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Impacts of wind energy on environment: A review

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ABSTRACT

Wind power is increasingly being used worldwide as an important contribution to renewable energy. The development of wind power may lead to unexpected environmental impacts. This paper systematically reviews the available evidence on the impacts of wind energy on environments in terms of noise pollution, bird and bat fatalities, greenhouse gas emissions, and land surface impacts. We conclude that wind energy has an important role to play in future energy generation, but more effort should be devoted to studying the overall environmental impacts of wind power, so that society can make informed decisions when weighing the advantages and disadvantages of particular wind power development.

Contents

1. Introduction

The dual challenges of climate change and energy security mean that renewable technologies are required in the future. Wind energy is considered to be an important source of renewable energy and has been used commercially to produce energy services in the United States (US) since the early 1980s. It has become an increasingly important sector of the renewable energy industry, and may help to satisfy a growing worldwide demand for electricity [1,2]. Wind power has been rapidly developed worldwide (Fig. 1) [3]. The European Union alone passed the 100 Gigawatts (GW) capacity in September 2012, while the US and China surpassed 50 GW and 50 GW in August 2012, respectively [4–6]. Worldwide, there are now over two hundred thousand wind turbines operating, with a total capacity of 282 GW at the end of 2012 and a global annual installed wind capacity of 44.71 GW in 2012 [3]. The average annual growth in new installations was 27.6% between 2005 and 2010 [3,7]. Based on current growth rates, the World Wind Energy Association (WWEA) [8] projects the global cumulative installed wind capacity to be 1,900 GW by the end of 2020. Wind power market penetration is expected to reach 8% by 2018 [9].

However, development of wind power could lead to unexpected environmental impacts on ecosystems, due to the many

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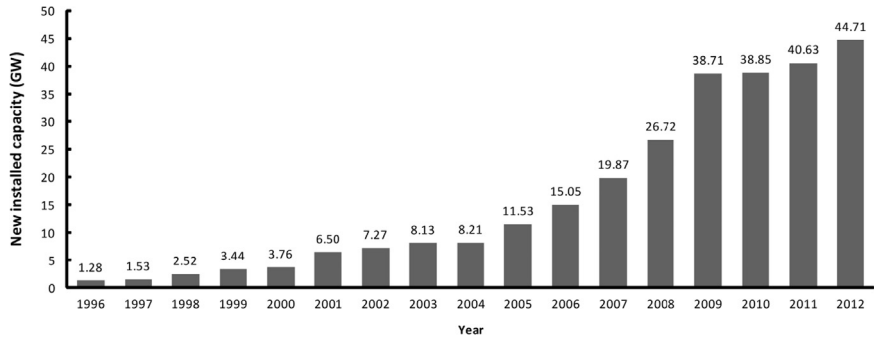

Fig. 1. Global annual installed wind capacity 1996–2012 [3].

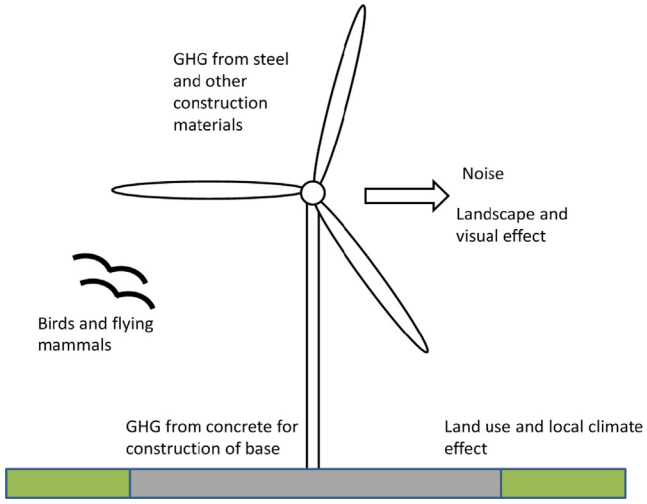

Fig. 2. Environmental impacts of wind power.

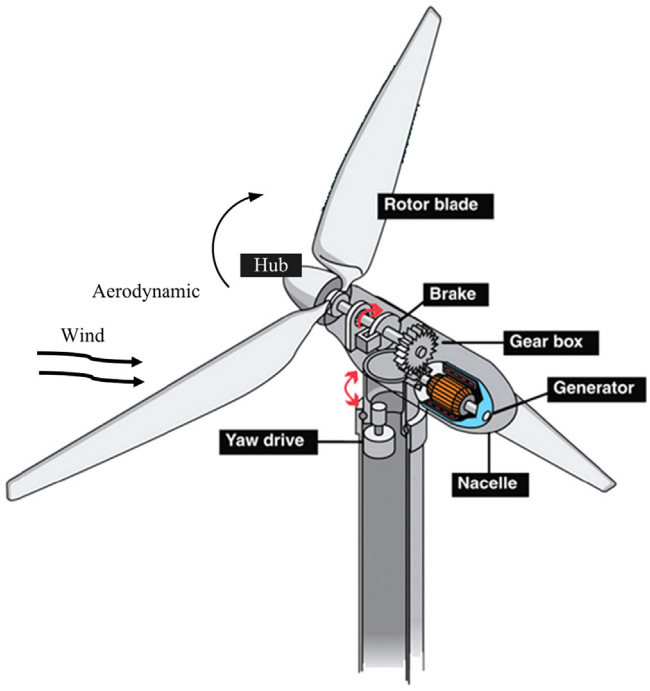

Fig. 3. Wind turbine noise sources. The mechanical noise includes the noise from hub, rotor blade, brake, gear box, generator, nacelle and yaw drive. The figure is adapted from Kunz et al. [2].

processes involved in the whole wind energy chain (raw materials procurement, construction, conversion to energy services, etc.) which will generate environmental impacts that affect the atmosphere, soil, water and living organisms. This review will collate information for use in the development of sustainable energy technologies and identify gaps in the study of environmental impacts of wind power as well as offer informative implications for policy makers. Noise pollution, bird and bat fatalities, greenhouse gas (GHG) emissions and local climate are the most significant environmental impacts, and are therefore the focus of this paper (Fig. 2).

2. Environmental impact assessment

The development of wind power will cause land use change and modify landscape settings, which will impact upon the living space, biological system and regional earth surface system, including noise pollution, bird and bat fatalities, GHGs and surface climate. Understanding these impacts will enable better mitigation and the creation of more effective renewable energy policies.

2.1. Noise pollution

Noise is defined as any unwanted sound. Wind turbines generate two types of noise: mechanical and aerodynamic. The mechanical noise is generated by the turbine's mechanical and electrical parts, while the aerodynamic noise is generated by the interaction of blades with the air (Fig. 3). The noise emission from wind turbine is a combination of both. Recently, due to the emergence of advanced mechanical design (e.g. proper insulation to prevent mechanical noise from proliferating outside the nacelle or tower, vibration damping), the mechanical noise has been reduced effectively, and is no longer considered to be as important as the aerodynamic noise, especially for utility scale wind turbines.

There are two main types of methods to measure the noise emissions from wind turbine. One is to use prediction models like semi-empirical models [10], and the other is to follow the international standards and/or International Environmental Agency (IEA) recommendations, with the help of devices such as IEA A-weighting. Recently, the prediction models have been more extensively developed. The most popular semi-empirical model is the one developed by Brooks et al. [11] which is derived by fitting a scaling law of Ffowcs Williams and Hall to the wind tunnel measurements of noise from two-dimensional NACA0012 aerofoil. However, the measurement of noise emissions from wind turbines is difficult: although several semi-empirical models have been designed, these models either are rather simplistic or make use of complex computational fluid dynamics solvers, and their application is rather time-consuming [10]; international standards and