Life cycle assessment of CO₂ emissions from wind power plants: Methodology and case studies

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Wind energy plays an increasingly important role in the world’s electricity market with rapid growth projected in the future. In order to evaluate the potential for wind energy to mitigate the effects of climate change by reducing CO₂ intensity of the energy sector, this study developed a new direct and simple method for estimating CO₂ emissions per kWh produced during the life cycle of four representative wind power plants (three in developed countries and one in China). The life cycle analysis focuses on the wind power plant as the basic functional object instead of a single wind turbine. Our results show that present-day wind power plants have a lifetime emission intensity of 5.0–8.2 g CO₂/kWh electricity, a range significantly lower than estimates in previous studies. Our estimate suggests that wind is currently the most desirable renewable energy in terms of minimizing CO₂ emissions per kWh of produced electricity. The production phase contributes the most to overall CO₂ emissions, while recycling after decommission could reduce emissions by nearly half, representing an advantage of wind when compared with other energy generation technologies such as nuclear. Compared with offshore wind plants, onshore plants have lower CO₂ emissions per kWh electricity and require less transmission infrastructure. Analysis of a case in China indicates that a large amount of CO₂ emissions could be saved in the transport phase in large countries by using shorter alternative routes of transportation. As the world’s fastest growing market for wind power, China could potentially save 780 Mt of CO₂ emissions annually by 2030 with its revised wind development target. However, there is still ample room for even more rapid development of wind energy in China, accompanied by significant opportunities for reducing overall CO₂ emissions.

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1. Introduction

In the past several years renewable sources of energy have won the support of governments in several countries, which has taken the form of various legal frameworks with stable and lasting premiums [1]. Wind energy, together with hydroelectricity, solar energy and biomass, is one of the most promising renewable energy sources. During operation, wind power plants are friendly to surrounding environments, releasing no direct emissions, harmful pollutants or CO₂. Newer technologies have made the utilization of wind energy much more efficient and cost-effective. Wind is arguably the most convenient method to generate electricity in remote locations. Wind turbines use less space than an average coal-fired power station. With these advantages, wind power is playing an increasingly important role in the global electricity market. In 2009, global cumulative installed capacity reached 158,505 MW (MW = 10^6 W), eleven times of that in 1996 [2]. Recent developments in wind energy have been particularly rapid with the annual growth rate of global installations reaching 29% and 32% in 2008 and 2009 respectively [2,3].

The total electricity generation from wind turbines installed globally reached 340 TWh (TWh = 10^{12} Wh) by the end of 2009, contributing 2% of the global electricity supply [4]. Denmark generates 20% of its electricity using wind. In Portugal, wind has come to cover 25% of its electricity needs [2]. China doubled its capacity from 12.2 GW (GW = 10^9 W) in 2008 to 25.8 GW in 2009, becoming the world’s largest market for wind energy [2]. About 1.4% of the total electricity consumption in China is now supplied by wind [5,6]. Current forecasts predict that annual growth rates from 2009 to 2014 will average 20.9% in terms of total installed capacity. These rates are modest compared to past developments: in the last ten years, we have seen an average increase of over 28% for both total and annual capacity additions [2].