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Proceeding Paper

Life Cycle Assessment of 2.0 MW Horizontal Axis Wind Turbine for Sustainability Analysis †

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Abstract: The world is increasingly experiencing unanticipated catastrophic events because of the impact of greenhouse gasses. The two major issues with the conventional energy system are unsustainability and global warming, which are extremely harmful for the climate. The core objective of this study is a compilation of the findings related to a life cycle assessment of horizontal axis wind turbines in regard to sustainable development. Sustainability aspects and concerns have been studied and reported in terms of the life cycle of wind energy technology. This article focused on energy consumed during the life of the 2.0 MW wind turbine, mostly in the production of primary materials, processes, and maintenance-related transport phase. The turbine's overall energy produced 1,750,000 kWh throughout a 20-year life. Over a 20year lifespan, the overall energy produced by the turbine is approximately 32% more than the energy needed to construct, and the destination for the turbine materials is a landfill at the end of the turbine's life. For a 40% wind turbine power ratio, with the wind turbine materials delivered to landfill at the end of the turbine's life, the electricity payback period is around 10 months, and for recycled materials it is 6 months. The comparison is also done for the wind turbine materials which are sent to landfill with and without recycling.

Keywords: LCA; wind turbine; energy; landfill; recycle

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1. Introduction

Energy plays a significant role in daily life. Nowadays, conventional sources are mostly utilized as energy. The major concerns regarding non-renewable sources of energy are sustainability and global warming [1]. The greatest approach to overcome these problems is sustainable energy. The natural resource that does not impact the atmosphere is wind. Most countries understand the importance of wind energy and utilize it as the predominant renewable energy source, due to its low cost as compared to other renewable resources of energy [2]. Wind energy is generated through converting the KE (Kinetic Energy) of ambient air into mechanical energy. The turbines used for transferring kinetic energy into mechanical energy are the horizontal axis wind turbine (HAWT) and vertical axis wind turbine (VAWT) [3].

Horizontal Axis Wind Turbine | HAWT

The horizontal axis wind turbine (HAWT) is commonly used for higher production volume, requiring massive investment, and occupying more installation space relative to the vertical axis wind turbine (VAWT). To produce electricity, the rotational axis of the

HWAT is parallel to the direction of wind [4]. The cost of production of the HWAT is lower, while producing a higher amount of electricity; as such, the performance of the HAWT is greater than the VAWT.

2. Life Cycle Analysis of Wind Turbine Material

To generate materials, feedstock and ore are extracted from the resources of the earth. These materials are processed into items which are utilized and recycled when their lives end, a fraction of which can join a recycling loop, with the remaining dedicated to combustion or a landfill. At every stage in this phase, energy and resources are depleted with a corresponding penalty of NOx, Sox, CO_2, and other pollutants, gases and heat, and solid and liquid waste. Previous research studies on the life cycle of wind turbines have analyzed the following: energy and resource flows in the procurement of raw materials; manufacturing and processing; storage and delivery (transport, cooling); use; repair and maintenance; and recycling [5].

Life cycle analysis (LCA), or eco audit, and techniques selected to direct the design, are as follows: The first phase is to build an estimated, but adequate discrimination tool to distinguish among alternative options [6]. There is a range of research levels, starting from basic eco-screening of a collection of restricted or unacceptable products and methods to a complete LCA, including costs and time overheads [7]. Selecting a single quantifier of eco-stress is the second step. The final phase is to distinguish the inputs of the life stages since the dominant one is contingent on subsequent behavior. If it is related to the production of material, then the choice of material with minimal "energy embodied" is considered.

3. Wind Turbine 2.0 MW LCA Results

This life cycle analysis describes the use of energy and carbon emissions within five stages (materials, production, transport, usage, and disposal) throughout the product's life [8]. Wind turbine (WT) power generation is sustainable and clean energy, but in the life cycle of WTs, sources of energy are used and pollution is generated during the development, production period, usage, transport, and disposal of raw materials. To evaluate the effect of wind turbine power production, all components required for the generation of electricity, including the rotor, nacelle, transmission, foundation, and tower, should be included in the study.

The bill of material for a 2 MW land base wind turbine is illustrated Figure 1. Energy used throughout turbine's life (approx. 20 years), mainly in the production of basic materials, production procedures, and maintenance-related transportation. The utilized energy for the transportation of large and small components of the wind turbine, as well as the energy used during servicing, was estimated from the assessment and servicing visit information contained in the Vestas report [9,10].

The total demand of energy and carbon dioxide impact at each stage of End of Life (EoL), for landfill and recycling, respectively, are summarized in Figure 2. The analysis of the life cycle of a wind turbine (WT) was conducted at first in the scenario wherein recycling materials from the WT were sent to landfill. Then, the analysis was conducted wherein WT materials were sent to be recycled. Higher energy is accumulated, and high concentrations of CO_2 are emitted into the environment throughout the wind turbine components' primary material manufacturing. The other dominating phase is the method of production where the turbine components are delivered to the landfill at the EoL point for the turbine.

The findings also demonstrate the effects of the components being recycled at the completion of the wind turbine's life. In the case where the wind turbine materials at the EoL are sent to landfill, the energy required for the disposal of these materials is 218,260,000 KJ, and 13,096 Kg of carbon dioxide is exposed to the environment. However, if the WT materials are recycled, the cumulative energy required is 6,851,200,000 KJ, which constitutes 54.8% of the overall energy being retained at the completion of the material's life. By recycling wind turbine materials, a total decrease of 495,917 Kg in CO_2 emissions is achieved.

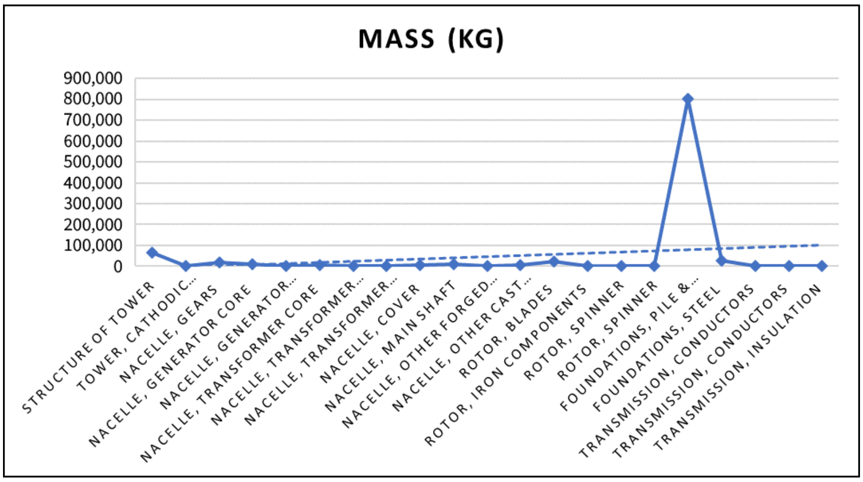

Figure 1. Wind Turbine of 2MW Bill of Material.

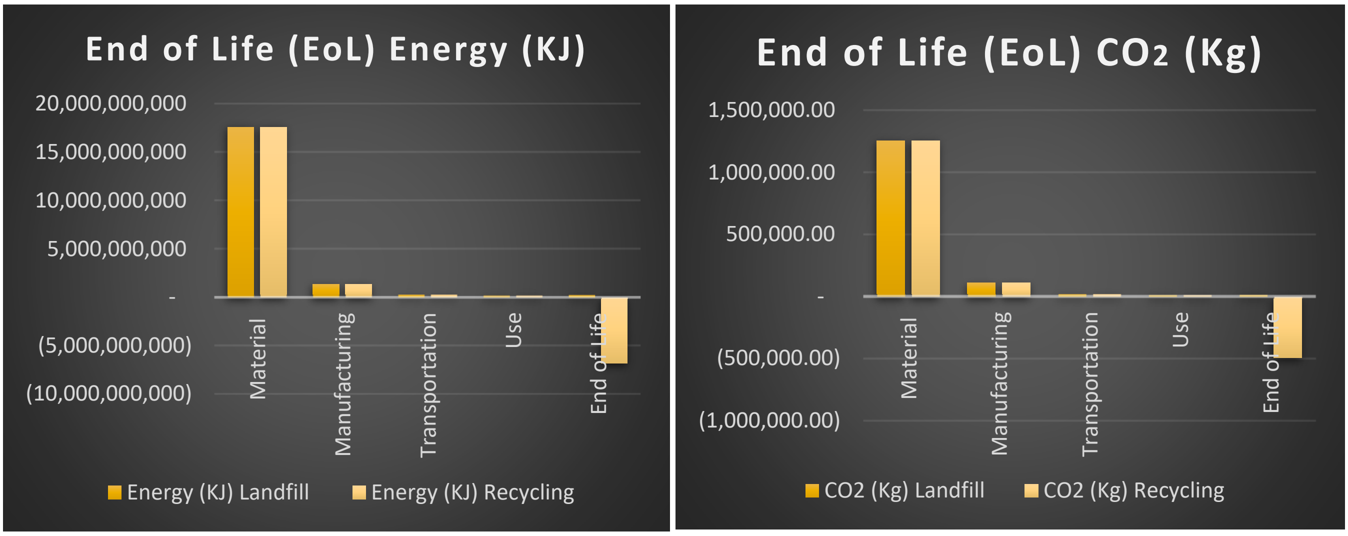

Figure 2. End of Life Energy and CO_2 with and without Recycling.

Figure 3 presents the overall view of wind turbine output energy, payback time, and energy construction at End of Life (EoL), for recycling and landfill, respectively.

The turbine operates at 40% average capacity in the optimistic outcome. Over a 20-year lifespan, the overall energy produced by the turbine is approximately 32% more than the needed energy to construct and operate it, if the materials of the turbine are sent to landfill at the turbine's EoL. If the components are reused, the turbine's cumulative energy produced over a lifespan of 20 years is around 50 times the energy needed to construct and operate it. For a 40% WT power ratio, if the WT materials are delivered to landfill at turbine's end life, the electricity payback period is around 10 months and for recycled materials it is 6 months.

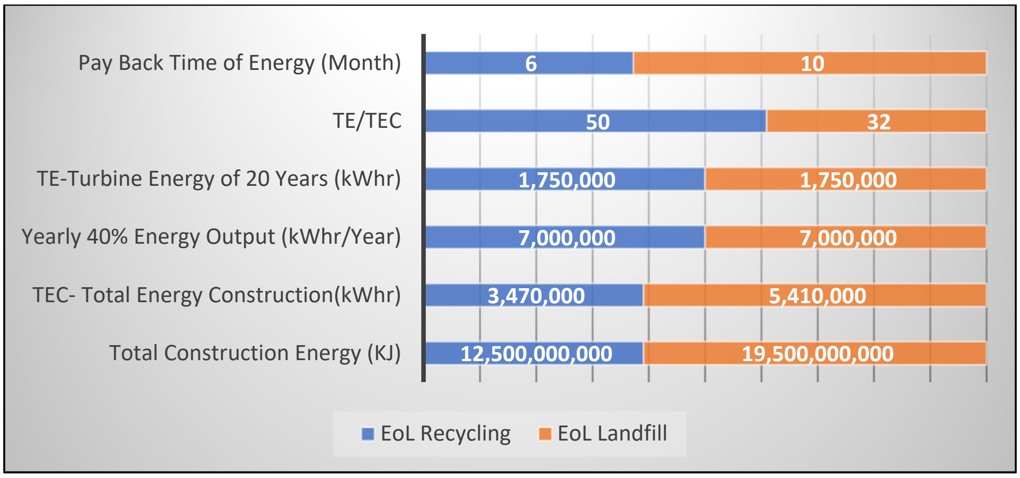

Figure 3. Wind Turbine Output Energy, Payback Time, and Energy Construction.

4. Conclusions

The effective future strategy development of energy creation is safer and more effective, and the use of modern and green sources of energy will play a significant role. Wind turbine power generation is a clean and sustainable technology; however, wind turbines use sources of energy from a life cycle approach and generate pollution throughout the raw material processing, production processes, transference of large and small components of WT, repair, and parts disposal at the end of the turbine's life. To assess the WT energy production impacts, all parts of the turbine required for the development of electricity, including the rotor, nacelle, tower, base, and transmission, must be involved in the study.

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