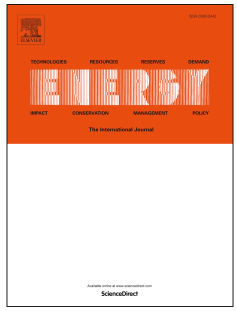
Accepted Manuscript



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D.P. Schlachtberger, T. Brown, S. Schramm, M. Greiner

PII: S0360-5442(17)30996-9

DOI: 10.1016/j.energy.2017.06.004

Reference: EGY 11008

To appear in: *Energy*

Received Date: 24 February 2017

Revised Date: 30 May 2017

Accepted Date: 1 June 2017

Please cite this article as: Schlachtberger DP, Brown T, Schramm S, Greiner M, The benefits of cooperation in a highly renewable European electricity network, *Energy* (2017), doi: 10.1016/j.energy.2017.06.004.

The Benefits of Cooperation in a Highly Renewable European Electricity Network

D.P. Schlachtberger[a,*], T. Brown[a], S. Schramm[a], M. Greiner[b]

[a] *Frankfurt Institute for Advanced Studies, 60438 Frankfurt am Main, Germany*
[b] *Department of Engineering, Aarhus University, 8000 Aarhus C, Denmark*

Abstract

To reach ambitious European CO_2 emission reduction targets, most scenarios of future European electricity systems rely on large shares of wind and solar photovoltaic power generation. We interpolate between two concepts for balancing the variability of these renewable sources: balancing at continental scales using the transmission grid and balancing locally with storage. This interpolation is done by systematically restricting transmission capacities from the optimum level to zero. We run techno-economic cost optimizations for the capacity investment and dispatch of wind, solar, hydroelectricity, natural gas power generation and transmission, as well as storage options such as pumped-hydro, battery, and hydrogen storage. The simulations assume a 95% CO_2 emission reduction compared to 1990, and are run over a full historical year of weather and electricity demand for 30 European countries. In the cost-optimal system with high levels of transmission expansion, energy generation is dominated by wind (65%) and hydro (15%), with average system costs comparable to today's system. Restricting transmission shifts the balance in favour of solar and storage, driving up costs by a third. As the restriction is relaxed, 85% of the cost benefits of the optimal grid expansion can be captured already with only 44% of the transmission volume.

Keywords: energy system design, large-scale integration of renewable power generation, power transmission, CO_2 emission reduction targets

1. Introduction

The European Council has set the goal to reduce CO_2 emissions in the European Union by between 80% and 95% in 2050 compared to their 1990 values [1]. Most European countries will rely on renewable energy sources to reach this goal. Although the majority of renewable energy comes from hydroelectricity today, the renewable sources with the greatest expansion potential are wind and solar energy.

The strong weather-dependent variations of wind and solar generation present a challenge to the balancing of production and demand in the electricity system. These variations have particular spatial scales (wind speeds have a correlation length of several hundreds of kilometres) and temporal scales (both solar and wind have daily variations, but also seasonal patterns and synoptic-scale variations of multiple days as large weather systems pass). The countries of Europe are small enough that the wind and solar generation inside each country is highly correlated. This means that if each country has to balance its own electricity generation, it must be able to deal with the extreme highs and lows of wind and solar generation by itself. Because exploitable hydroelectricity sites are limited and geographically very unevenly distributed, and backup generation from fossil fuel plants is restricted by the CO_2 cap, the rest of the balancing must come from storage solutions or, in part, from demand side flexibility. The need to invest in storage, on top of generation assets, tends to make these electricity systems expensive [2, 3, 4].

The alternative is to balance the fluctuations of wind and solar in space with inter-connecting transmission between countries, rather than in time with storage. These solutions require networks on the continental scale in order to smooth

*Corresponding author
Email address: schlachtberger@fias.uni-frankfurt.de (D.P. Schlachtberger)