Introduction

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1. THE TOPIC

In times of growing environmental and climate concerns and increasingly cross-national energy markets, issues surrounding the coordination of infrastructure development have become more important than ever before. Today, the idea of "welfare optimization" that was one of the main objectives of traditional infrastructure policy is no longer the sole point of reference. When it comes to planning and implementing cross-border coordination, many "seams issues" arise, including the optimal scope of integration into single market zones, the sharing of costs and benefits, or the concrete steps toward achieving cross-border agreements. Cross-border coordination refers both to physical transportation infrastructure (electricity transmission, natural gas, CO_2 pipelines) and to supply infrastructure, and involves questions of generation adequacy, natural gas and electricity storage, etc. The issue is of particular importance in the search for sustainable energy security, where efforts to achieve decarbonization targets must go hand in hand with an affordable and secure energy supply.

The objective of this Special Issue, "Sustainable Infrastructure Development and Cross-border Coordination," is to contribute original literature to this important ongoing debate, in particular on the role of infrastructure development in the cross-country context, and extending to the regional and even continental level. Our hypothesis is that to address the specific challenges that arise in coordinating infrastructure policies, rigorous modeling and institutional analyses of the surrounding regulations are required to fully understand the situation and to draw sound and meaningful policy conclusions. The papers in this Special Issue share the conviction that infrastructure development is an important element of any low-carbon strategy, but that it is not a panacea to all the problems and issues that arise on the path toward a sustainable, secure, and affordable energy future.

2. FOCUS ON EUROPE AND ITS NEIGHBORS

While most of the challenges addressed in this Special Issue are relevant throughout the world, the papers of this Special Issue all apply their models to the specific context of Europe and its neighboring regions. Like other national and international bodies, the European Union (EU) has set concrete goals of cutting greenhouse gas emissions: the objective is a reduction by at least 40% by 2030, and towards 80-95% by 2050 (basis: 1990). In addition, the EU aims to increase the share of renewable energy by at least 27% and improve energy efficiency by at least 27% by 2030.

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Coordination is a major challenge for infrastructure policy in the European Union and its Member States, as it is in many other regions worldwide. The European Commission declared that 12 (of the 28) EU Member States do not meet the EU's minimum interconnection targets, and at least 10% of installed electricity production capacity should be able to be cross borders. An effectively interconnected European energy grid could save consumers significant costs, but it could also contribute to fixing the current unsustainable energy mix. An appropriate regulatory framework is needed to ensure that investments are carried out at national and European levels. Cross-border investments still present a major challenge. Multinational and European-wide cooperation is needed to promote and support market integration.

3. THE STRUCTURE OF THIS SPECIAL ISSUE

Most of the papers in this Special Issue were presented at the Second Berlin Conference on Energy and Electricity Markets and Policies (BELEC) in 2015. BELEC was conceived as a forum for conceptual but also applied contributions, in particular work on infrastructure stemming from the Energy Modeling Forum (EMF) Round No. 28, "The Effects of Technology Choices on EU Climate Policy." All submitted papers went through the *The Energy Journal's* regular refereeing process. In addition to this introduction, the Special Issue contains eight contributions that shed light on different coordination issues, all related to the development of sustainable infrastructure in the context of low-carbon transformation. The papers can be grouped according to two criteria:

- By sector, along the "horizontal" axis: The Special Issue covers natural gas infrastructure, electricity transmission, and CO_2 pipelines, as well as electricity generation infrastructures.
- By level of coordination issues, along the "vertical" axis: Four levels can be distinguished, first, between neighboring countries, second, at the continental (here: European) level, third, across different technologies, and fourth, with respect to infrastructure relations between Europe and Russia, a special feature of this issue.

Three papers address coordination issues in *natural gas* infrastructure, and these also deal with the important geopolitical role of Russia in addition to other regional and European-wide issues. *Fodstad, Egging, Midthun, and Tomasgard* examine the natural gas sector using a stochastic modeling approach: "*Stochastic Modeling of Natural Gas Infrastructure Development in Europe under Demand Uncertainty.*" Their conceptual contribution compares results from the stochastic model and the expected value model (and finds the difference to be small). They analyze infrastructure expansion at a higher level of aggregation including not only Russia but the Asian region as a whole. They find that the largest pipeline investments will be in Asia, that there is a trend towards increasing gas supply from Africa to Europe, and that within Europe, eastward connections will be strengthened.

The second paper on natural gas by *Holz, Richter, and Egging* takes a European-wide approach, also looking in particular at the role of Russia: "*The Role of Natural Gas in a Low-Carbon Europe: Infrastructure and Supply Security*." The paper investigates different pathways for future natural gas consumption, and suggests that even in the case of natural gas use increase, current import infrastructure and intra-European transit capacity are sufficient to accommodate future import needs. However, due to strong demand in Asia, Europe will have to rely to an increasing degree on supply from Africa and the Caspian region, leading to new infrastructure capacity from these regions.

Kiss, Selei, and Toth propose "*A Top-Down Approach to Evaluating Cross-Border Natural Gas Infrastructure Projects in Europe.*" They examine the conceptual question of how to select infrastructure projects from a variety of proposed projects with a regional focus on Central and South-Eastern Europe. This region is particularly sensitive to cross-border integration because of the strong traditional ties with Russia and the slow pace of emerging European integration. The authors find that a small number of projects would be sufficient to raise regional welfare significantly. The paper also explores consequences of Russian gas permanently delivered to the EU border from northern and southern routes that bypass Ukraine, and finds modest negative welfare effects.

Two papers address coordination issues of *electricity* infrastructure, one at the regional level, the other at the European level: In the paper "*Coordinating Cross-Country Congestion Management: Evidence from Central Europe,*" *Kunz and Zerrahn* adopt a regional approach, addressing challenges of the institutional design of regional electricity exchanges in the presence of network congestion: the region comprises Germany, Poland, the Czech Republic, Austria, and Slovakia. They analyze different cases of coordination in congestion management between national transmission system operators, and produce results showing the beneficial impact of closer cooperation but also the challenges that arise due to distributional issues and the transaction costs of coordination.

Egerer, Gerbaulet, and Lorenz address the same sector at a somewhat broader level: "*European Electricity Grid Infrastructure Expansion in a 2050 Context.*" They use a bottom-up techno-economic electricity sector model to analyze different scenarios of European electricity sector transformation. The high granularity of their model allows them to compare the level of *domestic* grid upgrades and new construction with *cross-border* investments. Their findings show that the former are in fact more important, and also indicate that carbon emission reduction targets alone provide insufficient information for long-term network planning.

As the challenges of the low-carbon transformation increase, it becomes increasingly important to combine sectors that used to be separate in order to support efforts towards decarbonization. In this spirit, *Abrell and Weigt* explore the possibility of "*Combining Energy Networks in Electricity and Natural Gas Transmission in Europe.*" The paper analyzes different scenarios of long-term European decarbonization sketched out in the European Energy Roadmap 2050, and identifies criteria related to electricity and/or natural gas infrastructure and the interrelation of the two markets. If current network expansion plans are carried out, network congestion will play a minor role in the European natural gas and electricity markets, whereas a rapid increase of renewables generation in the electricity sector will reduce the dependence on natural gas imports quickly.

Another challenge of coordination in electricity markets arises around the choice of policy instruments to support a specific low-carbon technology: renewables. *Pahle, Gambarella, Schill, and Tietjen* examine this issue in a model-based comparison of different policy schemes: In "*Renewable Energy Support, Negative Prices, and Real-time pricing*," they find that distortions resulting from induced negative prices do not reduce the net consumer surplus of the feed-in premium relative to the capacity premium. Furthermore, surplus gains experienced by consumers who switch from flat-rate to real-time pricing are markedly higher under the Feed-in-Premium, which might be interpreted as an incentive for switching.

Last but not least, several particularly challenging coordination issues are raised by *Oei and Mendelevitch* in their paper on "*European Scenarios of CO_2 Infrastructure Investment.*" Until not too long ago, the idea of building continental-scale CO_2-infrastructure networks to support carbon capture, transport, and storage (CCTS) was popular among energy and climate economists. Based on a review of the current state of CCTS, the paper analyzes the layout and costs of a

potential CO_2 infrastructure in Europe with a time horizon of 2050. The authors apply the mixed integer model CCTSMOD to compute a CCTS infrastructure network for Europe, examining the effects of different CO_2 price paths with different regional foci. They find the degree of CCTS deployment to be more sensitive to variable costs of CO_2 capture than to investment costs. Scattered CCTS deployment increases unit cost of transport and storage infrastructure by 30% or more.

4. THANKS

This Special Issue contains selected papers presented at the Second Berlin Conference on Energy and Electricity Economics (BELEC), held in Berlin on May 28-29, 2015. The conference was co-organized by members of the research project "Modeling the Energy Transformation" (MASMIE), based at the German Institute for Economic Research (DIW Berlin), and the research project "Sustainable Energy Networks" (EE-Netze), based at Berlin University of Technology. We are grateful to the organizers of the conference and to all the contributors of papers to this Special Issue. Thanks also go to Stiftung Mercator for supporting both the research projects and the publication of this Special Issue. Some of the authors were involved in a previous modeling exercise in the framework of EMF 28, "The Effects of Technology Choices on EU Climate Policy." We thank all those who have made this round a success. Cooperation with IAEE Headquarters was excellent, thanks for pushing the Special Issue from this side, too. Last but not least, our thanks go to the anonymous referees of this Special Issue for their thorough and concise reviews and their very collaborative involvement in the entire process.