

Life cycle greenhouse gas (GHG) emissions from the generation of wind and hydro power

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ABSTRACT

This paper presents a comprehensive overview of the life cycle GHG emissions from wind and hydro power generation, based on relevant published studies. Comparisons with conventional fossil, nuclear and other renewable generation systems are also presented, in order to put the GHG emissions of wind and hydro power in perspective.

Studies on GHG emissions from wind and hydro power show large variations in GHG emissions, varying from 0.2 to 152 g CO₂-equivalents per kWh. The main parameters affecting GHG emissions are also discussed in this article, in relation to these variations.

The wide ranging results indicate a need for stricter standardised rules and requirements for life-cycle assessments (LCAs), in order to differentiate between variations due to methodological disparities and those due to real differences in performance of the plants. Since LCAs are resource- and time-intensive, development of generic GHG results for each technology could be an alternative to developing specific data for each plant. This would require the definition of typical parameters for each technology, for example a typical capacity factor for wind power. Such generic data would be useful in documenting GHG emissions from electricity generation for electricity trading purposes.

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1. Introduction

All energy systems emit greenhouse gases (GHGs)¹ and contribute to anthropogenic climate change. Analysis of all the

upstream and downstream processes pertaining to a power plant and the associated GHG emissions, e.g. the electricity generation stage, is necessary in order to obtain a complete climate account of power systems. If this is not carried out, the GHG emissions resulting from the various options for electricity generation can be underestimated. For conventional fossil fuel technology, upstream GHG emissions can be as much as 25% of the direct emissions from the power plant. For most renewable energy technologies and nuclear power, upstream and downstream GHG emissions can account for over 90% of cumulative emissions [1].

This paper presents a comprehensive overview of GHG emissions from wind and hydro power generation based on life-cycle assessments (LCAs), showing the variations in GHG emissions within homogeneous power generation technologies. A range of GHG emissions are presented, followed by selected factor analyses.

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¹ To compare GHGs emissions from different sources, the gases are indexed according to their global warming potential (GWP) per unit of weight. GWP is the ability of a GHG to trap heat in the atmosphere relative to an equal amount of carbon dioxide. According to the Intergovernmental Panel on Climate Change (IPCC), over a 100-year time span, carbon dioxide (CO₂) assumes the value of 1. The two other GHGs of importance in these analyses are methane (CH₄) and nitrous oxide (N₂O) which, according to a re-evaluation of the IPCC in 2007, take a value of 25 and 298, respectively.

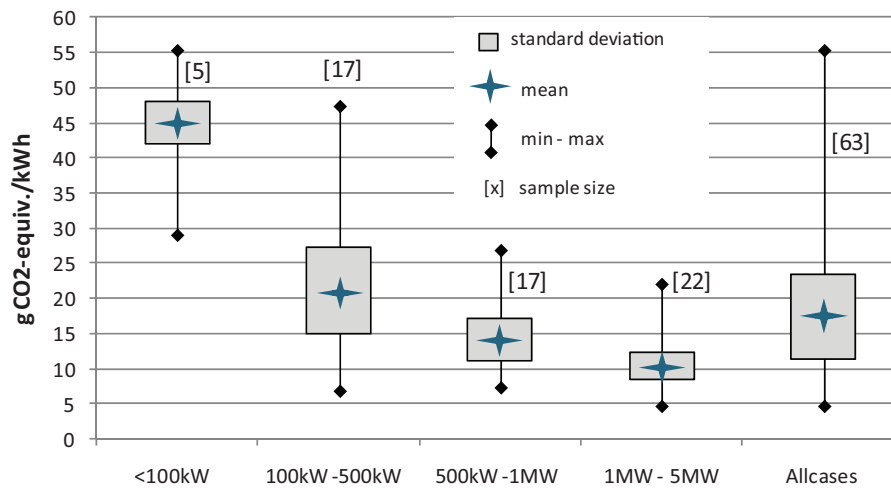


Fig. 1. Summary of life cycle GHG emissions from wind power [7–28] based on turbine size.

The focus is on GHG emissions, despite the fact that climate change is only one of several important environmental impacts when assessing different generation technologies. This work has been carried out as a part of the ongoing research project Energy Trading & Environment 2020 [2], which focuses on GHG emissions as one of the most significant impacts, according to the EU Electricity Directive (2003/54/EG, article 3). This EU Directive requires that suppliers of electricity disclose their electricity portfolio with regard to energy sources and their environmental impact, specifying the emissions of CO₂ and the amount of radioactive waste.

The paper is organised as follows: Section 2: Presentation of different methods for assessing life cycle impacts. Sections 3 and 4: GHG emissions from the generation of wind and hydro power, respectively. Section 5: A comparison of the performance of wind and hydro power in relation to other electricity technologies. Section 6: Discussions and conclusions. Section 7: Recommendations and outlook.

2. Life-cycle assessment methods for electricity generation

The LCAs referenced in this article have been carried out using a variety of methods. A short presentation of these methods is given in the following paragraphs.

Energy analysis is a tool used to assess both direct and indirect energy requirements for the provision of goods and services [3]. The method is based on a bottom-up approach, which means that both the energy requirements of the main production processes and some important contributions from suppliers are assessed in detail.

Process analysis was adopted in the official guidelines for Life Cycle Assessment (LCA), set out by the Society of Environmental Toxicology And Chemistry (SETAC) and is now standardised according to ISO 14 044 [4]. The advantage of this method is the holistic manner in which the value chain of the system is assessed, focusing on all significant processes. The results can be applied in two ways: firstly in optimising the impacts of a product throughout its life cycle and secondly in comparing the impacts of the various alternatives and thus enabling the choice of that which is shown to be most environmentally friendly. However, it is important to ensure that the system boundaries and assumptions are similar when comparing the output from such LCAs.

Input/output analysis (IOA) is another method for assessing the environmental aspects of products and services. IOA divides a product into its economic components (machinery, chemistry, services,

etc.) and then calculates an average performance for each economic sector. This average performance is then used as input in order to compute the energy required and the amount of GHGs emitted. The advantage of the IOA is that each input can be easily expressed as an economic value. The life cycle can then be interpreted as a sequence of economic activities. As each activity also has an influence on the monetary value of the product, a relationship between the price and the energy content can be established for each of the economic activities. This approach was inspired by the work of Herendeen [5] among others.

While *process analysis* is a typical bottom-up technique which considers the emissions in particular industrial processes and operations, the IOA method is a statistical top-down approach, which separates the entire economy into distinct sectors. In addition to this, a hybrid approach was developed by Bullard et al. [6], combining the advantages of both methods.

3. Wind power

This section presents the GHG emissions from wind power generation, based on 63 LCAs ([7–27] and [28]), published between 1990 and 2010.

Wind power represents a typical intermittent electricity generation technology, as power can be generated only when there is a sufficient level of wind. This means that wind power constantly requires a backup system to compensate for fluctuations. To make a fair comparison between different electricity generation systems, it is important to be aware of limitations such as the intermittent nature of a technology. In order to implement a fair comparison the following approaches can be used: a technology can be analysed in combination with a typical backup system, providing the same reliability as other “stand-alone” systems (e.g. hydro power with reservoir) or, if the assessment does not take into consideration the necessary backup system, it should be made clear that the assessment is at another level than that of other “stand-alone” systems.

The unit of the GHG emissions presented in this paper corresponds to 1 kWh of wind power. Grid losses and infrastructure relating to the grid are excluded from the analyses. The backup power necessary to provide a continuous electricity supply is also excluded from the analyses. Further, it should be noted that while some studies present results for a specific wind turbine (e.g. [12–14]), others present average data for specific wind power projects (many turbines) (e.g. [8]), while yet others are based on average data from several studies (e.g. [25]).

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