Institute of Energy Economics
at the University of Cologne

University of Cologne Forum Energy

Market design and regulation for stochastic electricity supply chains

Final Report

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1 Background and objectives

While combatting climate change, increasing amounts of intermittent and stochastic generation from wind and solar resources pose new challenges to all parts of the electricity supply chain. Our UoC Forum project aimed at providing answers to relevant yet unresolved problems in the field of market design and regulation of stochastic electricity supply chains by bringing together specific energy market know-how and methods from supply chain management. Moreover, our activities were supposed to deepen and to extend energy-related research activities of the UoC with a sustainable and long-term perspective.

2 Employed Researchers

With the financial resources granted to our project, we were able to hire three researchers for the project**. Dr. Simeon Hagspiel** was employed as a postdoctoral researcher. He was responsible for large parts of the project, including the proposal preparation, executing the research agenda, the project management as well as the supervision of the two other researchers. Overall, the project allowed Dr. Simeon Hagspiel to continue and push forward his academic work and career. **Jakob Peter** was hired as a researcher and doctoral candidate. He worked on a subproject dealing with the reliability of capacity-constrained multi-regional power systems. This research will become an integral part of his doctoral dissertation which he initiated and advanced substantially during the project**. Marius Overath** was employed as a student assistant. He supported the project mainly by literature reviews, data preparation, and preliminary analyses.

3 Project Activities

3.1 Research Contents

WP1: Stochastic elements in the electricity supply chain and economic implications. As one of the major challenges for today's electricity systems, we investigated the stochastic nature of wind and solar power plants. Specifically, we determined the individual and joint availability of wind turbines at different locations. These were found to exhibit positive dependencies which may be captured by means of linear correlation coefficients or more sophisticated Copula models. These interdependencies which essentially represent a (typically negative) externality to the system need to be taken into account in economic mechanisms (such as capacity mechanisms to ensure reliability of supply) to reach an efficient outcome. In contrast,

the reliability of conventional plants (such as coal, gas or nuclear) can be assumed independent, thus allowing for a straightforward convolution methodology. These findings are published in Hagspiel (2016a), Hagspiel (2016b), Hagspiel (under review).

WP2: Market design and regulation. In order to design efficient market mechanisms and regulatory rules, the true characteristics of stochastic elements need to be properly reflected. The abovementioned spatial interdependencies pose a particular challenge as the system value needs to be allocated to individual units. We investigated the Shapley Value as a promising tool to achieve desirable outcomes. Moreover, we found that cross-border cooperation of capacity-constrained network infrastructures is key for efficient outcomes. These contents are published in Bertsch, Hagspiel & Just (forthcoming), Bertsch, Brown, Hagspiel & Just (forthcoming), Hagspiel (2016a), Hagspiel (2016b), and Bertsch & Hagspiel (under review).

WP3: Case study implementation. Applicability and relevancy of our concepts was tested with a European dataset that was prepared and deployed during the project. Specifically, we collected demand data from ENTSO-E, as well as supply data from the Institute of Energy Economics (EWI) and the Wind Energy Output Model prepared within the UoC's Emerging Group on Energy Transition and Climate Change (ET-CC). Computations were conducted on the UoC's high performance computing center CHEOPS. Numerical results proved applicability and relevance of our analyses. Results can be found in Hagspiel (2016b), and Hagspiel, Knaut & Peter (2016).

3.2 Collaborations

Besides the chairs of the two applicants, the project included additional collaborations with internal and external partners.

The project had close ties with the UoC Emerging Group on Energy Transition and Climate Change (ET-CC). As a major activity, we organized a joint international expert workshop, entitled "Transition to power systems with weather-dependent generation", with approx. 25 participants from different German and European universities and research facilities (Participants list and agenda can be found here). The established network will last well beyond our Forum project. Moreover, we had regular joint meetings (approx. every two months) to exchange views and findings. A joint paper was elaborated and published in Hagspiel, Knaut & Peter (2016).

In a joint initiative with Prof. Rainer Schrader & Prof. Frank Vallentin from the Mathematical Institute, we defined of a Master's thesis on the non-linear optimization of electricity network capacities, for which the call is still open.

Jointly with the RRZK and with the friendly support of Prof. Ulrich Lang, Philipp Henckes from the ET-CC project and Dr. Simeon Hagspiel have been granted access to the CHEOPS high performance computer to conduct large and complex simulation and optimization studies. The account has for instance been used to derive the energy output of European wind turbines for a long-term high-resolution reanalysis dataset (Hagspiel (2016b) and Henckes, Obermüller & Knaut (2016)).

Dr. Simeon Hagspiel has been meeting with Andreas Fügener, Junior Professor at the SCMMS institute of Prof. Thonemann, to establish a research project on “Coalitions in Innovation Projects”, analyzing the behavior of individuals in coalition-formation for different innovation settings in a series of laboratory experiments.

Dr. Simeon Hagspiel has also been working on a research project jointly with Benjamin Tischler, postdoctoral student at the Institute of Econometrics and Statistics of Prof. Breitung. The project investigates welfare effects of design changes in the European electricity spot market.

3.3 Project Outputs (realized during the project period)

Overall, the project outputs include 1 dissertation, 3 conference presentations, 2 conference papers, 2 submissions under review, and 2 resubmissions of previous journal articles. Annex 5.1 contains a detailed list and links to the project outputs. A dedicated webpage contains further information on the project (Link).

4 Outlook

In order to pursue a long-term strategy, we have been preparing an extension of our activities beyond the project period:

- An internal workshop with all projects that have received funding within the UoC Forum Energy to exchange views and ideas about energy-related research at UoC.
- A stay abroad of Dr. Simeon Hagspiel with the group of Prof. Anthony Papavasiliou at the Center of Econometrics and Operations Research (CORE) at the Université Catholique de Louvain (UCL). The Forum project allowed to establish the contact and to write four proposals for external funding (EU Marie Curie Individual Fellowship, DFG Postdoc Fellowship, MOVE-IN Louvain: Incoming Post-doc Fellowships co-funded by the Marie Curie Actions, CORE Postdoctoral Fellowship)
- Dr. Simeon Hagspiel has applied for the following prices and awards: GEE Preis des Energieforums, 6th EEX Excellence Award 2016, PhD Thesis Award on Sustainable Supply Chains, where decisions are still pending.

5 Annex

5.1 List of Project Outputs (realized during the project period)

Doctoral dissertations

- S. Hagspiel (2016a). Essays on the Economics and Regulatory Design of Power Systems. Doctoral degree from the University of Cologne, Department of Economic and Social Sciences, received on July 4th 2016. Link

Conference presentations

- S. Hagspiel (2016). Supply Chain Reliability and the Role of Individual Suppliers. *OR 2016 - International Conference on Operations Research*, Hamburg, Germany. Link
- S. Hagspiel (2016). Reliability through Spatial Aggregation – The Capacity Value of Wind Power in Europe. *Wind Integration Workshop 2016*, Vienna, Austria. Link
- J. Peter (2016). The Capacity Value in Systems with Multiple Regions and Technologies. *Wind Integration Workshop 2016*, Vienna, Austria. Link

Conference papers

- S. Hagspiel (2016b). Reliability through Spatial Aggregation – The Capacity Value of Wind Power in Europe. *Wind Integration Workshop 2016*, Vienna, Austria. Link
- S. Hagspiel, A. Knaut, J. Peter (2016). The Capacity Value in Systems with Multiple Regions and Technologies. *Wind Integration Workshop 2016*, Vienna, Austria. Link
- P. Henckes, A. Knaut, F. Obermüller (2016). Twenty Years of European Wind Power Production - Balancing Effects in Europe with a Focus on Germany, Proceedings of the 15th Wind Integration Workshop 2016, Vienna, Austria. Link

Submissions under review

- J. Bertsch, S. Hagspiel (under review). Regulation of non-marketed outputs and substitutable inputs, published as *EWI WP* 15/06, under review at the *Journal of Industrial Economics.* Link
- S. Hagspiel (under review). Reliability with interdependent suppliers, published as *EWI WP* 16/05, under review at *Production and Operations Management*. Link

Resubmission of two previous journal articles:

- J. Bertsch, S. Hagspiel, L. Just (forthcoming). Congestion Management in power systems – Long-Term Modeling Framework and Large-Scale Application. *Journal of Regulatory Economics*. DOI 10.1007/s11149-016-9310-x. Link

- J. Bertsch, T. Brown, S. Hagspiel and L. Just (forthcoming). The relevance of grid expansion under zonal markets. *The Energy Journal*. DOI 10.5547/01956574.38.5.jber. Link

5.2 Declaration of budget expenditures

The following table recaptures the funding that was requested and granted to the project, and compares these figures with the realized expenditures. A detailed list of receipts will be handed in separately.

	Requested Funding	**Realized Expenditures**
Postdoctoral Researcher	43290 €	40425 €
Doctoral Researcher	23175 €	21217 €
Student assistant	9275 €	5690 €
Workshop	3000 €	1951 €
Travel (conferences)	3000 €	2704 €
Sum	**81740 €**	**71986 €**