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From nuclear phase-out to renewable energies in the Swiss electricity market

Sebastian Osorio*, Ann van Ackere

University of Lausanne, Faculty of Business and Economics (HEC Lausanne), Quartier UNIL-Dorigny, Anthropole, 1015 Lausanne, Switzerland

HIGHLIGHTS

- We model the long-term dynamics of the Swiss electricity market.
- Nuclear power is expected to be partially replaced by PV and imports.
- These changes in the energy mix and exchange patterns cause prices to rise.
- Import dependency and price rise are symptoms of a decreasing capacity adequacy.
- The annual energy margin shows a less reassuring picture than the de-rated margin.

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ABSTRACT

Liberalisation and the ever larger share of variable renewable energies (VRES), e.g. photovoltaic (PV) and wind energy, affect security of supply (SoS). We develop a system dynamics model to analyse the impact of VRES on the investment decision process and to understand how SoS is affected. We focus on the Swiss electricity market, which is currently undergoing a liberalisation process, and simultaneously faces the encouragement of VRES and a nuclear phase out. Our results show that nuclear production is replaced mainly by PV and imports; the country becomes a net importer. This evolution points to a problem of capacity adequacy. The resulting price rise, together with the subsidies needed to support VRES, lead to a rise in tariffs. In the presence of a high share of hydro, the de-rated margin may give a misleading picture of the capacity adequacy. We thus propose a new metric, the annual energy margin, which considers the energy available from all sources, while acknowledging that hydro-storage can function as a battery. This measure shows a much less reassuring picture of the country's capacity adequacy.

1. Introduction

Before the 1980s, electricity was mainly produced using hydropower, nuclear and thermal-based units. Most markets were monopolies, whose only concern was to ensure capacity adequacy (Lieb-Dóczy et al., 2003). The liberalisation process of electricity markets, which started in the 1990s, has led to the creation of competitive wholesale and retail markets and the unbundling of the sector segments (generation, transmission and distribution), often resulting in the privatisation of generators (Joskow, 2006). As a consequence, guaranteeing the electricity supply has become more complex. In this paper we focus on the challenges currently faced by Switzerland, one of the last European countries to start a liberalisation process.

Liberalisation enhances competition among generators, resulting in investment decisions being increasingly based on profitability, at the expenses of system security (Lieb-Dóczy et al., 2003). The resulting lack of coordination in investments results in price and capacity cycles, which add complexity to the investment decision process (Arango and Larsen, 2011).

The electricity sector has also experienced several changes in generation technologies. Combined cycle gas turbines (CCGT) gained in importance in the 1990s due to significant efficiency improvements, reduced pollution and shorter construction lead times (Ford, 1997). Over the last two decades, governments have encouraged investments in renewable generation, mostly in variable renewable energies (VRES), i.e., solar and wind. However, these technologies create a new challenge for the sector. Their

* Corresponding author.
E-mail addresses: sebastian.osorio@unil.ch (S. Osorio), ann.vanAckere@unil.ch (A. van Ackere).

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availability factors are significantly lower than those of, e.g., thermal generation, and their production is subject to inherent variability that needs to be balanced in real-time (Lise et al., 2013). Additionally, their large penetration has a price-lowering effect, which decreases the profitability of other generators. However, consumers do not benefit from these lower prices as they are charged cost of the subsidising renewable energies (BMWi, 2015). The uncertainty concerning new investments and rising tariffs due to VRES subsidies affects numerous markets. Many countries are thus facing the challenge of providing increasing amounts of affordable 'green' electricity, in the right place, at the right time.

Additionally, electricity markets are increasingly interconnected. This can improve security of supply (SoS) as it gives countries access to more supply, and helps balancing the load, e.g., in countries with complementary seasonal patterns. However, a high degree of dependency can discourage new investments in the long-term, negatively impacting SoS (Ochoa and van Ackere, 2009).

Although assessing SoS has been mainly addressed as a capacity adequacy problem, today other aspects such as import dependency, environmental issues and tariff affordability must be considered. Actions to enhance capacity adequacy may conflict with economic efficiency or environmental protection or both. Thus, understanding the dynamics of electricity markets is a necessity to develop appropriate policies.

We develop a simulation model calibrated to the Swiss electricity market to analyse the investment decision process and the impact on SoS of the changing generation mix. The model is developed using system dynamics (SD), which aims mainly at understanding a problem based on its causal structure, by analysing the feed-back loops among the key variables (Sterman, 2000). This methodology provides several advantages including (i) visualising the interactions and causal relationships between the different variables, (ii) providing understanding of the impact of delays on the system's evolution, and (iii) allowing evaluating SoS under different scenarios of energy policy.

As shown in Table 1, in 2013 nuclear energy accounted for 36% of Swiss electricity generation and hydro-power for 58%, split between run-of-river (26%) and hydro-storage (32%). The share of other sources was only 6%, with PV and wind energy accounted for barely 1% (SFOE, 2014a). However, the government is strongly encouraging these technologies through feed-in tariffs (FiTs). For instance, the FiT for PV installed since January 1st, 2014, lasts 20 years, and varies, depending on the nominal capacity, between 172 and 304 CHF/MWh.[1](The Swiss Federal Council, 2015). It is noticeable that PV capacity has increased nearly ten-fold between 2009 and 2013: 755 MW compared to 79 MW (SFOE, 2014a). Switzerland appears self-sufficient, achieving net exports equivalent to 3% of net production. However, when considering the hydraulic year, we observe net exports of 2.0 TWh between September 2012 and August 2013, but net imports of 2.6 TWh between October 2012 and April 2013, indicating a strong import dependency in winter.

Table 1
Main statistics of the Swiss electricity market in 2013 (SFOE, 2014b).

	Volume (GWh)	Share (%)
Total production	68,312	100
Run-of-river	*17,759*	*26*
Hydro-storage	*21,813*	*32*
Nuclear	*24,871*	*26*
Others	*3869*	*6*
Net production	66,180	
Pumping	2132	
Net exports	2396	
National consumption	63,784	

Switzerland currently benefits from long-term contracts for importing cheap off-peak energy from France but they will expire by 2040 (AES, 2012). Since the Federal Council plans to gradually decommission the nuclear power capacity, SoS is threatened in the middle- and long-term. The government expects VRES to partly replace the expiring contracts and the capacity that will be dismantled.

Besides the support to VRES, the government and the Swiss Federal Office of Energy (SFOE) aim to create a favourable framework for CCGT. This technology's availability is similar to nuclear power and it is flexible enough to complement hydro-storage to meet the balancing needs resulting from VRES. However, the high emissions challenge its profitability (carbon costs) and its acceptance by the Swiss population.

The next section motivates the methodology (SD) and describes the model. In Section 3 we present our results and we conclude with a discussion of policy implications.

2. Methods

Gary and Larsen (2000) argue that traditional economic equilibrium models do not adequately address the issues faced by recently liberalised industries: during their transition to competitive markets they do not comply with the equilibrium assumptions. We therefore model the system's structure explicitly to gain understanding of the dynamics of the industry, using SD.

SD models take a system's view of strategic problems and focus on capturing the feedback mechanisms (created by a series of causal relationships) and time delays that define the structure of a system as understood by the decision makers (Sterman, 2000). The system is represented by a set of differential equations. Modelling causality and delays is important in energy policy formulation since this helps investigate whether policies trigger instabilities which may affect future system performance (Arango, 2007). SD has been used to explain the dynamics of electric markets. Bunn and Larsen (1992), Ford (1999) and Ochoa (2007) were among the first to use SD to analyse how these new investment dynamics impact capacity adequacy, and in turn the SoS, in respectively England and Wales, the western market of the U.S.A., and Switzerland. More recently Pereira and Saraiva (2013) developed an hybrid SD-optimisation model for the Spanish–Portuguese market to evaluate expansion plans in view of the increased renewable generation. A detailed review of the main system dynamics models used to simulate electricity systems can be found in Teufel et al. (2013).

SD is particularly suitable for capturing the dynamics of markets at an early stage of liberalisation since it allows incorporating bounded rationality and stakeholders' behaviour. Given that there is no historical data for a competitive Swiss market, this approach offers an attractive way of understanding how the market might evolve, generating for instance insights into the effect of price shocks or parameter uncertainties as well as illustrating potential undesirable consequences of the proposed regulation (Larsen and Bunn, 1999). Given the huge uncertainty concerning the future of nuclear power in Switzerland, the possibility to evaluate different scenarios is essential.

Our model includes VRES generation and expansion, which allows us to understand their long-term effect on the SoS. The model is divided into three modules: market clearance and electricity exchange, which are shown in Fig. 1, and the investment

[1] 1 CHF=0.92 Euro (exchange rate December 2015).