howell (2011) used LCA to assess environmental burdens of Oyster wave energy converter and SeaGen tidal turbine comparatively. Mentioned study claimed that these devices had similar environmental impacts with large wind turbines which are expressed in terms of energy and CO₂ payback periods.

In this study integration of wave and wind energy generation in a single device is investigated in terms of environmental sustainability. To combine wind and wave energy converters in a single floating platform requires an innovative design and a new type of structure which has enough space for the shell and additional generators of wave energy converters. This innovative structure might have additional material requirements compared to other types of floating offshore wind turbines, which raises the question of, is this new type of structure produce enough additional energy to compensate the difference in design and is there really an increase in the environmental burdens compared to other floating concepts?

In this context, the aim of this study is to answer the abovementioned questions by deeply investigating an innovative multi-use offshore platform, designed for Atlantic Ocean Cantabrian offshore site conditions. Appraising the platform through LCA sensitivity and scenario analyses will also give an insight on the effect of estimated recycling ratios and location of the energy farm on environmental impacts of this innovative structure in the early design stage.

2. Material and method

Life Cycle Assessment (LCA) is a method to specify the environmental impacts of a product or a function during its life from cradle to grave. LCA differs from Environmental Impact Assessment (EIA) and Risk Assessment (RA) by its product orienting nature and it might be used for product improvement or comparison of products or functions. Quantitative results produced by LCA studies might be used during decision making processes. By using LCA during design processes, environmental impacts are also considered and this results in environmental benefits, additionally problem shifting due to reducing emissions in one process and increasing in another is prevented by considering all stages from material extraction to waste disposal.

Life Cycle Assessment comprised of four main stages which are described in ISO 14040 Environmental management- Life cycle assessment - Principles and framework. In the goal and scope definition phase; method, functional unit, system boundaries and detail level are designated; Life cycle inventory (LCI) phase is comprised of determining inputs and outputs through the life cycle according to system boundaries and methods specified in the first phase and in the Life Cycle Impact Assessment (LCIA) phase, life cycle inventory results are converted into related environmental impact categories (Baumann and Tillman, 2004). EDIP, CML 2001, TRACI etc. are common methods which are used to

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