



Analysis of life cycle thermo-ecological cost of electricity from wind and its application for future incentive mechanism



Barbara Mendecka^{a,*}, Lidia Lombardi^b, Wojciech Stanek^c

^a University of Florence, via S. Marta 3, 50139 Florence, Italy

^b Niccolò Cusano University, via don Carlo Gnocchi 3, 00166 Rome, Italy

^c Silesian University of Technology, Konarskiego 22, 44100 Gliwice, Poland

ARTICLE INFO

Keywords:

Wind energy
Wind turbines
Life cycle assessment
Environmental analysis
Thermoeological cost

ABSTRACT

In this paper, we apply a life cycle thermoeological cost (LC-TEC) approach to evaluate the environmental performance of wind turbines with different capacities and performance characteristics. LC-TEC expresses the cumulative consumption of non-renewable exergy burdening the fabrication of the considered consumption of the product with the additional inclusion of necessity of compensating adverse environmental effects due to harmful waste products rejection. Differently, from what has been recently done in the literature on the environmental performance of wind turbines, where the attention has been mainly drawn by analysis of single turbine, we focus on the synthesis of the results for wind turbines with different capacities and the generalisation of the results under different environmental conditions.

The selected functional unit for the comparison was 1 MJ of produced electricity, assuming a service lifetime equal to 20 years. Concerning the contribution analysis, the construction phase is the most intensive one for wind energy technologies with a share varying from 64 to 77% in the overall effect. Substantial differences in LC-TEC are observed for wind turbines of different capacity and different locations of the power plant. Results show that the LC-TEC of electricity significantly decrease while the turbine nominal power increases. For instance, for the average site, described by Weibull distribution parameters of mean wind speed of 5 m/s and shape coefficient 2, the TEC-LC for 1 kW micro wind turbine is estimated to be equal to 0.436 MJ_{ex}/MJ, while for a larger, 2 MW one, fall in the range of 0.053–0.063 MJ_{ex}/MJ. We found that a power function can successfully describe such a trend. Moreover, we observed considerable changes in the final results for different Weibull distribution parameters. Specifically, the LC-TEC differs significantly for the sites with lower mean wind speed and different shape factors.

Finally, we propose the supporting system for wind energy basing on the LC-TEC and pro-ecological taxing. According to this concept, the power units with LC-TEC below unity are to be supported, and the proposed level of pro-ecological support (ExTAX – Exergy TAX) is proportional to the thermo-ecological cost.

The obtained results of exergy supporting for wind energy technologies are applied in the Italian electricity market and compared with the existing financing system for wind energy based on green certificates and feed-in tariff system.

1. Introduction

The increase of the use of Renewable Energy Sources (RES) in the final energy consumption is one of the primary objectives of the European Countries Community. Member States can achieve the overall national targets by the employment of wind turbines. Such a solution is one of the most efficient ways allowing to increase the percentage share of energy from RES. Concerning the new installations, wind power is representing more capacity than any other energy technologies. In 2016, wind power accounted for 51% of total power capacity

installations in the EU. The share of wind power in total installed power capacity in the EU, with a total installed capacity of 153.7 GW, has increased from 6% in 2005 to 16.7% in 2016, overtaking coal as the second largest form of power generation capacity in the EU and remaining the first among renewables [1].

Wind energy is also promoted as one of the promising ways for reducing environmental concerns. The majority of the literature studies report a high environmental efficiency of wind power systems. The environmental impacts associated with the operational phase of wind power generation are significantly lower than the ones, generated

* Corresponding author.

E-mail address: barbara.mendecka@unifi.it (B. Mendecka).

during the combustion of fossil fuels. However, it was proved that the most significant contribution to the environmental impacts is derived from the manufacturing phase. The high contribution of this stage, justified by the high material consumption, affects the environmental impacts significantly. This is why particular attention should be given to assess the impact of the overall lifecycle of a wind turbine.

The life cycle assessment (LCA) studies available in the literature have been conducted for a broad range of turbine capacities in both, onshore [2–20] and offshore [8,21–26] locations. The majority of mentioned studies presents the analysis of the single turbine [3,5–7,9–14,16–20,22,23,26,24], while other studies concern the environmental impacts of electricity produced in the wind farm [2,4,8,15,21,25]. Concerning the broad range of available LCA studies on wind energy, various methods are applied to evaluate the environmental impacts. The majority of studies focus on the life cycle energy and greenhouse gas (GHG) emissions analysis [2,3,6,8,11,15,18,22–25]. Widely applied are also others LCIA methods such as a set of impact categories and characterisation methods developed by the Center of Environmental Science of Leiden University (CML). Such an approach has been applied to evaluate the impacts of wind turbines in the studies [4,5,7,9,20,26]. Ecoindicator 99 method has been used for the evaluation of wind power impacts in works presented by Huang et al. [21] and Zhong et al. [14]. Martinez et al. [16] compared the overall environmental impact results for 2 MW onshore wind turbine using seven different Life Cycle Impact Assessment (LCIA) methods which were: CML 2001, Eco-indicator 99, Ecopoints 97, EDIP, EPS 2000, IMPACT2002 and TRACI. The authors proposed the CML and Eco-indicator 99 impact assessments as tools which present the most robust results. As another example, Haapala and Prempreda [17] carried out a life cycle environmental impacts of two 2.0 MW wind turbines using the ReCiPe 2008 impact assessment method and energy payback time (EPBT) analysis. A synthesis and generalisation of the results for GHG emissions and EPBT for different size wind turbines - from 1 kW up to 3 MW has been presented by Lombardi et al. [18].

Another interesting concept that can be successfully applied to evaluate the environmental performance of energy systems is the life cycle thermoecological cost (LC-TEC).

The LC-TEC index is defined as the cumulative consumption of non-renewable exergy resulting from the manufacturing of a particular product. This includes, also, the consumption resulting from the necessity of compensation of environmental losses caused by the rejection of harmful substances to the natural environment [27,28]. Such a concept allows to evaluate the non-renewable natural resources consumption considering the different quality of energy carriers and natural resources by using exergy as a common measure of resource quality and assuming the balance boundary which reaches the level of resources extraction.

The economic profitability of wind power plants strongly depends on subsidies. Following the guidance of the European Commission, a large number of Member States have already moved towards feed-in-premiums, limiting the use of feed-in-tariffs to small installations and emerging renewable energy technologies. Green certificates is another market-based instrument supported by the European Commission. However, current support systems do not take into account the difference of the influence on depletion or savings in non-renewable resources. For this reason, the LC-TEC algorithm can also be used for division of subsidies between renewable power plants based on objective criteria as is the pro-ecological tax (ExTAX – Exergy TAX) or non-renewable resource savings. In the light of an increasing scarcity of non-renewable natural resources, it seems to be a reasonable criterion for evaluating the level of subsidies. The idea of ExTAX was previously developed by Szargut [29] and applied to polish energy system [30].

Although many papers have applied different LCA models to evaluate the environmental performance of wind turbines, only a few studies have considered LC-TEC approach. Previously, the LC-TEC was applied to assess the impacts of electricity produced by two micro wind

turbines with vertical axis [20], to analyse the influence of electricity generated by large system wind turbines on the part load operation of conventional plants in Poland and Italy [19] as well as to compare the impacts of electricity produced by biogas, wind and photovoltaic power plants [31]. However, the previous studies focus on the specific cases, and there are no currently available studies which compare LC-TEC for a broader spectrum of wind turbines capacities and report the results for different environmental conditions.

In this paper, we suggest to use LC-TEC in order to evaluate the environmental impacts of electricity generated by wind turbines with nominal capacity ranging from 1 kW up to 3 MW. For this reason, we build our databases to predict the LC-TEC of wind energy under different environmental conditions. Furthermore, we apply the LC-TEC to evaluate the level of financial support of wind energy in the Italian economic context.

The structure of the paper is as follows. The inventory analysis and the methodology used are defined in Section 2. Assessment of LC-TEC impact of electricity generated by wind turbines, synthesis and generalisation of results as well as the application of LC-TEC for pro-ecological support analysis are presented in Section 3. Finally, Section 4 summarises the paper with a few concluding remarks.

2. Materials and methods

The objective of our study is to investigate the life cycle thermoecological cost of electricity produced in wind power systems of different scale. In the first step, 20 different types of wind turbines, with different capacities ranging from 1 kW up to 3 MW are explored. Next, the results of LC-TEC are applied to evaluate the level of financial support of wind energy. Summarizing, this study contributes to the existing knowledge by reporting the synthesised and generalised results of LC-TEC and pro-ecological subsidies for wind energy systems of diverse scale.

2.1. Life cycle inventory analysis

The functional unit used in this study is 1 MJ of electricity produced in the considered energy systems during the designed lifetime. The analysis is performed assuming the standard design lifetime of wind turbines equal to 20 years [32]. The boundaries of the analysed systems include the following processes: the production of raw materials and manufacturing of components (1), operational and maintenance phase (2), end of life stage including the decommissioning and disposal or recycling of the turbine and other components (3) and the transportation among above-mentioned stages (4).

Life Cycle Inventory (LCI) was developed according to the ISO 14040 [33]. Data on the required energy and materials flows at the construction, maintenance, and transportation stages were gathered from several studies collected in the literature review and presented in detail in our previous work [18]. The maintenance phase was modelled by considering the substitution of the inverter and lubrication oil exchange. Regarding the end of life scenario, it was assumed that the concrete, fibreglass, plastics, and paints are entirely disposed of [2,13–15]. The rest of materials employed were partially disposed and recycled assuming the 5 and 10% rate of the recycling for copper and other metals, respectively [2,7,13,15]. Similarly to [10], it was considered that the permanent magnet of the magnetic generator could be entirely reused at the end life of wind turbine. The contribution the transportation stage was limited to the global transportation of the components of a wind turbine in order to be assembled and completed and finally delivered to the installation site, assuming the type of transportation and distances in agreement to what was found in the literature review [18], as reported in Tables 1–3.

Inventory data on the cumulative exergy consumption and emissions associated with the transport, electricity and heat generation, raw material production as well as waste management were retrieved from

Download English Version:

<https://daneshyari.com/en/article/7158074>

Download Persian Version:

<https://daneshyari.com/article/7158074>

[Daneshyari.com](https://daneshyari.com)