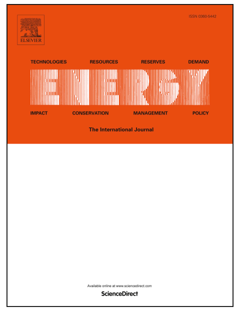
# Accepted Manuscript

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PII: S0360-5442(18)31602-5

DOI: 10.1016/j.energy.2018.08.070

Reference: EGY 13546

To appear in: *Energy*

Received Date: 26 March 2018

Revised Date: 3 August 2018

Accepted Date: 8 August 2018

# Cost optimal scenarios of a future highly renewable European electricity system: Exploring the influence of weather data, cost parameters and policy constraints

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**Abstract**

Cost optimal scenarios derived from models of a highly renewable electricity system depend on the specific input data, cost assumptions and system constraints. Here this influence is studied using a techno-economic optimisation model for a networked system of 30 European countries, taking into account the capacity investment and operation of wind, solar, hydroelectricity, natural gas power generation, transmission, and different storage options. A considerable robustness of total system costs to the input weather data and to moderate changes in the cost assumptions is observed. Flat directions in the optimisation landscape around cost-optimal configurations often allow system planners to choose between different technology options without a significant increase in total costs, for instance by replacing onshore with offshore wind power capacity in case of public acceptance issues. Exploring a range of carbon dioxide emission limits shows that for scenarios with moderate transmission expansion, a reduction of around 57% compared to 1990 levels is already cost optimal. For stricter carbon dioxide limits, power generated from gas turbines is at first replaced by generation from increasing renewable capacities. Non-hydro storage capacities are only built for low-emission scenarios, in order to provide the necessary flexibility to meet peaks in the residual load.

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

## 1. Introduction

In order to meet the ambitious target of reducing carbon dioxide ($CO_2$) emissions in the European Union by 80% to 95% in 2050 compared to 1990 values, the electricity system has to undergo a fundamental transformation (see for instance the Energy Roadmap 2050 from the European Commission [1]). Wind and solar power plants are already today both mature and cost-efficient technology options, which can be scaled up to act as the basis of a low-emission future power supply (see [2] for an analysis of the increasing cost-competitiveness of renewable power generation technologies, and [3] for a discussion of cost-effective renewable energy options for all EU Member States). The challenges presented by the temporal fluctuations in these resources can be met with low-carbon technologies such as existing hydroelectricity power plants, or with storage options like batteries or hydrogen storage, which still have significant potential for further development. The benefit of the flexibility provided by storage has for instance been studied for a simplified model of a highly renewable European electricity system in [4], or with a focus on pumped hydro storage and wind power generation for the Irish system in [5]. In [6] the authors focus on least-cost combinations of renewable generation and storage for a large regional grid, whereas in [7] also the role of the spatial distribution and dispatch of storage capacities on continental scale in an European electricity system with 80% power production from variable renewable energies has been studied.

With respect to the spatial variability of weather-dependent renewable generation, large-scale power transmission capacities play a decisive role to provide a smoothing effect and to connect generation capacity at favourable distant locations with the load centres. The systemic advantage of aggregating variable renewable power generation over large distances has already been observed in the pioneering study by Czisch in [8]. This benefit of transmission has been confirmed in studies using more detailed models, which also take into account limitations and costs of the transmission infrastructure (see for instance [9] for a systematic study with regard to the renewable penetration levels and mixes, [10] for additional detailed backup capacity optimisations, or [11] for a techno-economic optimisation study at high renewable shares.

Given the complexity of such a system, in particular with respect to the spatio-temporal patterns and correlations in the renewable generation and load time series, it is a difficult task to deduce a cost-efficient overall system layout from heuristic principles alone. As a consequence, computational models are a central element in the development of policy guidelines for

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