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The impacts of wind technology advancement on future global energy

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HIGHLIGHTS

- Integrated assessment model perform a series of scenarios of technology advances.
- Explore the potential roles of wind energy technology advance in global energy.
- Technology advance impacts on energy consumption and global low carbon market.
- Technology advance influences on global energy security and stability.

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ABSTRACT

To avoid additional global warming and environmental damage, energy systems need to rely on the use of low carbon technologies like wind energy. However, supply uncertainties, production costs, and energy security are the main factors considered by the global economies when reshaping their energy systems. Here, we explore the potential roles of wind energy technology advancement in future global electricity generations, costs, and energy security. We use an integrated assessment model performing a series of technology advancement scenarios. The results show that double of the capital cost reduction causes 40% of generation increase and 10% of cost decrease on average in the long-term global wind electricity market. Today's technology advancement could bring us the benefit of increasing electricity production in the future 40–50 years, and decreasing electricity cost in the future 90–100 years. The technology advancement of wind energy can help to keep global energy security and stability. An aggressive development and deployment of wind energy could in the long-term avoid 1/3 of gas and 1/28 of coal burned, and keep 1/2 biomass and 1/20 nuclear fuel saved from the global electricity system. The key is that wind resources are free and carbon-free. The results of this study are useful in broad coverage ranges from innovative technologies and systems of renewable energy to the economic industrial and domestic use of energy with no or minor impact on the environment.

1. Introduction

Nations around the world work on generating more energy from renewable resources and transitioning into energy systems to mitigate climate change and environmental degradation. Globally, renewable energy accounted for 19% of the energy consumption in 2012 and 22% of the electricity generation in 2013 [1], respectively. In more than 30 countries, renewable energy takes more than 20% of the energy supply. Global investment in renewable energies is more than 214 billion USD in 2013 [2]. Renewable energy markets are believed to continue rapidly grow in future decades [2].

Wind power has been seen as an important alternative to fossil fuels [3,4]. Studies focus on policy, technology, development and demonstration of wind energy system and their role on mitigation of environmental pollutants [5–10]. As an important renewable energy source, wind energy exists over wide areas and is seen as a way to limit greenhouse gas emissions to avoid the global warming threshold [11,12]. Internationally, there is strong support for promoting wind power [13]. At the end of 2014, the global cumulative installed capacity of wind power is 369,553 MW, which has increased 16% compared to 2013 [14]. Continuous development and deployment of wind energy helps climate

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mitigation, economic benefits, and energy security [15]. The long-term global technical potential of wind energy is believed to be five times the total current global energy production, or 40 times the current electricity demand, assuming all practical barriers needed were overcome [16]. What is more, supply uncertainties, costs of production, and energy security are the main concerns of current energy systems by the global economies [17]. There is no doubt that the technology advancement of wind energy could help reduce the costs of wind electricity generation construction and operation. It is important to understand how technology advancement would influence the global wind electricity production as well as energy system security and stability.

This study focuses on the impacts of wind technology on the future global energy. The purposes of this research are to study (1) the impacts of timescales on marginal effects of global wind electricity production to technology advancement; (2) the sensitivity of electricity costs to the change of capital costs; and (3) the impacts of wind energy development and deployment on energy system security and stability. The findings help to improve our understanding on the sensitivity of the future global electricity generation and costs to the technology advancement. The results could be helpful for the renewable energy studies, especially in the areas of the optimal use of energy resources, optimization of energy processes, mitigation of environmental pollutants, and sustainable energy systems.

2. Methodology

2.1. Model development for technology advancement

In this study, the technology advancement is represented by overnight capital cost (OCC) change. OCC is a typical parameter that is used in the power generation industry to describe the cost of building a power plant overnight [18]. OCC is useful to compare the economic feasibility of building plants with various technologies or technology advancement. OCC is also a parameter to represent technology, and does not take into account financing costs, and hence is not an actual estimate of construction cost.

If the OCC reduces from $C0$ \$/kW at year $yr0$ to $C1$ \$/kW at year $yr1$ with annual change rate r per year, then

$$C_1 = C_0(1 - r)^{(yr1 - yr0)}. \quad (1)$$

Annual OCC change rate (r) is

$$r = 1 - (C_1/C_0)^{1/(yr1 - yr0)}. \quad (2)$$

2.2. Simulation scenarios and data

We use the Global Climate Assessment Model (GCAM4.0) to do the simulation in this study. The model is a partial equilibrium model where economy, energy, agriculture, and land-use systems are modeled in an integrated framework (http://wiki.umd.edu/gcam).

We use the annual OCC change rate from year 2005 to year 2010 as the rate of business-as-usual (r_{BAU}), and the year 2010 as the baseline year for the simulation to the year of 2100. The parametrized XML file with OCC for GCAM in BAU scenario is shown in supplement.

In a scenario, if annual OCC change rate is α times of r_{BAU}, then r is

$$r = \alpha\, r_{BAU}. \quad (3)$$

We evaluate global total electricity generation and mean cost in this study.

2.3. Sensitivity analysis

We consider the sensitivity of global wind electricity generation and cost to the technology advancement. In this study, we use annual OCC change rates (r) to measure technology advancement. The considered OCC change rates are from 1 to 10 times of annual OCC change rate as business-as-usual (r_{BAU}) [3,4,6]. The baseline year of the simulation is 2010. Time horizons are near-term (2020), middle-term (2050) and long-term (2100).

3. Results and discussion

3.1. Impact on global wind electricity production

The technology advancement of wind energy impacts global wind electricity production (Figs. 1 and 2).

Fig. 1 illustrates the sensitivity of global wind electricity generation to the technology advancement when the annual overnight capital cost (OCC) change rate increase 1–10 times.

In the near term (2020), the global wind electricity generation (WEG) increases 19.5% on average for every additional increment of r (average marginal sensitivity). In the middle term (2050) and the long term (2100), the marginal sensitivities are 30.0% and 18.7%. In the middle term (2050), the first additional r increase causes 42.5% of WEG increments (first marginal sensitivity). Then this number decreases for every additional r increase. In the long term (2100), there is a similar result with that of the middle term. The first marginal sensitivity is 59.2%. The marginal sensitivities are smaller than 10% after the 6th increment of OCC change rates.

Fig. 2 shows the change of absolute values of global wind electricity generation under different annual capital cost change rate. The wind electricity generation is ∼1.23 EJ in based year 2010. With annual capital cost change rate of business as usual (BAU), the global wind electricity generation is evaluated to be ∼5.0 EJ in 2020, ∼17 EJ in 2050, and ∼40 EJ in 2100. If the rate is double, wind electricity generation expands rapidly to ∼63 EJ in 2100, which is 58% more than that of BAU scenario.

With the technology advancement, the wind electricity generation has increased 27% in 2007 [19]. Since then, the wind electricity became an important part in the global energy markets with 36 billion USD of annual additional installed generating equipment [19]. In reality, the wind electricity generation may fluctuate with global economic situations and policy options, such as the wind electricity generation that was affected by the 2009–2010 global financial crisis as well as other renewable energy industries. However, the wind electricity has ∼28% annual growth of new installations over the last five years, and wind electricity is projected to be 8% of global electricity market by 2018 [20].

In this study, we find that current technology advancement of wind energy could get the high benefit of increasing electricity production in future 40–50 years. The marginal electricity production declines with the technology advancement increase, i.e., for the same amount of capital cost reduction (due to technology advancement), the first reduction could help to generate more electricity than the second. The earlier the investment on wind energy development is, the more benefits could be received from the increased wind electricity generation.

3.2. Impact on global wind electricity economics

We also consider the technology advancement of wind energy impacts on global wind electricity economics (Figs. 3 and 4).

Fig. 3 illustrates the sensitivity of global wind electricity economics to the technology advancement. In the near term (2020), the average marginal global electricity cost to capital cost