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Original Research Article

Issues regarding wind turbines positioning: A benchmark study with the application of the life cycle assessment approach

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ABSTRACT

In the specific study a number of issues are addressed and discussed regarding wind turbines positioning in terms of land, coastal and offshore installation. More specifically, technical, environmental, energy, social and economical parameters are evaluated, providing thus a holistic assessment of the systems under examination. The analysis of the systems is based on literature references, theoretical calculations and simulation scenarios, taking into account life cycle thinking. The environmental assessment is performed with the application of special life cycle assessment software, and the results are considered to be representative for Greece and Mediterranean regions. Indicatively, it can be inferred that land wind turbines seem to be the environmentally friendliest choice. Significant questions are raised regarding wind turbines waste management schemes and their material usage. On the other hand, the offshore wind turbine surpasses the other two versions in terms of energy and financial reimbursement. However, existing barriers of different nature, i.e. financial, administrative and/or social may hold up the rapid development of the wind (onshore or offshore) energy in many European countries.

Introduction

Wind energy is a clean and inexhaustible solution in meeting the increasing demand for electrical energy and the planned targets of the carbon dioxide emission reductions. The increasing fossil fuel prices and the tendency for stricter environmental legislation and cleaner environment have upgraded wind energy to a vital factor for the economic development. As a consequence wind power generation experiences an era of rapid growth rate both globally (end of 2010 totally installed 194.559 MW, see Fig. 1) and more specifically in Greece (end of 2010 totally installed 1.323 MW, see Fig. 2) [1].

Significant amount of power can be generated by the selection of suitable wind farm sites. At this point, offshore wind farms seem to be advantageous due to the energy potential associated with the vast offshore areas, since increased wind potential, less turbulence and space availability promise great productivity of energy and make this form of energy more competitive. According to a scenario of the European Wind Energy Association, investments related to the offshore turbines will surpass those of onshore turbines after 2020 [2].

An increasing number of studies however, argue that a system is efficiently examined if viewed in the context of interconnections with other systems rather than viewed in isolation [2]. Systems thinking calls for a holistic approach to problem solving by examining problems as a part of a generic system. Especially for wind turbines utilization, decisions should not be taken hastily, due to the significant hidden material flows during their life cycle, and due to dependence on spatial characteristics and social and economical criteria.

Greece has a significant offshore aeolic potential. The goal of the specific study is the comparison of three wind turbines with diverse positioning characteristics, e.g. placed at land/onshore, coastal and off-shore sites in Greece. Most studies regarding wind turbines and wind energy in general, focus on the electromechanical and constructional related issues of the wind turbine. This is basically attributed to the struggle for achieving higher efficiency in all forms of energy.

A significant number of studies however, deal with the life cycle of specific wind turbines and farms placed in various areas worldwide. Martinez et al. in their study, indicate the key components of a 2 MW onshore wind turbine installed in Munilla, in terms of their environmental burden, highlighting foundation as the component significantly affecting various impact categories [3]. A 4.5 MW and 250 W wind turbines are compared in another study [4] indicating the need to minimize components transportation and recycling during decommissioning. Manufacturing of wind turbines is responsible for the largest energy requirement based on the results

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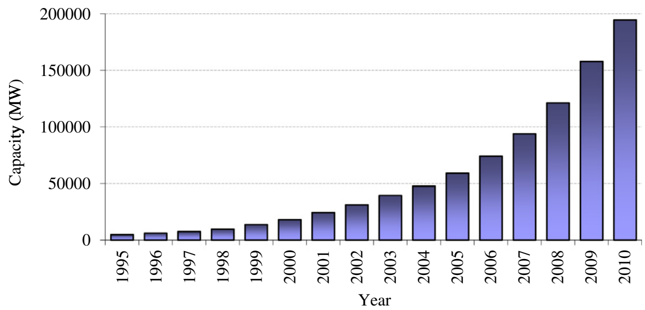

Fig. 1. Global wind power capacity [1].

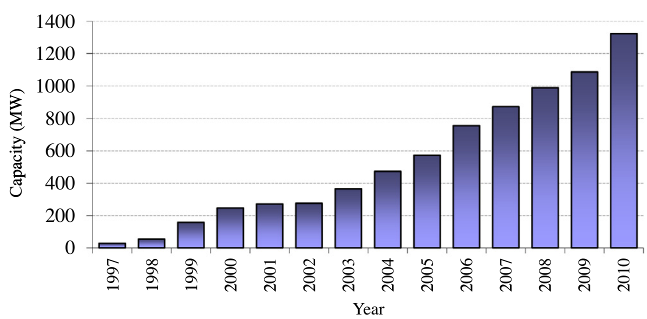

Fig. 2. Wind power capacity installed in Greece [1].

of the comparison of two different 2 MW class wind turbines [5]. Furthermore the location of the production of the wind turbine and background economy should be highly taken into consideration [6].

Life cycle studies are also available for more special and innovative wind turbine systems, such as floating offshore turbines [7] or wind-fuel cell integrated systems [8]. Additionally, life cycle assessment (LCA) related studies for larger scale (wind farms) projects can be found [9,10]. In any case, a number of assumptions have to be made increasing the level of uncertainty. A LCA sensitivity analysis could be proved useful in this case [11].

Most of wind technologies related LCA studies are merely focusing on the environmental-energy and/or economical aspects of life cycle assessment whereas social and legislative issues are usually neglected. It is generally agreed though that, even with life cycle thinking, wind power has high potential, is a clean form of energy and should be promoted.

Fewer studies are available trying to benchmark different spatial parameters (onshore–offshore) of wind turbines with the evaluation of various parameters [12]. Lenzen and Munksgaard have shown that energy and environmental intensities are influenced by a significant number of parameters and even for similar wind turbines, noticeable variations may be observed regarding their performance due to life cycle thinking [13].

Greece, although small in land size, has one of the longest shorelines in Europe, thus studies on the above mentioned issue (onshore vs. offshore) are critical for the development of strategic plans for the incorporation of wind energy technologies. In that aspect, the specific study is expected to contribute to the discussion regarding policies to promote wind energy utilization. More specific, the three scenarios analyzed in this study for the operation of the wind turbine versions take place in city of Xanthi (latitude: 41.1°, longtitude: 24.9°, 40masl (meters above sea level)) in the region unit of Xanthi, Thrace in North Eastern Greece, 25 km north from the Aegean-Thracean Sea and focus (a) to an onshore type wind turbine placed inland (b) to a coastal type wind turbine placed to an approximate sea depth of 10 m close to the coastline and finally (c) to a offshore type wind turbine placed to a maximum sea depth of 25 m within a range of 2 km from the coastline of the Aegean-Thracean sea.

Materials and methods

In the specific study the issue to be addressed is related with the pros and cons of the land (onshore), coast and offshore installation of wind turbines. According to systems thinking and in order to efficiently benchmark the specific types of wind turbines, various parameters should be examined.

For the specific study, the analysis of the systems was based on literature references, theoretical calculations and extensive simulation scenarios. The evaluated parameters that will be examined in this study are:

- Technical issues (e.g. installation issues, operation and maintenance needs, difficulty to repair).
- Environmental issues (e.g. impact on fossil depletion, climate change, human toxicity, particulate matter formation and others).
- Energy issues (e.g. renewable energy delivered/year, cost of energy).
- Economical issues (e.g. initial investment cost, net present value, internal rate of return).
- Social issues (e.g. visual and noise impact, land occupation, social acceptance);

The environmental impact was analyzed and assessed with the application of a relative life cycle assessment (LCA) software (SimaPro 7.2). LCA is considered as a complementary and a more comprehensive tool with respect to other environmental management systems (EMS) for supporting an effective integration of environmental aspects in business and economy [14]. The relative LCA standard four steps approach [15], namely (1) goal and scope, (2) inventory analysis, (3) impact assessment and 4) interpretation that has been developed according to the principles of ISO 14040 standard series was followed. A brief description of the implementation stages of LCA is presented in Table 1.

Goal and scope step includes actions such as defining the aim, functional unit and the boundaries of the system under examination. Life cycle inventory (LCI) is a list of all raw materials, extractions and emissions during the life cycle of a system. Impact assessment is necessary for the comprehension of the inventory results. During this step, the effects of the resources used and the emissions generated are grouped and quantified into a number of impact categories. Finally the results are interpreted according to the goal and scope of the study. More details regarding LCA can be found in relative reports [16,17].

The reason for choosing this methodology is that it highly incorporates the systemic thinking principles where a holistic view is fundamental. Life cycle stages such as transportation of the wind turbine parts to the installation site or maintenance needs may have a significant effect on the overall environmental profile of the examined wind turbine. Thus, LCA implementation can help identify areas of significant improvement potential that classical environmental assessment approaches may neglect.

System description

A typical wind turbine consists of the following key parts (Fig. 3):