Evaluating regulatory measures in the German energy transition – A European multimodal market optimization approach including distributed flexibilities

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Overview

The United Nations committed themselves to ambitiously reduce greenhouse gas emissions ensuring a deceleration of global warming [1]. These efforts have to be manifested in national (or European) law supporting energy efficiency, renewable energies and sector coupling [2]. Those regulatory measures are often applied using incentives, subsidies and resulting economical costs which can be rolled over in levies. The political challenge is to provide cost efficient interventions in order to reach the climate targets and corresponding constraints. This leads to a need for fundamental optimization models which allow an economic assessment of individual dispatch decisions and their systemic feedback. Fundamental models enable the evaluation of the power system's sensitivity to interventions. Mathematical optimization delivers the framework for formulating rational decisions of entities within the power sector. Common fundamental models simplify distributed energy resources (DER), mainly wind and photovoltaics (PV), through heavy aggregation and usually define their dispatch decision exogenously in a pre-processing procedure due to complexity reasons [3]–[7]. The systemic feedback is therefore not considered adequately in decentralized generation. This distortion is inadmissible especially in energy systems with high levels of renewable energies that actively participate in the market. Detailed unit commitment models which can cope with conventional power stations but also a large amount of active dispatched decentralized renewable power plants enables more precise techno-economic evaluations. This paper delivers an approach to optimizing the interconnected European power system including all large scale (>10 MW) hydro-thermal power plants in the European energy system (covering all interconnected zones of European Network of Transmission System Operators for Electricity; abbr.: ENTSO-E). Furthermore a data set of 22 million individual buildings is used to model decentralized flexibilities and renewables bottom-up within Germany. The objective is to integrate user- and technology-specific regulatory incentives into a bottom-up power system optimization with a high spatial resolution. This provides realistic conclusions by taking region-specific conditions into account. This paper's objective is developing a methodical approach which is able to include highly spatial resolved distributed resources into a pan-European unit commitment model. The applied regulatory framework focuses on German law. Nevertheless the approach can easily be applied to other legal environments.

Methods

The European Market Simulation is based on macroeconomic optimization approach with the objective to minimize the overall costs of electricity generation. All market zones within the ENTSO-E area are taken into account (coloured in green in Figure 1). The integration of decentralized power plants as autonomous agents capable of acting in a European electricity market model on a high geographical resolution requires a modelling environment that enables distributed computing on a high-performance computer (HPC) with many computing cores. The simulation model developed in this paper uses mathematical optimization and dynamic programming to find the optimal unit commitment decision for the entire

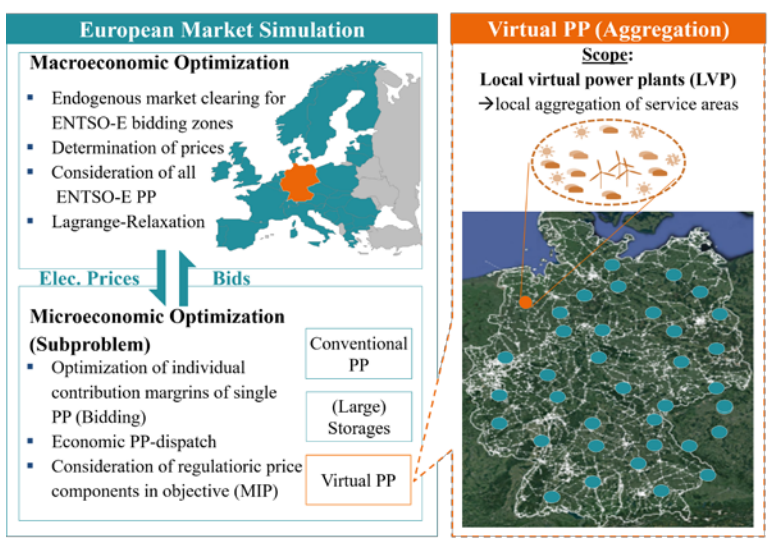

Figure 1: Overview of Market Simulation

system. In addition to the spatially highly distributed renewables, hydrothermal power plant units are considered individually as independent entities. The complex technical properties require a mixed integer programming (MIP) formulation for thermal power plants, a dynamic programming (DP) approach for hydro power plants and a linear programming (LP) approach for the virtual power plants (VPP) containing detailed information on decentralized units [8]. Even large scale HPCs are not suited for solving such problems. Therefore, the application of suitable decomposition algorithms is necessary. The given blockdiagonal structure in the unit commitment optimization problem of the power system for power plants with its coupling load constraints in each market zone imposes the use of Lagrangian Relaxation. This facilitates the contribution margin maximizing optimization of each entity using the Lagrangian multipliers which can be interpreted as wholesale electricity prices. Other methods, such as the Benders decomposition or Branch-and-Price (extension of the Dantzig-Wolfe decomposition by mixed-integer decision variables in the subproblems) have proved inefficient for this problem formulation.

Results and Conclusions

The power system is characterized by long depreciation periods. A fast transition in the power system therefore requires detailed simulations of regulatory measures for future scenarios to cope with these systematic inflexibilities. The goal of this paper was to present a model which allows quantitative analyses to facilitate political decisions regarding regulatory measures needed to support (and not to burden) technologies which are needed in the energy transition. When applied to the German power market the results point towards a reduction of inhibitory levies and incentives to establishing local power markets. The correct quantification of economically-optimal financial incentives for local energy markets or relieving measures for power to heat appliances shall be subject to investigation of further scientific treatises.

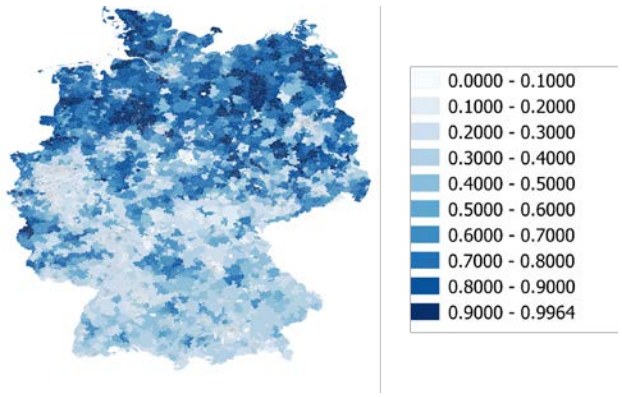

Figure 2: Local supply vs. wholesale supply

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