The Impacts of Governmental Policies on the Investment Decision for Renewable Energies in the Swiss Electricity Market

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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. These shifts need to be managed while ensuring a secure electricity provision. The investment decision for the specific technologies is a central leverage point in the system. Currently a feed-in remuneration tariff policy with a fixed tariff is implemented to support new renewable energy technologies in their development.

A System Dynamics simulation model is built to improve the understanding of central developments in the system and the interplay of different electricity technologies in the electricity production. 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 building of electricity technologies, depending on different public policies. This paper makes a practical contribution to the management of the energy transition by shedding a more dynamic light on the capacity expansion in relation to different forms of feed-in tariff policies.

Keywords: Energy, electricity, System Dynamics, Switzerland, feed-in tariff, nuclear phase out, long-term simulation.

1. Introduction

Switzerland has two self-made 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), due to the disastrous accident in Fukushima and lacking security of the nuclear technology in general. The stepwise phase out from nuclear power causes a gap in the future coverage of the electricity consumption in Switzerland (Prognos, 2007; Prognos, 2012). This gap needs to be filled with locally produced electricity to maintain political sovereignty (Swiss energy enactment Art. 6; Swiss Federal Council, 2011). Additionally, a commitment to a more sustainable electricity production was made (Swiss Federal council, 2011; Swiss energy enactment Art. 3b). Especially the expansion of hydropower and new renewables energies will be supported. Nevertheless, the Swiss Federal Council does not consider an electricity provision based on only renewable energies as feasible.

A System Dynamics model is built to improve the understanding on the dynamic interplay of central factors in the electricity capacity expansion system and simulate likely future developments. The focus in this framework lies on the investment decision taken for the different technologies und how this can be steered by governmental policies. This simulation model contrasts itself from other energy models currently used in Switzerland, by the endogenous simulation of the investment decision, which is driven by the internal dynamics of the system.

Central characteristics of the system as well as policy attack points are tested with the simulation model. The impact and effectiveness of the currently applied model of the feed-in remuneration policy is tested and compared with other feed-in tariff models described in Couture and Gagnon (2010).

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 proof to be a good instrument to push the electricity system in its transition, but they fail to sustain the system in its new state.

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

2. Background

Energy is a catalyst for every economy. It is the most relevant input for an entire system, for all kinds of production and consumption. Today we are facing a situation where the commonly used energies such as oil and gas are getting scarcer but new renewable energies are not yet completely competitive over the traditional energies (Jacobsson and Johnson, 2000). Environmental effects of the use of fossil fuels make an early transition necessary (European Commission, 2011; Dangerman, 2012). The electricity industry has already undergone multiple transitions, from wood to coal to oil and gas (Naill, 1992; Jacobsson and Johnson, 2000). Now a transition towards new renewable energies is necessary. So far the new renewable energies are not yet competitive over traditional energy sources, which creates the special situation where the government decides to push the transition. This research focuses on the challenges of a transition in the area of electricity production within the specific case of Switzerland.

The coverage of demand for electricity by households and industry in Switzerland is not guaranteed in the mid-term future. Power plants achieve their maximum lifetime, import contracts expire, but most important the nuclear power plants will be switched off, when they don't fulfil the required security standards anymore (Prognos AG 2007, Prognos AG 2012). The Swiss Federal council decided on the nuclear power phase out in 2011 after the happenings in Fukushima (Swiss Federal Council, 2011). No replacement and any major renovations will be made on the existing five nuclear power plants. The result is a steadily decreasing electricity production. *Figure 1* visualizes this problem. In this graph the electricity production based on the currently existing installed capacity, the expected lifetime of these plants and the planned switch off time for the nuclear power plants is simulated over 40 years. However, in the essence the match of the supply with the demand for electricity is much more important. In *Figure 1* three demand scenarios are included. The demand scenarios are called "business as usual", "new energy politics" and "political measures" and are the same as considered in the Prognos study (2012). The graph clearly highlights, that no matter which scenario is chosen, a huge gap in the electricity provision results.

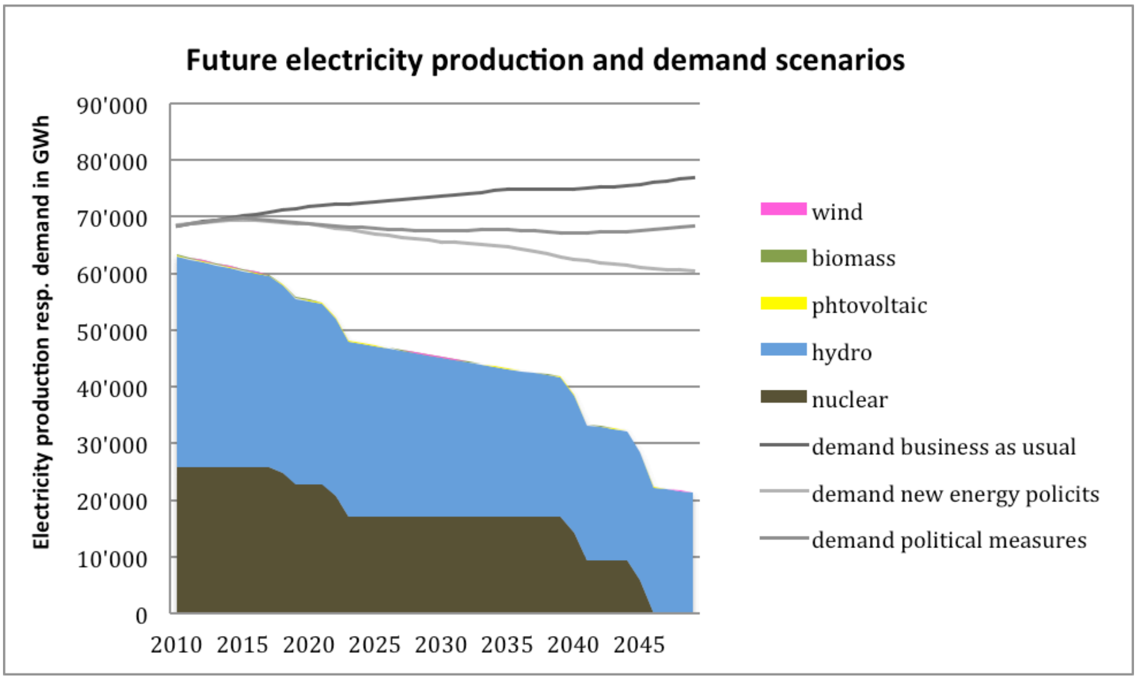

Figure 1: Gap in electricity production without new investments

The obvious question is - how to fill this upcoming gap in electricity provision. Prognos (2007, 2012) discuss in energy strategy 2035 (Prognos 2007a) and energy strategy 2050 (Prognos 2050) several constellations of technologies how the upcoming gap in electricity provision could be filled. These investigations are the major decision-making basis for the Swiss Federal council. Multiple energy models are combined and analysed with a scenario method. An extensive bottom up calculation for demand is made. For supply a static model of the power plant park is used. The investment decision is considered as exogenous but limited by the physical and economic potential of the technology. All scenarios designed by Prognos (2012) include gas combined cycle power plants. An electricity provision with only renewable energies is considered up front as unfeasible.

Supercomputing Systems Ltd. (SCS) provides a different answer how this gap in electricity provision could be filled. SCS suggests a power plant park constellation with only renewable energies (SCS 2013). The electricity model they present is a very detailed representation of the Swiss electricity production of one 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 production of 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 park constellations are derived that can provide the demand for electricity of 60 TWh per year with only renewable energies. 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 (2007; 2012) that combined heat and power units and also gas combined cycle power plants are necessary to guarantee a secure electricity production.

A major capacity expansion would be necessary to achieve a completely renewable electricity provision, no matter which model is considered. Neither the model by Prognos (2007; 2012) nor the model by SCS (2013) give an answer how and when these investments will be realized or whether these investments are an economic choice by investors or forced by the government. The investment decision for future investments is a very essential aspect for the future development of the form of the electricity production. 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 decision into the various technologies necessarily 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 very relevant when the feasibility and reliability of the final state derived by a long-term model should be tested.

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 the complement for the SCS model as well as a testing environment for various scenarios or policies to support renewable energy sources.

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 but its shareholders are to a major part the 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, 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 Commission (2008) observed that feed-in tariffs are the most effective policy in support renewable energies. Nevertheless the effect on the different technologies varied. Couture and Gagnon (2010) distinguish between seven different forms of feed-in remuneration tariffs. Switzerland shifted applies a *fixed price model* (Couture and Gagnon 2010, Swiss energy enactment). The *fixed price model* is a model independent of the current market price for electricity. This feed-in tariff (FIT) supports specific energy sources with 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 et al., 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* are profiting of the support.

Interface et al. (2012) analyse the effectiveness of the applied FIT policy in Switzerland. They conclude that the FIT policy has the potential to increase investments into new renewables to reach the goals by the Swiss Federal Council. Nevertheless, a long waiting list resulted and it is observed that 26% of the receivers of the FIT policy are free riders, investors who would do their investment anyway also without the FIT policy. An effect on innovation is not expected. Although the FIT policy evaluation by interface et al (2012) is fairly extended, an analysis of the long-term effects of the policy on the electricity market is not made nor is the sustainability of this policy discussed. SwissCleanTech (2013a) reveal with an economic thinking experiment, based on some general economic models, that the 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. Regulatory electricity technologies will struggle to amortize their investment. Also new renewables struggle in their profitability due to the gap between the marginal costs of production and their full costs (including the production unrelated costs) (SwissCleanTech, 2013b). Furthermore, SwissCleanTech (2013a) fear that after a stop of the FIT policy there will be no reinvestment into the new renewables.

3. Model

This study aims to increase understanding of the investment decision in the electric power industry and its dynamic impacts on the electricity provision system. A System Dynamics simulation model is used to gain insights into the dynamics of the system. With the simulation of different scenarios knowledge is built how investment decisions affect the constellation of the power plant park and which structure parts feedback to the investment decision itself. Furthermore, options are tested how the investment decision can be steered by public policies. This project sheds an aggregated and long-term view on the electricity capacity expansion system and focuses on the phenomena arising during the next 40 years. The simulation timeframe until 2050 is chosen in line with the planning horizon of the Swiss energy strategy 2050 (Swiss Federal Office of Energy, 2013b).

System Dynamics is chosen as suitable simulation method to simulate the high complexity of this system. Major delays in the system, interlinkages between the physical, economic and natural system require an interdisciplinary and complex method of analysis. The option to easily conduct sensitivity analysis and scenario testing made System Dynamics an ideal choice. Furthermore the transparent and visual representation of the simulation model was considered as a clear benefit.

Insights on likely developments of the power plant park in Switzerland in dependency of different external conditions are gained. Due to the complex interactions in the system an investigation based on dynamic simulation is necessary and promises to give more insightful results than a linear analysis of the problem.

The simulation model used for this study 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.

The System Dynamics model used for this study was constructed in the framework of the 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) under the supervision of Prof. Erling Moxnes (University of Bergen). The research process was oriented on the suggestion by Saunders and Lewis (2012). This project setting allowed that numerous alternatives for model structures were developed, tested, improved or also rejected. The model version presented here is the version considered as the most valid, most direct to the point and with the highest explanatory value. A more detailed description of the model, the underlying assumption and more in depth analysis can be found in the report on the master thesis: **WEBLINK**. The web link is currently not available yet. If you like to receive the full report contact the author under merla@merla.net.

3.1. Model structure

The model is built on 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 line 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 and of course the market price for electricity. The section *investment decision* is the central determinant for the development of the installed capacity.
The model distinguishes for ten different electricity sources. The array used is called *technology*. The elements of this array are: photovoltaic, wind, nuclear power, gas combined cycle, hydropower - distinguished into run-off-river hydropower, seasonal storage lakes (called dam in the model) and pumped storage lakes; thermal power from incineration, biomass and batteries. This separation of technologies is made to allow understanding the different impacts of the overarching system on the individual technologies and their development over time. The specific production characteristics of the different technologies are the most central reason for this distinction. For instance, while the production of photovoltaic plants is not controllable and totally dependent on the incidence of solar radiation, biomass plants can produce flexible on request. In the case of biomass plants the limiting factor are the availability of the input resources or even more frequent the economic constraints of the production costs. Treating photovoltaic plants and biomass as the same element in the array would therefore be strongly misleading. Distinguishing the technologies enables a precise definition of the seasonal electricity price, which determines production and investments. Electricity cannot be distinguished by its source, if it is once fed into the grid. Consequently technologies are heavily interplaying through the electricity price.
Additionally, using this array for technology allows seeing the actual components of the electricity mix and measure the share of renewable sources. The chosen elements of the array are consistent with the technologies considered in the SCS model to allow the exchange of results.

The central dynamics included in the System Dynamics model are represented in a simplified causal map in Figure 2. In the next section the major feedback loops are described in more detail.

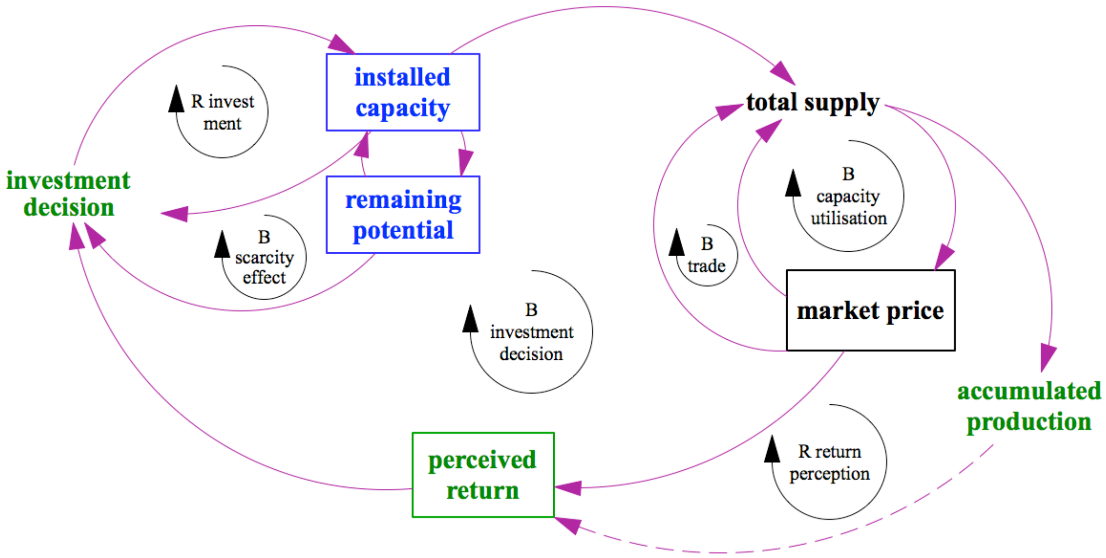

Figure 2: Central dynamics represented in the System Dynamics model

The focus of this model lies on the development of the capacity expansion of the different technologies and the investment decision steering the development of capacities. The installed capacities of the technologies determine the production of electricity at a specific point in time. Here the technology specific production characteristics influence the amount and time of production. Additionally a feedback loop for the capacity utilisation is included, ensuring that the flexible producing technologies only produce at times where it is economic. Trade is represented very rough. Electricity can be imported or exported to a certain capacity. The actual amount traded depends of the relation between the local market price in Switzerland and abroad. The market price is a very quick adjusting stock structure that represents the Swiss market price in a seasonal manner.

A generalized market oriented investment structure is chosen. The exact number, specific characteristics and the purchasing power of the investors are not modelled explicitly. It is assumed that there are multiple investors all making their decisions based on economic principles. Environmental thinking is not in their nature, as long as it doesn't match with profitability criteria. Nevertheless, the investors are not computers and also don't behave like homo economicus. Kahneman (2003) highlights that decision makers (in his work called agents) frequently make intuitive decision based on what they observe in the system, and not what they are able to calculate. Hampl (2012) confirms in her three-part dissertation various behavioural and social effects on decision-making in the energy industry. Investors in this model, although they aim to make an economic decision, still have biases towards their experience and limited perceptions. In line with these research the model uses *perceived return* as the relevant input for the investment decision. Perceived return is an adjustment process based on the annual return currently generated with on 1 GW installed capacity. The speed of adjustment is determined by the 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, on the other hand the adjustment was much quicker when they had few experience with the stock. Hampl (2012) confirms this relation in the specific field of energy. With the perceived return and the investment costs the investor calculates the net present value (NPV) of an investor. Investment costs are altered in relation to the remaining expansion potential of the technology. A scarcity effect on the investment costs cause the investment costs to raise. Based on the NPV a distribution of the investments is assumed in an investment function. This function is multiplied with the existing installed capacity. This relation reflects the investment power for certain technologies. To prevent a complete lock in effect a minimum capacity is assumed that new technologies can develop in the model too.

Looking at Figure 2 we realize that the model mainly consists of balancing feedback loops. This means, that the system has already a strongly self-regulating power. Central in these dynamics is the market price, which governs the majority of the feedback loops. Usually in System Dynamics a model focuses more on reinforcing feedback loops that accelerate the problem under study. In this investigation the relation that causes problems is the emission of green house gas emissions. This is not explicit part of this model, but this fact determines the political will to define policies to support new renewable energies. As this model is designed as a policy testing environment besides other scenarios, the pressure for change is exogenous and is represented by the will of the user to apply/test a policy. The same counts for the nuclear phase out and the desired level of independency.

3.2. Model analysis and validation

The formal validation process was oriented on the suggested procedure by Barlas (1996). All structure and structure-behaviour tests were conducted and passed. Statistical behaviour tests were not conducted, since the reference mode is to short to give reasonable results. However, the simulation results fit the reference data well but as the reference mode is so short this is not very surprising. As an example, the fit of the simulated price with the historic data is presented in Figure 3.

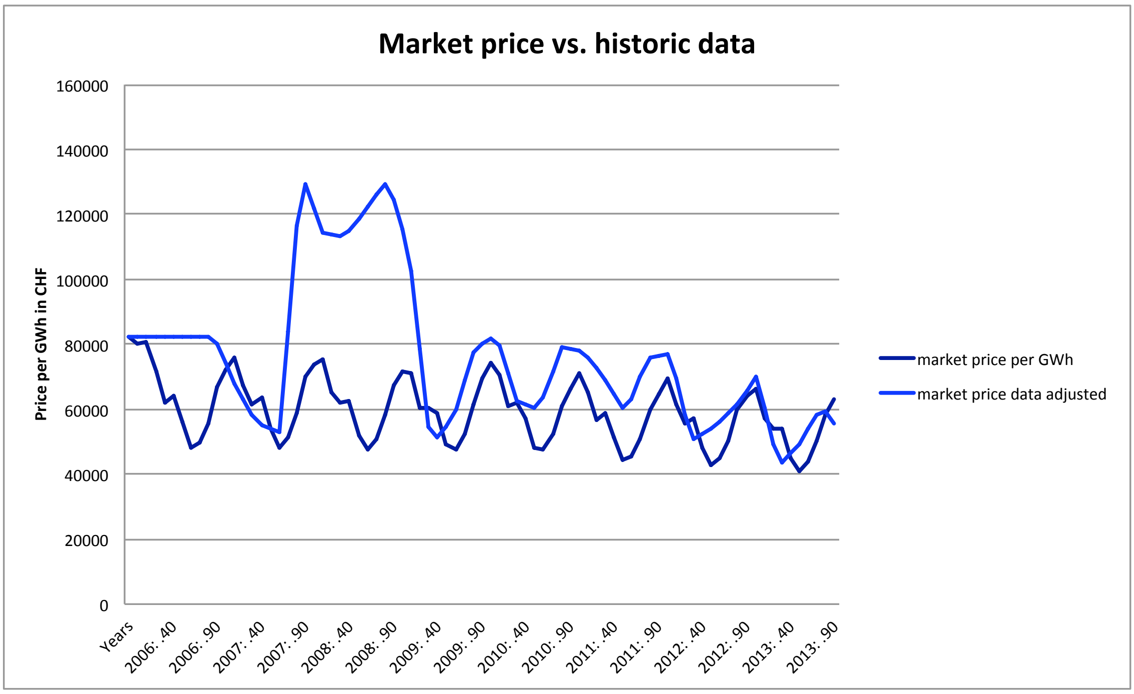

Figure 3: Simulated and historic market price for electricity

Sensitivity tests were made based on stable model condition. All policies were removed. The model does not have a natural equilibrium despite all the balancing feedback loops. Reason for this is that the model does not contain an automatic compensation for depreciations. In this model this is deliberately not made. This model is focussing on the capacity expansion seen from a market perspective. Investment is purely driven by profitability and the available expansion capacity. Industrial dynamics by Forrester (1961) as well as the beer game by Sterman (1989) analyse this mode of behaviour and its determinants in more detail.

Removing the currently established feed-in tariff policy reveals that there would be no investments into new renewables. The most drastic difference appears at the technology *dam*, so the seasonal storage lakes. In the equilibrium model there is no installed capacity for seasonal storage lakes at all. Today, with the current electricity price and the investment and marginal costs seasonal storage lakes are simply not profitable. These facts are supported by 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[1].

The exact shape of the investment function *investment relative to capacity* is very sensitive in the system. Here changes in the height, shape or base of the curve have a significant impact in the system. It is observed that the system reacts especially sensitive to changes in the height of the curve within the area of 0.3 and 0.6.

1 http://bazonline.ch/wirtschaft/unternehmen-und-konjunktur/Die-Axpo-fragt-sich-Wie-konnte-es-so-weit-kommen/story/19719269 accessed: 9.6.2014

Further more, significant drivers for change are the costs, which are treated as exogenous in this model. The cost development of new renewable energies will determine the speed and strength of an upcoming energy transition.

The price abroad and the trade capacity have a very similar and strong effect on the system. The incentive and ability to import and export electricity lead to major changes in the local price. A low price abroad, combined with sufficient trade capacity, leads to a constant underinvestment in the local capacity expansion. A very high price abroad on the other hand can lead to high investments in the beginning of the simulation period, which leads to a lower local price in the mid-term. This phase is followed by a period of high prices in the end of the simulation due to low investment as a consequence to the previously low price. Trade is in first line working as a buffer for irregularities, but it also can be seen as a 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.

For the sensitivity analysis four runs with transmission capacities of 0, 1, 2 or 3 GW were simulated. Here we notice, that trade is in first line working as a buffer for irregularities. In scenario 1, where there is no transmission capacity, we see that a gap between demand and supply lead to an enormous shock in price (Figure 4). On the other hand with a transmission capacity of 4 GW there is only a slight and quite steady increase in the price. Logically the price is influencing the perceived return of the technologies and with this it has an impact on the investment decision (Figure 4). In this light the more balanced price development enabled by the high transmission capacity gets the negative aspect of blocking new investments. Ochoa (2007) and Ochoa and van Ackere (2009) analyse this issue in the light of trade liberalization.

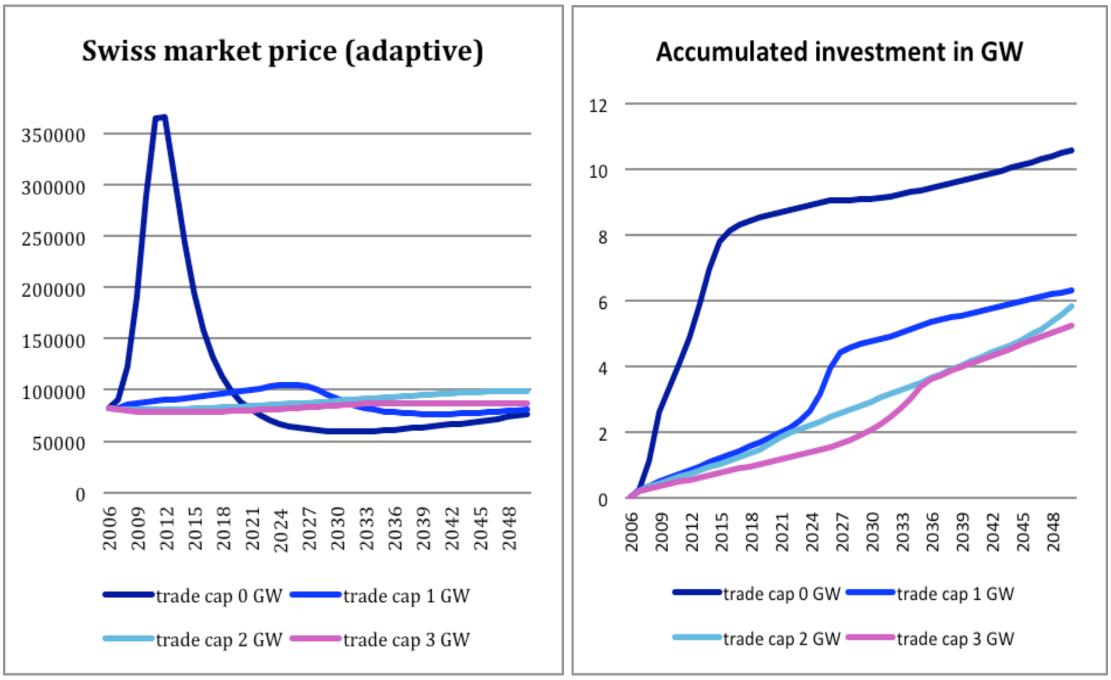

Figure 4: Sensitivity test with changes in transmission capacity – market price and accumulated investment

4. Results

In the previous chapter we got a good overview on the model structure, improved understanding the sensitive parts of the model and already tested the effect of nuclear phase out in a deregulated model. In this chapter we are running the model with real data. We start the simulation in the year 2006 and simulate it until 2050.

As a first step the base run is presented. We look into the major determinants shaping the base run to understand, where relevant dynamics come from. In the next step we experiment with policies to support the new renewable energies and analyse their effectiveness.

4.1. Base run

The simulation run called *base run* is the basis for our analysis as well as for policy comparison in the next section. The base run starts in year 2006. Table 2 in the appendix shows the used initial values. The initial value for the market price is 82520 CHF per GWh, as it was in 2006 (Swiss Federal Office for Energy, 2014).

For the base run the following conditions are included in the model. The fixed price FIT policy is stopped in the year 2015. For these years the new renewables receive the FIT tariff according to the historic data. Afterwards the market price at the time of production time counts for all technologies. The trade capacity is 2 GW at any point in time. The price abroad is set on 70’000 Swiss Franks per GWh with variations of a sinus curve of an amplitude of 5’000 Swiss Franks per GWh. The political will persists on the nuclear phase out. The nuclear power plants are shut down according to the dates currently expected. A hypothetical tax is set on electricity from nuclear power plants preventing new investments. Production with the currently installed capacity of nuclear power is allowed and not taxed.

We simulate the model with these conditions. Generally demand is covered in most of the cases despite the nuclear phase out. Local supply of electricity first increases to level higher than the initial value and also higher than demand. This rises exports of electricity, therefore net imports are negative. 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.

Correspondingly to this development is the curve of the electricity price. The market price first drops slightly in line with the oversupply of electricity. When the last nuclear power plants are shut down and also the effect of the stopped FIT policy kicks in prices start to rise again and reach higher levels (Figure 5). Important to notice is that the fluctuations in the electricity price are increasing with higher share of renewables in the power plant park and every nuclear power plant that is switched off. The fluctuations moving along the production characteristics of photovoltaic and wind cause price lows during their peak production times and price highs when their production is low. With no nuclear power the share of these fluctuating technologies in the electricity production increase and cause the price to fluctuate stronger. Interesting to see is that the annual return for the technologies causing this fluctuations (so photovoltaic and wind) only increases slightly with the increasing price in the end of the simulation, for flexible producing technologies such as biomass and pumped hydro power plants the annual return rises high.

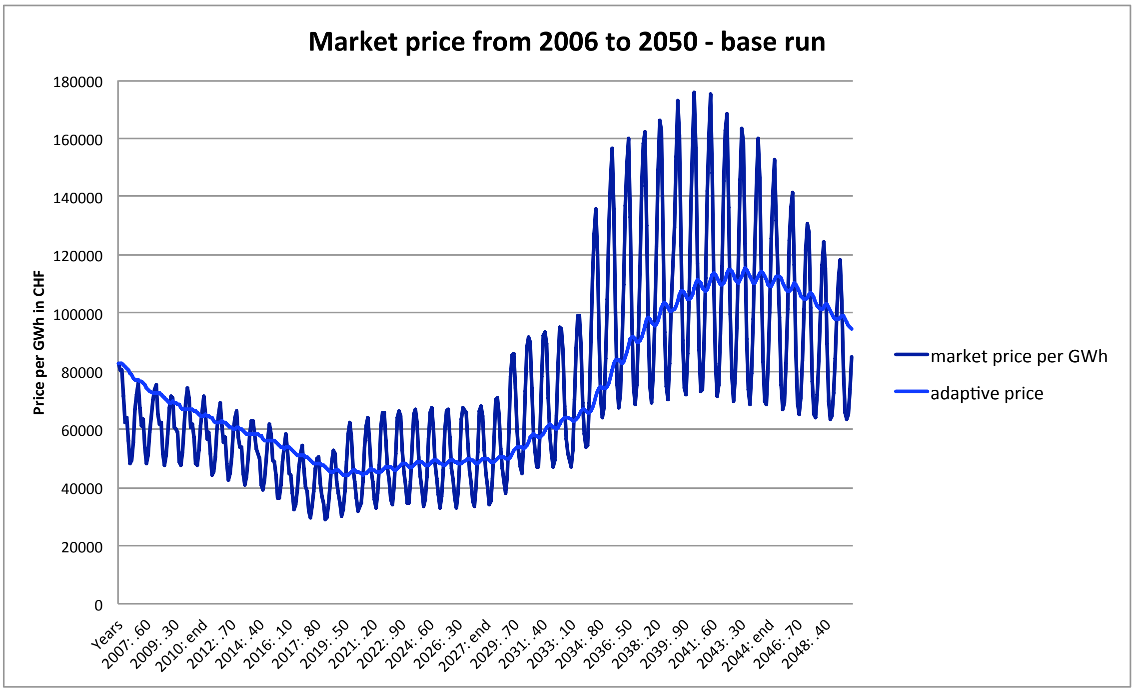

Figure 5: Base run – market price

Investments follow for the specific technologies fit the reference mode from 2006 until 2013 in satisfying manner. Afterwards the investments follow a realistic pattern (Figure 6). There is a major expansion of photovoltaic and wind as a consequence of the FIT policy.

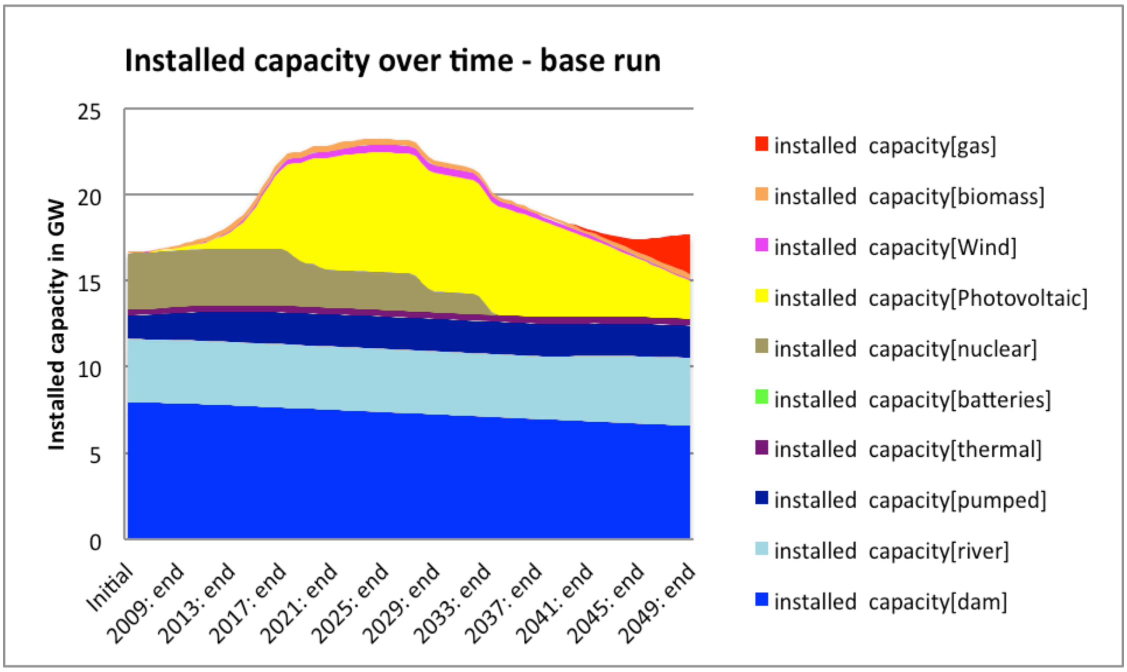

Figure 6: Base run – installed capacity

After the ending of the FIT policy in 2015 the investments into new renewables fall to zero. Despite the increase in price, there is no reinvestment into the technologies that were originally supported by the feed-in remuneration policy. In the year 2045 an increase in installed capacity for gas-fired power plants is observed. In other words, the FIT policy pushes to system to a real energy transition towards new renewable energies. But the policy is not sustaining the system in a state with new renewables. With stopping the policy the transition is removed and the system falls back into normal patterns (gas replaces nuclear in this moment). This confirms the apprehension communicated by SwissCleanTech (2013a). The development of the investment into new renewables is on one hand clearly determined by the Fit policy, as intended, on the other hand there is also a significant development going on the costs. The data taken from the Prognos study (Swiss Federal Office of Energy, 2007) are known as rather conservative. The cost development for photovoltaic is updated with the real data for 2013, since already there the estimation were clearly above the value reached in 2013.

4.2. Policies

The simulation model is used to test different forms of FIT policies to support new renewable energies and evaluate their effectiveness. We test 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. A set of variables is used to compare the effectiveness of the policies. The selection of the variables is oriented on the suggestions by IREA (International Renewable Energy Agency, 2014) but does by far not reach that level of detail. The set of variables can be seen in Table 1. Accumulated costs are not discounted.

The fixed tariff FIT policy is the policy applied in the base run. The policy enables a good start into an energy transition towards new renewable energies. The share of new renewable energies within the electricity production rises to around 20%, but then drops down to 11% after the policy is stopped. Investment into new renewables is stopped completely after the ending of the policy, despite significant cost improvements of the new renewable energies. In the end of the simulation period there is even investment into gas-fired power plants.

We analyse the impacts of applying the currently established feed-in remuneration policy with fixed tariffs for the entire period until 2050. This policy is currently under revision and will certainly be changed in the future. Nevertheless, we test the impacts of the feed-in remuneration policy on the system when it is applied in the future with the current format. For this simulation it is assumed that the feed-in remuneration tariffs remain on a constant level after 2014. We observe that the effect of the policy goes in the desired direction – a significantly increasing share of new renewable energies in the total electricity production results. Initially the development is the same as in the base run, where the same FIT policy with fixed tariffs is applied but stopped after 2015.

With remaining feed-in remuneration tariff the share of new renewables rises to a level of about 0.25. In the end of the simulation period the percentage dropped a little. This comes from lacking reinvestment as investments become more expensive with lower expansion potential. Together with hydropower sustainable energies have a share in the local production of 87 %. The remaining percentage is covered with imports. Total investments in general accumulate to a value of 63'420 million CHF of which the new renewables are 60'194 million CHF.

The spot market price gap FIT is another market price independent form for a feed-in remuneration tariff discussed by Couture and Gagnon (2010). The policy ensures a minimum receiver price for the producers benefiting of that policy with covering the gap between the market price and the threshold set by the policy. The electricity producers with new renewable energies receive the market price plus the difference to the threshold. If the market price is higher than the threshold only the market price will be paid off. This policy is, from a producer perspective, very similar to the fixed price model. Theoretically the only difference is that they can receive a higher return when the spot market price is very high. In practice this policy is usually implemented without a purchasing guarantee for the produced electricity. So the investors have to sell the produced electricity themselves on the electricity spot market. This could be a hurdle for smaller investors such as households (Couture and Gagnon, 2010). This kind of implications of a policy are not included in this simulation model but have to be kept in mind when evaluating the policy. Simulation results will therefore be very similar to the fixed price policy in terms of capacity expansion and price. Nevertheless, it is interesting to see the difference in the total amount spent for the policy and the total costs on consumers.

A premium FIT pays a fixed premium for the production of electricity of new renewable energies. This premium comes in addition to the market price. This is the system that is most likely to be applied as the new policy instead of the fixed price policy. For this simulation a constant premium is chosen that leads to a share of new renewable energies that is comparable to the other policies to allow comparison of costs. The premium necessary to reach this level is 52'000 CHF per GWh. In terms of implementation this policy is easier to handle and doesn't create access barriers to small investors. Nevertheless, the return risk is higher as there is no guaranteed price for the produced electricity.

An alternative to the previously discussed policies is a FIT that gives a percentage of the market price to the producers. This policy is artificially accelerating the fluctuations of the market price in the view of the investors and gives incentives to produce, when the market price is high. For implementation this policy is rather complicated, as one would need to know how much every producer was producing at a specific point in time. Usually the measuring system is not that developed to enable this properly. The percentage was chosen in the manner that again a similar share in new renewable energies is resulting at the end of the simulation period. 60% is the percentage reaching this.

In this investigation four alternative policies for the support of new renewable energies were tested in a dynamic simulation model. The policies are compared in Table 1, Figure 7. Table 1 lists the results values for the policy evaluation criteria for the four tested policies and the base run.

	Base	FIT fixed price 2050	spot market price gap FIT	premium FIT	percentage market price FIT
avg weigthed price	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 plus hydro	77%	87%	87%	80%	81%
accumulated investment in mio CHF	31‘737	63‘420	63‘433	33‘214	34‘157
acc investment into new renewables in mio CHF	26‘155	60194	60205	27‘053	28‘003
Policy costs in mio CHF	9‘213	69‘025	51653	11‘905	11‘010
consumer spendings in mio CHF	205‘784	182‘398	183013	229‘083	229‘421
total costs on consumers in mio CHF	214‘997	251‘423	234‘666	240‘987	240‘431

Table 1: Policy comparison with evaluation set

The table highlights that all tested policies have a positive impact on the expansion of new renewables. The share of new renewables increases significantly. The share of green energies in the total electricity mix reaches levels between 80 and 87 percent. In all scenarios the coverage of demand also uses imported electricity from abroad. In the case of the premium FIT and the percentage of market price FIT there is even investment into gas-fired power plants as can be seen in Figure 7.

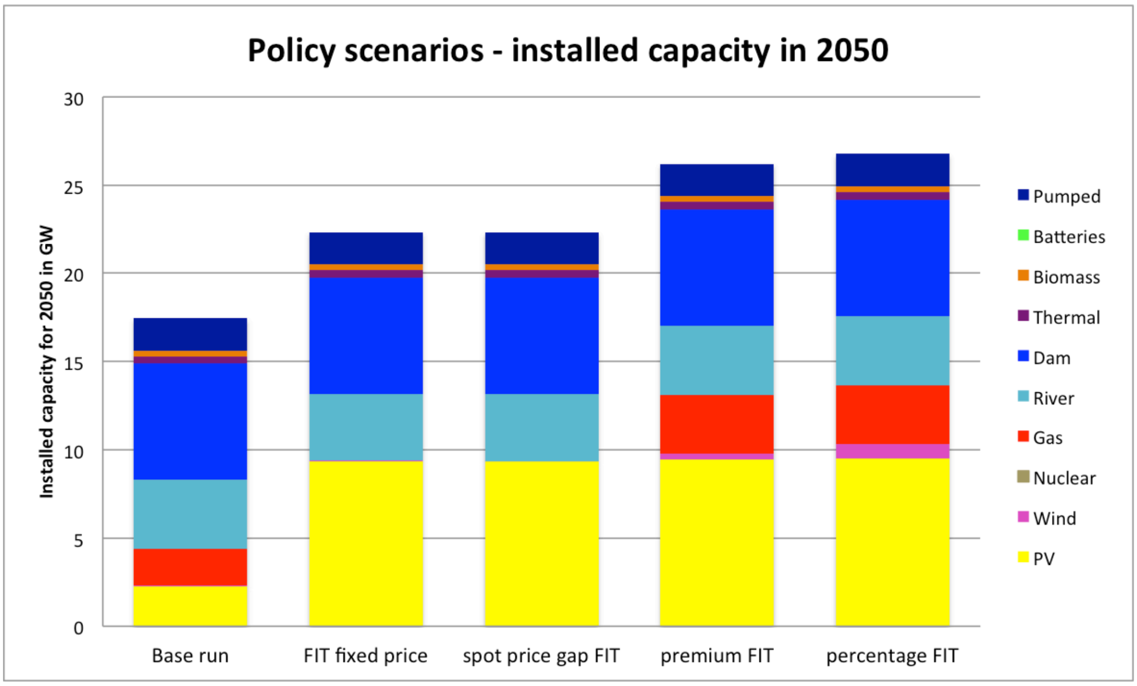

Figure 7: Comparison of policy scenarios – installed capacity

Table 1 highlights that the costs to conduct the policy are the lowest for the premium FIT and the percentage of market price FIT. They both cause costs of only around 11'000 million CHF. Although only is also here belittling. Those two policies are low in costs but the market price is on a higher level with these support systems. Therefor the consumer spendings and the total costs on consumers are high. Oriented along the costs on consumers the FIT policy based on the gap between the spot market price and a defined tariff is the most efficient support policy.

Interesting to see is that in this simulation the spot market price gap FIT can reach the same goal as the fixed price FIT with clearly fewer costs. The money saved is about 20'000 million CHF. This indicates that with a shift from the currently applied fixed price FIT to the spot market price FIT a lot of money could be saved. However, as already mentioned earlier, the spot market price gap FIT brings hurdles for small investors. This could have a significant impact on the expansion of photovoltaic, since these plants are frequently built on the house roofs of private persons.

However, this investigation will not be able to draw a final conclusion or recommendation on which policy is best to support the new renewable energies in their investment. The policies were not tested within their full potential. It was always assumed that the tariff or the quota remain on the same level. Generally it would be possible that these tariffs or percentages are adjusted to the current state of the system. This would allow to steer the system in more precise manner.

However, we are able to draw some general conclusions on the effectiveness of the tested policies and what might be improved to reach a higher policy effectiveness. All the FIT policies can significantly increase the expected annual return of an investment and also reduce the investment risk. As the European Commission (2008) correctly says, the 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 forms very cost intensive. Simulation results clearly showed that the policies don't have a sustainable effect on the system. Without the policy there is a lack of incentives for reinvestment into renewables. Therefore 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 generally already observed that investors hesitate to invest in technologies that depend on or are affected by public policies (Hampl, 2012). There might be very relevant dynamic aspects that are currently not considered in the simulation model. Incorporating an endogenous modelling of risk in the model is definitely a considered step for future research. Policies that are very sophisticated and have the theoretical potential to steer the system very well might fail in this point and be to complicated for investors and prevent instead of support their investment. It would also be for example also interesting to see the effect of the time of communication of the feed-in remuneration tariffs by the government on the risk perception. A model capturing all these aspects would be extremely interesting and could lead to very relevant insights.

5. Discussion and conclusion

Switzerland is facing two major challenges in its electricity provision. First, the Federal council decided on the withdrawal of nuclear power. The stepwise shut down of the five nuclear power plants of 3.28 GW will cause a major gap in the future electricity provision. Second, a clear commitment to new renewable energies was made. This situation brings challenges and chances.

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 specific technologies, and the investment decision connected with it. The model captures the development of ten different electricity production technologies: photovoltaic, wind, nuclear, gas, run-off river, seasonal storage lakes, thermal power, biomass, batteries and pumped hydro-power. Investments in this model are made upon a market-oriented investment structure. There is no central planning entity included in this model. Investors are modelled as profit-oriented, but not perfectly rational. Most important input for the investment decision is the perception of return, which could be generated with an investment into this technology per year. This is heavily determined by the market price and the time and shape of its fluctuations. The production characteristics of a technology define at what time electricity can be produced and very relevant to which price the technology can be sold.

Analysis of the model reveals that an electricity system, designed as in this simulation model, always leads to long-term oscillatory behaviour, because there is no central management compensating for depreciation of installed capacity. In this model gas-fired power is the technology that is most frequently used to fill this gap, but also suffers from the oscillations. This is important to know, as the Swiss Federal Council plans to construct gas-fired power plants to compensate for the phased out nuclear power plants. Sensitivity tests showed that the capacity for trade of electricity and the electricity price abroad are very sensitive elements in the system that have the potential to cause major changes in the model and system behaviour. More investigation is needed to understand how these elements can be used to support the new renewable energies. Additionally, the investment function used in the model has very sensitive areas. More detailed research would be necessary to investigate in the exact shape of this curve. With increasing shares of renewable technologies the price tends to fluctuate stronger. In this framework the development of profitable storage options is very important. Currently the most relevant storage technology, namely the seasonal storage lakes, are not profitable and no further investments are made. This observation is supported 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 all FIT policy models cannot bring a sustainable change into 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 an old state. Further research is necessary, on how these policies can be combined over time to enable an ideal energy transition. Further more, 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 sustainable 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 much broader scenario testing in the wide field of electricity supply.

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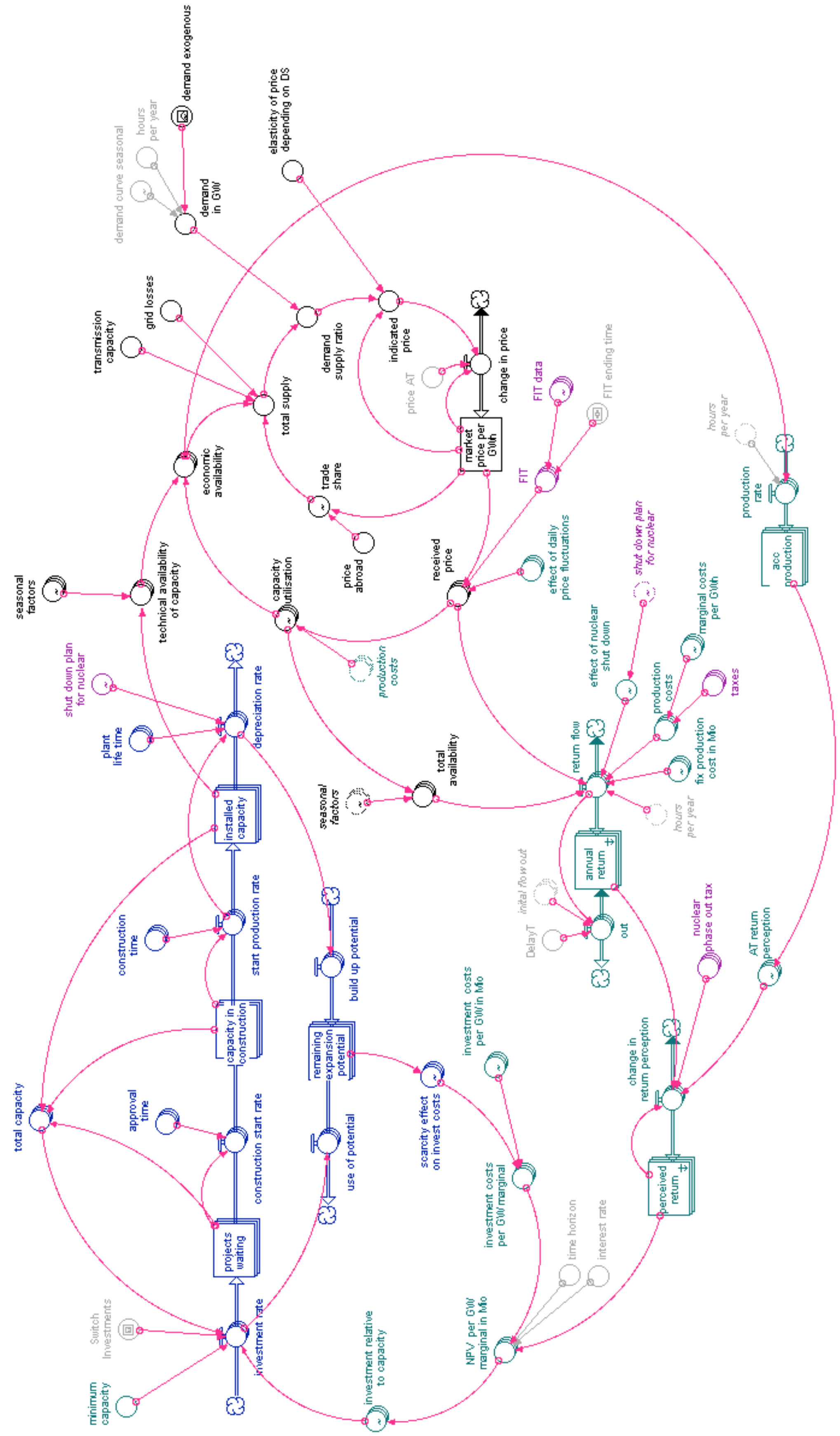
Appendix

I. Complete stock-and-flow diagram



II. Initial values

	projects waiting	capacity in construction	installed capacity	remaining potential
Photovoltaic	0.011	0.05	0.029	10.9
Wind	0.002	0	0.012	1.156
Nuclear	0	0	3.278	0.002
Gas	0	0	0	3.85
River	0.01	0.005	3.652	0.303
Dam	0.001	0.1	7.961	0.298
Thermal	0.01	0	0.355	0.055
Biomass	0	0	0.032	0.358
Batteries	0	0	0	1
Pumped	0	0	1.383	0.497

Table 2: Initial values used for the stocks in the sector physical system