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Financial viability of grid-connected solar PV and wind power systems in Germany

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Abstract

The German electricity sector is in a period of transition, spurred by the German government's endeavor to maintain a sustainable, secure, climate-friendly and affordable energy supply system. The most important aspects of this *Energiwende* are the phase out of nuclear energy, promotion of renewable energy technologies, and reduction of greenhouse gas (GHG) emissions. As a consequence, huge investments in power generation systems and infrastructure are needed. Wind and solar photovoltaics (PV) are important renewable energy sources for achieving the goals, but power generation depends on spatial and meteorological conditions on site. For new build PV systems, the level of on-site solar irradiation is crucial, whereas the yield of wind turbines is mainly determined by the wind speed on site. In the model-based analysis with the RETScreen software, we distinguish between three different regions in order to take differences in climatic and geographical conditions in Germany into account. For each region, six locations with specific site conditions are used for the calculations. Projections are made for the base year 2015 and the future year 2030. We find that PV systems achieve levelized cost of electricity (LCOE) below 11 €-ct/kWh in 2030, with a GHG reduction potential of 133-289 €/tCO_2. The LCOE of wind power ranges from 5.1-16.1 €-ct/kWh and the related GHG mitigation costs from 101-321 €/tCO_2. In light of these results, it seems to be possible to restructure the German electricity generation system in a cost-effective and environmentally efficient way. Due to decreasing unit investment costs and increasing capacity, solar PV and wind power become increasingly competitive against conventional power generation. Hence efforts are needed to enhance and optimize the grid integration of wind energy and PV and to maintain the long-term security of electricity supply during the transition process.

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1. Introduction

Primary energy consumption in Germany is highest in Europe (2014: 13,088 PJ), and well ahead of France and the United Kingdom, and is ranked as the world's number seven [1]. Because of its limited domestic reserves, Germany is an energy-importing country. By counting nuclear as an imported energy source the total share of imported energy in the total primary energy supply was 70% in 2013 [2]. This leads to a dependency on exporting countries, which must be reduced by a wide-range diversification of supply sources [3]. Natural gas and crude oil completely depends on import from different countries. Petroleum has quantitatively the largest share in terms of energy consumption, followed by gas, and electricity. In 2013, 594.3 TWh of electricity were consumed in Germany. Renewable energy technologies have been increasing in recent years and provide a significant part of the domestic primary energy supply today [4, 2].

Total installed capacity in 2014 with all power plants was 195 GW in Germany [5]. Wind power and PV had the largest share, followed by natural gas, hard coal, lignite, oil, nuclear and water. The electricity generation technologies differ, thereby, in their availability and utilization hours. Conventional thermal power plants such as nuclear power, lignite, and hard coal, are characterized by a high number of utilization hours per annum. They have low variable costs and default rates. In contrast, wind power and solar PV depend on the weather and therefore show large fluctuations in their feed-in to the grid. Although wind power and solar PV accounted for 39.7% of the total installed capacity, they only generated 16% of the total energy demand in 2014 [5]. Nuclear, lignite, hard coal and gas jointly contributed 55% of the total generated electricity, despite their comparatively low installed capacity. However, due to the increasing share of renewable but fluctuant nature, thermal power plants are still indispensable for a stable energy supply today [6, 7].

In the context of GHG emissions, Germany is the largest emitter in the European Union. However, GHG emissions have declined since 2000. In the Energy Concept, the German Federal Government has established ambitious targets for GHG emissions reduction. In 2010, CO_2 emissions from fuel combustion accounted for the largest share of GHG emissions in Germany, with a total of 81.5%. More than 75% of CO_2 emissions by fuel combustion came from coal and oil usage (41.6% and 34.2%, respectively), in 2010 [8]. The power generation sector accounted for 43.4% of energy-related emissions in 2010 [9]. By considering the government's targets and the price competitiveness along with the carbon mitigation potential, wind and PV are realistic options for future electricity generation.

Within the energy transition Germany pursues an ambitious target to switch from a leading industrialized nation to a sustainable, secure, climate-friendly, affordable, and nuclear power-free energy supply nation. Besides of the expansion of renewable energies and the increase in energy efficiency, energy-saving measures are important to mitigate climate change, save energy resources, and to boost Germany as a business location for sustainable and innovative development [5]. In general, Germany is on the way to achieve these ambitious goals. The expansion targets for renewable energy technologies have been fulfilled satisfactorily, however, at very high costs [10].

The basis for the development of renewable energies is the German Act on Granting Priority to Renewable Energy Sources (Erneuerbare Energien Gesetz, EEG). The rapid expansion led to a high share of renewables in German energy supply system, it can also increase the reallocation charge and then electricity prices. In order to reduce the costs for the further expansion of renewable energy the new Renewable Energy Sources Act focuses on less expensive technologies like wind energy and PV [5,6]. Based on this amendment, the share of renewable energy to be reached is up to 40-45% by 2025 and then to be raised further to 55-60% by 2035 [6].

In this paper, the techno-economic potentials of wind power and PV for different regions in Germany are determined. Thereafter, the power generation costs are estimated for the current year 2015. Expected future market prices are based on a literature review. Finally, associated CO_2 reduction costs are estimated and an assessment of the mitigation potentials carried out. The model-based computations are performed with RETScreen 4.0 (www.retscreen.net; cf. section 3.1). Overall, the present work includes an analysis of the role of grid-connected PV