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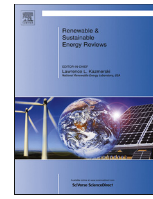

Impacts of large-scale Intermittent Renewable Energy Sources on electricity systems, and how these can be modeled

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ABSTRACT

The electricity sector in OECD countries is on the brink of a large shift towards low-carbon electricity generation. Power systems after 2030 may consist largely of two low-carbon generator types: Intermittent Renewable Energy Sources (IRES) such as wind and solar PV and thermal generators such as power plants with carbon capture. Combining these two types could lead to conflicts, because IRES require more flexibility from the power system, whereas thermal generators may be relatively inflexible. In this study, we quantify the impacts of large-scale IRES on the power system and its thermal generators, and we discuss how to accurately model IRES impacts on a low-carbon power system. Wind integration studies show that the impacts of wind power on present-day power systems are sizable at penetration rates of around 20% of annual power generation: the combined reserve size increases by 8.6% (6.3–10.8%) of installed wind capacity, and wind power provides 16% (5–27%) of its capacity as firm capacity. Thermal generators are affected by a reduction in their efficiency of 4% (0–9%), and displacement of (mainly natural gas-fired) generators with the highest marginal costs. Of these impacts, only the increase in reserves incurs direct costs of 1–6€/MWh_{wind}. These results are also indicative of the impacts of solar PV and wave power. A comprehensive power system model will be required to model the impacts of IRES in a low-carbon power system, which accounts for: a time step of <1 h, detailed IRES production patterns, flexibility constraints of thermal generators and interconnection capacity. Ideally, an efficient reserve sizing methodology and novel flexibility technologies (i.e., high capacity interconnectors and electricity storage and DSM) will also be included.

Contents

Abbreviations: CCS, carbon capture and storage; CHP, combined heat and power; DSM, demand side management; ELCC, effective load carrying capacity; GCSI, Global Clear Sky Index; IRES, Intermittent Renewable Energy Sources; NC, nameplate capacity; LOLE, Loss Of Load Expectation; LOLP, Loss Of Load Probability; RMSE, root mean square error; TSO, transmission system operator; UCED, unit commitment and economic dispatch

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1. Introduction

The electricity sector in OECD countries is on the brink of a large shift towards low-carbon electricity generation. This process is driven by concerns about climate change, depletion of fossil fuels, and energy security [1]. To realize the emission reduction targets put forward by the European Commission and the White House, the respective EU and US power sectors will have to reduce 2005 level CO_2 emissions by 58% and 42% by the year 2030, and even by as much as 79% and 83% by the year 2050 [2,3].

As a result, the shares of low-carbon generators in the electricity mix have been forecasted to increase. In the 2 Degree Scenario of the IEA for 2050, the worldwide shares of renewable technologies are forecasted to increase to 57% of the load served, and the shares of nuclear power plants and power plants with carbon capture are also projected to increase to 19% and 15% of the load served [4]. In the 2050 roadmap of the European Commission, wind power is projected to become the largest source of power in the EU by 2050, combined with significant shares of nuclear and CCS generators [3].

It is currently unclear how the generators of a low-carbon electricity system will affect each other, because low-carbon generators can have specific operating properties. Intermittent Renewable Energy Sources (IRES) such as wind, solar PV, and wave power require more flexibility, while low-carbon generators may be less flexible. Nuclear power plants and coal-fired power plants (which can be equipped with carbon capture) are currently relatively inflexible [4,5]. The variability and limited predictability of IRES result in a number of “power system impacts”, which can become a challenge at high penetration levels [6–10]. Holttinen has classified four short-term impacts of wind power that depend on the operational properties of the electricity generation