Simulating the Capacity Expansion of Renewable Energies in the Swiss Electricity Market

Merla Kubli[a*], Erling Moxnes[b]

a. Institute for Sustainable Development, Zurich University of Applied Sciences, Switzerland

b. System Dynamics Group, University of Bergen, Norway

Abstract

Switzerland faces two major challenges in the electricity sector. The existing nuclear power plants will be phased out and at the same time new renewable electricity sources should increase their share in production. A System Dynamics simulation model is built to improve the understanding of central dynamics in the Swiss electricity provision system and the interplay of different electricity technologies in the electricity production. The investment decision for the specific technologies is a central leverage point in the system. The model is used to simulate likely developments of the Swiss electricity power plant park and test the effectiveness of feed-in remuneration policies. Results are gained on the long-term dynamics of capacity expansion of electricity technologies, depending on different public policies. This paper makes a practical contribution to the management of the energy transition by shedding dynamic and endogenous light on capacity expansion.

Word count: 4933 (without references)

Keywords: Energy, electricity, System Dynamics, simulation, Switzerland, feed-in tariffs.

* Corresponding author: Merla Kubli, Institute of Sustainable Development, Zurich University of Applied Sciences, Switzerland, merla.kubli@zhaw.ch, +41 58 934 72 59.

1. Introduction

Switzerland has two challenges in the electricity provision sector to be solved mutually in the years to come. The Swiss Federal Council and the parliament decided on the withdrawal from nuclear energy in 2011 (Swiss Federal Council 2011). The stepwise phase out from nuclear power causes a gap in the future coverage of the electricity consumption in Switzerland (Prognos AG 2007, 2012) . This gap should be filled with locally produced electricity to maintain political sovereignty ((Swiss Federal Council 2011);Swiss energy enactment Art. 6). Additionally, a commitment to a more sustainable electricity production was made ((Swiss Federal Council 2011); Swiss energy enactment Art. 3b). Especially the expansion of hydro-power and new renewables energies is encouraged and will be supported. Nevertheless, the Swiss Federal Council does not consider an electricity provision based on only renewable energies as feasible.

Currently used electricity models provide a high level of detail and are convincing in terms of the amount and quality of data. However, essential dynamics of the electricity system are not represented, modelled and simulated explicitly. A System Dynamics model is built to improve the understanding on the dynamic interplay between types of electricity supply, demand, and technology developments. With this model we aim to provide a dynamic interpretation of the electricity system, supporting the gained understandings of previous mathematical models. The focus is on endogenous investments in capacity expansion of different electricity production technologies and how these can be influenced by governmental policies.

The simulation results reveal that a transition towards an electricity system based on only renewable energies is feasible. Insights are gained on the dependency of the different technologies on market design and regulations. The widely applied feed-in tariff policies prove to be a good instrument to push the electricity system in a desired direction, but they fail to sustain the system in its new state.

This paper is organized as follows. The theoretical background follows the introduction. The third section gives an overview and detailed description of the simulation model. Results are presented in the fourth section. The article closes with a discussion of the results and further research needed in this area.

2. Problem and previous analysis

Commonly used energy sources such an oil and gas are getting scarcer and more expensive while new renewable energies are not yet competitive in many market segments (Jacobsson und Johnson 2000). On a global scale, climate effects of the use of fossil fuels make an early transition necessary. The electricity industry, which we focus on, has already undergone multiple transitions, from wood to coal to oil and gas (Naill 1992, Jacobsson und Johnson 2000). Now a transition towards new renewable energies is necessary. To speed up this process, governmental initiatives are needed. Our focus is on the case of Switzerland.

The transition in Switzerland must be seen in the following light. Over the coming years existing power plants reach their maximum lifetime, import contracts expire, and most important, the nuclear power plants will be shut down when they no longer satisfy the required security standards (Prognos AG 2007, 2012).The Swiss Federal council decided on the nuclear power phase out in 2011 after the Fukushima accident (Swiss Federal Council 2011). No replacement and no major renovations will be made of the existing five nuclear power plants. The result is a steadily decreasing electricity production. The simulation in *Figure 1* illustrates this problem. For this simulation the currently known nuclear phase out plans and life times for hydro power of 70 years are assumed. Declining supplies of nuclear and hydro power are shown together with three demand scenarios called "business as usual", "new energy politics" and "political measures" (Prognos AG 2012). No matter which scenario is chosen, a huge gap between supply and demand results.

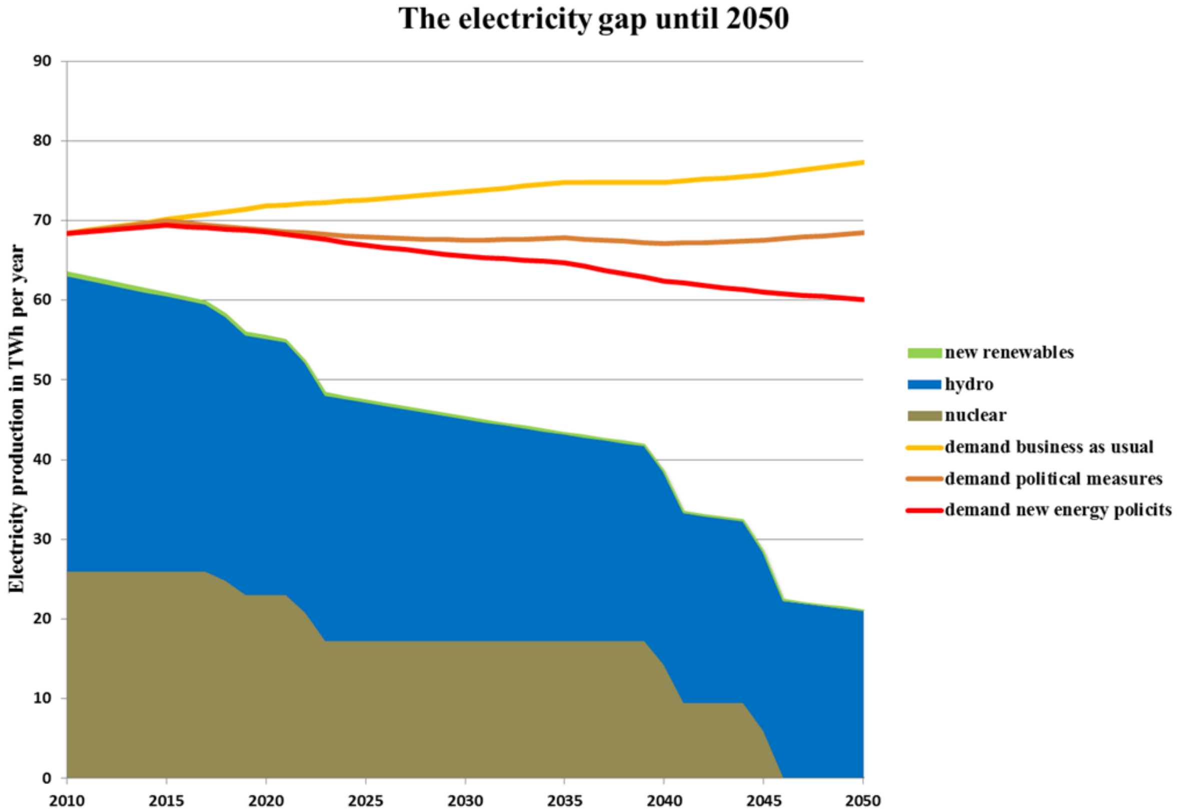

Figure 1: Without future investments Switzerland is facing a huge gap in electricity provision

The widening gap triggers interesting questions. Will the market be able to fill the gap at reasonable electricity prices? Are much higher prices needed to increase supplies and also to trigger conservation and reduced demand? What will the environmental consequences be, particularly in terms of CO2 emissions? And finally, what role should the government play? Prognos has analysed how to close the gap by focusing on choices between power generation technologies (Prognos AG 2007, 2012). These investigations represent the major decision-making basis for the Swiss Federal council. Multiple energy models are combined and analysed with a scenario method. Demand is based on extensive bottom up calculations. Supply side investment decisions are exogenous, however they are limited a priori by the physical and economic potentials of the technologies. All scenarios designed by Prognos (Prognos AG 2007, 2012) include gas-fired power plants. An electricity provision with only renewable energies is considered up front as unfeasible.

On the other hand, Supercomputing Systems Ltd. analyses a future where all new power sources are renewable (Supercomputing Systems Ltd. 2013) The electricity model they present is a very detailed simulation of the Swiss electricity production for one representative year. The simulation starts with a predefined constellation of the power plant park. Parameters are set for production costs. Different geographical regions for weather conditions are considered as determinants of the electricity production from renewables technologies. A priority list is integrated in the model to ensure that the power plants are operating in the interest of the overarching system. On the basis of this model several power plant constellations are derived that can satisfy a demand for electricity of 60 TWh per year. The major challenge is to compensate for the volatility of the new renewable energies, determined by their stochastic

nature of the electricity production. With their results SCS are challenging the assumption by the Swiss Federal Council and Prognos (Prognos AG 2007, 2012) that combined heat and power units as well as gas combined cycle power plants are necessary to guarantee a secure electricity production.
Major capacity expansions are needed whether the Swiss Federal council follows suggestions from Prognos or SCS. Remaining questions pertain to how learning, scale, and costs will develop over time and influence technological progress and whether investments become economic choices by investors or require governmental interventions. Investments have very long-lasting implications on the electricity provision system due to the long life times of the power plants. There is a need for a complementary model, which can simulate the development of the power plant constellation over time depending on the state of the system. Modelling the investment decision endogenously is essential to gain knowledge on potential future developments of the system. A model representing the investment decisions has to be more aggregated than the SCS model. The level of detail that the SCS model provides is not desired for a long-term model focussed on the development of the system. But this depth is again relevant when the feasibility and reliability of the final state derived by a long-term model should be tested. On the other hand, the 900 pages report by (Prognos AG 2007, 2012) are not a suitable tool for practitioners in the energy system to understand the energy transition and necessary actions.
This study provides this long-term model that can simulate the investment decision endogenously and over the time horizon from 2006 until 2050. It can be seen as a long-term complement to the SCS model, or simply a testing environment for policy initiatives. Furthermore it gives an easier understandable interpretation of the challenges of the Swiss energy transition than the Prognos study.

Official policy initiatives and implementation must be seen in light of the laws and regulations that apply in the Swiss electricity market. The provision of electricity in Switzerland is the task of the electric power industry (Art. 2, chapter 2, Swiss energy law). Local electricity companies are responsible for providing their area with electricity. The local electricity companies are working according economic principles. Their major shareholders are local governments. In 2011 the public hand held 87.9% of the shares of the electric power companies in Switzerland (Swiss Federal Office of Energy 2013). The national government is responsible to ensure favourable conditions for the energy industry. The government has the option to introduce incentives, to steer the system into a desired direction (Art. 2, chapter 2, Swiss energy law).

In the current system a subsidiary support policy for renewable energies, a so-called feed-in remuneration at cost policy (FIT), is established. The general aim of this policy is to increase the competitiveness of renewable electricity sources over the non-renewables and reduce the investment risk. The European Comission (2008) observed that feed-in tariffs are the most effective policy to support renewable sources of energy. Nevertheless the different FIT models vary in their impact on the technologies. Couture und Gagnon (2010) distinguish between seven different forms of feed-in remuneration tariffs. Switzerland applies a fixed price model (Couture und Gagnon 2010). The fixed price model is independent of the current market price for electricity. This feed-in tariff supports specific energy sources by paying a guaranteed tariff over a defined period of time per kWh electricity that is fed into the grid (Art.3, paragraph 2, Swiss energy enactment). The costs of the feed-in tariffs paid to the producers are transferred to the electricity consumer through a grid charge rate (Interface Ltd. und Ernst Basler + Partner AG 2012). The feed-in remuneration in Switzerland is guaranteed for specific technologies with individual tariffs. Currently wind, photovoltaic, small-scale hydropower, geothermal power, biomass power, incinerations and combustion of sludge benefit from this support.

Interface Ltd. und Ernst Basler + Partner AG (2012) analysed the effectiveness of the applied FIT policy in Switzerland. They concluded that the FIT policy had the potential to increase investments in new renewables to reach the goals set by the Swiss Federal Council. Nevertheless, a long waiting list resulted. It was observed that 26% of the receivers of the FIT policy were free riders who would have investment even without the FIT policy. An effect on innovation is not expected. Although the FIT policy evaluation is fairly extended, an analysis of the long- term effects of the policy on the electricity market was not made, nor was sustainability discussed. SwissCleanTech (2013a) found that strong support of the new renewables will have significant impacts on the electricity market. First of all they expect that during some times of the day the electricity price will fall to zero or even become negative. Balancing technologies will struggle to amortize their investment. Also new renewables struggle to remain profitable due to the gap between the marginal costs of production and their full costs (including all fixed costs) (SwissCleanTech 2013b). Furthermore, SwissCleanTech (2013a) fear that after a stop of the FIT policy, there will be no reinvestment into new renewables. These findings imply that variability in both supply and demand is an important aspect to consider, also in long-term models.

3. Model

This paper sheds an aggregated view on the electricity capacity expansion system. It focuses on phenomena arising over the period until 2050, in line with the planning horizon of the Swiss energy strategy 2050 by the Swiss Federal council (Swiss Federal Office fo Energy 2013). A System Dynamics simulation model was built to increase understanding of investment decisions in the electric power industry and their impacts on the electricity provision system. When the provision system changes this feeds back to future decisions. Within this environment, impacts of public policies are tested.

System Dynamics is chosen as suitable method for both, to formulate and simulate this complex system. The method builds on causal relationships and allows for models that capture nonlinearities, delays, and feedbacks. It is also amenable to interdisciplinary analysis of the electricity system, with its interlinkages between physical, economic, and environmental parts of the system. The method facilitates sensitivity analysis and scenario testing. The transparent and visual representation of the simulation model further enhances system understanding.
The simulation model used for this study was built during the first author's master thesis project and is specifically designed for the purpose of this analysis. The System Dynamics software iThink 10.0.5 was used for the model construction and simulation. Simulation results were exported and displayed in Microsoft Excel. This paper reports on the main elements of the model structure and most essential results of the simulation analysis. Readers wishing for more thorough description of the model structure, the set of equations included, the validations tests conducted and the full analysis of scenarios and polices are referred to the master thesis document, which can be found online under: https://bora.uib.no/handle/1956/8591.

3.1. Model structure

The model has three main sectors. The sector *physical system* is the core of the model. It represents the currently installed capacity for the different technologies and the corresponding capacity supply lines for capacity expansion. Also part of the physical system is the remaining expansion potential for the various electricity sources. The sector *electricity market* represents the immediate local electricity production, trade of electricity across the country border, and the market price for electricity. The section *investment decision* is the central determinant for the development of the installed capacity. *Figure 2* shows a simplified diagram of the model.

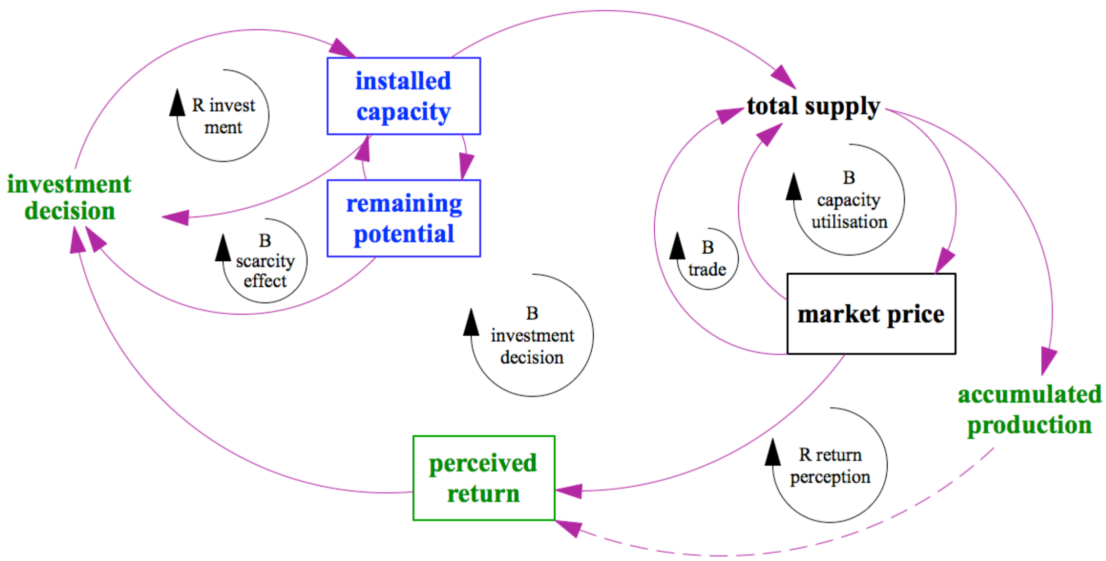

Figure 2: Central dynamics represented in the System Dynamics model

Installed capacities of the technologies determine the production of electricity at a specific point in time. A feedback loop for capacity utilisation is included, ensuring that the flexible producing technologies only produce at times when this is economic. For this reason the model distinguishes between operating costs, fixed costs and investment costs. Electricity can be imported or exported within grid-capacity limits. The actual amount traded depends of the local market price in Switzerland relative to the price abroad. The market price adjusts quickly and captures seasonal variations in addition to long-term developments.

All investors are assumed to make decisions based on economic considerations. However, in line with general behavioural theory (Kahneman 2003) and specific investigation of energy industries (Hampl 2012), it is assumed that decision-makers are biased towards own experiences and that they have to rely on limited and delayed information. In line with this research the model uses *perceived return* as the relevant input for the investment decision. Perceived return is a measurement for the marginal return generated over one year with 1 GW installed capacity of the specific technology. This structure allows including the effect of changing return due to different production patterns, caused for instance by volatility driven market price fluctuations.

The speed of adjustment is determined by previous experiences by the investor. Wang et al. (2011) found that investors adjust their perceptions of a stock slower when they have much experience with the stock and vice versa. Hampl (2012) confirms this relation in the specific field of energy. Based on perceived return and unit investment costs, investors calculate net present values (NPV). Unit investment costs vary with the remaining expansion potential of the technology. Scarcity causes unit costs to increase. NPVs influence investments, which are also scaled to existing installed capacities. The latter relation reflects the interests and financial strengths of the individual production sectors. To prevent a complete lock in, new technologies are assumed to have a certain financial leverage.

The model distinguishes ten different electricity sources: nuclear power, hydropower - distinguished into run-off-river hydropower, seasonal storage dams, and pumped storage dams;

thermal power from incineration, biomass, gas combined cycle, photovoltaic, wind and batteries. Production technologies are represented because they either contribute importantly to electricity production in Switzerland or represent interesting potential technologies for the future. Some storage technologies are also included since the demand for storage is likely to increase with wind and solar electricity. The production characteristics vary among the technologies and are strongly determined by seasonality. Electricity cannot be distinguished by its source once it is fed into the grid. Hence the electricity price plays a very important role.

3.2. Qualitative analysis of the dynamics of the system

The structure of the model brings in two novelties to electricity modelling. The feedback structure for the scarcity effect and the inclusion of the link between actual return and perceived return influencing the investment decision are usually not represented in electricity models. Looking at Figure 2: Central dynamics represented in the System Dynamics modelFigure 2, the model mainly consists of balancing feedback loops. Consequently the system has already a strongly self-regulating tendency.

The model is particularly suited to shed light on contributions to two environmental problems, emissions of greenhouse gases and the risks of having nuclear power stations.

The model has been subjected to a range of structure and behaviour tests (Barlas 1996). Formal statistical behaviour tests were not conducted, since the historical time-series are short. However, the simulation results do fit the data well. As the time-series are short, passing this test is necessary but not by itself a guarantee that the model gives reasonable results in the long run.

4. Results

The model behaviour is first described with no public policies and then with policies. Data for exogenous variables come from the Swiss Federal Office of Energy (2013). Cost estimates and learning curve assessments are provided by (Prognos AG (2007), 2012) and Paul Scherrer Institute (2005). Estimations on technological potential are based on Paul Scherrer Institute (2005). Effects of scarcity are estimations by the authors.

4.1. Electricity investment dynamics until 2050

The base run used assumes that the currently applied feed-in tariff is continued in the same manner until 2015. After that the market is without incentives and taxation. The trade capacity is 2 GW at any point in time, in both directions. The price abroad is defined as a sin-wave (with an amplitude of 5'000 Swiss francs and the length of one year) around 70'000 Swiss francs per GWh to represent the seasonality of the electricity price abroad. The political will persists on the nuclear phase out. The nuclear power plants are shut down according to the expected plans. Demand is based on historical data. After 2013 demand remains constant on the level of this year (63 TWh).

Figure 3 displays the simulation results for the development of the installed capacity of the different technologies in the base run. *Figure 4* shows the simulated market price and a smoothed price.

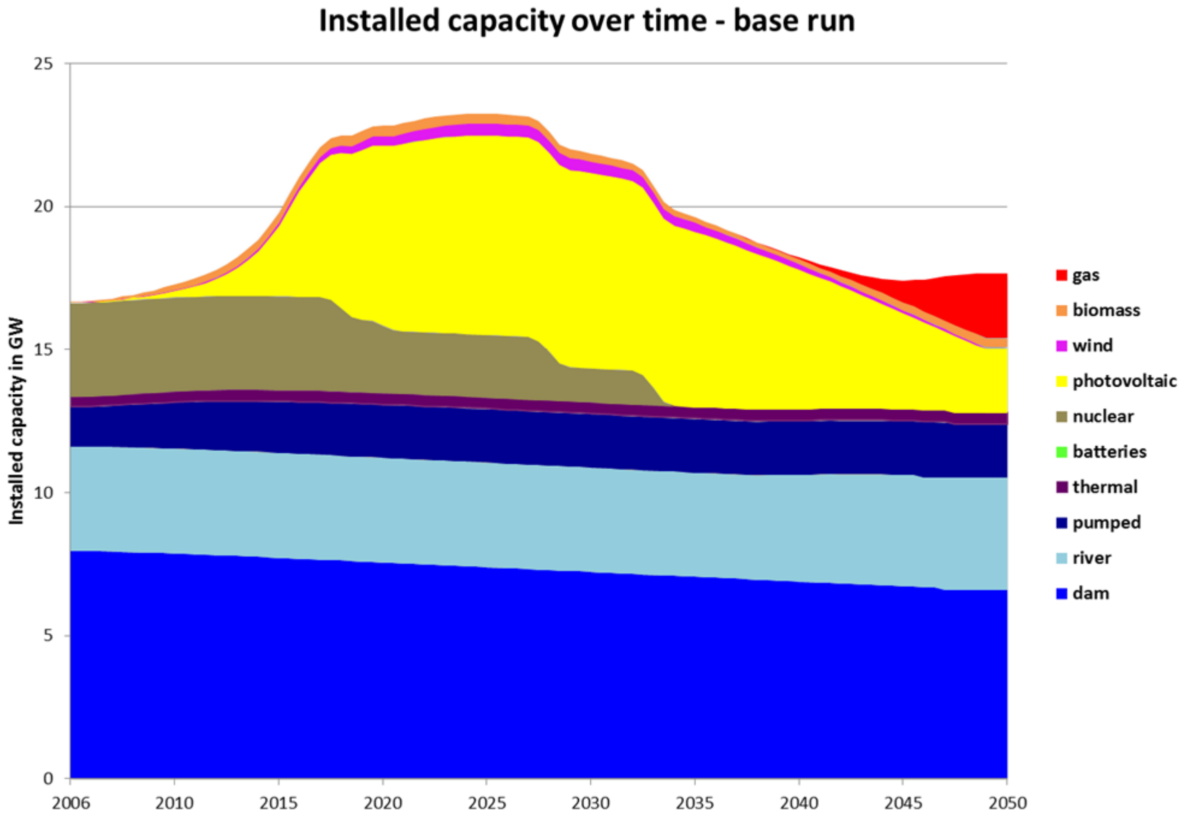

Figure 3: The graph shows the simulated installed capacity of the different electricity technologies in the base run.

The simulation results reveal that the electricity demand is covered despite the nuclear phase out. The simulated investments fit the historical data from 2006 until 2013 in satisfying manner. There is a major expansion of photovoltaic and wind as a consequence of the FIT policy. After the ending of the FIT policy in 2015 the investments into new renewables fall to zero. The capacity expansion continues for a few more years due to a delay in the perception and the model assumption that initiated projects are always realized as planned. Despite the increase in price, there is no reinvestment into the technologies that were originally supported by the feed-in remuneration policy. An increase in installed capacity for gas-fired power plants in year 2014 is observed. In other words, the FIT policy pushes the system to an energy transition towards new renewable energies, but fails in stabilizing the system in a stable state with a self-sustaining amount of new renewables. Without policy support the transition to renewables is stopped and the system turns back to a fossil-based electricity provision. This confirms the apprehension communicated by SwissCleanTech (2013a).

Local supply of electricity first increases and exceeds demand, which raises exports of electricity. In course of progressing nuclear phase out local supply of electricity cannot remain on this high level and drops, after 2035 even under the demand. Consequently the electricity market price first drops slightly in line with the oversupply of electricity. Price raise again when the last nuclear power plants are shut down and the FIT policy is stopped. Fluctuations in the electricity price are increasing with larger share of renewables in the power plant park and the decreasing number of nuclear power plants. In contract to flexible producing technologies, the annual return for the new renewable technologies only increases slightly, despite the strong price increase in the end of the simulation.

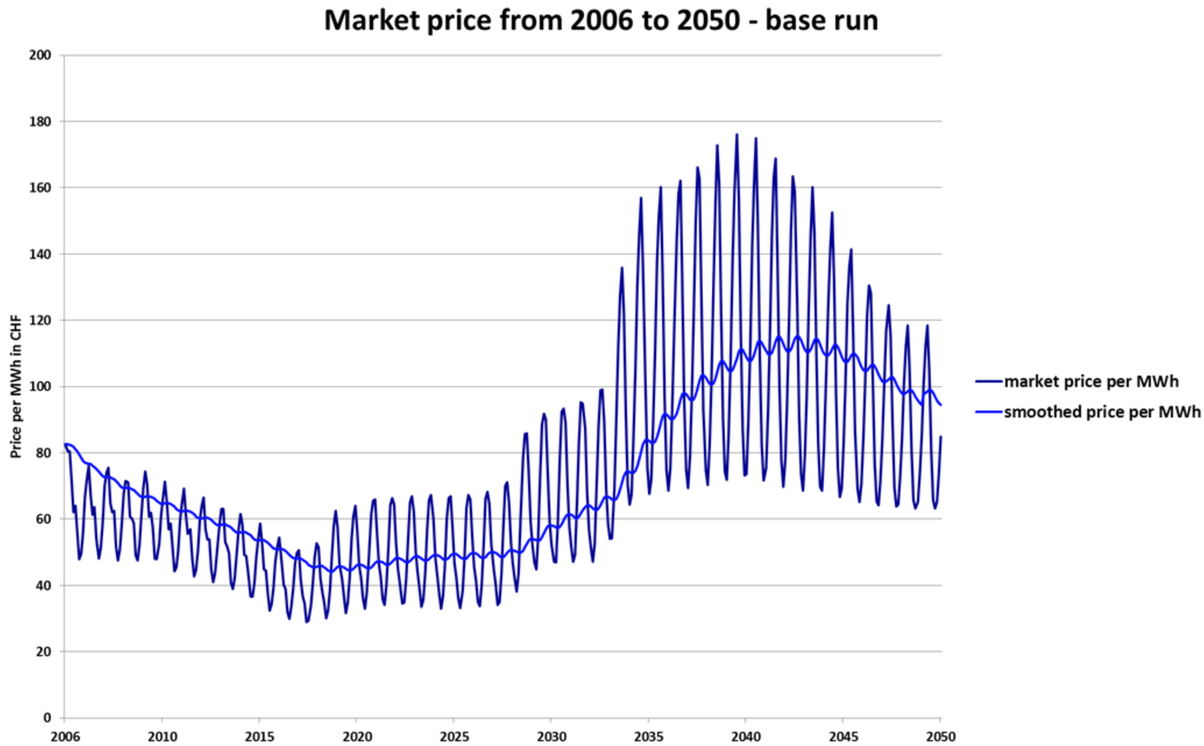

Figure 4: Simulated market price for electricity

The simulation results confirm the currently communicated refinancing problems of hydro power plants[1]. There are no investments into seasonal storage dams, since they appear to be not sufficiently profitable. The increasing volatility of the electricity price prevents the profitability of seasonal storage dams from rising to a profitable level due to reduced production hours.

Sensitivity analysis highlights the sensitive reactions of investments on changes of cost development. Furthermore, the price abroad and the trade capacity have a very strong effect on the development of the electricity system. The incentives and ability to import and export electricity cause major changes in the local electricity price. A low price abroad, combined with sufficient trade capacity, leads to a constant underinvestment in the local capacity expansion, and vice versa. Trade is in first line working as a buffer for irregularities, but it also can be seen as hidden capacity. Altering the transmission capacity is a politically sensitive policy, but it also has significant impacts on the investment decision in the electricity provision system. Ochoa (2007) and Ochoa und van Ackere (2009) analyse this issue in the light of trade liberalization and reach at the same results.

4.2. **Policies**

We test different forms of FIT policies to support new renewable energies and evaluate their effectiveness. The policies are selected from the analysis by Couture und Gagnon (2010). We simulate the currently established FIT model with a fixed tariff, the spot market price gap model, the premium FIT model and FIT model granting a percentage of the market price. For detailed description of the policies we refer to the paper by Couture und Gagnon (2010). The selection of evaluation variables is oriented on the suggestions by IREA (International

[1] *We refer to the statement of Robert Lombardini, the director of the board of directors of Axpo, the largest electricity producer in Switzerland, in an interview for Basler Zeitung: http://bazonline.ch/wirtschaft/unternehmen-und-konjunktur/Die-Axpo-fragt-sich-Wie-konnte-es-so- weit-kommen/story/19719269 (accessed: 9.6.2014)*

Renewable Energy Agency 2014). Accumulated costs are not discounted. The simulation results for the different policies and the evaluation are represented in *Table 1* and *Figure 5*.

	FIT fixed price 2015	FIT fixed price 2050	spot market price gap FIT	premium FIT	percentage market price FIT
Avg. weigthed price (CHF per GWh)	73'878	65'483	64'960	82'243	82'364
Standard deviation price	0.23	0.25	0.25	0.19	0.19
Share new renewables (%)	11%	25%	25%	25%	26%
Share renewables (%)	77%	87%	87%	80%	81%
Accum. investment (mio CHF)	31'737	63'420	63'433	33'214	34'157
Accum. investment into new renewables (mio CHF)	26'155	60'194	60'205	27'053	28'003
Policy costs (mio CHF)	9'213	69'025	51'653	11'905	11'010
Consumer spendings (mio CHF)	205'784	182'398	18'3013	229'083	229'421
Total costs on consumers (mio CHF)	214'997	251'423	234'666	240'987	240'431

Table 1: Evaluation of the feed-in tariff policies

The share of new renewables increases significantly with all tested policies and reaches levels between 77 and 87 percent. In all scenarios the coverage of demand requires additionally imported electricity. The premium FIT policy and the percentage of market price FIT policy make investments into gas-fired power plants necessary (*Figure 5*).

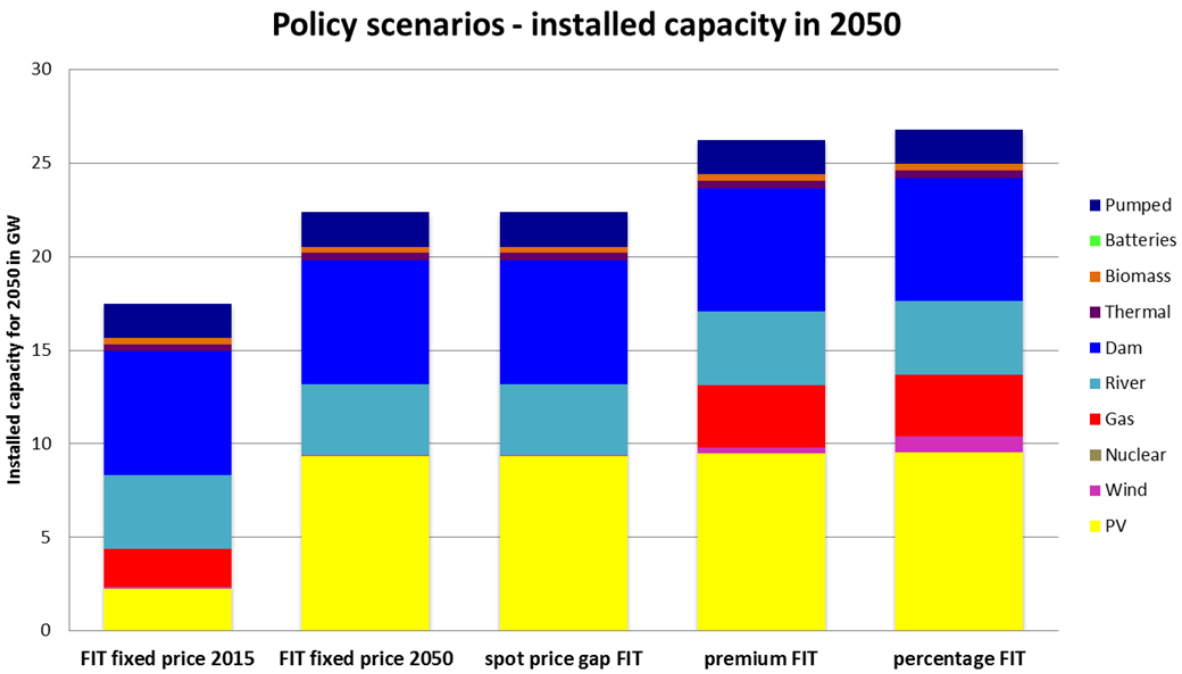

Figure 5: Comparison of the resulting installed capacity based on different policy scenarios

With expenditures of around 11'000 million CHF the direct policy costs are the lowest for the premium FIT and the percentage of market price FIT. However, the market price reaches higher levels. Consequently, the consumer expenditures and the total costs on consumers are high. Taking the total costs put on consumers as the reference the FIT policy spot market price gap and the FIT policy fixed tariff are the most efficient policies. Interestingly, the spot market price gap FIT reach the same goals as the fixed price FIT with 20'000 million CHF lower costs.

Since the policies were not tested with their full potential (i.e. including the adoption of the remuneration rates over time) we do not seek to give a final recommendation for a policy. However, we are able to draw some general conclusions on the effectiveness of the tested policies and how to improve policy effectiveness. This research confirms the conclusion drawn by the European Comission (2008) that FIT policies have the potential to strongly push the new renewable energies in their development and kick start an energy transition. Nevertheless, the feed-in remuneration is in all policy models are very cost intensive. Simulation results clearly showed that the policies don't have a sustainable effect on the system. Without policies there is a lack of incentives for reinvestment into renewables; when the policy is removed the energy transition is reversed. The necessity of an external entity to define the tariffs, points towards a lacking dynamic structure of these policies. Further research is needed to design a policy that can sustain the electricity provision system in the state after the transition without generating enormous costs.

Strongly regulated systems and frequent changes in policies bring the risk of confusing the investors, and therefore increase the perceived risk. It is observed that investors hesitate to invest in technologies that depend on or are affected by public policies (Hampl 2012). Incorporating an endogenous model structure for perceived risk could provide important insights on policy effectiveness. Another aspect not considered sufficiently in the model are social network effects in the diffusion of decentralized power plants. Incorporating network effects could result in better policy responses of the system, as this has a reinforcing character and could enhance the look-in effect for new renewable energies.

5. Conclusion and further research needed

Switzerland is facing two major challenges in its electricity provision. First, the Swiss Federal council decided on the withdrawal of nuclear power. The stepwise shut down of the five nuclear power plants causes a major gap in the future electricity provision. Second, a clear commitment to new renewable energies was made.

In this investigation a System Dynamics simulation model of the Swiss electricity production was build. The focus lies on the dynamic interactions of the determinants of the capacity expansion of the different electricity production technologies, and the investment decision connected with it. The model captures the development of ten different technologies: photovoltaic, wind, nuclear, gas, run-off river, seasonal storage dams, thermal power, biomass, batteries and pumped hydro-power dams. Investments in this model are made upon a market-oriented investment structure. Investors are modelled as profit-oriented, but not perfectly rational. Most important input for the investment decision is the perception of return for an investment. The return perception is heavily determined by the market price and the time and shape of its fluctuations.

Analysis of the model revealed capacity of trade, the electricity price abroad and the volatility of the electricity market price as sensitive points in the system. With increasing shares of new renewable technologies the price tends to fluctuate stronger and discourages investments into these investments. Under these circumstances the development of profitable storage options is very important. Currently the most relevant storage technology, the seasonal storage dams, are not profitable and no further investments are made, which is confirmed by the model results.

The model was used to test the effect of the currently established fixed price feed-in remuneration tariff (FIT) policy and alternative forms of FIT policies. Comparison of the effectiveness of these policies revealed that FIT policies are good instruments to boost the initial development of new renewable energies. Market independent FIT models are very cost intensive, while market price dependent FIT models lead to fewer governmental costs for the policy. The *spot market price gap FIT* model caused the lowest total costs for the consumers. Simulation results indicate that FIT policies cannot bring a sustainable change to an electricity provision system. Whenever a policy is stopped, the power plant park constellation that just made a transition towards new renewable energies moves back to fossil fuel based state. Further research is necessary, on how these policies can be combined over time to enable an ideal energy transition and what the effect of social networks is. Furthermore, a dynamic policy should be developed and tested that can maintain the system in its state after the transition.

This research contributes to the existing knowledge about the Swiss electricity provision system and its transition to a more renewable state, with simulating the investment decision for the different technologies endogenously. The simulation framework was here used to test different models of FIT policies. The developed System Dynamics model gives options for further and broader scenario testing in the wide field of electricity supply.

Acknowledgement

The System Dynamics model used for this paper was constructed in the framework of the first author's master thesis for the completion of the Erasmus Mundus European Master in System

Dynamics. The project was a collaboration of the University of Bergen (Norway) and the Supercomputing Systems Ltd. (Zürich, Switzerland). I would like to thank Erling Moxnes, Alain Brenzikofer and Andreas Kettner for the interesting collaboration and the numerous advices.

References

Barlas, Y. 1996. Formal aspects of model validity and validation in system dynamics. *System Dynamics Review* 12/3: 183-210.

Couture, T., Y. Gagnon. 2010. An analysis of feed-in tariff remuneration models: Implications for renewable energy investment. *Energy Policy* 38/2: 955-965.

European Comission. 2008. *The support of electricity from renewable energy sources*. European Union.

Hampl, N. 2012. *Energy Investment Decision-Making Under Uncertainty: The Influence of Behavioral and Social Effects – Dissertation*. University of St. Gallen.

Interface Ltd., Ernst Basler + Partner AG. 2012. *Evaluation der kostendeckenden Einspeisevergütung (KEV)*. Swiss Federal Office of Energy.

International Renewable Energy Agency. 2014. *Evaluating Renewable Energy Policy: A Review of Criteria and Indicators for Assessment*. International Renewable Energy Agency.

Jacobsson, S., A. Johnson. 2000. The diffusion of renewable energy technology: an analytical framework and key issues for research. *Energy Policy* 28/9: 625-640.

Kahneman, D. 2003. Maps of Bounded Rationality: Psychology for Behavioral Economics. *American Economic Review* 93 (5): 1449-1475.

Naill, R. F. 1992. A system dynamics model for national energy policy planning. *System Dynamics Review* 8/1: 1-19.

Ochoa, P. 2007. Policy changes in the Swiss electricity market: Analysis of likely market responses. *Socio-Economic Planning Sciences* 41/4: 336-349.

Ochoa, P., A. van Ackere. 2009. Policy changes and the dynamics of capacity expansion in the Swiss electricity market. *Energy Policy* 37/5: 1983-1998.

Paul Scherrer Institute. 2005. *Neue erneuerbare Energien und neue Nuklearanlagen: Potenziale und Kosten*. Paul Scherrer Institut.

Prognos AG. 2007. *Die Energieperspektiven 2035 (alle Bände)*. Swiss Federal Office of Energy.

Prognos AG. 2012. *Die Energieperspektiven für die Schweiz bis 2050*. Swiss Federal Office of Energy.

Supercomputing Systems Ltd. 2013. *SCS Energiemodell – Simulation der elektrischen Energieversorgung der Schweiz anhand von konfigurierbaren Szenarien*. Supercomputing Systems Ltd.

Swiss Federal Council. 2011. Press release – Bundesrat beschliesst im Rahmen der neuen Energiestrategie schrittweise Aussteig aus der Kernenergie. S. F. Council: Swiss Federal Council.

Swiss Federal Office fo Energy. 2013. *Energieperspektiven 2050 –Zusammenfassung*. Swiss Federal Office of Energy.

Swiss Federal Office of Energy. 2013. *Schweizerische Elektrizitätsstatistik 2012*. Swiss Federal Office of Energy.

SwissCleanTech. 2013a. Die Zukunft des Strommarketdesigns: SwissCleanTech.

SwissCleanTech. 2013b. Investitionskosten-Refinanzierungszuschlag (IRZ): SwissCleanTech.

Wang, M., C. Keller, M. Siegrist. 2011. The Less You Know, the More You Are Afraid of—A Survey on Risk Perceptions of Investment Products. *Journal of Behavioral Finance* 12/1: 9-19.