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A life cycle co-benefits assessment of wind power in China

Bing Xue [a,b,c,*], Zhixiao Ma [a,e,g], Yong Geng [a], Peter Heck [b], Wanxia Ren [a], Mario Tobias [c], Achim Maas [c], Ping Jiang [d], Jose A. Puppim de Oliveira [e], Tsuyoshi Fujita [f]

[a] Key Lab of Pollution Ecology and Environmental Engineering, Institute of Applied Ecology, Chinese Academy of Sciences, Shenyang 110016, China
[b] Institute for Applied Material Flow Management (IfaS), Environmental Campus Birkenfeld, University of Applied Sciences Trier, Birkenfeld D-55768, Germany
[c] Institute for Advanced Sustainability Studies (IASS), Potsdam D-14467, Germany
[d] Department of Environmental Science and Engineering, Fudan University, Shanghai 200433, China
[e] Institute of Advanced Studies, United Nations University, Shibuya-ku, Tokyo, 150-8925 Japan
[f] National Institute for Environmental Studies, 16-2 Onogawa, Tsukuba, Ibaraki 305-8506, Japan
[g] University of Chinese Academy of Sciences, Beijing 100049, China

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ABSTRACT

Wind power can help ensure regional energy security and also mitigate both global greenhouse gas and local air pollutant emissions, leading to co-benefits. With rapid installation of wind power equipment, it is critical to uncover the embodied emissions of greenhouse gas and air pollutants from wind power sector so that emission mitigation costs can be compared with a typical coal-fired power plant. In order to reach such a target, we conduct a life cycle analysis for wind power sector by using the Chinese inventory standards. Wind farms only release 1/40 of the total CO_2 emissions that would be produced by the coal power system for the same amount of power generation, which is equal to 97.48% of CO_2 emissions reduction. Comparing with coal power system, wind farms can also significantly reduce air pollutants (SO_2, NO_X and PM_{10}), leading to 80.38%, 57.31% and 30.91% of SO_2, NO_X and PM_{10} emissions reduction, respectively. By considering both recycling and disposal, wind power system could reduce 2.74×10^4 t of CO_2 emissions, 5.65×10^4 kg of NO_X emissions, 2.95×10^5 kg of SO_2 emissions and 7.97×10^4 kg of PM_{10} emissions throughout its life cycle. In terms of mitigation cost, a wind farm could benefit 37.14 US$ from mitigating 1ton of CO_2 emissions. The mitigation cost rates of air pollutants were 7.94 US$/kg of SO_2, 10.79 US$/kg of NO*x*, and 80.79 US$/kg of PM_{10}.Our research results strongly support the development of wind power so that more environmental benefits can be gained. However, decentralized wind power developers should consider not only project locations close to the demand of electricity and wind resources, but also the convenient transportation for construction and recycling, while centralized wind power developers should focus on incorporating wind power into the grids in order to avoid wind power loss.

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* Correspondence to: Institute of Applied Ecology, Chinese Academy of Sciences, No. 72, Wenhua Road, Shenhe District, Shenyang City, 110016, PR China. Tel.: +86 24 83970433; fax: +86 24 83970371.
E-mail address: xuebing@iae.ac.cn (B. Xue).

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1. Introduction

China's energy system relies heavily on fossil fuels. The total amount of energy consumption in 2012 reached 3.62 billion tons of standard coal in which the fossil fuels accounted for 90.61% [1]. Since 2010 China has overtook the United States and become the world's largest energy consumer [2], contributing to 21.92% of the global energy consumption in 2012 [3]. With its rapid industrialization process and urbanization, China's tremendous energy demand will continue to grow [4]. Moreover, China accounted for one-quarter of global carbon dioxide emissions in 2011 which mainly contributed by the fossil fuel consumption [5] and 80% of the world's rise in CO_2 emissions since 2008 [6]. In order to diversify the energy mix dominated by fossil fuels and fulfill the responsibility for global climate change mitigation[7], China's energy policy focuses on sustainable energy supply and reducing the overall intensity of carbon emissions by increasing the proportion of renewable energy use and reducing the fossil fuel consumption [8]. Chinese central government set up an ambitious target on increasing the proportion of non-fossil fuel energy sources so that such sources can account for 15% of the total primary energy consumption by 2020 [9], which indicates that 35% to 40% of the total electricity should be generated from renewable sources..

As one of the world's major renewable energy sources, wind power plays a key role in helping solve the energy supply problems in many countries [10,11]. Total electricity generation capacity to from wind power has grown rapidly from almost zero in 1980 to 197 gigawatts (GW) in 2011 globally [12], and the total installed capacity projected to reach 1150 GW by 2020 and more than 2500 GW by 2030, contributing to decarbonizetheglobal electricity supply [13]. Due to the fact that wind is one of the most abundant renewable energy resources in China, the National Energy Administration established in 2008 decided to develop wind power as one key measure for diversifying China's energy mix [14]. Since then, the installed capacity of wind power plants in China has experienced a fast growth. During the period of China's 11th five-year plan (2006–2010), the total installed capacity of wind power has reached 43.5 GW, accounting for 8.9% of China's the total new installed power capacity during that period, in comparison, the installed thermal power was 449 GW, accounting for 92% [15]. By the end of 2012, the cumulative installed capacity of wind power in China had reached 76 gigawatts (GW), the largest country in the world.

Coal-fired power plants are the main source of ambient air pollutants (including nitrogen oxides, sulfur oxides, dust, and other suspended particulate matter), leading to both global climate change and local air pollution [16,17]. Since wind power does not consume fossil fuels during its operation period and therefore does not emit greenhouse gas and air pollutants from its electricity generation [18,19], the application of wind power can achieve co-benefits, namely reducing both greenhouse gas and air pollutants [20]. The co-benefits effect has been discussed extensively in the international political arena such as in the United Nations Framework Convention on Climate Change [21], the United States Agencies [22], and Japanese Environment Strategies [23]. In general, co-benefits refer to the development and implementation of activities that simultaneously contribute to tackling climate change (such as reducing CO_2 emission) and solving local environmental problems (such as reducing the emissions of SO_2, NO_X and/or particulates) [24]. In the case of energy-related projects, strong linkages exist between global climate change and local environmental pollution [20]. For example, emissions from the combustion of fossil fuels contribute significantly to both global climate change and local environmental pollution, while developing renewable energy projects could have the co-benefits effect [25], approaches to mitigate global climate change can lead to less local environmental pollution or vice versa [26,27]. For instance, electricity production is responsible for a major portion of air pollution and carbon dioxide emission in USA, in which electric generation causes 64% of all emissions of sulfur dioxide, 40% of all man-made emissions of carbon dioxide and 26% of all emissions of nitrogen oxides [28].

Few studies have been carried out to investigate the contribution of wind powers to respond climate change and to reduce pollutants, but little attention has been paid to the overall performance of the whole life cycle of wind power plants. Yousuf and his colleagues calculated the greenhouse gas (GHG) contribution from grid connected power plants by employing the methodologies of Intergovernmental Panel on Climate Change (IPCC) and United Nations Framework Convention on Climate Change (UNFCCC), shows that the weighted average baseline emissions factor for wind power project in Pakistan is 0.606 t CO_2/MW h [29]. Another study chose Xinjiang of China as a case and found that during 2006–2010, emissions mitigation by wind power accounted for 4.88% (1.07×10^7 t) of carbon dioxide, and 4.31% (4.38×10^4 t) of sulfur dioxide, 8.23% (3.41×10^4 t) of nitrogen oxides, 4.23% (3.2×10^3 t) of $PM_{2.5}$ emission compared to emissions by the coal fired thermal power sector [20]. However, from the life cycle point of view, wind power plants have to consume resources including iron, steel, copper, fiberglass, epoxy, concrete, and other materials in the manufacturing and construction phase. Plus, all components have