Schweizerische Eidgenossenschaft
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Department of the Environment, Transport, Energy and Communication DETEC

Swiss Federal Office of Energy SFOE
Energy Research

Annual report 2017

Impact of different market designs in the CWE market area on electricity prices and on the competitiveness of Swiss hydropower (PowerDesign)

Date: March 15th, 2018
Town: Karlsruhe

Publisher:
Swiss Federal Office of Energy SFOE
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www.bfe.admin.ch

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SFOE contract number:	SI/501308-01

The author of this report bears the entire responsibility for the content and for the conclusions drawn therefrom.

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1. Project goals

This project aims to assess the impact of market design choices in the neighbouring electricity markets on the competitiveness of hydropower and on the costs of support schemes for renewable energy sources (RES) in Switzerland.

2. Summary

The main objective of the research project is to assess how changes in the framework conditions of European and Swiss energy markets (e.g. market design and support schemes for renewable energy) affect the competitiveness of hydropower and funding volumes for RES in Switzerland. For this, we investigate the price effect of changes in the market design in Switzerland and its neighbouring countries. Different market scenarios are developed taking into account the most recent version of the EU energy roadmap and the Energy Strategy 2050 scenarios (Prognos AG 2012). The scenarios are input to an agent-based spot market model of the market coupling area of Central-Western Europe[1] (CWE), Switzerland and Italy. The model evaluates medium and long-term price developments and forms the core of this research project.

To carry out the analysis a sequential approach is applied. Firstly an econometric analysis identifies the main drivers of the Swiss electricity prices and the ones of the neighbouring countries. Then, the agent-based model PowerACE simulates the future capacity development of power plants and the resulting wholesale electricity prices for different market design assumptions. The resulting prices will be used to analyse the required RES subsidies due to alternative support schemes and RES scenarios. Subsequently, stochastic scenario trees will be generated and used for the stochastic optimization of the dispatch of Swiss hydropower storage plants.

In 2016, an econometric analysis of Swiss electricity prices has been carried out (Dehler et al. 2016). The analysis focuses on main drivers from neighbouring countries of the Swiss wholesale electricity prices. The results indicate that in summer Swiss prices correlate with the day-ahead wholesale prices of neighbouring countries. E.g. high wind power production in Germany decreases wholesale prices in Switzerland and Germany. In winter, high demand in Switzerland, France, and Italy raises wholesale prices in Switzerland.

This results were presented on several occasions in 2016:

- 14th Symposium Energieinnovationen in Graz, Austria (Dehler et al. 2016)
- IAEE International Conference in Bergen, Norway (Keles und Dehler 2016)
- Energy Research Conference Disentis 2016, Switzerland
- Workshop organized by the Swiss Federal Office of Energy (SFOE) in Zürich, Switzerland

In 2017, the agent-based electricity market simulation model PowerACE was further expanded (e.g. additionally extended to Austria, Italy and Switzerland) and a methodology for heuristic hydropower (seasonal storage as well as pumped storage power plants) dispatch was developed. Also the scenarios for the remainder of the project have been defined. Moreover, the modelling of pumped-storage plants was further advanced with unit tests following a novel optimization approach. For the

[1] CWE: Belgium, France, Germany, Austria, Luxemburg, the Netherlands

dispatch modelling of pumped-storage plants, the novel methodology uses stochastic optimal control theory.

Results and the project were presented at several conferences in 2017:

- 10th Internationale Energiewirtschaftstagung (IEWT) in Vienna, Austria (Zimmermann et al. 2017)
- IAEE International Conference in Singapore
- Energieforschungsgespräche 2017 Disentis, Switzerland
- CEE Inaugural Conference at ZHAW, Winterthur, Switzerland

3. Work undertaken and findings obtained

Econometric analysis: Swiss electricity prices
Electricity prices are determined by a variety of factors. In the short-term (e.g. on a day-ahead basis), such factors include weather conditions, electricity generation from RES, fuel and carbon emission allowance prices, demand levels and availabilities of power plants. The combination of these drivers causes the strong temporal cycles (e.g. daily, weekly) of electricity prices. Furthermore, European electricity markets are integrated through physical interconnections and various trading arrangements which make national electricity prices dependent on developments in interconnected regions.
Given the geographical situation, the Swiss electricity market - although not directly part of the European day-ahead market coupling - is affected by developments in neighbouring countries (e.g. German wind power production). An econometric analysis was carried out to determine the main fundamental drivers of Swiss electricity prices (and that of neighbouring countries). Suitable econometric methods (e.g. multiple regression) were applied and allowed to assess the quantitative impact of relevant factors on Swiss electricity prices.
This analysis was discussed at several occasions (Energieforschungsgespräche Disentis 2016, IAEE International Conference, SFOE-Workshop) and published in Dehler et al. (2016)[2]. The paper focuses on fundamental drivers from neighbouring countries of the Swiss wholesale electricity prices. The investigation shows that in summer, Swiss prices significantly correlate with the day-ahead wholesale prices of neighbouring countries (Germany and France). Especially German renewable power production significantly influences the Swiss prices. In winter, high electricity demand in Switzerland, France and Italy raises the Swiss prices, while the German load plays a larger role in summer. At the same time, gas prices impact the price for electricity in summer and winter, notwithstanding the fact that Switzerland has no major plants running on fossil fuels.

Modelling: Agent based electricity market modelling with the PowerACE model
In order to analyse the effect of heterogeneous designs of European electricity markets on wholesale spot prices, the existing agent-based simulation model PowerACE is appropriately extended. The PowerACE model is an agent-based, bottom-up simulation model for wholesale electricity markets (see Genoese 2010). The model allows the integration of dedicated capacity remuneration mechanisms (e.g. Keles et al. 2016) which can be selected for different market areas. Besides the short-term operation of power plants, the investment in new generation units or the decommissioning of existing plants are individual agent decisions. The decisions are based on a net present value approach. In general, the advantage of the decentralized agent decision modelling is that imperfect market conditions like oligopolistic bidding behaviour can be taken into account.

[2] Further publications are in preparation

In 2016 and 2017 the PowerACE model was extended. In the beginning, the geographical focus of the model has been on Germany. Now, the model covers Switzerland and its neighbouring countries plus Belgium and the Netherlands (as these countries were needed for other reasons). For this expansion, collection of relevant input data was necessary, e.g. the existing conventional power plants and their operators, electricity demand, electricity generation from RES and interconnector capacities.
The future feed-in of renewable sources in neighbouring countries will be provided exogenously according to the EU Reference Scenario 2016 (de Vita et al. 2016). Swiss policy and economic development is assumed to follow the scenarios developed by PROGNOS (Prognos AG 2012). With regard to Switzerland, a new methodology dispatching hydro pumped-storage and hydro seasonal storage is developed to consider this generation types in the model.
After setting up the market areas for the PowerACE model, the simulation was executed (e.g. Zimmermann et al. 2017). In addition to a mere regional extension, capacity mechanisms are considered in PowerACE (e.g. a decentralized capacity market in France (Kraft 2017) or the capacity reserve in Germany (Keles et al. 2016)) in order to assess the different market design options and their influence to the Swiss electricity market.

Work in progress: Analysis of impacts on RES subsidies in different support schemes for Switzerland and other policy measures in the electricity sector
Under the current Swiss support scheme for RES based on fixed feed-in tariffs, the transmission system operator sells the electricity generated from subsidized RES on the wholesale market and electricity consumers are generally charged with the difference between the FiT and wholesale spot prices via a surcharge. Consequently, in case of decreasing wholesale electricity prices, the TSO's revenues are reduced as well as the consumer surcharge needs to increase.
Based on the simulated wholesale electricity spot prices of the PowerACE model, the required funding of RES under different support schemes in Switzerland will be assessed. First, the required subsidies in a business-as-usual scenario (FiTs and RES expansion according to the Swiss Energy Strategy 2050 (Prognos AG 2012)) are calculated.
In this setting, changes in the funding volume due to alternative market designs in European electricity markets and their respective effects on Swiss wholesale prices are estimated. Since changes in the European market design are assumed to have a negative price effect on the Swiss electricity market, the volume of renewable support schemes could increase.
Secondly, the volume of subsidies under alternative RES support schemes, such as the proposed market premium e.g. from the 2013 draft of the energy act, is evaluated. The introduction of auctions for RE production units and the expansion of investment aid schemes for different renewables will be taken into account. Output will be an estimation of support volumes. Especially the case of hydropower can be assessed thoroughly in the framework of this project.

Work in Progress: Assessment of profitability of hydropower storage plants
The real-world dispatch of a stored-hydropower plant (or a set of interconnected storage plants) has to take into account the uncertainties caused by the stochastic natural water inflow and the electricity market prices. The obtained clearing-prices from the PowerACE model are used as a basis for stochastic prices under the different future market designs. The stochastic inflow process is based on a standard autoregressive process. High time-resolution inflow-data is specific to individual stored-hydropower plants, because alpine conditions can vary substantially. Moreover, in most cases such data is not publically available. Apart from using already available data for some plants, we may use existing contacts to Swiss power utilities and to the association of Swiss electricity producers to retrieve data for additional plants. The aim is to analyse a small set of typical stored-hydropower plant configurations of Switzerland.

Secondly, the dispatch of hydropower is optimized against uncertain electricity prices (derived from PowerACE) and under seasonal water inflow exogenously given. To measure the operational profitability under realistic conditions, we use a novel stochastic optimal control model. Major inputs are the techno-economical characteristics of the plants (single or several interconnected reservoirs) and the stochastic spot priced from PowerACE. The model is based on the concepts in Densing (2013), which allows modelling the hourly dispatch-decision under uncertainty over longer time-horizons. The linearly formulated problem maximizes the expected operational profit of a pumped-storage plant over the time horizon. We evaluate the impact of different market designs simulated in PowerACE. The model is suitable to incorporate several of the proposed policy measures to strengthen the competitiveness of large hydropower: Among currently discussed measures are investment loans or other financial guarantees from the government, or a change of the legislation of the water-use charges (Wasserzinsen; for plants above 1MW gross power).

4. International cooperation

The project team:

Chair of Energy Economics at Karlsruhe Institute of Technology

The ***Chair of Energy Economics*** belongs to the Institute for Industrial Production (IIP) at the ***Karlsruhe Institute of Technology (KIT).*** The Chair of Energy Economics (established in 2008, ~30 employees) is headed by Prof. Dr. Wolf Fichtner and consists of four research groups: "Renewable Energy and Energy Efficiency", "Energy Markets and Energy System Analysis", "Distributed energy systems and networks" and "Transport and Energy".
Activities at the Chair of Energy Economics include the interdisciplinary research and teaching, especially the conjunction of engineering-economic approaches and quantitative methods of operations research and informatics. A major focus is the analysis of security of supply aspects and market design options for electricity markets.

Team members:
Joris Dehler is member of the group energy markets and energy system analysis (EMESA) since 2014. He holds a Diplom in mathematics from Albert-Ludwigs-University Freiburg, Germany.
Florian Zimmermann is member of the group EMESA since 2014 and focuses on agent-based energy market modelling. He holds a master's degree in Industrial Engineering and Management from the KIT.
Dr. Dogan Keles leads the EMESA group at KIT since 2013 and has more than 8 years of experience in modelling of prices, markets and energy systems.
Prof. Dr. Wolf Fichtner leads the Chair of Energy Economics at KIT and has a long experience in energy markets and system analysis.

Energy Economics Group of Paul Scherrer Institute

The ***Energy Economics Group (EEG) of the Laboratory for Energy Systems Analysis (LEA) of Paul Scherrer Institute (PSI)*** has extensive experience in analysing energy technology development and identifying policy strategies towards the realisation of sustainable energy systems at the Swiss, European and global levels. The group has participated in a series of projects funded by the BFE, Swisselectric Research, European Commission and third party organisations such as the World Energy Council.

Team member:
Dr. Martin Densing has over 10 years of experience in energy system modelling (mostly global models) and stochastic hydropower dispatch planning.
Back-up "stand-by" members: Evangelos Panos (PSI/EEG) and Stefan Hirschberg (PSI/LEA)
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5. Evaluation 2016

As a preparatory work package, an econometric analysis of the Swiss electricity price was conducted, discussed at several occasions and published in 2016. The results were presented

- at the 14th "Symposium Energieinnovationen" in Graz, Austria (Dehler et al. 2016),
- at the IAEE International Conference in Bergen, Norway (Keles und Dehler 2016),
- at the "Energieforschungsgespräche" 2016 Disentis, Switzerland and
- in Zürich, Switzerland, at a workshop organized by the Swiss Federal Office of Energy (SFOE).

As a major finding, influencing factors could be differentiated by season and country of origin. Apart from providing insights into different drivers of Swiss electricity prices, the international research team could gain an understanding for the Swiss market in its international context. Based on the experiences made, the following work packages will allow deeper insights into the interdependencies of European energy markets and particularly Switzerland.

In the PowerACE model new market design options have been implemented. A strategic reserve was modelled, a central capacity market was improved, and a decentralized market has been adjusted for the new French capacity market implementation.

Further, in November 2016, Florian Zimmermann stayed at the Paul Scherrer Institute (PSI) in Villigen. The aim of this stay was to intensify the collaboration between the Energy Economics group at PSI and the Chair of Energy Economics at KIT. Further data research for Switzerland and the transfer of methodologies for the models were discussed and a joint publication was elaborated and structured.

6. Evaluation 2017 and outlook for 2018

The agent-based power market simulation model PowerACE has been further improved and extended to embed various market areas. The model now includes the markets of Belgium, Germany, France, Italy, the Netherlands, Austria, and of course Switzerland. Non-modelled adjacent market areas were implemented as a static profile based on historical data. For this purpose, data from various sources were collected, processed and integrated for the entire modelling process. Adjustments were also made for the capacity markets in Belgium, Germany, France and Italy. With the focus on Switzerland, a methodology for hydroelectric power plants to dispatch seasonal hydro storage and pumped storage power plants was developed in order to consider these generation technologies accordingly. Finally, various scenarios were defined for the project, which were simulated, analysed and compared with the agent-based power market model PowerACE.

In 2017, the first unit tests of the novel pumped-storage modelling were successfully completed, and also reported to BFE in form of a slide deck. In these tests, the electricity prices were still artificial. In 2018, the hydropower modelling will use the more realistic output prices from the PowerACE model and realistic, historical yearly inflow patterns to evaluate the profitability of stylized Swiss hydropower plants under different policy options.

Results and the project were presented at several conferences in 2017:

- 10th „Internationale Energiewirtschaftstagung (IEWT)“ in Vienna, Austria (Zimmermann et al. 2017)
- IAEE International Conference in Singapore
- “Energieforschungsgespräche” 2017 Disentis, Switzerland
- CEE Inaugural Conference at ZHAW, Winterthur, Switzerland

For 2018, several publications in scientific journals are planned as part of the project. In addition, the results and methodology, in particular the novel pumped-storage approach, will be presented and discussed to the scientific society at conferences (e.g. IAEE International Conference, International conference on the European energy markets (EEM), or the European Conference On Operational Research (EURO)). Furthermore, the remaining work packages will be finished during the year.

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