National-strategic investment in European electricity transmission capacity

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(1) Overview

The decarbonisation of the European electricity sector, as envisaged in the EU Road Map 2050 (EC 2011), requires both a transformation of the generation portfolio as well as a significant expansion of the power transmission system. There are several recent studies that aim to determine the optimal investment plans for a decarbonised electricity sector (Fürsch, Nagl, and Lindenberger 2012; Tröster, Kuwahata, and Ackermann 2011): these use a pan-European welfare maximization approach, where all investment decisions are taken by a benevolent central planner (or, equivalently, by competitive market players).

These studies do not consider that transmission investment has a strong impact on national welfare. Network expansion is still a national prerogative, both regarding the planning and the funding. Beneficiaries of transmission investment may be in a different jurisdiction than those bearing the costs. National governments, regulators and/or Transmission System Operators (TSO) may be reluctant to invest if the benefits accrue elsewhere, if no appropriate compensation mechanism is in place. Egerer, Hirschhausen, and Kunz (2012) discuss the implications on supplier and consumer welfare for different topologies of the North and Baltic Sea offshore connectors. While some countries gain from upgrades in the network, others may also lose. The allocation of costs is therefore of paramount importance (Buijs and Belmans 2011). Theoretically, the right allocation of benefits and costs through side payments results in a grand coalition and in a system welfare optimal expansion on the European level. There is a string of scientific literature examining various allocation methods based on cooperative game theory (Gately 1974; Nylund 2013).

On the European level, the inter-TSO compensation (ITC) mechanism is intended to allocate the long-run cost of transmission infrastructure to beneficiaries. Due to the large volumes at stake and the difficulty of defining a transparent and fair allocation scheme, the current volume of the ITC mechanism is insufficient to cover more than a very small share of long-run infrastructure costs (EC 2010).

Any analysis of the power market is particularly complicated due to the specific characteristics of electricity transmission: if two parties engage in a trade, power does not only flow on the direct line between the two parties, but may adversely affect other TSOs. Applying an incentive regulation approach, Hogan, Rosellón, and Vogelsang (2010) propose a mechanism to incentivize a monopolistic TSO to expand the grid in a welfare-maximizing way. However, this mechanism uses Financial Transmission Rights (FTR) as a simplification, When several TSOs are affected, as is usually the case in Europe, this approach is not valid due to loop flows. In order to properly capture how each network zone is affected, we therefore base our analysis on the actual power flows rather than the FTR simplification.

Our work combines the issue of a pan-European investment with national-strategic considerations; these include (national) funding requirements of investment, as well as the considerations of national welfare implications in transmission investment and the tariffs for funding operation and expansion of the grid. We use the term *"national-strategic"* to differentiate our work from other studies that treat generators as strategic players (Neuhoff et al. 2005; Schröder, Traber, and Kemfert 2013).

(2) Methodology

To address and better understand the national perspective of transmission investments we propose an equilibrium model that explicitly incorporates three aspects of transmission investment:

- An explicit funding requirement: investments in transmission capacity must be funded either through congestion rent or transmission tariffs. These requirements are enforced on a national level. Congestion rents are calculated based on actual load flows, rather than the simplification of FTRs.
- Effects of transmission tariffs on demand patterns on a national level.
- Financial transfers between TSOs to evaluate the effect of cost sharing. The sensitivity of the maximum amount redistributed on investments is tested exogenously.

This model is mathematically challenging: it includes binary variables, since transmission expansion options are usually discrete choices. It is a two-level problem, where investment is decided on the upper level, while the competitive power market forms the lower level. Congestion rents based on actual flows rather than

FTRs are included in the funding requirements; they are bilinear (product of the endogenous variables *line flow* and *price difference*), making this a non-convex integer two-level problem. We combine the approaches of disjunctive constraints (Gabriel and Leuthold 2010), strong duality (Ruiz and Conejo 2009) and integer-constrained complementarity problems (Gabriel et al. 2013) to derive and solve a convex Mixed Integer Complementarity Problem, and discuss properties of the solution.

(3) Results

We apply this model to stylized data based on the region Germany, Austria, Switzerland, France and Italy. The Alps region is of particular importance for the German "Energiewende" for its hydro storage potential. Its location in the heart of Europe makes it the major transit region in European transmission networks. Thus investment decisions in additional cross-border and capacities will provide better integration for renewable generation. It may also alter national production and consumption patterns as well as market prices. Preliminary results indicate that individual countries have strong incentives to invest less than the overall welfare-optimal solution. With the introduction of side payments to finance investments, high-price countries decide to bear some of the infrastructure costs of the transit countries. Even though this increases their transmission fees, lower prices of electricity have, overall, a beneficial effect on their national welfare.

(4) Conclusions

Compared to other aspects of the renewable energy system transformation, the costs of expanding transmission infrastructure are negligible. However, given regional opposition towards infrastructure investments and the associated costs, their necessity is often justified based on national transmission expansion plans. Yet planning with the objective of national welfare optimization does not sufficiently consider positive or negative externalities from a pan-European perspective. We prove in a stylized model that without the possibility of compensatory payments the network expansion results in equilibria that are not Pareto-optimal, This effect increases with higher shares of renewables when national electricity price can assume very low values in the marginal pricing scheme. Further research will therefore also have to consider tariffs or tax money used for capacity payments.

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