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Trade-offs between integration and isolation in Switzerland's energy policy

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In response to the Fukushima nuclear accident, Switzerland has targeted to phase out nuclear power by 2050. Two diametrically opposite pathways to accomplish Switzerland's nuclear phase-out are quantitatively investigated for the year 2035 using a novel high-resolution power systems simulation framework. The first pathway, “Island in Europe”, installs new natural gas power plants to ensure a self-sufficient Swiss energy system. The second pathway, “Battery of Europe”, increases Switzerland's engagement with central Europe with new pumped hydro storages and increased cross-border electricity trade of European renewable energy. The results show that the “Battery of Europe” scenario enables a threefold increase in financial surplus of cross-border electricity trade compared to the “Island in Europe” scenario. This surplus translates to 15–23% lower domestic Swiss electricity prices, thereby enhancing the competitiveness of the Swiss marketplace; however, Switzerland is then exposed to more technical and political engagement with its neighbours. Additionally, successful implementation of the “Battery of Europe” scenario requires reinforcing 5% of the Swiss transmission grid, which necessitates more streamlined legal processes for new transmission infrastructure. Along a different political dimension, electricity price reductions of up to 22% are possible if the targeted increase of efficiency in Switzerland's energy policy is accomplished.

1. Introduction

Switzerland's energy policy has been driven for several decades by the desire to have a secure, competitive and ecological energy supply despite the lack of significant amounts of domestic natural resources for energy production [1]. In the 1960s and 1970s, nuclear power was identified as most suitable complement to hydropower; the latter being the most abundant renewable energy resource in Switzerland. In the years following the Chernobyl nuclear accident of 1986, the phase-out of nuclear power was discussed in Switzerland, but a public vote in 2003 halted moratorium plans and effectively paved a long-term path for nuclear power to be the backbone of the Swiss electricity system [2]. However, the Fukushima nuclear accident of 2011 greatly changed the public perception of nuclear safety and prompted a political shift to support plans for the phase-out of nuclear power. Switzerland's Energy Strategy 2050 (ES2050) is an outcome of the Swiss parliament's decision to initiate the phase out of nuclear power by 2050 [3] in reaction to the Fukushima nuclear accident. In a recent referendum, the Swiss population rejected a proposal to shut down all Swiss nuclear power plants by 2029 [4], but nevertheless the Swiss parliament maintains its position of gradually phasing out nuclear power over next three decades. This political decision has far-reaching consequences for Switzerland's energy sector, as 38% of Switzerland's electricity production comes from nuclear power [5]. In ES2050, the Swiss Federal Office of Energy proposes, on the generation side, new hydropower plants and new renewable power plants (such as wind farms and photovoltaic installations), and on the demand side, increased energy efficiency, as measures to compensate for the decommissioning of nuclear power [6]. Within the framework of ES2050, large-scale hydropower will be supported by imposing a surcharge of up to CHF2/MWh on the consumer electricity price; this surcharge is effectively an additional federal support in the order of CHF100 million per year for Swiss utilities [3]. Further it is proposed in ES2050 that domestic non-hydro renewable production should cover one fourth of the Swiss electricity demand by 2035 [3]. At the same time, Switzerland's power system remains deeply embedded within the pan-European power grid, as the Swiss transmission network connects four major

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European power markets: Germany, France, Italy and Austria. Cross-border trading contributed CHF440 million to Switzerland's economy in 2014 [5]. However, the neighbouring countries have very different approaches in the planned transformations of their power systems: The German government aims to fully phase out the use of nuclear power by 2022. This phase out will be accomplished by a transformation of Germany's energy system, such that by 2020 the renewables share of electricity will be 39% [7]. From 2010 to 2014, the installed renewable capacities in Germany have increased from 27 GW to 39 GW for wind and from 18 GW to 38 GW for solar [8]. France plans to continue running its large fleet of nuclear power plants and additionally seeks to increase the share of renewable energy in the final energy consumption from 14% to 32% in 2030 [9]. Between 2010 and 2014, the installed wind capacity in France has increased from 6 GW to 9 GW, while solar capacity has increased from 1 GW to 5 GW [10]. Italy seeks to reduce its continuing shortage of power generation by investing heavily in photovoltaics and biofuels [11]. Between 2010 and 2014, the installed photovoltaic capacity in Italy increased five-fold from 4 GW to 19 GW [10]. Austria sees an opportunity to provide power to its neighbours by investing in both hydro and combined heat and power plants. From 2008 to 2012, the installed hydropower capacity increased from 12 GW to 13 GW and the installed combined heat and power capacity increased from 5 GW to 6 GW [12] [13]. The transformations in the power markets of neighbouring countries shall have profound political, technical and economic impacts on Switzerland, for a number of reasons. First, renewables are non-dispatchable; therefore, storage is required to account for the variability of renewable-generated electricity. From an energy political perspective, this creates the opportunity for Switzerland to act as power balancing hub in central Europe by applying its abundance of hydro storage. Second, there is a need to maintain security of supply in order not to be vulnerable to supply disruptions or failures in infrastructure. Third, it is desirable to promote the deployment of renewables in order to maintain a low carbon intensity in the power generation sector. Addressing these different issues is a challenge as Switzerland is both interconnected to and in the centre of the European power system.

This work quantitatively assesses two diametrically opposite energy political pathways to realise the transformation of Switzerland's power system, which is driven by the phase-out nuclear power, in order to accomplish the objectives of the Energy Strategy 2050. Several previous works have investigated the implications of a nuclear phase-out on energy systems. As [14] shows using a statistical model for the United States, preserving nuclear power plants is one of the most cost-effective solutions to reliably supply electricity with low carbon emissions. This highlights Switzerland's challenge of phasing out nuclear power while maintaining the competitiveness of the domestic electricity supply. Similarly, the significant investment costs associated with a nuclear phase-out are highlighted in Ref. [15] using a combined dispatch-investment model for France. For the Swiss case, several previous works have applied top-down models to examine the impact of Switzerland's nuclear phase-out on domestic electricity costs [16]-[19], system adequacy [17], CO_2 emissions [18] and cross-border trade balances [19] [20]. Common feature of such top-down models is the substitution of the precise power grid topology with a “copper plate” simplification, where power transmission within a country is considered unlimited and lossless. While being suitable to assess general long-term trends over large geographic areas, an assessment of network insufficiencies and financial performances of individual generators is not possible with such top-down models. Since domestic short-term energy policy decisions are oftentimes driven by security-of-supply issues and financial implications on large-scale utilities, investigating the effects of domestic energy policy on the power system requires a more detailed methodology. In this regard, the present work differs from the prior works, because a bottom-to-top approach is used to provide a comprehensive quantitative assessment of a broad range of impacts. Compared to aforementioned works, this work is novel in the following respects:

- Firstly, the individual high-voltage transmission lines in the interconnected power systems of Switzerland, Germany, Poland, the Czech Republic and Austria are modelled; thus the constraints in the delivery of generated electricity to the locations of demand are accounted for in detail.
- Secondly, mesoscale simulations of weather are used to derive renewable-generated electricity of the solar and wind power plants in the aforementioned power systems; as increased penetrations of renewables are a key characteristic in the transformations of these power systems, the solar- and wind-power generation are accurately modelled as a function of geographic location and time (for every hour of a year).
- Thirdly, the hourly techno-economic operation of individual power plants – conventional and renewable – in the interconnected power systems is modelled; thus the actual behaviour of the power plants due to availability, maintenance, minimum load operation, load following, starting-stopping, etc. is accounted for.
- Fourthly, the hourly cost optimised dispatch of the power plants, including physical constraints of the generation and transmission, that is required to meet the hourly demand is simulated for a given year; thus the analysis accurately represents the operation of the real power market.

Therefore, this novel, bottom-to-top approach provides a rigorous data-driven quantitative assessment of the costs and benefits of different pathways that may be undertaken to realise policy objectives.

The two pathways that are assessed in this work are termed “Island in Europe” scenario and “Battery of Europe” scenario. In the “Island in Europe” scenario, the primary intent is to have an energy policy that maintains Switzerland's security of electricity supply through the replacement of the decommissioned nuclear capacity with new natural gas power plants; in this way Switzerland's dependence on energy-related policy decisions in the neighbouring nations is reduced at the expense of increased greenhouse gas emissions. In the “Battery of Europe” scenario, the intent is to increase Switzerland's engagement in Europe through the further development and exploitation of Switzerland's abundant pumped hydro storage capacity to serve as large-scale storage for the increased penetrations of renewables in central Europe. However, as a consequence, Switzerland is then exposed to more political, technical and economic risk, as unexpected policy changes in neighbouring countries will more directly affect the Swiss power market. The analysis in this work quantifies for the first time what the trade-offs are, if the “Island in Europe” scenario, the “Battery of Europe” scenario, or variant thereof is pursued by 2035.

The paper is organized as follows. In the methodology section, the framework for the power system simulations of central Europe is described. Several simulated scenarios are presented subsequently. In the results section, the simulation outcomes are analyzed with regard to the effects on loadings of Swiss transmission lines, on operating modes of Swiss power plants, on domestic Swiss electricity prices and on financial surplus for Switzerland from the power import-export balance.