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Buffering volatility: A study on the limits of Germany's energy revolution[☆]

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ABSTRACT

Squaring hourly demand and wind-solar production data for Germany and a number of neighbouring countries with the results of the EU's ESTORAGE project, this paper studies the limits of Germany's energy revolution in view of the volatility of wind and solar power. In addition to pumped storage, it considers double-structure buffering, demand management, Norwegian hydro-dam buffering and international diversification via grid expansion. If Germany operated in autarchy and tried to handle the volatility of wind-solar production without using stores while replacing all nuclear and fossil fuel in power production, on average 61%, and at the margin 94%, of wind-solar production would have to be wasted, given the current level of other renewables. To avoid any waste, the wind-solar market share in an autarchic solution must not be expanded to more than 30%. By using Norway's hydro plants the share could be expanded to 36%. If Norway were to build all the pumped-storage plants the ESTORAGE study deems feasible, Germany's wind-solar market share could be expanded by another 24 percentage points to about 60%, which corresponds to 48% of the combined German and Norwegian markets. Additionally expanding the market to Switzerland, Austria and Denmark and building the maximal number of pumped stores would increase the combined wind-solar market share for all five countries to nearly 50%.

1. Introduction: Germany's energy revolution

With its *Energiewende* Germany is planning a true energy revolution,[1] dramatically boosting the market share of wind and solar energy in the production of electric power, crowding out fossil energy in general, and exiting nuclear energy. This paper studies the challenges posed by this endeavour, focusing on the difficulties of coping with the enormous volatility of wind and solar energy.

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[1] For discussions of the feasibility, see Nitsch et al. (2010), Klaus et al. (2010), and Sachverständigenrat für Umweltfragen (2011). For a discussion of the economic aspects, see Edenhofer et al. (2013).

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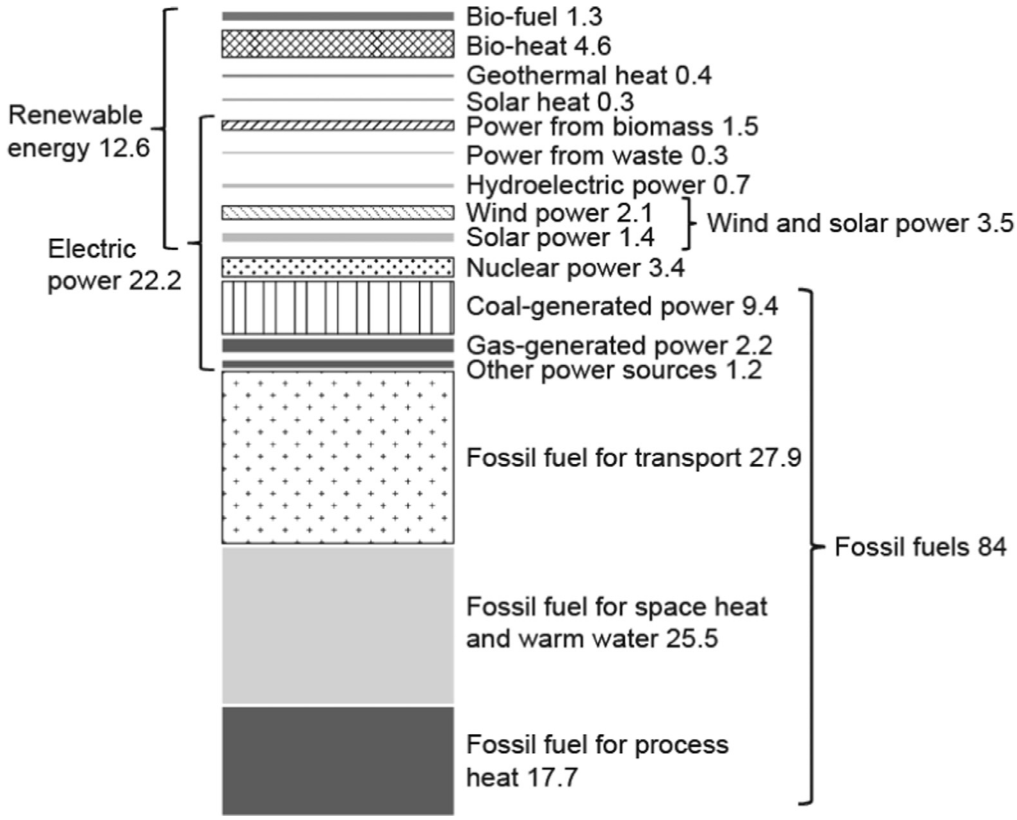

Fig. 1. Germany's final energy production (2014, %).
Calculations based on: Arbeitsgemeinschaft Energiebilanzen (2015, 2016), Arbeitsgemeinschaft Energiebilanzen, Bruttostromerzeugung in Deutschland nach Energieträgern, http://www.ag-energiebilanzen.de/index.php?article_id=29&fileName=20160128_brd_stromerzeugung1990-2015.pdf.
Note: The percentages shown relate to Germany's final energy production of 2450.2 TWh by source. Final energy production is defined as aggregate production minus the energy sector's own consumption.

Arguably, the most prominent and promising strategies to buffer volatility involve pumped-storage plants, demand management, double structures retaining conventional plants as back-ups as well as grid expansion to other countries including Norway's hydro plant facilities. This paper discusses these options, squaring hourly production and consumption data for Germany and a number of neighbouring countries with new data on the geological and economic possibilities for the construction of pumped-storage stemming from the EU's ESTORAGE project. According to the EU Commission, pumped storage plants "offer a new era of smarter energy management" that would help Europe to move to green energy and fight climate change.[2]

Germany's green energy revolution has been going on for two decades, but accelerated substantially after the 2011 Fukushima accident, as Germany reacted with the decision to abandon all of its 17 nuclear power stations, which at that time accounted for a good fifth of the country's production of electric power. By the end of 2015, nine nuclear plants were shut down, with a phase-out of the remaining plants scheduled for 2022.

Germany also wants to phase out fossil fuel. In the Kyoto agreement the EU committed to an 8% reduction (United Nations, 1998) in CO_2 emissions, and in the subsequent EU negotiations it agreed to contribute by cutting its own emissions by 21% (European Communities, 2002) by 2012. Moreover, Germany announced that it will reduce its emissions by a further 19 percentage points by 2020, so as to achieve an overall reduction of 40% versus 1990.[3] Following the EU decisions, it intends to cut emissions by 80% by 2050.[4]

The double exit from nuclear and fossil energy is ambitious. The dimensions of this task are illustrated in Fig. 1, which offers an overview of Germany's entire final energy structure by sources and final uses of energy in 2014 (which happens to be very similar to that of the OECD as a whole).

The figure shows that in 2014, with a share in final energy production of 3.5%, wind and solar power contributed about as much energy as the remaining nuclear power plants, which accounted for 3.4%. Thus, a near doubling of Germany's

[2] See DNV GL (2015) and European Commission (2016).
[3] Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (2014).
[4] European Commission (2011).