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Life cycle assessment of 50 MW wind firms and strategies for impact reduction

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ABSTRACT

The world today is continuously striving toward a carbon neutral clean energy technology. Hence, renewable wind power systems are increasingly receiving the attention of mankind. Energy production with structurally more promising and economically more competitive design is no more the sole criterion while installing new megawatt (MW) range of turbines. Rather important life cycle analysis (LCA) issues like climate change, ozone layer depletion, effect on surrounding environments e.g. eco-system quality, natural resources and human health emerge as dominant factors from green energy point of view. Hence, the study covers life cycle impact analysis (LCIA) of three wind farms: one onshore horizontal, one offshore horizontal, another vertical axis. It appears that vertical axis wind farm generates per unit electricity with lowest impact followed by horizontal offshore and horizontal onshore farms. The study, henceforward, discovers most adverse impact contributing materials in today's multi megawatt wind turbines and subsequently substitutes copper, the topmost impact contributor, with more eco-friendly aluminum alloys and its corresponding process routes. In this process, it reduces overall life cycle impacts up to 30% for future greener wind farms. In later stages, it compares all major electricity production technologies, viz., oil, diesel, coal, natural gas, wind, solar, biomass, nuclear, hydro plant in a common platform which demonstrates the wind farms performing the best except the hydro-kinetic ones. However, as the study suggests, offshore VAWT farm may even perform better than hydro-kinetic farms because of higher capacity factors in the high sea. Findings from the study can be deployed to harness massive scale green electricity from environmentally more clean and green turbines.

Contents

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Nomenclature

C_m	material cost per kg
ρ_{elr}	electrical resistivity
kPt	kilo ecopoint
tkm	transportation of 1 t goods over 1 km
personkm	movement of 1 person over 1 km
A/E	acidification/eutrophication
C	carcinogen
CC	climate change
DALY	disability adjusted life years
E	ecotoxicity
EQ	ecosystem quality
FF	fossil fuels
HH	human health
LU	land use
M	minerals
OL	ozone layer depletion
PDF	potentially disappeared fraction
PDF $\times$ m^2 $\times$ yr	1 PDF $\times$ m^2 $\times$ yr indicates disappearance of all species from a 1 m^2 area for 1 year
R	radiation
Re	resources
RO	respiratory organics
RI	respiratory inorganics

1. Introduction

World's fossil fuel reserves that once accelerated the drive to modern civilization and powered its industries are now been marked as predominant green house gas emitters and environmental contaminators in earth's atmosphere. These grim realities provide huge impetus for embarking on an alternative energy platform with clean and green outlook [1–4]. As being one of the most ubiquitous, in-exhaustible and sustainable energy on planet earth, the wind power plays a consequential role in this concourse [1,4]. Wind power is relatively cheaper than solar power. Solar power is not financially viable due to high commissioning cost; specially in high latitudes ($>40^{\circ}$ north or $>40^{\circ}$ south) it will be long time for solar power to achieve the parity with existing fossil fuel based plants whereas wind power can be commercially installed in any part of the world with wind speeds around 8 m/s or more. European countries like Denmark has already envisaged a plan to meet almost 50% of its electricity demand from wind power by 2025 [4]. In the end of year 2011, the global wind power installed capacity increased to 240 GW which is a massive 220% increase in just a time span of last 5 years. Along with onshore wind farms, offshore and floating turbines are also quickly penetrating the energy market. By October 2010, 3.16 GW of electricity started reaching the national grids from offshore wind plants which is expected to rise to 16 GW by 2014 and to 75 GW by 2020 [5]. Northern European countries are leading offshore wind power generation race with 53 farms installed by the end of 2011. Floating offshore wind turbine concept has also been materialized very recently. Hywind 2.3 MW, the world's first large-scale deep-water floating turbine, is generating electricity for the Norwegian grid since its inception in September 2009 in the North Sea. The turbine cost was US$62 million to build and deploy and it is expected to generate about 9 GWh of electricity annually [5]. In turn, vertical axis wind turbine system offers smaller weight, simpler foundation and less maintenance cost, however, its power co-efficient is still to match with horizontal axis wind turbine. As worldwide electricity demand is doubling itself in every 10 years and commercial scale wind farm development has expanded over 80 countries, it is of absolute importance to evaluate the wind technologies according to environmental perspective [4] apart from economics. To this implication, an overall life cycle inventory (LCI) and life cycle impact assessment (LCIA) of existing horizontal and vertical wind farms are explored in this paper. Besides determining the inventory and emission aspects of only the operation phase, life cycle inventory and impact assessment study performs a cradle to grave investigation of entire stand-in technology [28]. Guidelines of such LCI and LCIA analyses are epitomized by industry wide well-reckoned standardization bodies. Out of these, LCA guidelines of International Standard Organization (ISO) cover life cycle documentations extending from LCA principle and framework to goal, scope definition, inventory analysis, life cycle assessment and its interpretation [6,7]. Based on these guidelines, the study evaluates existing wind farm LCA study and, henceforward, redesigns it for a better carbon neutral, greener environment.

Worldwide only a few researchers have, so far, explored LCA studies for onshore and offshore turbines. Ardente et al. [8] have studied the energy performance and life cycle assessment of a horizontal axis onshore wind farm under solid waste, air and water emission categories using environmental product declaration (EPD) methodology. This study revealed the manufacturing phase to be the largest environmental impact contributor to the wind turbine. Weinzettel et al. [9] have evaluated the life cycle impact of a conceptual floating offshore wind turbine by CML 2 baseline 2000 V2.03 method. Here they compared the floating turbine concept with another offshore one where the life cycle impacts appear to be equivalent for both turbines. Fleck and Huot [10] have evaluated the environmental impact and life cycle cost of a small wind turbine for residential off-grid use. While comparing to a diesel generator system, the 0.4 kW wind turbine system offers almost 93% green house gas emission reduction. A 2 MW Gamesa onshore wind turbine with 80 m rotor blade installed in a Spanish wind farm has been the focus of Martinez et al.'s LCA study [11]. Here 95% material weight is considered for the life cycle inventory to calculate the impact with accompanying sensitivity analysis. However, these farms have never been compared in any article at sub-assembly level. Also how different primary, secondary and tertiary manufacturing processes contribute to overall LCA impact is left untouched. In addition, it is of utmost importance to identify how each and every engineering material contributes to overall wind turbine life cycle impact; this can eventually pave the way to substitute the existing materials with environment friendly ones. Conversely, life cycle analysis of vertical axis wind technology is entirely in its infancy. There is no referred work published in this domain, as prominent citation databases affirm. Reason behind this endures in non-existency of major scale commercial basis vertical axis wind farm as compared to the horizontal ones. This paper considers all these issues as potential areas of LCA study and compares the LCA impacts of three 50 MW wind farms based on SimaPro software [12]: one of which comprises of onshore horizontal axis wind turbine, another consists of offshore horizontal axis wind turbine and the last one incorporates onshore vertical axis wind turbine. For simplicity, these turbines will be represented as HAWT onshore, HAWT offshore and VAWT, respectively in the remaining text.