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

by

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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.

TABLE OF CONTENTS

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.

2.1. The gap in electricity provision

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.

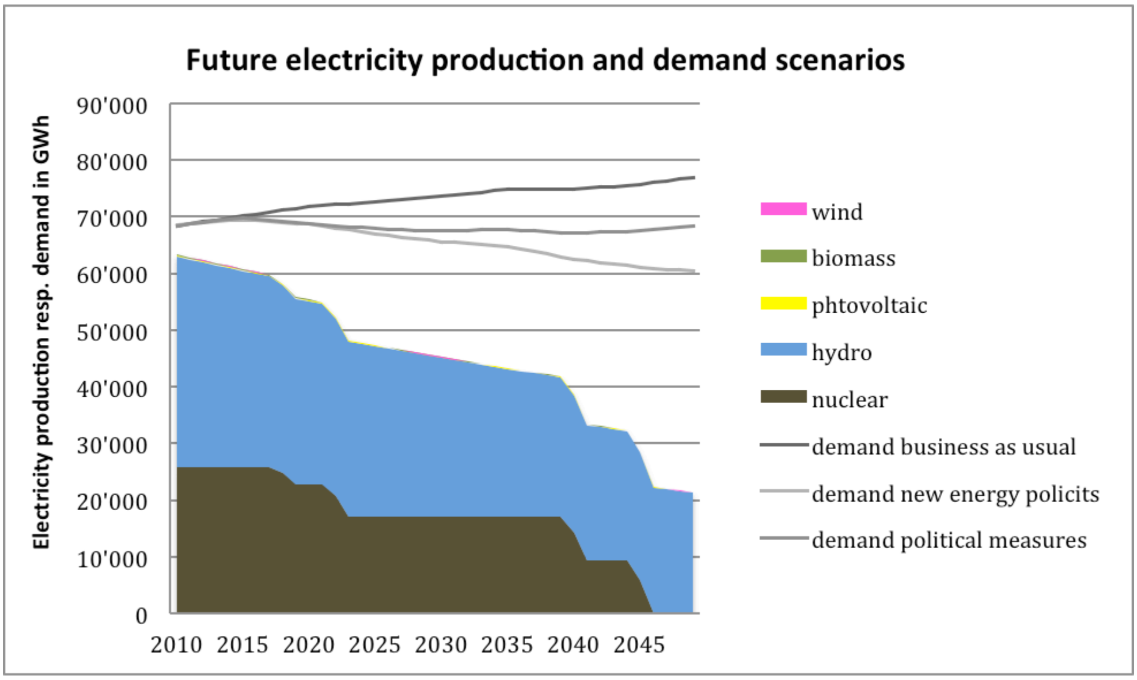

Figure 1: Gap in electricity production without new investments

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. *Figure 2* compares the difference between the currently installed capacity in Switzerland and the installed capacity from the SCS scenario "renewable A". Due to the higher production volatility of new renewables the installed capacity needs to be generally higher. It has to be keep in mind that the currently installed nuclear power capacity will not persist in the future.

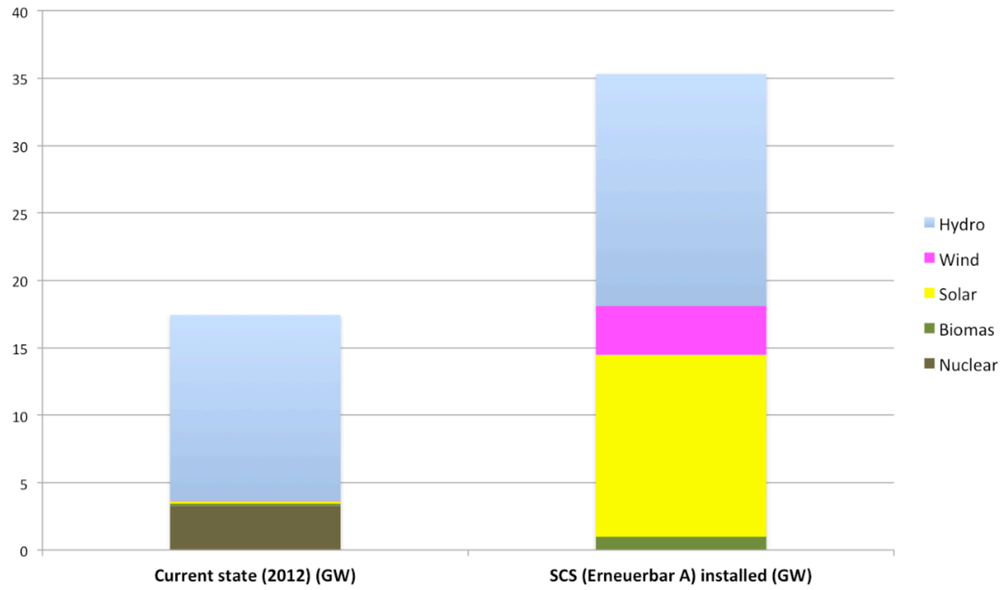

Figure 2: Comparison of the installed capacity in the SCS scenario „renewable A" and the current state (2012). Data sources: Swiss Federal Office of Energy (2013) and SCS (2013).

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.

2.2. Current legal and regulative framework

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). For example, today a photovoltaic plant of an installed capacity of 100 kWp receives 22 Rappen per kWh over 20 years. With guaranteeing a certain cash flow over a defined period of time the investment risk is significantly reduced and therefore investments are encouraged (Couture and Gagnon 2010). In the Swiss system the tariffs are defined based on the technological development, the costs of the input material and the long-term chances of the technology on the electricity market (Swiss Energy Enactment, Art. 3). In the case of photovoltaic also the desired capacity expansion contingent plays into the definition of the tariff (Swiss Federal Council 2008). 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 huge benefit.

At hand of the simulation model internal as well as external knowledge of the system is gained. Internal knowledge is gained on the relations between variables in the electricity provision system. Especially the determinants of the investment decision are of major importance. The simulation model allows testing these relationships and control if this produces the expected behaviour as well as the behaviour observed in historic data. External knowledge focuses on achieving a better understanding of the development of the Swiss electricity provision system. Insight 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 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. 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. The model used here captures some elements of these findings. Investors in this model, although they aim to make an economic decision, still have biases towards their experience and limited perceptions.

In most of the model parts variables are distinguished for different electricity sources. The array used for the distinction between the electricity sources is called "technology" and has ten elements. 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. Although the technologies are distinguished and separated in the model they are still influencing each other. Electricity cannot be distinguished by its source, if it is once fed into the grid. Consequently technologies are heavily interplaying through the electricity price. 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, which vary over season, are another reason why the distinction between these technologies is essential. Electricity production is determined by the technology specific production characteristics. 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. 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.

3.1. Model structure

3.1.1. Overview

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 actual annual return influences the return perception and together with the investment costs this determines the investment rate for the different technologies.
Figure 3 gives a very simplified overview on the model structure entailed in the System Dynamics simulation model. The figure captures the three sectors and displays the major stocks of the system. The complete model includes more variables and is more elaborated in the details. The complete stock-and-flow representation is developed and

explained with the relevant equations in the next three sections. The explanation follows the sectors described above, starting with the electricity market (3.1.2), moving to the physical system (3.1.3) and closing with the investment decision (3.1.4). In part 3.2 the central dynamics incorporated in the model structure are discussed.

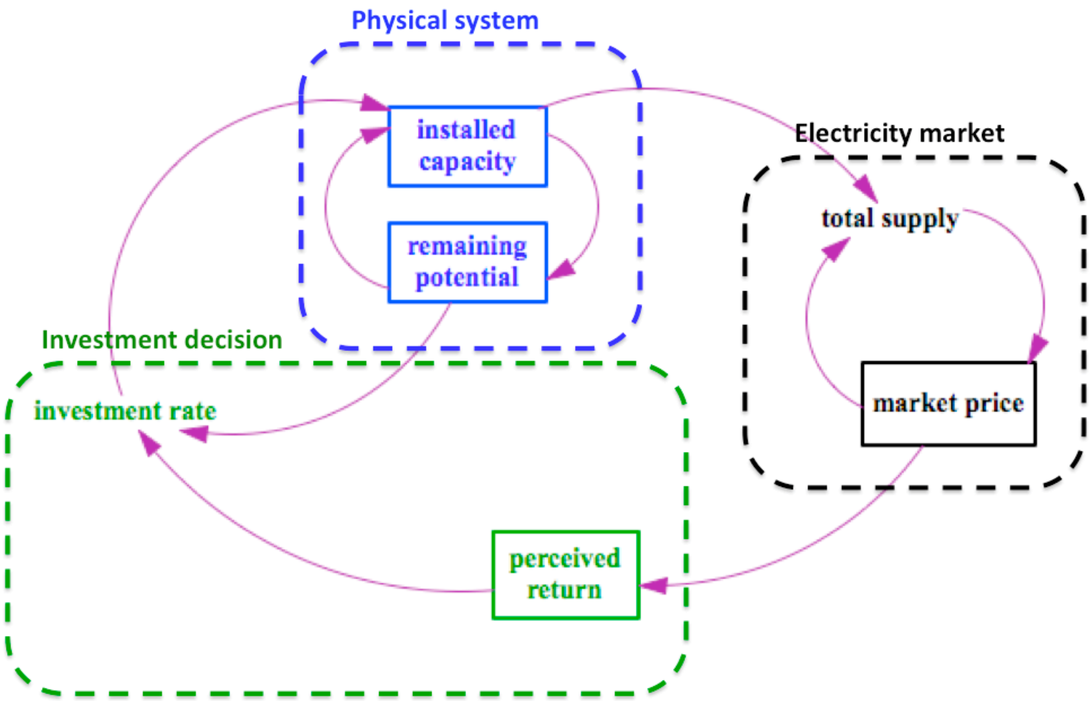

Figure 3: Overview on the sectors and central stocks included in the model.

3.1.2. Electricity market

The sector *electricity market* simulates the local electricity production, the development of the electricity price and trade of electricity. In Figure 4 the stock and flow diagram of the elements of the simulation model in the sector electricity market is given. In the next steps the variables and the used equations are explained.

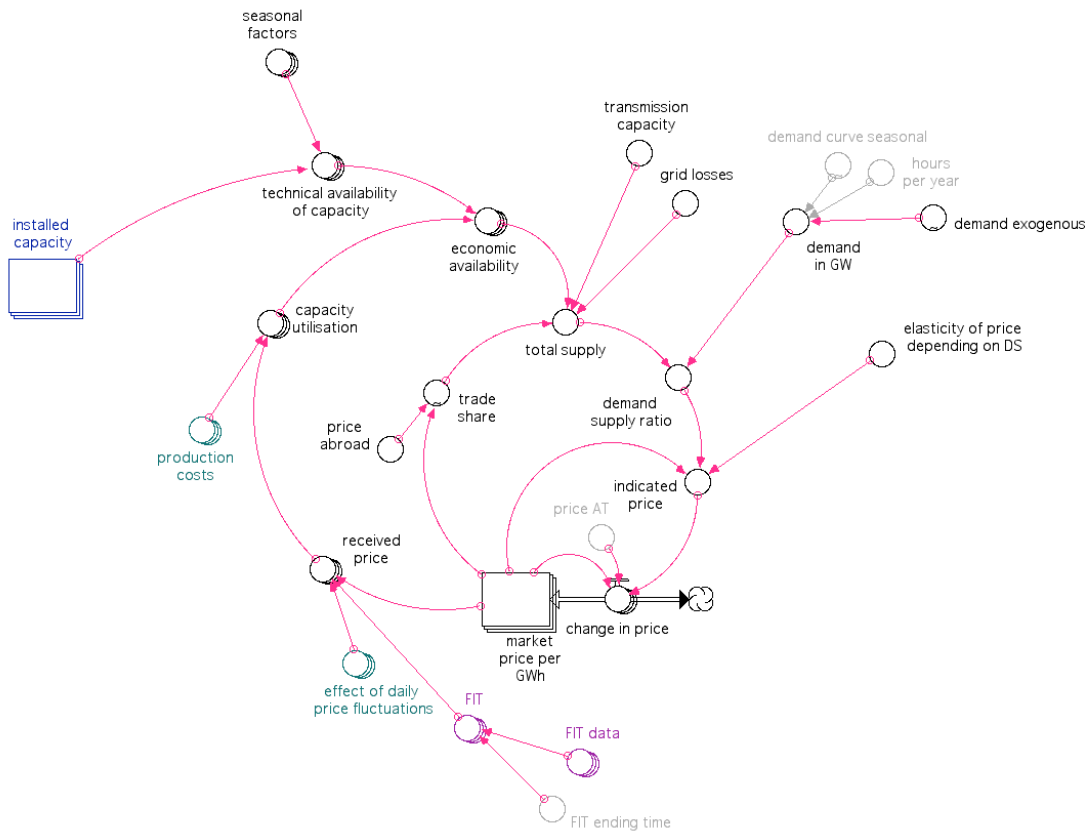

Figure 4: Stock-and-flow diagram of the sector electricity market

The core variable of the System Dynamics model is the stock *installed capacity*. This stock represents the currently installed production capacity of all ten technologies at a specific point in time. It is the basis for the electricity production. It is important to understand that this stock does not represent the produced electricity; it only represents the capacity that can produce electricity, when the necessary conditions are given. These conditions are very central and vary heavily among the different technologies. The stock is measured in gigawatt (GW), while produced electricity is measured in gigawatt hour (GWh). The stock *installed capacity* foregoes a supply line for new capacity. This is part of the physical system and will be explained in the section 3.1.3.

Whether capacity in fact can be used depends on two main factors, the seasonal availability and the capacity utilisation. First the capacity needs to be technically available or useable. This depends on technology specific seasonal factors. In the model these aspects are captured in the variable *seasonal factors*. Second capacity is only used under sufficient economic conditions. The combination of these two factors determines the actual availability of capacity and with this the electricity production.

The technical availability heavily depends on seasonal factors, which are different for all considered technologies, but there are also aspects such as mandatory maintenance. In the next steps the determinants of the seasonal factor for every technology and the origin of the data or the included assumptions are explained.

Photovoltaic depends on solar radiation and the duration of the solar radiation over the day. Of course the specific weather circumstances cannot be predicted, but the general pattern of the solar radiation over the year can be represented since the days are longer in summer and the exposure to the sun higher. For this purpose monthly average values of the city Basel, which is considered as averagely exposed to the sun compared to other Swiss places, where used. Data stems from meteonorm (www.meteonorm.com). Access was granted through my partnership with SCS. Of the 15 min values data the monthly average was calculated for this model.

Wind power relies on the occurrence of wind. Wind is way less predictable than solar radiation, but still always remains in a certain range. Here average monthly values of a wind power plant on the Crêt Meuron (in the west of Switzerland) where fed into the model. The data used here is from the SCS model. Originally the data was taken from http://wind-data.ch.

Nuclear power is generally able to produce constantly and at full capacity over time. Nevertheless, it is necessary that nuclear power plants go through a major maintenance once per year. This is usually executed in summer, since in this season electricity production is high and the lack of electricity from nuclear power plants can be compensated easier. The data set used is generated by SCS for future electricity production by nuclear power plants. It assumes that the nuclear power plants are sequentially shut down in summer (SCS 2013).

Gas power plants do not face any technical restrictions. Nevertheless it is assumed that at some point in time maintenance is necessary and temporary limitations in the gas import might occur. Therefore the seasonal factor is assumed to be 0.9. The overall limitations in gas import are captured in the expansion potential of the technology and will be discussed under 3.1.3 the physical system.

Run-off river power plants depend on the volume of the stream of the river they are built on. Rivers carry different volumes of water over the season, mainly due to the melting of snow but also due to rainfall. In winter and early spring the water level is rather low, while in summer and autumn the volume has its peak. The data for the seasonal factor of run-off river plants comes from the weekly electricity statistics of the Swiss Federal Office of Energy (2007), it was interpolated by SCS and averaged to monthly values for the purpose of this model.

Seasonal storage lakes, in the model simply called “dam”, produce electricity in fact based on the amount of water stored in the lake and the timing of use. This storage is not explicitly modelled as an inventory in this model. This was left out for simplification reasons, but also due to the risk of stretching/worsening the simulation results due to overly determining model structure. Here the electricity production from seasonal storage lakes is treated as a capacity. The availability is according to the current use of seasonal storage lakes. Data stems from the weekly statistics on electricity production in Switzerland (Swiss Federal Office of Energy, 2007).

Thermal power is produced by waste burned in incinerations. Consequently the production is based on the availability of waste. Storage capacities of incinerations are very limited, therefore much more the stream of waste is relevant. Over the previous years the waste flow was fairly constant with a slight high in the summer. The data used originally comes from the weekly electricity statistics by the Swiss Federal Office of Energy (2010). It was translated to production values of 15 minutes by SCS. This data was used to generate monthly average values for this simulation model.

Biomass electricity production doesn't face any technical constraints, besides hypothetically a limitation of input material. The aspect of input material is captured in the expansion potential of the technology, since it does not vary over season.

Batteries in large scale or other forms of short-term storages are not used in Switzerland yet. It is here assumed that their technical availability is depending on the overproduction of photovoltaic plants during peak production hours. Therefore the technical availability of batteries is a smoothed function of the photovoltaic seasonal production coefficient.

Pumped storage lakes produce the electricity with moving water between two storage lakes. Water is drained from the upper storage lake, to produce electricity (such as a normal storage lake). The water is captured in lower storage lake and pumped up again in phases when the electricity is cheap. In detail the technical availability depends on the size of the capturing lake at the bottom of the storage lake, since this determines the volume of water that can be pumped up in the other storage lake. This model does not go in such a detail, therefore a constant seasonal factor of 0.8 is assumed to represent this limitation.

These seasonal factors combined with the installed capacities of every technology determine the seasonal sensitive *technical availability of capacity*. In a next step the economic availability of capacity is discussed.

The economic availability of the capacity depends on the capacity utilisation of the specific technology. The capacity utilisation is a function of the current market price and the marginal production costs of every technology. The capacity utilisation function is different for every technology, reflecting their specific production characteristic. One can distinguish between flexible and non-flexible production technologies. Non-flexible production technologies, such as photovoltaic and wind, are basically producing all the time, since their marginal production costs are zero or almost zero, as long as they are technically available. Therefore their capacity utilisation function is simply one, as it is used as a multiplier. Flexible producing technologies all have marginal costs of production higher than one. Flexible producing technologies can be shut down, when the economic conditions are not satisfying the minimum requirements. The minimum requirement is generally that the received price for a unit of electricity has to be higher than the marginal production costs plus occasional taxes. But shutting down certain plants in some cases requires an effort. Imagine for example shutting down a nuclear power plant. Shutting down a nuclear power plant costs 500 CHF per installed MW (Paul Scherrer Institute, 2005) and requires some time. In this case production is only reduced when the received price is clearly below the marginal costs of production. Therefore the capacity utility function is flat in this case. For gas-fired power plants, biomass, dams, batteries and pumped storage lakes the shut down time is short. This allows them to quickly reduce their production, when the market price falls below their marginal costs of production. Nevertheless, for a price only slightly lower than their marginal production costs it still might be worth for the producers to keep the plant running to avoid costs for stopping and starting again. Their capacity utilisation function slopes down to zero quickly when the market price for electricity is below their marginal costs of production. For nuclear power the function is very stretched and does never reach zero. The capacity utility functions for flexible producing technologies are shown in Figure 5.

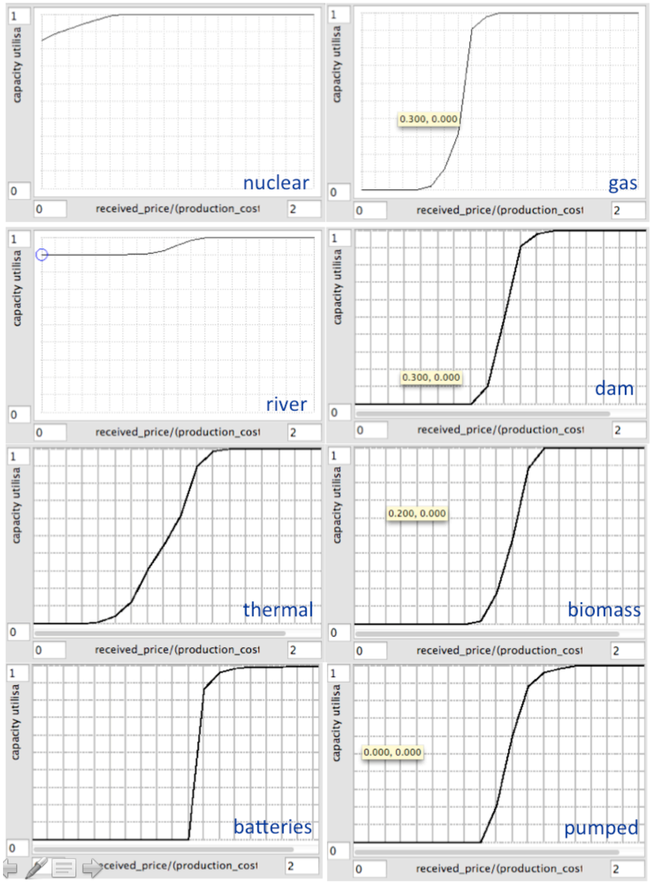

Figure 5: Capacity utility function for the flexible producing technologies

In this framework it is important to be aware of the *production costs* of the different technologies. Production costs are the sum of the marginal costs of production and occasional taxes. All types of hydro-power are obliged to pay a water tax of 1.1 rappen per produced kWh electricity (Prognos 2007b, page 22/23). Gas-fired power plants emit CO2-emission and therefore have to pay the CO2 tax. The CO2 tax in the model is set on 35 CHF per ton of CO2 (Prognos 2007b, page 453). The Swiss Federal Council can adjust this tax between 30 and 120 CHF. Recently the tax was moved up to 60 CHF per ton of CO_2[1]. This system might change in the future to emission permits, which are not fully incorporated in Switzerland by now but are in the rest of Europe well established. For the model it is assumed that this tax remains constant for the entire simulation period. Of course this can be changed as a policy scenario. The Swiss Energy Foundation (2006, page 4) assumes 246 g CO_2 emissions per kWh produced with a gas fired power plant. Therefore the CO_2 tax for gas is 8'610 CHF per GWh. Marginal costs of production can be reduced with technological development, but also raise with higher input costs, such as in the case of gas. In the model the marginal costs of production are captured in the exogenous variable *marginal costs per GWh*. In 2006, the start of our simulation, the technologies can be ordered according their marginal costs of production in the following manner: photovoltaic (0.- CHF/GWh), wind (0.- CHF/GWh), river (0.- CHF/GWh), dam (0.- CHF/GWh), biomass (15'000.- CHF/GWh), nuclear (20'000.- CHF/GWh), thermal (20'000.- CHF/GWh), pumped hydro power (40'000.- CHF/GWh), gas (90'000.- CHF/GWh) and batteries (150'000.- CHF/GWh). The data stem from BFE (2007) and Kettner (2013). Taxes are not included in these values. Looking at these values and the ranking one notices that most of the new renewable technologies can produce at zero marginal costs, while the fossil fuels are costly in this aspect. This will be source for major challenges in the future. SwissCleanTech (2013a) provide a very interesting analysis of this problem. They imagine a power plant constellation with mainly new renewable energies, such as photovoltaic and wind. This leads to periods where the market price for electricity falls to close to zero due to their low production costs. On the other hand there are phases during the day with high prices, because all the new renewable technologies cannot produce. Technologies with a regulative power struggle therefore to amortize their plants, as phases with high prices are too short.

The capacity utilisation is multiplied by the seasonal availability of the technology. This gives the economic availability of the technology at a specific point in time.

Economic availability of technology =
*technical_availability_of_capacity*capacity_utilisation*

The sum of the economic availability of the technologies, subtracting a fraction for grid losses, is equal to the local electricity supply. For the variable total supply additionally the trade volume is added, which is the multiplication of the trade share and the transmission capacity.

Total supply =
*(SUM(economic_availability)+(trade_share*transmission_capacity))*(1-grid_losses)*

[1] http://www.bafu.admin.ch/co2-abgabe/12357/index.html?lang=de, accessed: 27.6.2014

Here supply is measured in GW, and not in GWh, since it is for a flexible time span. Correspondingly demand is also measured in GW. The input can be given as a number in GWh though, since people are usually more used to this format. The annual demand in GWh is transformed into a demand curve based on the average distribution of demand over the year. The price formulation is oriented on the generic structure for prices by Sterman (2000). The indicated price is defined by the current market price and the ratio of demand and supply raised by the power of the "sensitivity of price to demand/supply balance" (Sterman, 2000, p. 540). In this model the "sensitivity of price to demand/supply balance" is simply called *elasticity*. The value for this elasticity is 0.8. No research was found for this specific value. This is an assumption made based on model behaviour responding to different values for elasticity.

*Indicated price = market price * (demand supply ratio^elasticity)*

The market price is adjusted to the indicated price with a classical goal seeking structure with a very short adjustment time. This structure is able to simulate the seasonal variations in market price. It is necessary, to build price as a stock to avoid circular connections for the capacity utilisation and trade feedback loop. The market price represents a seasonal average value of the prices on the electricity market.

The average seasonal market price cannot be considered as the direct receiver price for certain technologies. Earlier in the text seasonal variations of the technical availability of technologies were discussed. Of course there are also significant variations over the course of a day determining the production of electricity. For this long-term oriented model a factor is used to capture these variations in an aggregated and simplified manner. The actual received price by a producer is determined by the market price and the *effect of daily variation on receiver price*. This effect substitutes for the daily variations that significantly can influence the return of a technology, but is not explicitly modelled in this long-term oriented model. The effect is a multiplier put on the price for technologies producing during price peaks. For example, pumped hydro power plants produce electricity when the price is very high. Due to this production characteristic they can expect to always receive a higher price than average. Of course these technologies typically also have a lower average availability. Modelling the daily variations of the electricity price explicitly and endogenous would be an enormous effort, which only leads to minor gains in the results and significantly reduces the explanatory value of this model. Therefore this effect is considered as a good solution to give credit to this aspect but not over-complicate the model. The receiver price is also the point where the currently applied feed-in remuneration policy is attached.

In the current electricity system in Switzerland a policy is at work to support the renewable energies. The policy is a feed-in remuneration for new renewable energies. The price for renewable technologies the governmental policy feed-in remuneration applies, which guarantees a fixed price for feeding in the electricity into the grid. This feed-in remuneration differs among the technologies and is newly defined every year. For the non-renewable electricity sources the price on the electricity market is the orientation point. Details about this policy are discussed in the section back ground – current legal framework (2.2). The technologies eligible for the feed-in remuneration included in this model are: photovoltaic, wind, biomass and thermal power. Hydropower is not considered as supported since no distinction is made between small-scale and large-scale projects of hydropower in this model. The policy only supports small-scale hydro projects. Since the significant share in the electricity production from hydropower comes from large-scale projects that are not eligible for the remuneration they are not considered as supported. The model allows the user to define whether the policy is applied or not and for how long it is applied. The equation used for the receiver price looks as follows:

Received price =
*IF(FIT>0)THEN(FIT)ELSE(market_price_per_GWh*effect_of_daily_price_fluctuations)*

The received price is input fort he capacity utilisation as well as calculations oft he annual return.

The model includes trading of electricity. Electricity can be imported or exported depending on the price relationship between the local price (market price) and the price abroad, restricted in amount by the transmission capacity. For simplification reasons it is assumed that imports and exports are traded for the same price, nonetheless the trade volume, as long as within the transmission capacity. The traded volume is defined over a graphical function of the ratio of the local price and the price abroad. This function simply says that when the local price is higher then the price abroad then electricity will be imported; when the price abroad is higher then electricity will be exported. The function is s-shaped, because trading higher amounts of electricity is more cost intensive. The graphical function for trade share is displayed in Figure 6.

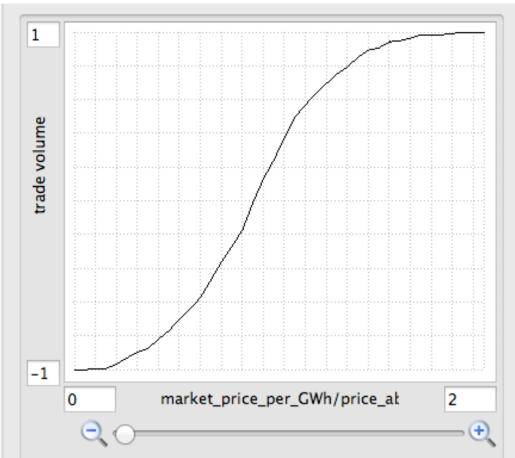

Figure 6: Graphical function for trade share

The traded electricity is added respectively subtracted from the locally produced electricity. The transmission capacity in Switzerland is assumed to be around 2 GW. In fact the transmission capacity in Switzerland is about the same amount as the total electricity production within Switzerland. Due to its very central position Switzerland became an electricity trading hub. But most of this capacity is used for transmitting electricity from Germany or France to Italy (Swiss Federal Office of Energy, 2013). Due to this transmission to other countries through Switzerland it cannot be assumed that the full transmission capacity can be used for imports or exports of the local supply.

Completing this part of the model we can have a look at typical production over one year. We simulate the electricity production depending on the factors described above and with the installed capacity in 2006 (see Figure 3), based on these variables and the simulation of the price (initial value of 82’520 CHF/GWh) and an annual demand of 62’124 GWh (varying over season). Figure 7 represents the electricity production over the base year 2006. Technologies are ordered along their flexibility and the installed capacity. Since their very low share in the capacity park photovoltaic, wind, gas and batteries are not even visible.

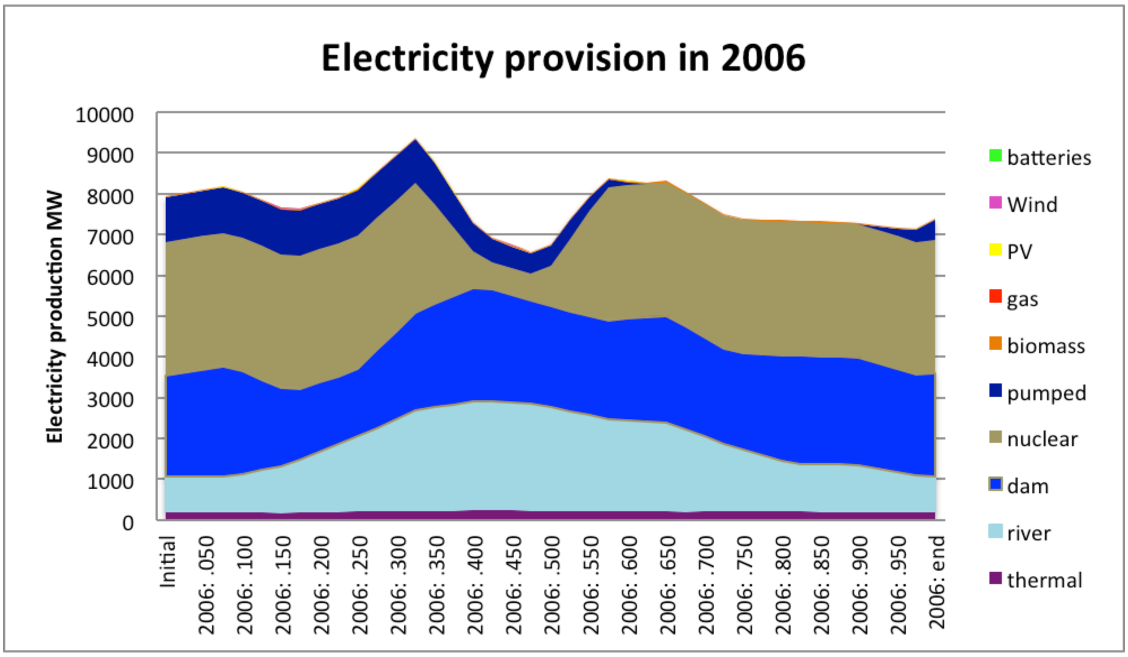

Figure 7: Simulation of the electricity production over one year

Clearly visible is the shut down of the nuclear power plants for the yearly maintenance. This leads to a significant break in in electricity production, but which can be sufficiently compensated by the remaining technologies.

Alternatively the production over one year with the capacity constellation as suggested by SCS in their scenario renewable A (Figure 8) is simulated. Here the renewable energies become more visible.

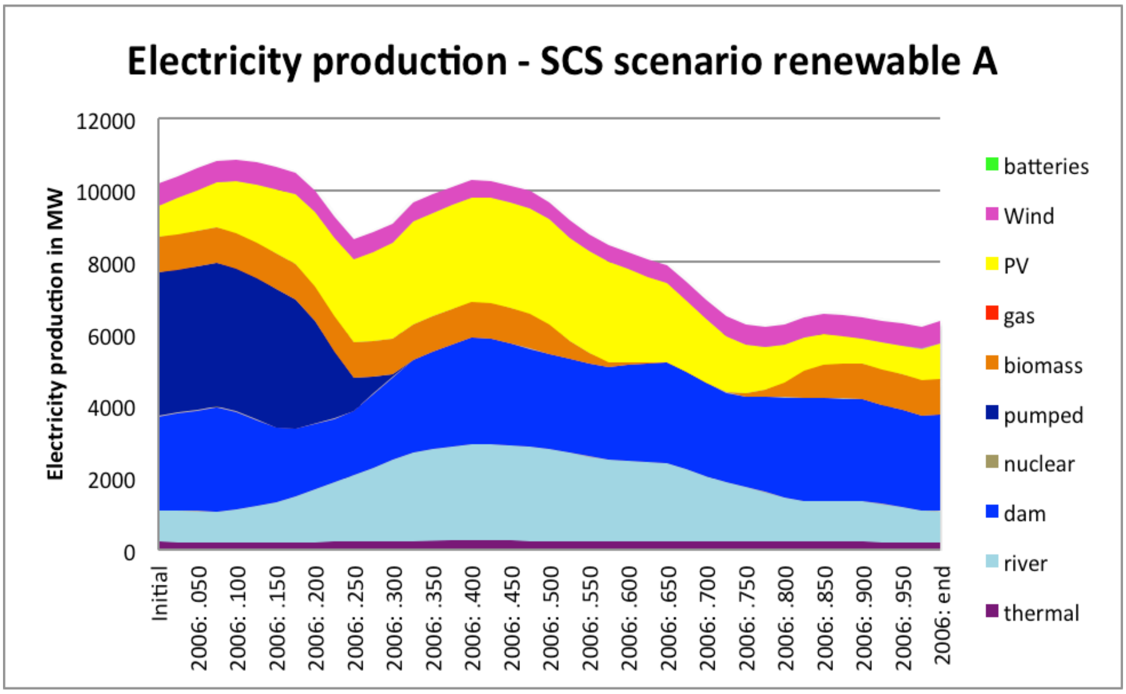

Figure 8: Simulation of the electricity production over one year, scenario of the SCS model

3.1.3. Physical system

We just looked at the electricity production based on the installed capacity. In the next step the physical system is explained. The physical system captures the installed capacity and the capacity in the process to become productive. An additional very relevant factor is the remaining expansion potential for the specific technologies. The sector *physical system* is represented with the stock-and-flow diagram in Figure 9.

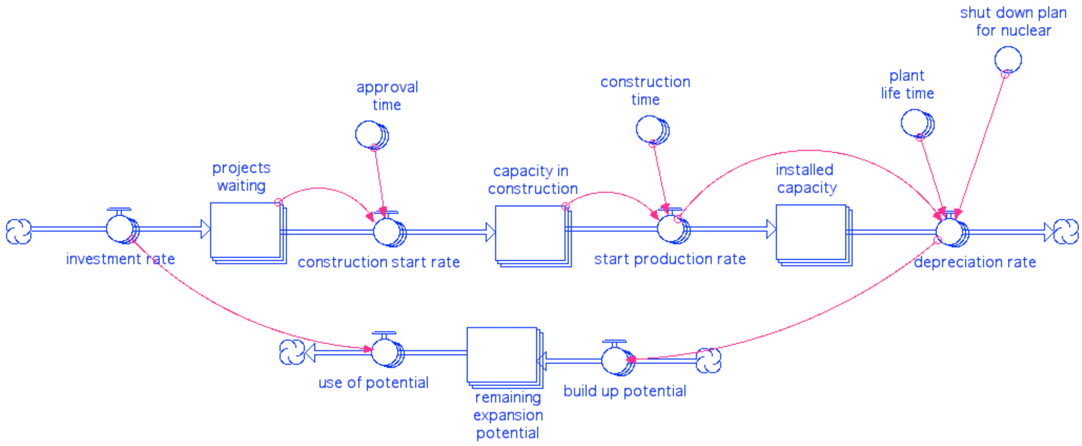

Figure 9: Stock-and-flow diagram of the physical sector

The stock *installed capacity* foregoes a supply line consisting of the stocks *capacity in construction* and *projects waiting*, as commonly used in other supply chain models (Sterman 2000). This process represents the delay between the investment decisions taken until the actual capacity is ready to produce electricity. The delay time for project approval and construction vary among the technologies. Significant differences are especially observed in the project approval time. Projects based on technologies that are usually built as large-scale projects and / or in environmentally critical areas have to expect major delays in the project approval. On the other hand technologies frequently built as small-scale project don't suffer that much from this phenomenon. This long delay for big projects is enlarged by an extended basis democracy in Switzerland. In worst case (from an investor perspective) a referendum is taken; that brings the issue to elect for all voters in Switzerland or only in the respective region. This does not only bring a heavy retardation in the project start, it also brings the risk of a complete cancellation. Nevertheless, the issue of project cancellation is not considered in this simulation model, since this is dependent on numerous case specific factors, which cannot be projected over the next 40 years. The depreciation rate of installed capacity is defined by a material delay of 10^{th} order. The 10^{th} order is chosen because the shape resembles a natural form of depreciation the most.

Depreciation rate = DELAYN(start_production_rate,plant_life_time,10)

An exception here is nuclear power. Here the expected dates for nuclear shut down are defining the depreciation and not a gradual depreciation. The nuclear plants are phase out stepwise. The most up to date expectations for the phase out are used[1].

The initial values used for the stocks are represented in Table 1. This reflects the situation in year 2006. Data for the capacities stems from the IEA/OECD Renewables

[1] http://de.wikipedia.org/wiki/Kernenergie_nach_Ländern#Schweiz; accessed: 15.3.2014

Statistics1, statistics of hydro power by the Swiss Federal Office of Energy2 and the electricity statistics 2012 (Swiss Federal Office of Energy, 2013). Estimations on the potential originate from the Prognos study (2007) and a report by the Paul Scherrer Institute (2005).

	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 1: Initial values used for the stocks in the sector physical system

Whenever a project is started, the necessary expansion potential for the corresponding technology is reduced on the same amount. For explanatory purposes the remaining expansion potential is represented as a physical stock. Remaining expansion potential represents the difference between the total potential of a technology and the potential already used for existing capacity and capacity in construction. The remaining expansion potential can be built up again, when installed capacity has achieved its lifetime. Modelling remaining potential as a stock is not very common in System Dynamics. The explanatory value of this representation was considered as very relevant in this aspect; especially as it was observed that the communication of the potential for technologies in research reports is frequently designed in this format. This allows direct

1 http://www.iea.org; accessed: 1.4.2014

2 http://www.bfe.admin.ch/geoinformation/05061/05249/index.html?lang=de&dossier_id=01049; accessed: 1.4.2014

testing the implications of the estimations made in these research reports. It is likely that the expansion potential is not as rigid as it is represented here. Probably more realistic is, that the expansion potential will be shifted with more severe limitations for the electricity production. This aspect is not explicitly modelled here to avoid contortions, since it heavily depends on political will and to allow comparison and the implications of the assumed expansion potential from these research reports.

Estimations for the remaining expansion potential are difficult to be made and strongly vary between the different sources. But this is exactly what makes it interesting to model remaining expansion potential explicitly. The data used for the remaining expansion potential stems from the report by Prognos (BFE 2007). An exception was made for photovoltaic. There the estimation of 1.4 GW seems overly pessimistic. PSI (2005) is more convincing in their argumentation and come to a remaining potential of 10.9 GW for photovoltaic. Other sources, such as SCS (2013) suggest to additionally place photovoltaic panels in the Alps, where the solar radiation is much higher, which leads to an even higher potential. This is not considered here. Nevertheless, this is a changeable parameter in the simulation model and can be adjusted to different values.

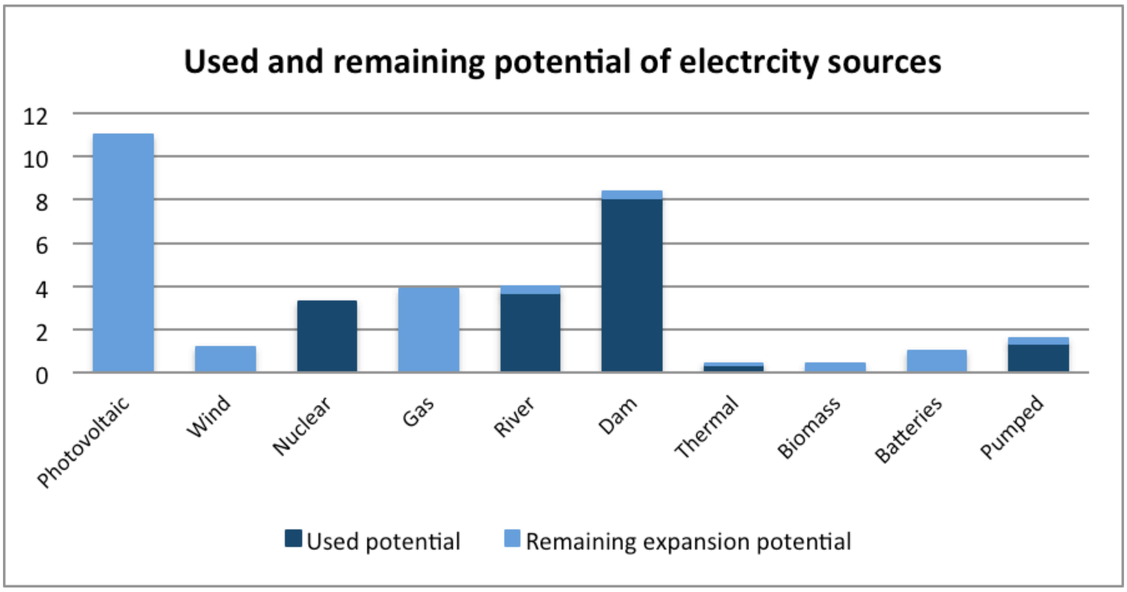

Figure 10: Used and remaining expansion potential of the technologies

In the base case the technologies with the highest expansion potential are photovoltaic, gas, wind and batteries (Figure 10). For the three different kinds of hydropower, as well as thermal and biomass power the potential is already used to a major extent. Following this we already get an idea where major investments can be made to compensate for the nuclear phase out.

3.1.4. Investment decision

In this section the model parts that govern the investment rate are described. The investment rate is the first flow into the capacity supply line and therefore one of the most central variables in the model. The first structure part of the sector *investment decision* is displayed in Figure 11. The second part is displayed in Figure 14 and follows later in the text.

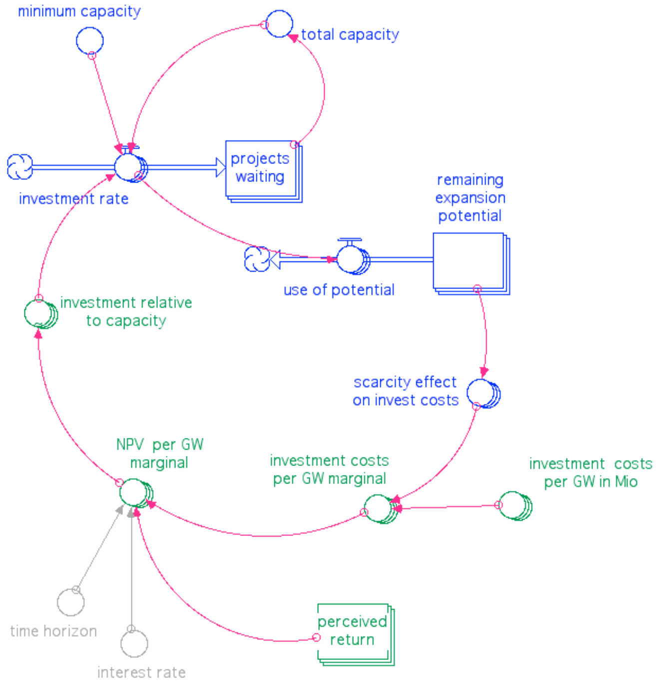

Figure 11: First part of the stock-and-flow diagram oft he investment decision sector

The investment rule chosen for this model is very market driven. Earlier model structures were made with more central planning oriented mechanisms. The model assumes that there is an unknown number of investors all investing according their own financial interests. The actors assumed here are not perfectly rational and also don't have perfect information, as frequently assumed in economic models. Investors invest into the technologies based on their perceived net present value (NPV) of the technology. The higher the profitability the technology the more investors are attracted. On the other hand, the more capacity is installed the more money is

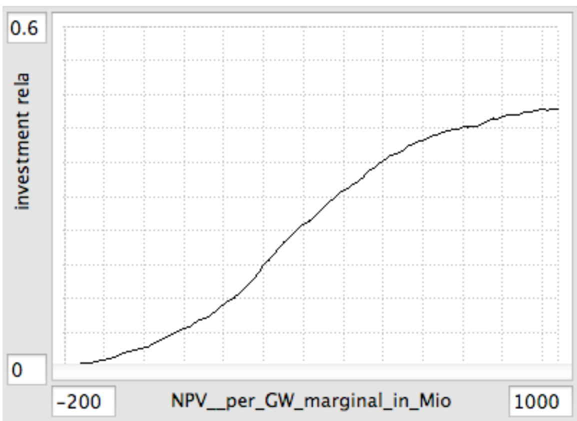

Figure 12: Graphical function for investment relative to capacity

available for new investments into the same technologies.
Structurally this idea is represented with a reinforcing feedback loop of the *total capacity* to the *investment rate* and a variable called *investment relative to capacity*. *Investment relative to capacity* is calculated based on the NPV of investment of 1 GW. For this matter a graphical function is applied, which defines the investment relative to capacity. The graphical function represents the attractiveness to the investors indicated by the NPV. The s-shaped curve gives credit to the fact that there are only few investments when the NPV is only slightly positive or even negative and that the investment is raising with higher NPV. The increment is slowing with very high NPVs (Figure 12). The height as well as the steepness of the curve may differ. A proper validation of this curve would require bigger investigation into the investment behaviour of investors in the electricity sector. Empirical research directly usable for this purpose was not found. A specific empirical analysis of this aspect is beyond this research project. Therefore the curve is adjusted as far as possible to a realistic range. Under *3.3* Model analysis and validation we test the sensitivity of this curve. Additionally this graphical function is opened for scenario analysis and can be changed by the user of the model.

The actual investment rate is defined with this factor *investment relative to capacity* and the *total capacity* of the technology. Total capacity refers to the sum of the stocks *projects waiting*, *capacity in construction* and *installed capacity*. Since a few technologies are not developed at all in the time of 2006, a minimum is capacity of 0.2 GW is assumed to prevent that new technologies are stopped in their development. The equation is formulated as follows:

Investment rate =
*IF(total_capacity>minimum_capacity)THEN(total_capacity*investment_relative_to_capacity)ELSE(minimum_capacity*investment_relative_to_capacity)*

The equation could be simplified as:

Investment rate =
*MAX(total capacity, minimum capacity)*investment relative to capacity*

The formulation with an IF-THEN-ELSE function is necessary, because the software doesn't allow using a MAX-function within arrays (or better the MAX-function has a different meaning).

NPV is calculated with the commonly know formula. Input variables are the marginal investment costs per GW and the perceived return for 1 GW over one year as well as the time horizon and the interest rate. The time horizon is chosen to be 20 years, since investments in this sector are necessarily oriented on long-term. The interest rate is 5%. This interest is also considered for the calculation for the currently applied policy of feed-in remuneration (Swiss directive for FIT, photovoltaic).

NPV per GW marginal in Mio=
-investment_costs_per_GW_marginal
+(perceived_return(((1+interest_rate)^time_horizon)-1)/*
*(((1+interest_rate)^time_horizon)*interest_rate))*

In the variable *investment costs per GW marginal* a very important balancing feedback loop closes. Investment costs are not assumed as constant over time. They are a function of the remaining potential. A graphical function reflects the fact that with reduced expansion potential the favourable locations with either very high return or easy construction circumstances are already taken and only more expensive and less profitable locations are available. An additional factor is also the raising competition for the remaining spots. The fewer capacity left to the higher the price for it in general. When the remaining expansion potential is approaching zero the "effect of scarcity on invest costs" raises to almost infinity, ensuring that there is no investment beyond the expansion potential. In the model it is made sure that the scarcity effect is on 1 in the simulating starting year, since the value in *investment costs per GW in Mio* includes the real data for the investment costs in 2006, the starting year of the model. An exemplary curve for this graphical function is given in Figure 13. This effect is multiplied with the variable *investment costs per GW in Mio*. This variable captures the estimations for the development of the investment costs over time without including the scarcity effect. While the base investment costs for established technologies such as hydropower are assumed remain stable over the coming years, it is expected that especially for new renewable energy sources the investment costs will decrease significantly. Data is used from the Prognos study (Prognos 2007), for details see appendix. This pathway has a very sensitive impact on the model, but still cannot be modelled endogenously in this case. The electricity market in Switzerland is too small to contribute significantly to the development of the technologies with higher investments.

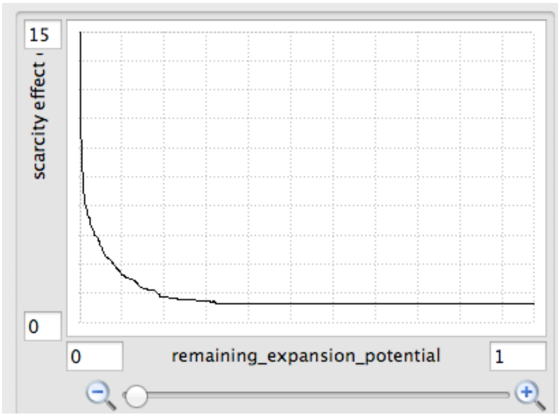

Figure 13: Graphical function effect of scarcity on invest costs

We finished the discussion of the first part of the investment decision sector. We now move to the second part, which elaborates on the determinants of the perceived return. In Figure 14 shows the stock and flow diagram for the second part of the investment decision sector.

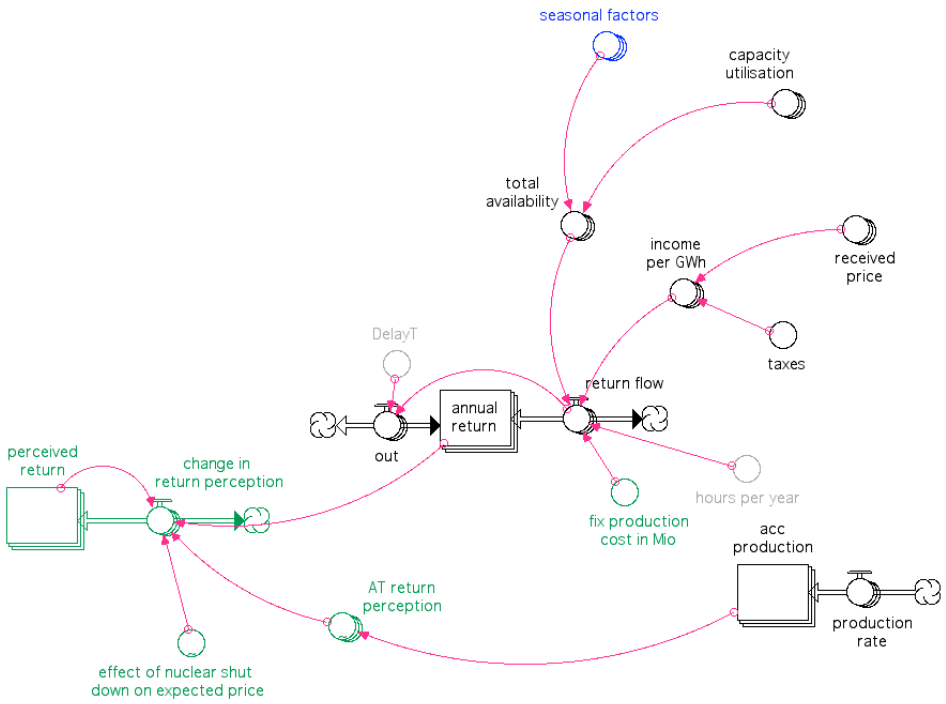

Figure 14: Second part of the stock-and-flow diagram of the investment decision sector

Human decisions are made based on the perception of attributes relevant for the decision (Kahneman 2003, Sterman 2000). Investment decisions for a specific technology are built on the perception of return. The basis for the decision is therefore not the statistically measured return, it is much more the perceived return. Consequently the relevant input in the investment function used here is also the perceived return. Perceived return is formed on the basis of the current annual return of 1 GW of installed capacity of one certain technology. Perceived return is generally an ordinary adjustment process known from Sterman (2000) based on the current annual return of a technology.

In literature on behavioural finance the familiarity with a stock is found to be a significant input for all investment decisions, as it is influencing the perception of the stock (Wang et al 2011). In this System Dynamics model this was interpreted in the way that the adjustment time for the return perception is altered by the accumulated production of the technology. With a higher accumulated production it is assumed that the adjustment time for the return perception is higher than when only few experiences where made with the technology. This means that when an investor has already made many experiences with a technology, he his adjusting his perception slower as he

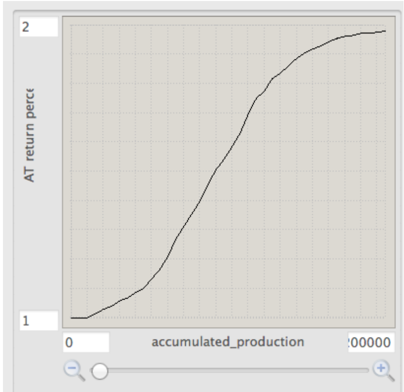

Figure 15: Graphical function for the adjustment time of return perceptions

would, with a technology with which he only has few experience. The graphical function in the variable *AT return perception* does reflect this idea. The learning curve, or in other words, the accumulated production, is currently a drawback for renewable energies since technological experiences already made (SwissCleanTech 2013b).

The adjustment time for the return perception is a graphical function driven by the accumulated production of every technology. The adjustment time first increases slowly with a rising accumulated production and then increases with a faster slope. With very high accumulated production it is assumed that the perception time doesn't change that fast anymore.

The flow altering the return perception is defined with the following equation:

Change in return perception = ((annual_return-nuclear_phase_out_tax)-perceived_return)/AT_return_perception

In the base run a tax for nuclear power is included in the variable income per GWh. This is a theoretical tax, enormously high to prevent further investment into nuclear power, since the Federal council decided on the withdrawal from nuclear power in 2011 (Swiss Federal Council, 2011). The initial value for perceived return is set equal to the initial value of the annual return, implying that the investor's perceptions are in equilibrium with the current annual return.

Accumulated production is simply the accumulation of the production determined by the economic availability times the hours per year. The initial values for accumulated productions are estimations for the cumulative production of the technologies over the last 10 years. Starting at zero would lead to a skewed impression in the adjustment time for return perception.

When modelling the perceived return per technology it would had been attractive to include additional factors such as perceived risk, as well as a premium reflecting other factors in the investment decision. Moxnes (1990) made an interesting calculation of such a premium for coal, oil and gas, which revealed that there is a strong preference for coal. Unfortunately values of this premium are not available for all technologies included in this model, and are there it is not included.

The stock annual return keeps track of the profit an investor generates with one GW installed capacity of a certain technology over one year. The inflow to the stock is the current profit based on the current production. *Total availability* is the multiplication of the *capacity utilisation* and the *seasonal factor* determining the actual production. This coefficient has values between 0 and 1 representing to which percentage a technology is actually producing during the year. Therefore it is multiplied by the *hours per year,* to get the actual production hours per year. The production is multiplied by the income per GWh. Income per GWh is the receiver price for a produced unit of electricity minus the marginal costs of production and occasional taxes. This term is defined by one million for equal numerical format and good readability. Subtracted from this are the production independent fix production costs per year (measured in million already).

*Return flow = ((((received_price*effect_of_nuclear_shut_down)-production_costs)*(total_availability*hours_per_year))/1000000)-fix_production_cost_in_Mio*

Here a special factor influencing the return perception is included with the effect of the nuclear power shut down. It is assumed that the exact date for the shut down of a nuclear power plant is communicated five years in advance. This information is influencing the return perception of the return that could be made with an investment. This structure implies that investors assume that the electricity price would rise, when a nuclear power plant is shut down due to reduced electricity production capacity. The effect assumes, that the exact information about when the nuclear power plant will be shut down is known five years in advance. The installed capacity shut down is transferred into a multiplier.

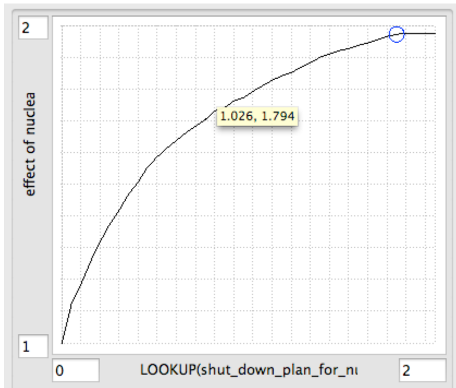

Figure 16: Graphical function for the effect of nuclear shut down on perceptions

The outflow of the stock annual return is a material delay of the inflow with the duration of exactly one year.

Outflow=DELAY(return_flow,DelayT,inital_flow_out)

The initial value of the stock is calculated as follows:

*Initial value stock = (((INIT(received_price)-INIT(production_costs)-INIT(taxes))*INIT(average_availability) *hours_per_year)/1000000)-INIT(fix_production_cost_in_Mio)*

Average availability is used instead of the actual availability, to avoid a bias towards flexible producing technologies, which don’t suffer from constraints in winter.

3.2. Central dynamics of the system

Figure 17 gives a more detailed overview on the stock-and-flow diagram used for the simulation model. For better readability some auxiliary variables are omitted. 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.

As already noticed the model mainly consist of balancing feedback loops. Due to the avoided automatic compensation for depreciation the system in this model can oscillate. There is no natural equilibrium. In the section this issue will be discussed in more detail. 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.

Trade capacity can be a significant driver or blocker for the development of capacity expansion as described in the qualitative System Dynamics analysis by Ochoa (2007). The higher the transmission capacity and the higher the actual imports, the lower is the incentive to invest into expand local capacity. In their proceeding investigation Ochoa and van Ackere (2009) confirm these relationship. These same behaviour is expected for this model. This will be tested in part 3.3.2.

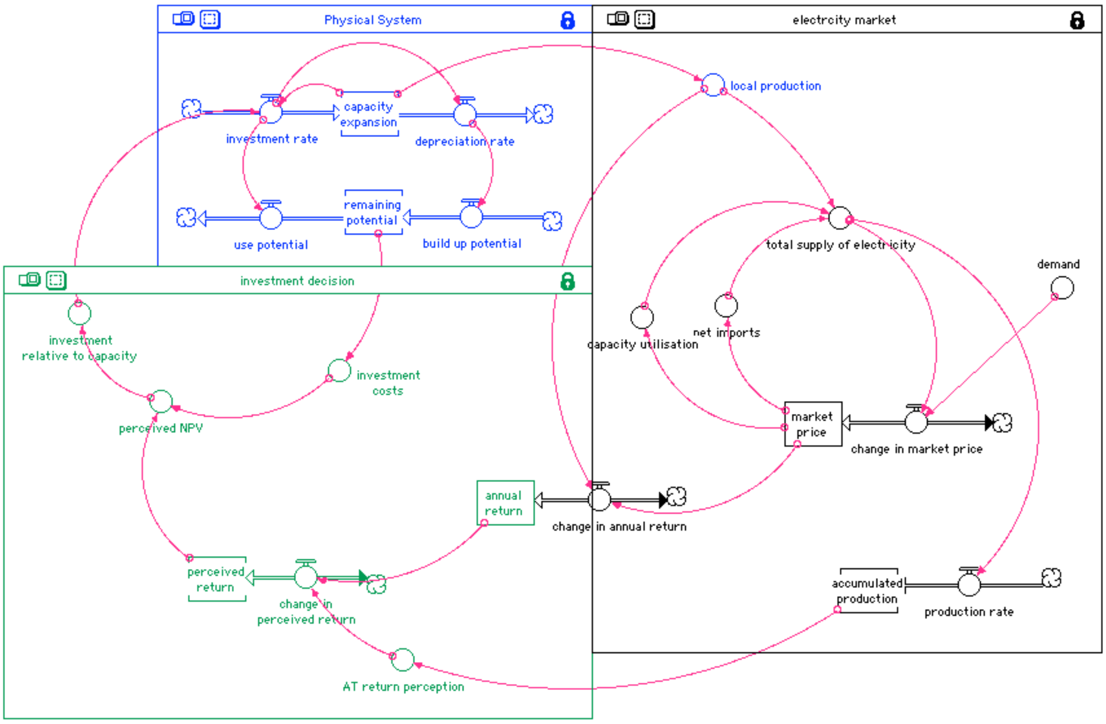

Figure 17: Overview on the stock-and-flow diagram

3.3. Model analysis and validation

3.3.1. Construction process and validation

This investigation was conducted in the framework of a master thesis for the Erasmus Mundus European Master in System Dynamics. The development of the model, the analysis and the composition of this report were done within a time span of about 5 months. This thesis was supervised by Prof. Erling Moxnes, University of Bergen, Norway. Additionally the collaboration with the company Supercomputing Systems SA, Zürich, Switzerland, brought in the expertise of the authors of the SCS model (2013). 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.

Besides this natural evolution of the model that already included many implicit validation tests, a formal validation process was executed with the final version of this model. The formal validation process was oriented on the suggested procedure by Barlas (1996). All suitable validations tests mentioned where conducted. The simulation results fit the reference data well. The fit of the simulated price with the historic data is presented in Figure 18. For other comparison of the simulation results with historic data it is referred to the graphs directly included in the model[1]. Generally the installed capacities follow the historic data well. But due to the short reference time this is not very surprising.

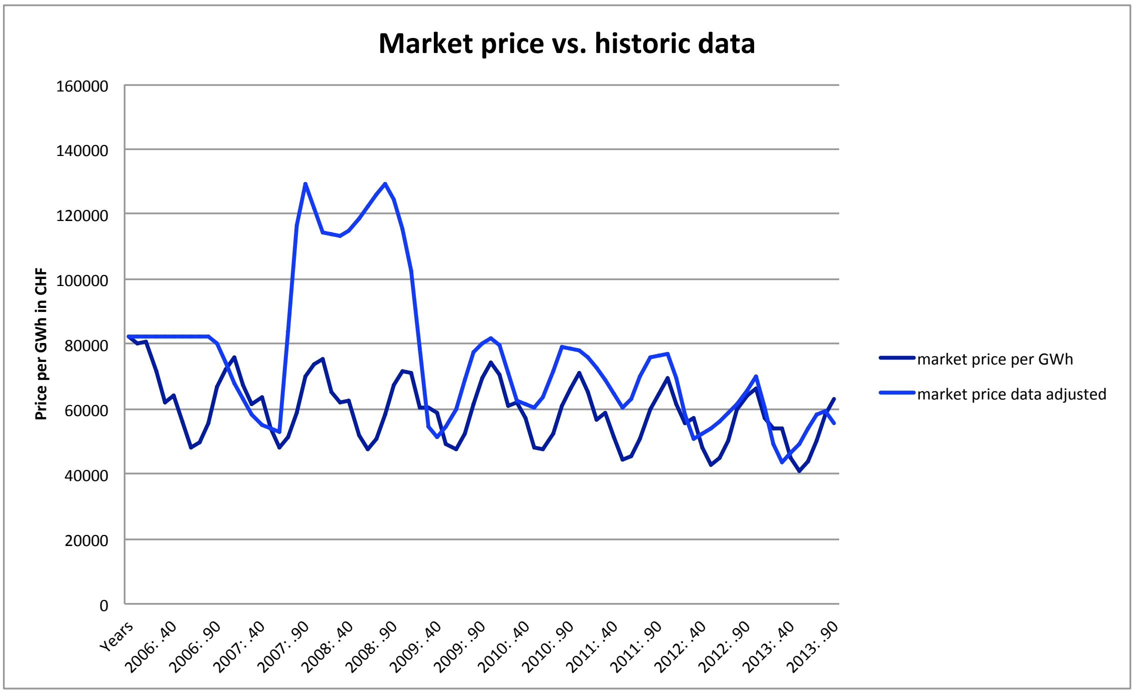

Figure 18: Simulated and historic market price for electricity

Statistical behaviour tests were not formalized for the same reason. The reference modes are too short to be compared to the total simulation time span on a realistic basis. In terms of the results of the validation process can be said that all conducted tests were passed. Interesting results of the sensitivity analysis are presented and discussed in the next section.

It was found that the model formulation leads to incomplete robustness in the investment decision, since an extremely high price can lead to investments higher than the expansion potential. This comes from the fact that the graphical function determining the effect of scarce expansion potential on investment costs theoretically should reach infinity at point zero, but in fact it is a finite number. Nevertheless, this does only happen when for some reasons the price goes higher than a multiple fold of the current price. It is ensured that this does not happen in all presented scenarios.

The same structure element, the stock for remaining expansion potential, has a weakness. If a technology uses all the remaining expansion potential, but at the same time there the depreciation rate is above zero, this can lead to very short fluctuations in the investment costs, when the time step is not chosen to be very low. This is not a

[1] Contact the author under merla@merla.net if you received this report without model.

mistake, but it is not elegant to either have an extremely low time step in a long-term simulation model or graphs that show a series of strong and short fluctuations. This structure element was kept in the model in this form due to the simple reason of worse alternative. The structure probably classically used for capturing a scarcity effect on costs is an effect of accumulated production of the technologies on the investment costs. This structure brings the drawback that, first technologies which were built but not used don't affect that scarcity effect and second that the depreciation of plants does not lead to an increase in the remaining potential respectively to lower investment costs. The second aspect is especially important in a long-term model as this one. Depreciated plants need to be available for reinvestment, to ensure sufficient capacity to provide electricity.

An aspect not modelled explicitly is the perception of risk by the investors. Generally risk is a very relevant input for investment decisions also found in the electricity sector (Hampl, 2012). The uncertainty from the production and the production estimation as well as the price risk influence the perception of risk and with this the investment decision. Additionally the change in the different policy designs can lead to significant changes in the perception of risk of an investor, as discussed in Couture and Gagnon (2010). Generally it is found that exposure to public policy is an investment hindering factor (Hampl, 2012). Nevertheless, modelling and simulating risk is a very demanding task and literature in the System Dynamics field about the explicit modelling of risk was not found. For these reasons risk is not a part of the model structure and will only be discussed in implementation issues.

3.3.2. Sensitivities

Every model is more sensitive to some parameters or to some structure elements than others. Understanding these sensitive points is an important step to a better system understanding, as well as a good preparation for policy design. In this section the most relevant insights form the overall sensitivity testing of the validation procedure are reported. Some sensitivity tests are graphically presented to reach a clear understanding. On a complete reportage of all the sensitivity tests conducted is relinquished to avoid boredom of the reader.

For the sensitivity analysis it is common in System Dynamics to use a model initialized in equilibrium. This is done to avoid miss interpreting the effect of parameter changes by change process already going on in the transitory state. An equilibrium state is where all stocks in the model don't change over time and always remain constant (Sterman 2000). This means that the inflows and outflows of a stock have to be equal at every point in time. To derive the equilibrium, all currently applied policies were turned off (fixed price feed-in remuneration), as well as the nuclear phase out was removed. Remaining in the model are the taxes for water and CO2 emissions, since these are incorporated in the long-term system. Costs were treated as constant based on the level they have in 2014.

Solving the equilibrium analytically in a model with an array of ten elements is nearly impossible; therefore an iterative process was applied. Attempting to reveal the equilibrium state of this model confirms the perceived dynamics discussed in 3.2. For most technologies it was unproblematic to find an initial value of the installed capacity and the corresponding values for the initial values in the stocks *projects waiting* and *capacity in construction* that leads to a constant value of the stock over time. Nevertheless, for the technologies *gas* and *nuclear* it is impossible to find a condition that leads to constant behaviour. Changes in the capacity influence the market price sufficiently strong to cause a change in the investments that lead to capacity expansion in the opposite direction. As an example, if the installed capacity for gas is put rather low, say 1 GW, market price rises high, which encourages additional investment into gas. Since the market price is only determined by the installed capacity, which is actually producing, the price rises until the invested capacity is really ready for use. This enables an over investment, which causes the price to fall as a consequence. Now the depreciation of the gas capacity is not compensated because it is not profitable anymore. In other words the capacity is oscillating over a very long phase lag. Theoretically all technologies can get into this oscillatory mode of behaviour. This depends on the market price resulting form the installed capacities of the different technologies in the power plant park. The reason for this phenomenon is, that the model does not incorporate an automatic compensation for depreciation. Compensation for depreciation is only made when the price ensures sufficient profitability for new investment into this technology. Additionally there is the delay of the capacity expansion supply line. This constellation naturally leads to oscillations. 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. System Dynamics supply chain models frequently use a structure element compensating for the losses. Sterman (2000, section on stock management problems; 1989) adds the expected loss rate (depreciation rate) to the desired acquisition rate to prevent the model/system from oscillating.

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. A structure automatically compensating for depreciation is referring to the presence of a central planning entity in the system. In Switzerland there is no central planning entity managing the overall system. The electricity supply is the task of the energy industry (Art. 2, chapter 2, Swiss energy law). These regional companies are in some form indeed working as a central planner, but they are also obliged to take and sell electricity from private investors (Swiss energy enactment). This is especially the case for photovoltaic. Nevertheless, the structure in the overall system is more market oriented than central planning oriented. In this model a market driven investment is chosen. Therefore it would be a contradiction to include this element resembling a central planning form.

With the cost structure of 2014, gas fired power plants and nuclear power plants are very sensitive to price changes. This indicates that the market price is close to their critical price for investment. The initial condition used for the sensitivity tests are for these reasons not a perfect equilibrium. The values are selected in a manner that they minimize the movements of the stocks. Most technologies are in equilibrium with these values, but gas ad nuclear power are slightly changing (oscillating with a very long lag). These values are presented in Table 2.

Installed capacity in GW	PV	Wind	Nuclear	Gas	River	Dam	Thermal	Biomass	Batteries	Pumped hydro
Equilibrium value	0	0	1.9	2.2	3.725	0	0.4	0	0	1.72
Real value in 2014	0.71	0.05	3.28	0	3.83	8.08	0.355	0.032	0	1.8

Table 2: Comparison of the initial values of the equilibrium model and the base run

In some cases the values significantly differ from the real data for 2013 This points towards a system that had significant changes in costs development as well as regulatory interventions. For photovoltaic, wind and biomass to value zero is not surprising. These technologies are currently still strongly depending on the FIT policy and are not profitable in a classical use without the FIT support. Without this policy there is no investment into these technologies. Since the FIT policy was removed for deriving this equilibrium an installed capacity of zero is the logical consequence. The same explanation can be given for thermal energy. Thermal is also profiting of the FIT policy, but only 50% of the produced electricity is treated as renewable and receives the FIT tariff (Swiss energy enactment). The installed capacity for nuclear power is clearly lower than the currently installed capacity in Switzerland. This difference can be explained with the higher investment and project costs we have today due to higher security standards than decades ago. The installed capacity for run-off river hydro power as well as pumped hydro power is slightly lower, than it is today. It is assumed that this is partly due to higher investment costs due to scarcity effects as well as the FIT policy, which is in this model generally not applied for hydro power as in reality only small scale projects are supported. 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]. He says that seasonal storage lakes are not profitable anymore and that Axpo only invests where it is emergently used. This situation leads to an equilibrium based on todays costs of zero installed capacity for seasonal storage lakes. The equilibrium model suggests that there is an installed capacity for gas of about 2.2 GW. Today Switzerland has no gas-fired power stations. This difference comes mainly form the lacking seasonal storage lakes in the equilibrium model. The missing seasonal storage lakes create a need for regulatory energy such as gas-fired power. As already mentioned before, it is not possible to stabilize the installed capacity of gas and nuclear power in a constant level. The chosen value leads to a fairly stable condition but not perfect equilibrium. In the basis of this constellation the sensitivity tests were conducted. In the following sections the most relevant results are communicated.

Minimum capacity: In the equilibrium changes in minimum capacity don't have an effect on the system. There are any technologies in the area where the minimum capacity really matters. Technologies are either not invested in at all or have already pretty much reached their maximum level, such as thermal energy.
The sensitivity testing in the base run model – the model including cost development and the FIT policy - shows that a higher minimum capacity used for the investment function shifts investments forward in time and result in higher investment volume, which is followed by lower investments at the end of the period due to lacking expansion potential. Deleting minimum capacity completely, with putting it to zero, causes that technologies with very low installed capacity at simulation start (mainly wind energy and photovoltaic) have a hard time to get started and increase their capacity to a higher level.

Investment relative to capacity: The graphical function *investment relative to capacity* determines the investment rate for new capacity. It is a very central variable in the model. When testing the sensitivity of changes in the height, the shape and base of the curve in the model initialized in equilibrium we surprisingly notice that chances have almost no visible impact. But putting the curve to zero reveals that the variable is working. This result is not as surprising, as it seems at first. The model initialized in

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

equilibrium doesn't demand for much investment, since there is no nuclear phase out and therefore also no significant shift in profitability. Only compensation for depreciation is needed. Due to the long life times of the plants also depreciation is rather low and so is investment.

The reaction to changes in the graphical function *investment relative to capacity* looks completely different in the base run. 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. This is presented in Figure 19. Changes below and above these values don't have such a strong impact.

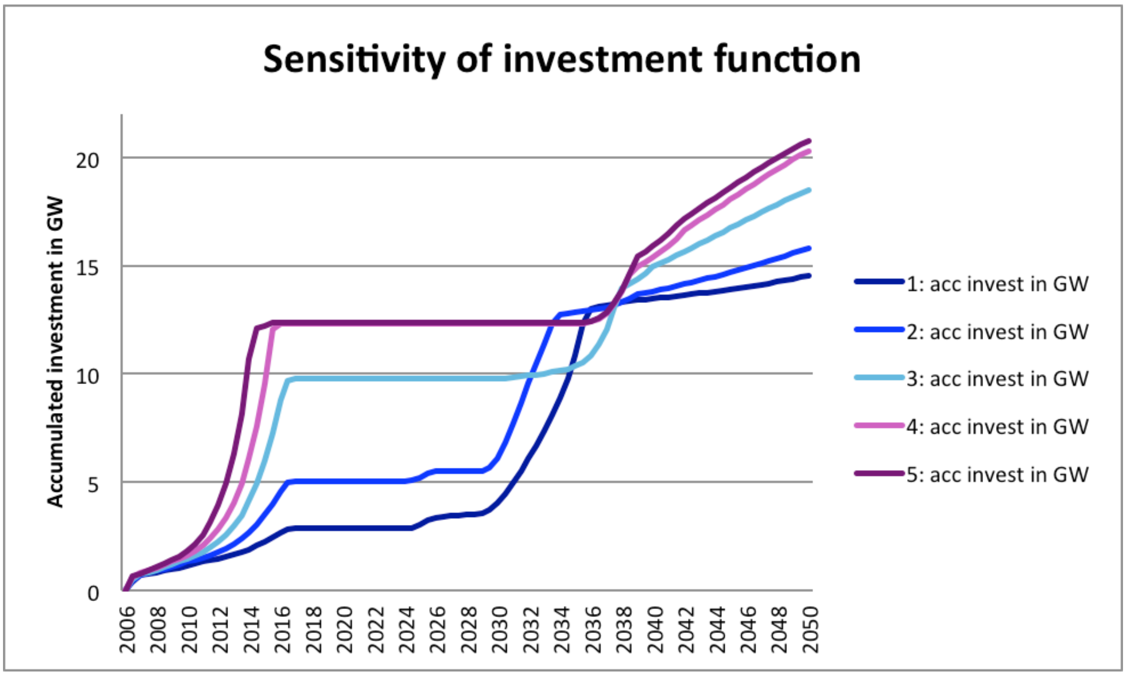

Figure 19: Sensitivity test of the investment function, varying height (1: 0.3; 2: 0.37, 3:0.45; 4: 0.52; 5: 0.6)

We notice, that a low investment function leads to less investment, but it is also more stable in the beginning of the situation. The phase of strong investment around 2032 (due to nuclear phase out) kicks in very strong, since there was not extra investment in the beginning of the simulation. With a high investment function the investment are very strong in the beginning, but also stop earlier as they reach maximum expansion potential. Consequently the investment necessary for compensating nuclear phase out is lower. Interesting to see is also that the incentive to invest comes later with a higher investment function. This is because of the earlier investments made that keep the price low for a longer period of time.

Price abroad

Another sensitive factor is the price abroad. Price abroad is the price for which Switzerland can import or export electricity. The price is assumed as constant over time multiplied by a SINWAVE of 5000 CHF/GWh to represent the seasonality of the price. Different values for the price abroad can lead to major changes in the local price. A low price abroad for example raises the incentive to import electricity. Consequently the Swiss market price remains low and capacity expansion is going on slowly. Resulting is a constant underinvestment. 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. This relationship is represented in the two graphs in Figure 20. Price abroad is here named as

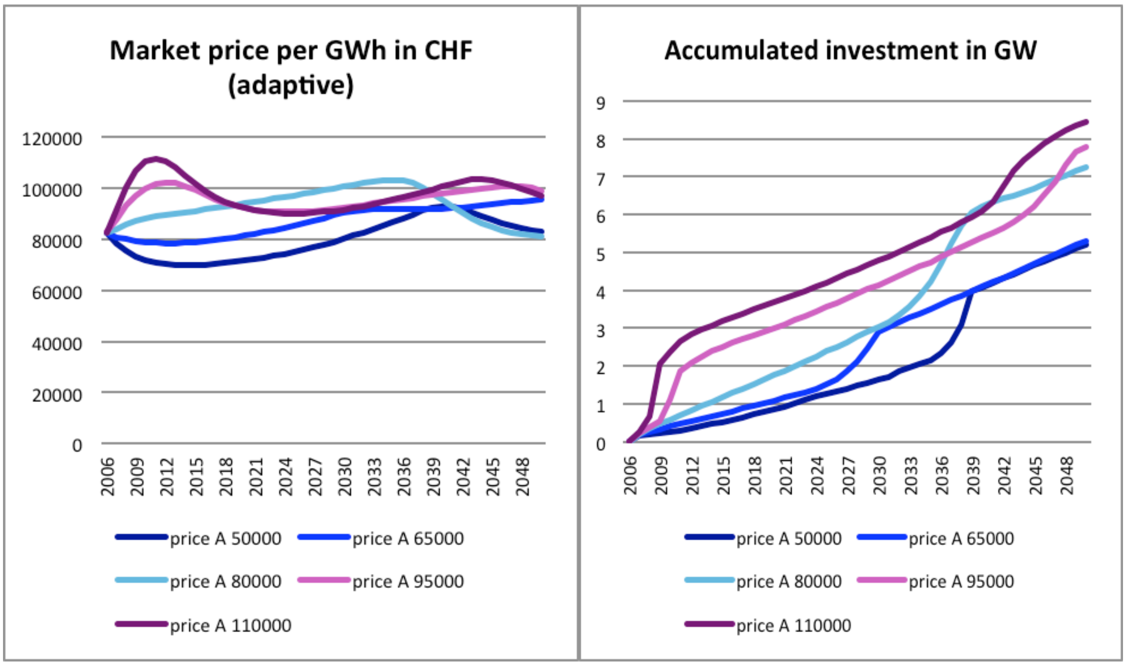

Figure 20: Sensitivity test with changes in price abroad, market price and accumulated investment

A and has values from 50’000 to 110’000.

Trade capacity

Closely related to the price abroad is of course the capacity for transmission. In this model it is assumed that there is no option to import or export more electricity than this transmission capacity. In the case of Switzerland this assumption is not totally realistic, since there is a much higher transmission capacity as actually used for own use. Due to the central location of Switzerland the Swiss electricity market became a trading hub for electricity and transports major amounts of electricity from and to Germany, France and Italy (Swiss Federal Office of Energy, 2013). In the base run a transmission capacity of 2 GW is assumed. This does not reflect the actual transmission capacity, but the share of the transmitted electricity that could be used or exported. 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 21). On the other hand with a transmission capacity of 4 GW there is only a slight and quite steady increase in the price. This looks nice, but the price development is only one side of the picture. Logically the price is influencing the perceived return of the technologies and with this it has an impact on the investment decision (Figure 21). In this light the more balanced price development enabled by the high transmission capacity gets the negative aspect of blocking new investments. In these terms the effects of price abroad and the transmission capacity are fairly similar. As already mentioned, Ochoa (2007) and Ochoa and van Ackere (2009) analyse this issue in the light of trade liberalization.

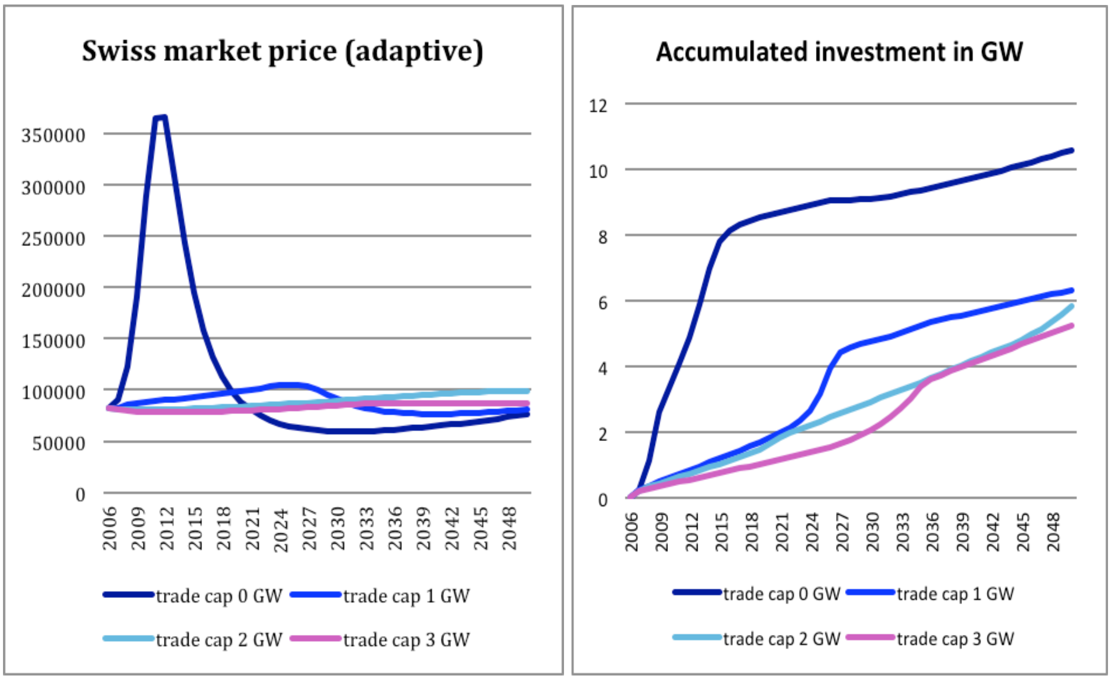

Figure 21: Sensitivity test with changes in transmission capacity – market price and accumulated investment

Nuclear phase out

One of the most important reasons for this study is the planned nuclear phase out. We first test the effects of a nuclear phase out in the equilibrium model before we analyse the implications in the model representing the real constellation of the system. Three runs are compared. The base run with nuclear power installed of 1.9 GW; nuclear phase out; and nuclear phase out with a variable included for the early communication of the nuclear phase out, which determines return expectations. The nuclear phase out follows the shut down plan currently known for the existing nuclear power plants in Switzerland. The last shut down doesn't happen anymore since the installed capacity is lower then the real installed capacity for nuclear power plants. In the base run the accumulated investments follows a linear pattern and the price is rather stable (but not constant as discussed earlier). With the nuclear phase out the depreciation of nuclear power is totally shifted to the exogenously determined rate. There is no gradual depreciation included anymore. This structural change is reason for the lower investment and correspondingly the lower price in the beginning of the run with the nuclear phase out. The interesting part comes afterwards. The first nuclear power plant is shut down in year 2019, followed by two at the same time in 2021 and the remaining, but biggest plants will be shut down in 2030 and 2034. The abrupt shut down of the nuclear power plants leads to a significant rise in the price, which attracts investment. The investments go mainly into gas-fired power plants since their profitability is the most ideal at this point in time. The price decreases after these investments and rises again with the additional phase out. It seems that price is going to stabilize slightly below the price of the base run (Figure 21). Run 3 includes clear communication of when the nuclear power plants will be turned off 5 years ahead. This information influences the return expectation of the investors and potentially raises their investment. The compensating investment starts earlier and the price never reaches a high level as in run 2. The graph for accumulated investment shows that besides earlier investments there are also overall fewer investments necessary to fulfil the compensation. Interesting is also that in run 3 with a early communication the investment is spread into more technologies, while with no communication only gas and biomass are profiting of the gap in electricity production.

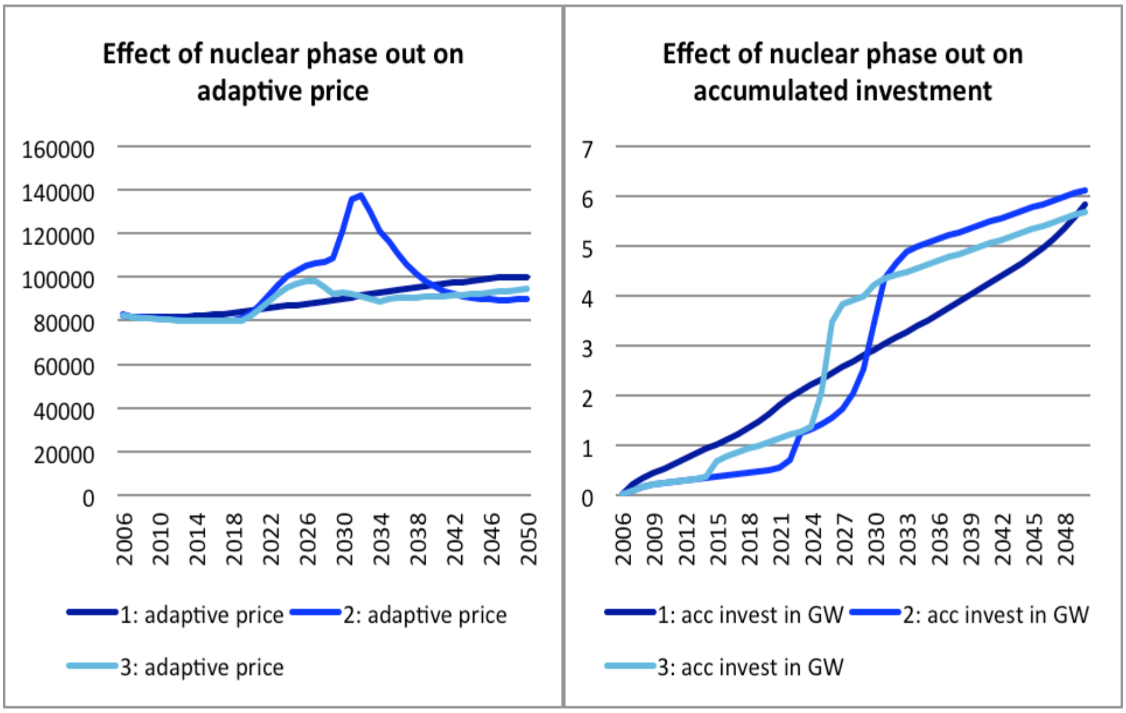

Figure 22: 1: base run, 2: nuclear phase out, 3: nuclear phase out with early communication and price expectation formulation

Trigger point for investment

The relevant criteria for the investment function is the net present value (NPV) for an investment of 1 GW. This NPV is build based upon investment costs and the perception of return. The market price is a very significant input for this calculation, especially also since it is influencing the capacity utilisation. There is no linear relationship between the market price and the investment rate. Since technologies have different production characteristics the price at the specific point of production is much more relevant. This price varies depending on the actual constellation of the power plant park. For example a boom in price can have almost no impact on the annual return of photovoltaic, when there is already a huge installed capacity of photovoltaic. This comes due to the simultaneous production, that presses the price down at photovoltaic production time.

Nevertheless, the average price still has an important impact on the investments of course. To achieve a better understanding of what the trigger points for investment for the certain technologies are, a test was conducted to see with which price the investment phase begins. For this a constant market price was assumed that was increased from zero to 250’000. With this we got an indication where the investment phase begins. However, to stress it again, this is not an absolute critical price. The actual investment depends on many factors and this varies among different constellations of the power plant park. Therefore the bars in Figure 23 are marked with colour transitions to stress that this is not an absolute value.

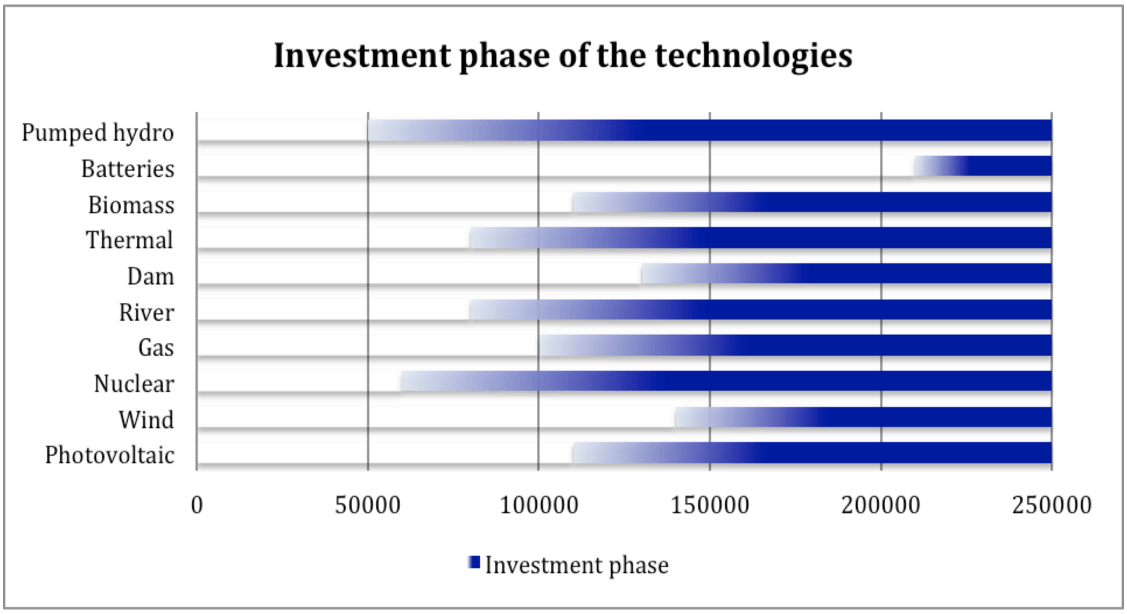

Figure 23: Critical phase for investments

We notice that pumped hydro, nuclear power, run-off river power and thermal power seems to be the most attractive options to invest in with the used cost data structure for 2014. The new renewables, batteries as well as seasonal storage lakes rank low without any supporting policies. Surprisingly also gas-fired power plants are also only in the middle of the field. This ranking can change significantly in future, and already did in past. Especially for the new renewable energies a strong cost reduction is expected.

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. 2050 is on the one hand the planning horizon of the Federal council in terms of energy issues, on the other hand this time horizon is sufficiently long to see severe long-term dynamics of the market, the nuclear phase out and policies. The model results for the period of 2006 to 2013 can be compared with the history data for this time. As a first step the base run is presented. The base run includes the real data from 2006 as well as expectations for cost development for the future. It is assumed here that the FIT policy is stopped after 2015 and the energy market is left to itself. 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. Figure 10 in chapter 3.1.3 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.
- The costs and potential are set on the presented in 3.1.3.

We simulate the model with the conditions for the base run. Generally demand is covered in most of the cases despite the nuclear phase out. Nevertheless in the end of the simulation period more imports were necessary to cover demand. In Figure 24 demand, the local supply of electricity as well as the net imports are displayed. The unit of measurement is GW. 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.

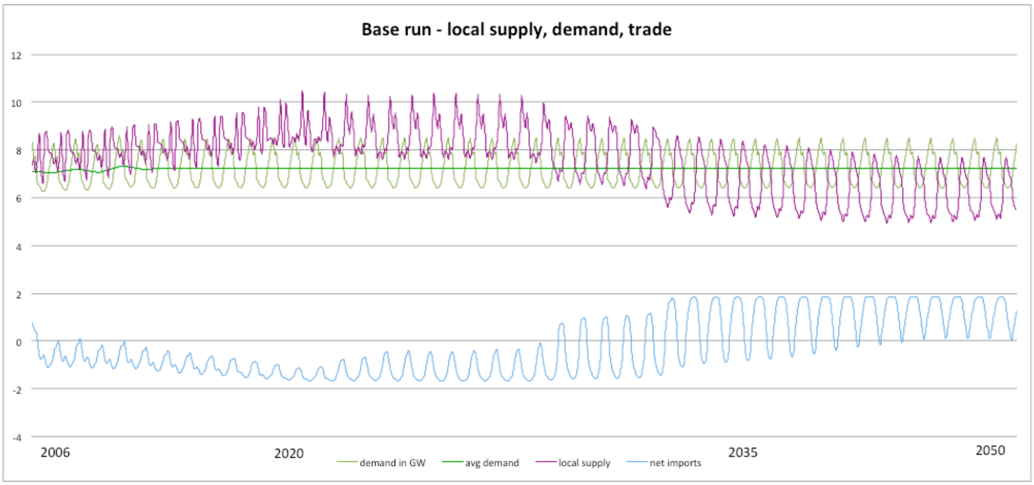

Figure 24: Base run - local supply, demand and trade

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 25). 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.

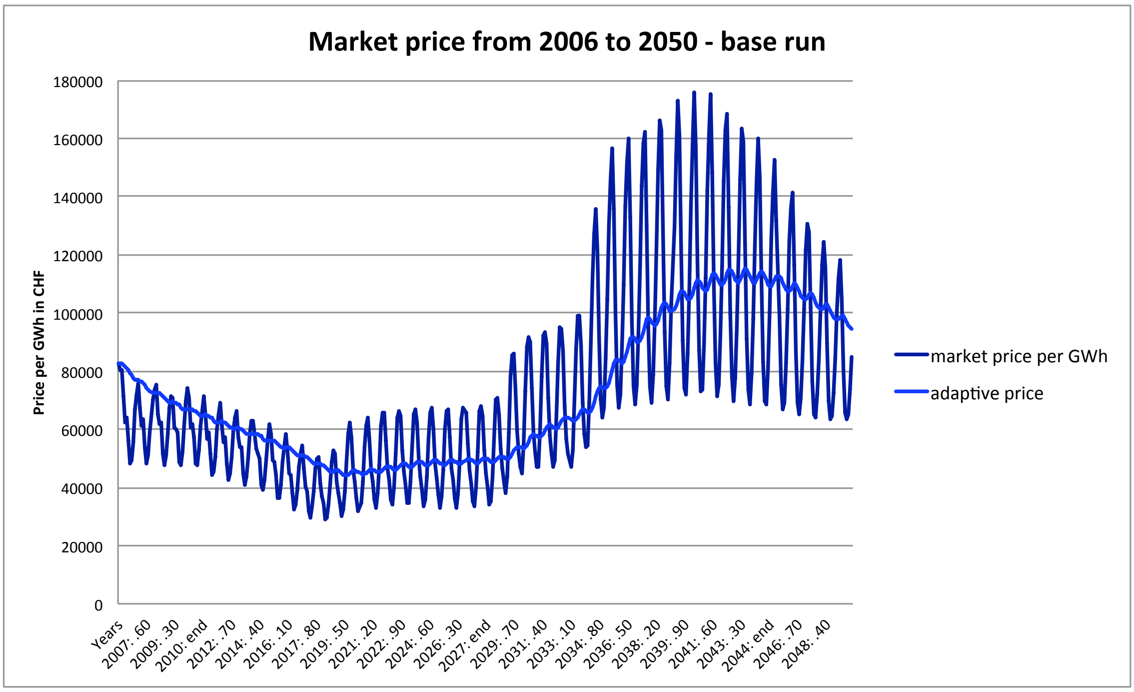

Figure 25: Base run – market price

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 26). There is a major expansion of photovoltaic and wind as a consequence of the FIT policy.

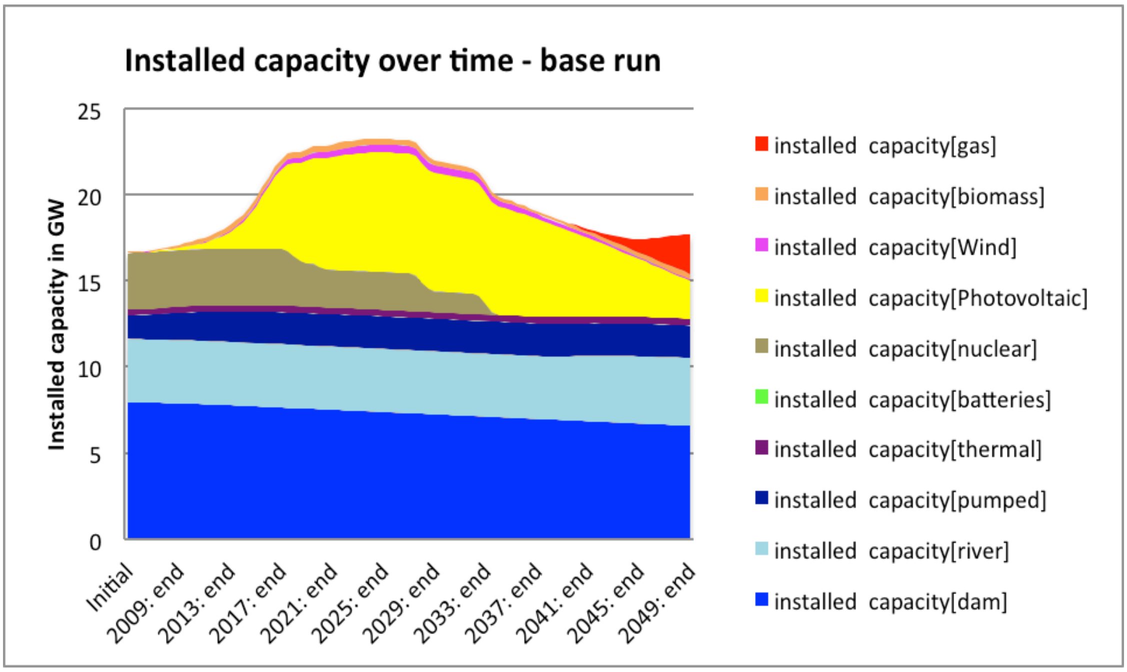

Figure 26: Base run – installed capacity

After the ending of the FIT policy in 2015 the investments into new renewables fall to zero (see run 4 in Figure 27). 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.

In Figure 27 the development of the system under four different assumptions is compared. Run 1 assumes a system where the costs for all technologies remained on the same level as they were in 2006. Additionally there is no FIT policy pushing the new renewables and also no nuclear phase out. Run 2 simulates the system with the estimations for cost development but neglects the FIT policy and the nuclear phase out. In run 3 the currently established FIT policy is included but there is no nuclear phase out. Run 4 combines all elements and incorporates the stepwise nuclear phase out. Run 4 is equal to the base run. We see that with every run the investments into new renewables increase. The decreasing costs alone don't have a significant impact, since the technologies are not profitable without the FIT policy. In all cases investments stop after the FIT policy ends. Correspondingly to the investments is the price behaviour, since demand is rather stable. Important to notice is that in case of nuclear phase out the price rises again due to the reduced capacity, although in this scenario the investment is the highest.

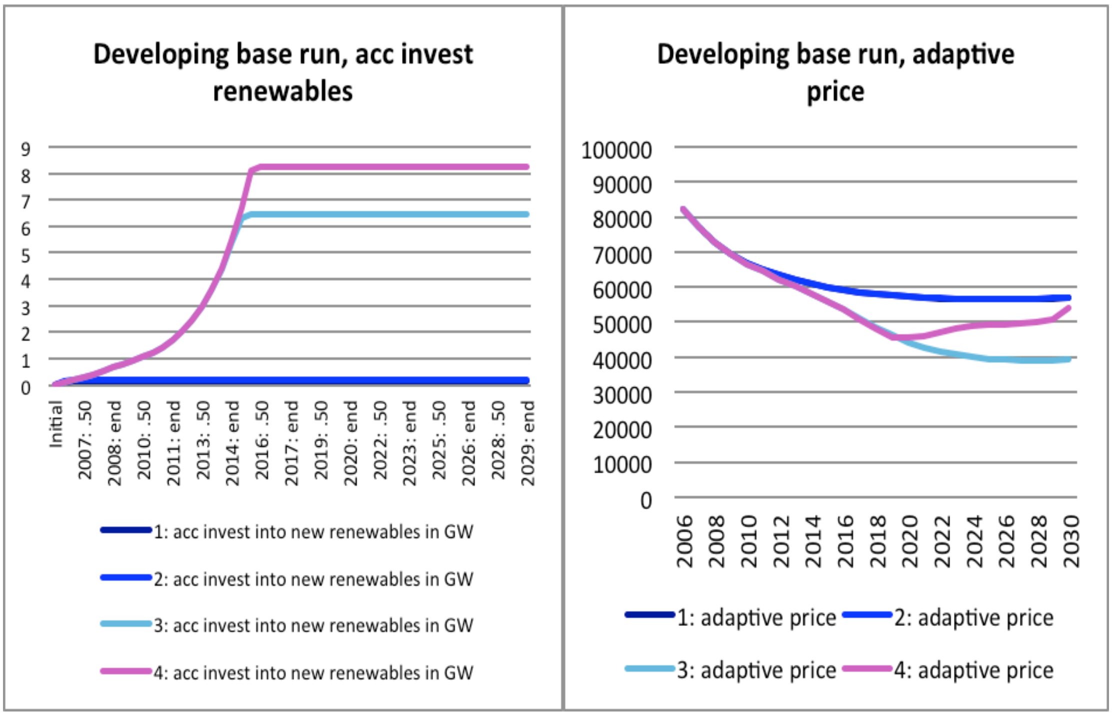

Figure 27: Developing the base run – accumulated investment into renewables and price (1: constant costs 2006, 2: cost data, 3: cost data and FIT, 4. Cost data & FIT & nuclear phase out)

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 variables considered as relevant for comparison are:

- The price averaged over time and weighted by demand at the specific point of consumption.
- Average standard deviation of the price. Here it has to be mentioned that the values have a bias towards the trend due to the structure used for calculation.
- The adaptive share of new renewables in production.
- The adaptive share of renewables including hydro-power in production.
- The accumulated investments into all technologies in million Swiss franks.
- The accumulated investments into new renewables in million Swiss franks.
- The total costs of the FIT policy

- The consumer spendings, so the market price times the demand accumulated over time. This does in fact not represent the real consumer spendings, since in reality there is a major factor of grid charges added to the electricity price.
- The total costs on consumers – the sum of the costs for the FIT policy and the consumer spendings, since the costs of the policy will be transferred to the consumer in some form, either as an additional part to the gird charges or via taxes on income.

Accumulated costs are not discounted. This means that costs in 2050 weight the same as in 2014.

4.2.1. Fixed tariff FIT policy 2015

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.

The total governmental expenses of the policy lead to costs of 9’213 million Swiss francs until 2050. This is due to the structure of the policy, which ensures that all plants built and started within the policy time are eligible for the feed-in remuneration for 20 years (except of thermal power that only is supported for 10 years after 2014) (Swiss energy enactment) despite the policy is stopped in 2015. Investments into new renewables are taken of the amount of 26’155 million Swiss francs. This leads to a low installed capacity in times where the nuclear power plants are shut down, which pushes the price higher. The average weighted price is 73’878 CHF per GWh. The average standard deviation of the price is at 0.23 at the end of the simulation. Accumulated consumer expenditures are therefore with 205’784 rather high. Since there are fewer costs for the policy, which is stopped early, the total costs on consumers are comparatively low with 214’997 CHF (consumer spendings plus policy costs).

4.2.2. Fixed tariff FIT policy 2050

As a next step 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. This is a bit unrealistic since the tariffs are adjusted at least every year upon the investments costs, the marginal and fix production costs as well as the desired expansion of the technology (Swiss energy enactment Art. 3; Swiss Federal Council, 2008). Nevertheless, the future costs developments are not as extreme as they were in recent years. 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. Clearly the major investments are made into new renewable energies. The average weighted price is with 65’483 clearly lower than in the previous scenario. The standard deviation though has risen to a higher level, which can be explained with a higher share of fluctuating technologies such as photovoltaic and wind. The consumer spendings are due to the lower price lower than in the previous scenario with 182’398 million CHF. Total governmental expenditures for the payment of the feed-in remuneration tariffs reach a level of 69’025 million CHF. Interestingly the governmental expenditures for the feed-in remuneration are higher than the actual investment costs made for these technologies. This is due to that the KEV tariff is just remaining on the level of 2014 while the investment costs of certain technologies decrease. Realistically, would the FIT system be continued in this manner, the tariffs would be adjusted to the new and lower investment costs. But as this system also includes desired expansion planning this is not modelled endogenously in this model. Total costs put on the consumers, including their own consumption, is 251’423 million CHF. This is almost 40’000 million CHF higher than in the scenario where the FIT policy is stopped in 2015. Result of this is of course that they can consume a much greener electricity mix.

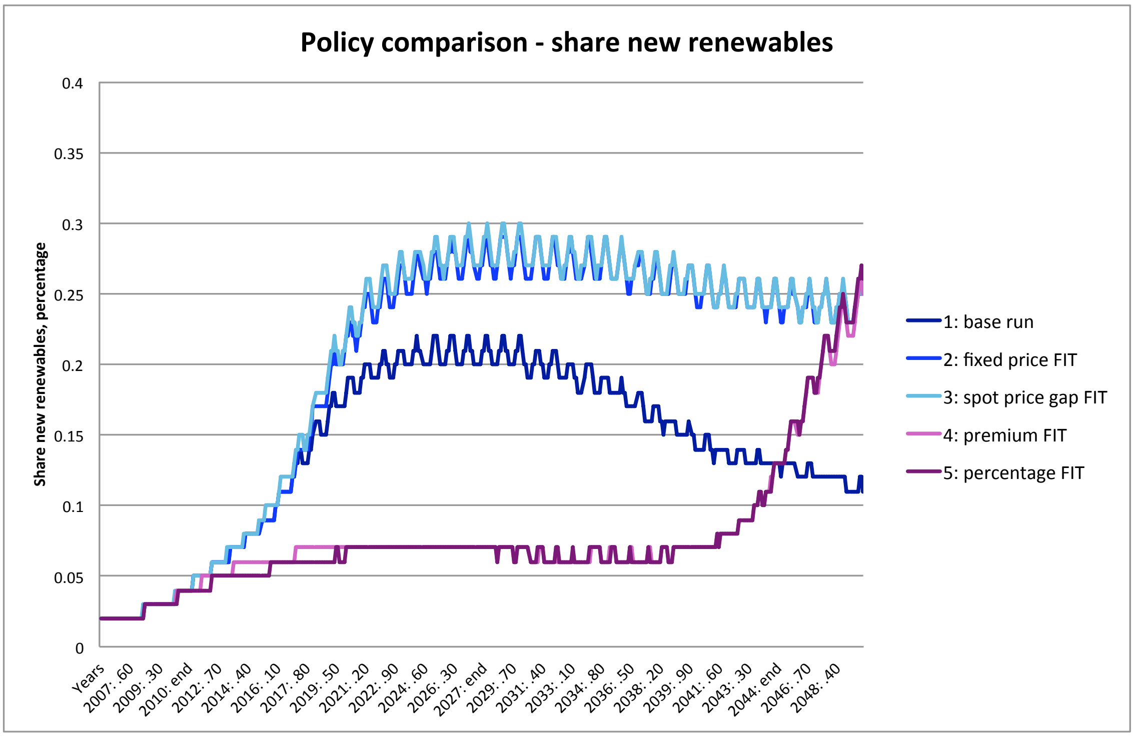

Figure 28: Comparison of policy scenarios – share new renewables

4.2.3. Spot market price gap FIT

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.

The simulation results reveal, that with the average weighted electricity price is 64’960 CHF per GWh the price is almost equal to the resulting price with the fixed tariff policy. The share of new renewable energies is also 25 precent and the accumulated investment in total and the accumulated investment for only new renewable energies differ only slightly from the fixed tariff FIT. Interesting to see is that the governmental expenditures for the policy are only 52'438 million CHF. This is clearly lower than the costs for the fixed tariff policy (69'025 million CHF). Consequently also the total costs on consumers is clearly lower with 233'380 million CHF over all years until 2050.

4.2.4. Premium FIT

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 average weighted market price of 82'243 CHF per GWh results. The share of new renewables is 25%. The accumulated investment overall is 33'214 million CHF of which 27'053 million CHF go into new renewables. Important to understand is that with this constant premium the new renewable energies reach the profitability benchmark much later than in the other policies. Therefore investments are made much later and less capacity depreciation is necessary to keep the share of new renewables at a high level until the end of the simulation period. Governmental costs for the premium are 11'905 million CHF. As the price was higher for a longer period of time consumer spendings are 229'093 million CHF over the simulation period. When adding the governmental expenditures for the premium FIT this results in costs put on the consumer of 240'987 million CHF. This amount is in between the fixed price Fit and the spot market price gap FIT.

4.2.5. Percentage of market price FIT

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.

An average weighted price of 82'364 CHF per GWh is resulting out of a system with this policy. Accumulated investment is 34'157 million CHF of which new renewable energies make 28'003 million CHF. Investments in new renewable energies are made very late in the simulation period, as the technologies are initially not profitable. The governmental expenditures for the policy are 11'010 million CHF. Consumer spendings are high due to the high electricity price, 229'421 million CHF. This results in costs put on consumers of 240'431 million CHF.

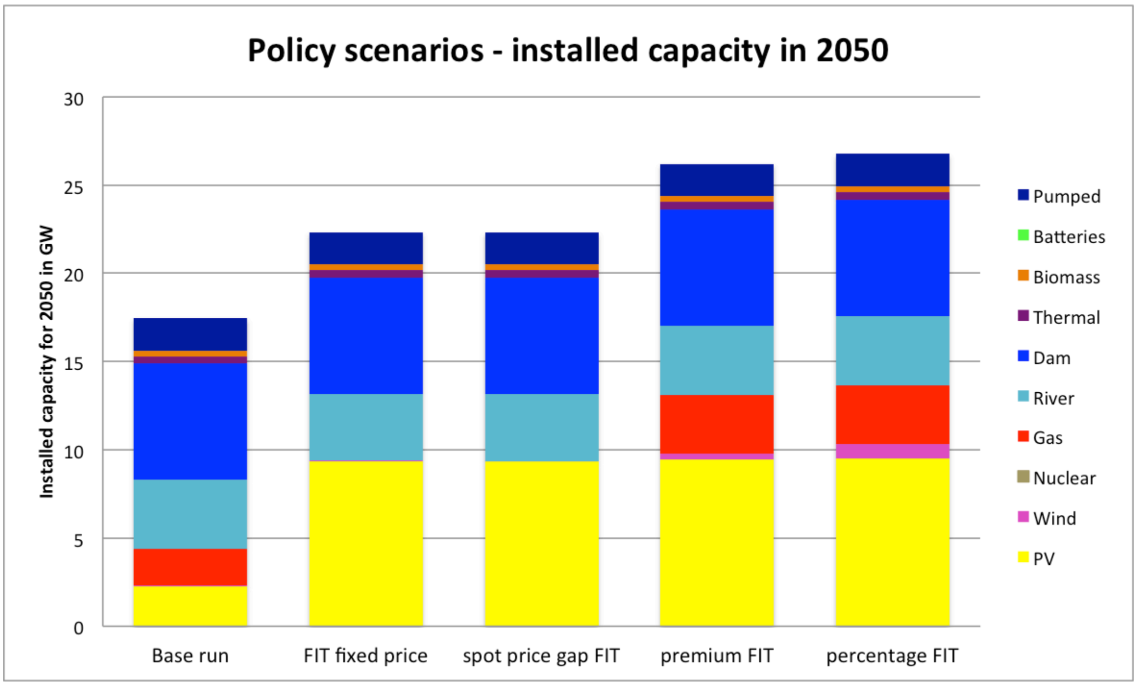

Figure 29: Comparison of policy scenarios – installed capacity

4.2.6. Policy comparison and further research needed

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 3, Figure 29 and Figure 28. Table 3 lists the results values for the policy evaluation criteria (discussed under 4) 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 3: 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 (Figure 29).

The table 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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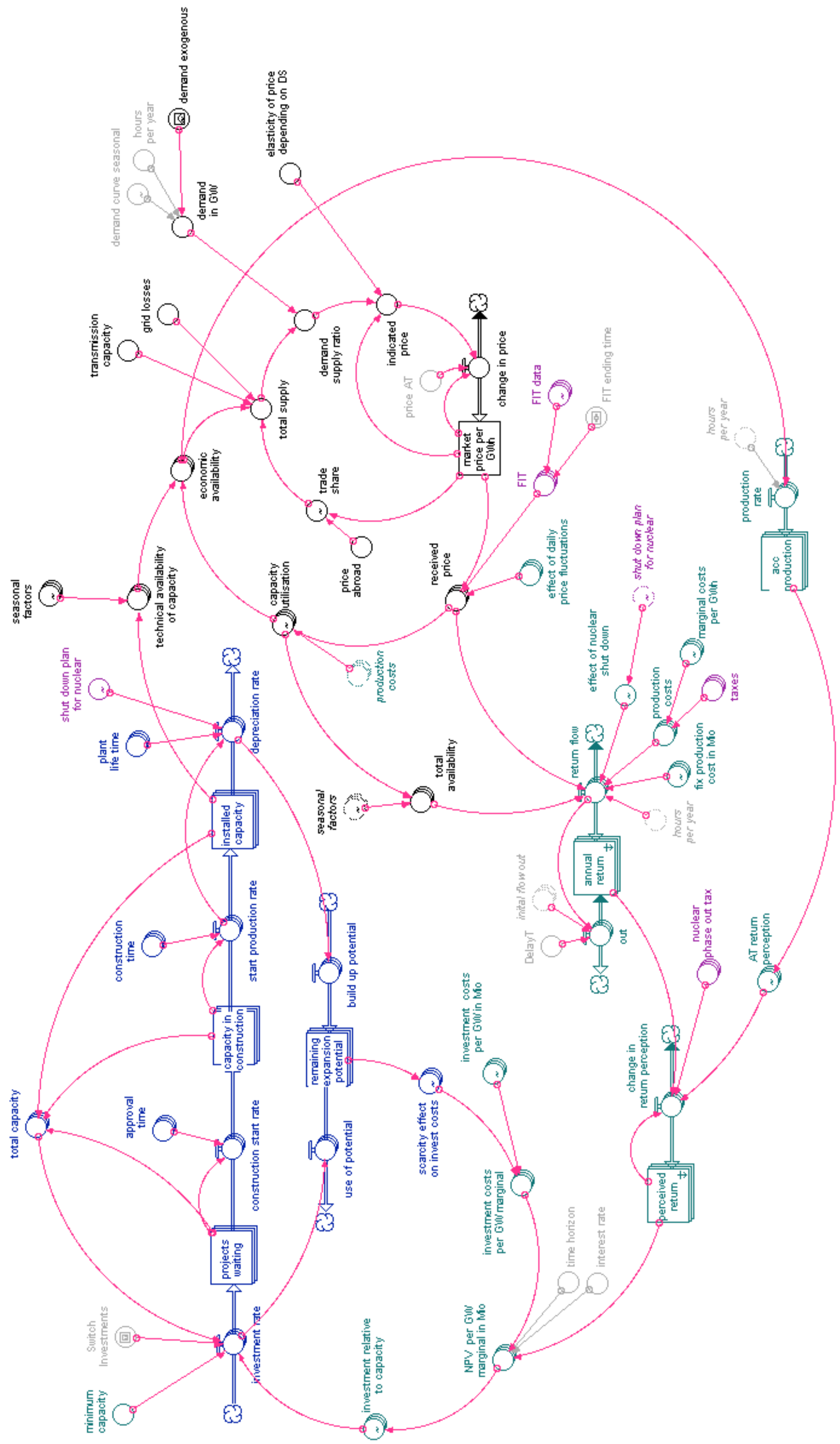
Appendix

I. Complete stock-and-flow diagram



II. Full set of equations

annual_return[Technology](t) = annual_return[Technology](t - dt) + (return_flow[Technology] - out[Technology]) * dt
INIT annual_return[Technology] = (((INIT(received_price)-INIT(production_costs)-INIT(taxes))* INIT(average_availability) *hours_per_year)/1000000)-INIT(fix_production_cost_in_Mio)

INFLOWS:

return_flow[Technology] = ((((received_price*effect_of_nuclear_shut_down)-production_costs)*(total_availability*hours_per_year))/1000000)-fix_production_cost_in_Mio

OUTFLOWS:

out[Technology] = DELAY(return_flow,DelayT,inital_flow_out)

perceived_return[Technology](t) = perceived_return[Technology](t - dt) + (change_in__return_perception[Technology]) * dt
INIT perceived_return[Technology] = INIT(annual_return)-INIT(nuclear_phase_out_tax)

INFLOWS:

change_in__return_perception[Technology] = ((annual_return-nuclear_phase_out_tax)-perceived_return)/AT_return_perception

accumulated_demand(t) = accumulated_demand(t - dt) + (demand) * dt
INIT accumulated_demand = 0

INFLOWS:

demand = demand_in_GW*dt

accumulated_sales(t) = accumulated_sales(t - dt) + (sales_rate) * dt
INIT accumulated_sales = 0

INFLOWS:

sales_rate = market_price_per_GWh*demand_in_GW*dt

acc_costs_FIT_percentage(t) = acc_costs_FIT_percentage(t - dt) + (Flow_7) * dt
INIT acc_costs_FIT_percentage = 0

INFLOWS:

Flow_7 = SUM(expenditures_FIT_percentage)/1000000

acc_costs_premium_FIT(t) = acc_costs_premium_FIT(t - dt) + (Flow_8) * dt
INIT acc_costs_premium_FIT = 0

INFLOWS:

Flow_8 = SUM(expenditures_premium_FIT)/1000000

acc_expenditures_for_FIT_in_Mio(t) = acc_expenditures_for_FIT_in_Mio(t - dt) + (FIT_payments) * dt
INIT acc_expenditures_for_FIT_in_Mio = 0

INFLOWS:

FIT_payments = SUM(production_in_KEV_time)/1000000

acc_investment(t) = acc_investment(t - dt) + (investment_in_monrey) * dt
INIT acc_investment = 0

INFLOWS:

investment_in_monrey = SUM(investment_per_technology_in_monrey)

acc_invest_into_new_renewables(t) = acc_invest_into_new_renewables(t - dt) + (invest_KEV_tech) * dt
INIT acc_invest_into_new_renewables = 0

INFLOWS:

invest_KEV_tech = (investment_costs_per_GW_marginal[Photovoltaic]*
investment_rate[Photovoltaic])+(investment_costs_per_GW_marginal[Wind]*
investment_rate[Wind])+(investment_costs_per_GW_marginal[thermal]*
investment_rate[thermal])+(investment_costs_per_GW_marginal[biomass]*
investment_rate[biomass])

acc_invest_into_new_renewables_in_GW(t) = acc_invest_into_new_renewables_in_GW(t - dt) + (Flow_4) * dt
INIT acc_invest_into_new_renewables_in_GW = 0

INFLOWS:

Flow_4 = investment_rate[Photovoltaic]+investment_rate[Wind]+
investment_rate[thermal]+investment_rate[biomass]

acc_invest_in_GW[Technology](t) = acc_invest_in_GW[Technology](t - dt) + (Flow_3[Technology]) * dt
INIT acc_invest_in_GW[Technology] = 0

INFLOWS:

Flow_3[Technology] = investment_rate

acc_production[Photovoltaic](t) = acc_production[Photovoltaic](t - dt) + (production_rate[Technology]) * dt
INIT acc_production[Photovoltaic] = 0

acc_production[Wind](t) = acc_production[Wind](t - dt) + (production_rate[Technology]) * dt
INIT acc_production[Wind] = 0

acc_production[nuclear](t) = acc_production[nuclear](t - dt) + (production_rate[Technology]) * dt
INIT acc_production[nuclear] = 100000

acc_production[gas](t) = acc_production[gas](t - dt) + (production_rate[Technology]) * dt
INIT acc_production[gas] = 0

acc_production[river](t) = acc_production[river](t - dt) + (production_rate[Technology]) * dt
INIT acc_production[river] = 50000

acc_production[dam](t) = acc_production[dam](t - dt) + (production_rate[Technology]) * dt
INIT acc_production[dam] = 50000

acc_production[thermal](t) = acc_production[thermal](t - dt) + (production_rate[Technology]) * dt
INIT acc_production[thermal] = 10000

acc_production[biomass](t) = acc_production[biomass](t - dt) + (production_rate[Technology]) * dt
INIT acc_production[biomass] = 0

acc_production[batteries](t) = acc_production[batteries](t - dt) + (production_rate[Technology]) * dt
INIT acc_production[batteries] = 0

acc_production[pumped](t) = acc_production[pumped](t - dt) + (production_rate[Technology]) * dt
INIT acc_production[pumped] = 10000

INFLOWS:

production_rate[Technology] = economic_availability*hours_per_year

adaptive_price(t) = adaptive_price(t - dt) + (chng_in_avg_price) * dt
INIT adaptive_price = INIT(market_price_per_GWh)

INFLOWS:

chng_in_avg_price = (market_price_per_GWh-adaptive_price)/AT_avg_price

avg_standard_deviation(t) = avg_standard_deviation(t - dt) + (av_volatility) * dt
INIT avg_standard_deviation = 0

INFLOWS:

av_volatility = (SQRT(((market_price_per_GWh-adaptive_price)/adaptive_price)^2))*(1/44)

capacity_in__construction[Photovoltaic](t) = capacity_in__construction[Photovoltaic](t - dt) + (construction_start_rate[Technology] - start_production_rate[Technology]) * dt
INIT capacity_in__construction[Photovoltaic] = 0.05

capacity_in__construction[Wind](t) = capacity_in__construction[Wind](t - dt) + (construction_start_rate[Technology] - start_production_rate[Technology]) * dt
INIT capacity_in__construction[Wind] = 0

capacity_in__construction[nuclear](t) = capacity_in__construction[nuclear](t - dt) + (construction_start_rate[Technology] - start_production_rate[Technology]) * dt
INIT capacity_in__construction[nuclear] = 0

capacity_in__construction[gas](t) = capacity_in__construction[gas](t - dt) + (construction_start_rate[Technology] - start_production_rate[Technology]) * dt
INIT capacity_in__construction[gas] = 0

capacity_in__construction[river](t) = capacity_in__construction[river](t - dt) + (construction_start_rate[Technology] - start_production_rate[Technology]) * dt
INIT capacity_in__construction[river] = 0.005

capacity_in__construction[dam](t) = capacity_in__construction[dam](t - dt) + (construction_start_rate[Technology] - start_production_rate[Technology]) * dt
INIT capacity_in__construction[dam] = 0.1

capacity_in__construction[thermal](t) = capacity_in__construction[thermal](t - dt) + (construction_start_rate[Technology] - start_production_rate[Technology]) * dt
INIT capacity_in__construction[thermal] = 0

capacity_in__construction[biomass](t) = capacity_in__construction[biomass](t - dt) + (construction_start_rate[Technology] - start_production_rate[Technology]) * dt
INIT capacity_in__construction[biomass] = 0

capacity_in__construction[batteries](t) = capacity_in__construction[batteries](t - dt) + (construction_start_rate[Technology] - start_production_rate[Technology]) * dt
INIT capacity_in__construction[batteries] = 0

capacity_in__construction[pumped](t) = capacity_in__construction[pumped](t - dt) + (construction_start_rate[Technology] - start_production_rate[Technology]) * dt
INIT capacity_in__construction[pumped] = 0

INFLOWS:

construction_start_rate[Technology] = projects_waiting/approval_time

OUTFLOWS:

start_production_rate[Technology] = capacity_in__construction/construction_time

consumer_spendings_total(t) = consumer_spendings_total(t - dt) + (consumer_spendings) * dt
INIT consumer_spendings_total = 0

INFLOWS:

consumer_spendings = (market_price_per_GWh*demand_in_GW*hours_per_year)/1000000

installed__capacity[Photovoltaic](t) = installed__capacity[Photovoltaic](t - dt) + (start_production_rate[Technology] - depreciation_rate[Technology]) * dt
INIT installed__capacity[Photovoltaic] = 0.029

installed__capacity[Wind](t) = installed__capacity[Wind](t - dt) + (start_production_rate[Technology] - depreciation_rate[Technology]) * dt
INIT installed__capacity[Wind] = 0.012

installed__capacity[nuclear](t) = installed__capacity[nuclear](t - dt) + (start_production_rate[Technology] - depreciation_rate[Technology]) * dt
INIT installed__capacity[nuclear] = 3.278

installed__capacity[gas](t) = installed__capacity[gas](t - dt) + (start_production_rate[Technology] - depreciation_rate[Technology]) * dt
INIT installed__capacity[gas] = 0

installed__capacity[river](t) = installed__capacity[river](t - dt) + (start_production_rate[Technology] - depreciation_rate[Technology]) * dt
INIT installed__capacity[river] = 3.652

installed__capacity[dam](t) = installed__capacity[dam](t - dt) + (start_production_rate[Technology] - depreciation_rate[Technology]) * dt
INIT installed__capacity[dam] = 7.961

installed__capacity[thermal](t) = installed__capacity[thermal](t - dt) + (start_production_rate[Technology] - depreciation_rate[Technology]) * dt
INIT installed__capacity[thermal] = 0.355

installed__capacity[biomass](t) = installed__capacity[biomass](t - dt) + (start_production_rate[Technology] - depreciation_rate[Technology]) * dt
INIT installed__capacity[biomass] = 0.032

installed__capacity[batteries](t) = installed__capacity[batteries](t - dt) + (start_production_rate[Technology] - depreciation_rate[Technology]) * dt
INIT installed__capacity[batteries] = 0

installed__capacity[pumped](t) = installed__capacity[pumped](t - dt) + (start_production_rate[Technology] - depreciation_rate[Technology]) * dt
INIT installed__capacity[pumped] = 1.383

INFLOWS:

start_production_rate[Technology] = capacity_in__construction/construction_time

OUTFLOWS:

depreciation_rate[Photovoltaic] = DELAYN(start_production_rate[Photovoltaic],plant_life_time[Photovoltaic],10)

depreciation_rate[Wind] = DELAYN(start_production_rate[Wind],plant_life_time[Wind],10)

depreciation_rate[nuclear] = shut_down_plan_for_nuclear

depreciation_rate[gas] = DELAYN(start_production_rate[gas],plant_life_time[gas],10)

depreciation_rate[river] = DELAYN(start_production_rate[river],plant_life_time[river],10)

depreciation_rate[dam] = DELAYN(start_production_rate[dam],plant_life_time[dam],10)

depreciation_rate[thermal] = DELAYN(start_production_rate[thermal],plant_life_time[thermal],10)

depreciation_rate[biomass] = DELAYN(start_production_rate[biomass],plant_life_time[biomass],10)

depreciation_rate[batteries] =
DELAYN(start_production_rate[batteries],plant_life_time[batteries],10)

depreciation_rate[pumped] =
DELAYN(start_production_rate[pumped],plant_life_time[pumped],10)

market_price_per_GWh(t) = market_price_per_GWh(t - dt) + (change_in_price) * dt
INIT market_price_per_GWh = 82520

INFLOWS:

change_in_price = (indicated_price-market_price_per_GWh)/price_AT

policy_costs_spot_price_gap_FIT[Technology](t) =
policy_costs_spot_price_gap_FIT[Technology](t - dt) + (spot_price_gap_costs[Technology]) * dt
INIT policy_costs_spot_price_gap_FIT[Technology] = 0

INFLOWS:

spot_price_gap_costs[Technology] = production_in_KEV_time_1*spot_gap_FIT

producing_with_FIT[Technology](t) = producing_with_FIT[Technology](t - dt) +
(start_FIT[Technology] - ending_of_KEV_support[Technology]) * dt
INIT producing_with_FIT[Technology] = 0

INFLOWS:

start_FIT[Technology] = IF(FIT_ending_time>TIME)THEN(start_production_rate*
FIT_with_thermal_special)ELSE(0)

OUTFLOWS:

ending_of_KEV_support[Technology] = DELAY(start_FIT,KEV_duration)

producing_with_FIT_1[Technology](t) = producing_with_FIT_1[Technology](t - dt) +
(start_FIT_1[Technology] - ending_of_KEV_support_1[Technology]) * dt
INIT producing_with_FIT_1[Technology] = 0

INFLOWS:

start_FIT_1[Technology] = start_production_rate

OUTFLOWS:

ending_of_KEV_support_1[Technology] = DELAY(start_FIT_1,KEV_duration_1)

projects_waiting[Photovoltaic](t) = projects_waiting[Photovoltaic](t - dt) +
(investment_rate[Technology] - construction_start_rate[Technology]) * dt
INIT projects_waiting[Photovoltaic] = 0.011

projects_waiting[Wind](t) = projects_waiting[Wind](t - dt) + (investment_rate[Technology] -
construction_start_rate[Technology]) * dt
INIT projects_waiting[Wind] = 0.002

projects_waiting[nuclear](t) = projects_waiting[nuclear](t - dt) + (investment_rate[Technology] -
construction_start_rate[Technology]) * dt
INIT projects_waiting[nuclear] = 0

projects_waiting[gas](t) = projects_waiting[gas](t - dt) + (investment_rate[Technology] -
construction_start_rate[Technology]) * dt
INIT projects_waiting[gas] = 0

projects_waiting[river](t) = projects_waiting[river](t - dt) + (investment_rate[Technology] -
construction_start_rate[Technology]) * dt
INIT projects_waiting[river] = 0.01

projects_waiting[dam](t) = projects_waiting[dam](t - dt) + (investment_rate[Technology] - construction_start_rate[Technology]) * dt
INIT projects_waiting[dam] = 0.001

projects_waiting[thermal](t) = projects_waiting[thermal](t - dt) + (investment_rate[Technology] - construction_start_rate[Technology]) * dt
INIT projects_waiting[thermal] = 0.01

projects_waiting[biomass](t) = projects_waiting[biomass](t - dt) + (investment_rate[Technology] - construction_start_rate[Technology]) * dt
INIT projects_waiting[biomass] = 0

projects_waiting[batteries](t) = projects_waiting[batteries](t - dt) + (investment_rate[Technology] - construction_start_rate[Technology]) * dt
INIT projects_waiting[batteries] = 0

projects_waiting[pumped](t) = projects_waiting[pumped](t - dt) + (investment_rate[Technology] - construction_start_rate[Technology]) * dt
INIT projects_waiting[pumped] = 0

INFLOWS:

investment_rate[Technology] = (IF(total_capacity> minimum_capacity)THEN(total_capacity* investment_relative_to_capacity)ELSE(minimum_capacity* investment_relative_to_capacity))*Switch_Investments

OUTFLOWS:

construction_start_rate[Technology] = projects_waiting/approval_time

remaining_expansion_potential[Technology](t) = remaining_expansion_potential[Technology](t - dt) + (build_up_potential[Technology] - use_of_potential[Technology]) * dt
INIT remaining_expansion_potential[Technology] = INIT(total_potential_constant)-INIT(projects_waiting)-INIT(capacity_in__construction)-INIT(installed__capacity)

INFLOWS:

build_up_potential[Technology] = depreciation_rate

OUTFLOWS:

use_of_potential[Technology] = investment_rate

SCS_status_renewable_A[Photovoltaic](t) = SCS_status_renewable_A[Photovoltaic](t - dt)
INIT SCS_status_renewable_A[Photovoltaic] = 13.5

SCS_status_renewable_A[Wind](t) = SCS_status_renewable_A[Wind](t - dt)
INIT SCS_status_renewable_A[Wind] = 3.6

SCS_status_renewable_A[nuclear](t) = SCS_status_renewable_A[nuclear](t - dt)
INIT SCS_status_renewable_A[nuclear] = 0

SCS_status_renewable_A[gas](t) = SCS_status_renewable_A[gas](t - dt)
INIT SCS_status_renewable_A[gas] = 0

SCS_status_renewable_A[river](t) = SCS_status_renewable_A[river](t - dt)
INIT SCS_status_renewable_A[river] = 3.7

SCS_status_renewable_A[dam](t) = SCS_status_renewable_A[dam](t - dt)
INIT SCS_status_renewable_A[dam] = 8.5

SCS_status_renewable_A[thermal](t) = SCS_status_renewable_A[thermal](t - dt)
INIT SCS_status_renewable_A[thermal] = 0.355

SCS_status_renewable_A[biomass](t) = SCS_status_renewable_A[biomass](t - dt)
INIT SCS_status_renewable_A[biomass] = 1

SCS_status_renewable_A[batteries](t) = SCS_status_renewable_A[batteries](t - dt)
INIT SCS_status_renewable_A[batteries] = 0

SCS_status_renewable_A[pumped](t) = SCS_status_renewable_A[pumped](t - dt)
INIT SCS_status_renewable_A[pumped] = 5

smoothed_share_new_renewables(t) = smoothed_share_new_renewables(t - dt) + (Flow_5) * dt
INIT smoothed_share_new_renewables = 0.02

INFLOWS:

Flow_5 = (share_new_renewables-smoothed_share_new_renewables)/AT_NR

smoothed_share_renewable_plus_hydro(t) = smoothed_share_renewable_plus_hydro(t - dt) + (Flow_6) * dt
INIT smoothed_share_renewable_plus_hydro = 0.56

INFLOWS:

Flow_6 = (share_renewable_plus_hydro-smoothed_share_renewable_plus_hydro)/AT_NR

acc_invest_in_GW__total = SUM(acc_invest_in_GW)
annual_production_in_GWh_per_GW_production_capacity_by_SCS[Photovoltaic] = 1297
annual_production_in_GWh_per_GW_production_capacity_by_SCS[Wind] = 1947
annual_production_in_GWh_per_GW_production_capacity_by_SCS[nuclear] = 7884
annual_production_in_GWh_per_GW_production_capacity_by_SCS[gas] = 5000
annual_production_in_GWh_per_GW_production_capacity_by_SCS[river] = 4324
annual_production_in_GWh_per_GW_production_capacity_by_SCS[dam] = 1536
annual_production_in_GWh_per_GW_production_capacity_by_SCS[thermal] = 5000
annual_production_in_GWh_per_GW_production_capacity_by_SCS[biomass] = 5860
annual_production_in_GWh_per_GW_production_capacity_by_SCS[batteries] = 3000
annual_production_in_GWh_per_GW_production_capacity_by_SCS[pumped] = 392
approval_time[Photovoltaic] = 0.5
approval_time[Wind] = 3
approval_time[nuclear] = 12
approval_time[gas] = 2
approval_time[river] = 2
approval_time[dam] = 3
approval_time[thermal] = 2
approval_time[biomass] = 1
approval_time[batteries] = 0.5
approval_time[pumped] = 3
AT_avg_price = 3
AT_NR = 1

AT_return_perception[Technology] = GRAPH(acc_production)
(0.00, 1.03), (5128, 1.04), (10256, 1.07), (15385, 1.11), (20513, 1.16), (25641, 1.20), (30769, 1.23), (35897, 1.28), (41026, 1.34), (46154, 1.43), (51282, 1.56), (56410, 1.68), (61538, 1.83), (66667, 1.91), (71795, 2.10), (76923, 2.21), (82051, 2.41), (87179, 2.57), (92308, 2.81), (97436, 2.96), (102564, 3.18), (107692, 3.39), (112821, 3.53), (117949, 3.66), (123077, 3.89), (128205, 4.03), (133333, 4.19), (138462, 4.30), (143590, 4.43), (148718, 4.54), (153846, 4.64), (158974, 4.69), (164103, 4.77), (169231, 4.81), (174359, 4.84), (179487, 4.89), (184615, 4.90), (189744, 4.91), (194872, 4.94), (200000, 4.96)

average_availability[Technology] = average_seasonal_factor*capacity_utilisation
average_seasonal_factor[Photovoltaic] = 0.141287
average_seasonal_factor[Wind] = 0.15168317
average_seasonal_factor[nuclear] = 0.868712
average_seasonal_factor[gas] = 1
average_seasonal_factor[river] = 0.46188
average_seasonal_factor[dam] = 0.30297
average_seasonal_factor[thermal] = 0.65484
average_seasonal_factor[biomass] = 1
average_seasonal_factor[batteries] = 1
average_seasonal_factor[pumped] = 0.8
avg_demand = demand_exogenous/hours_per_year
avg_weighted_price = accumulated_sales/(accumulated_demand+0.000000000000001)
capacity_utilisation[Photovoltaic] = GRAPH(received_price/(production_costs+0.0000000000001))
(0.00, 1.00), (0.2, 1.00), (0.4, 1.00), (0.6, 1.00), (0.8, 1.00), (1.00, 1.00), (1.20, 1.00), (1.40, 1.00), (1.60, 1.00), (1.80, 1.00), (2.00, 1.00)

capacity_utilisation[Wind] = GRAPH(received_price/(production_costs+0.0000000000001))
(0.00, 1.00), (0.2, 1.00), (0.4, 1.00), (0.6, 1.00), (0.8, 1.00), (1.00, 1.00), (1.20, 1.00), (1.40, 1.00), (1.60, 1.00), (1.80, 1.00), (2.00, 1.00)

capacity_utilisation[nuclear] = GRAPH(received_price/(production_costs+0.0000000000001))
(0.00, 0.85), (0.1, 0.887), (0.2, 0.915), (0.3, 0.944), (0.4, 0.967), (0.5, 0.991), (0.6, 1.00), (0.7, 1.00), (0.8, 1.00), (0.9, 1.00), (1.00, 1.00), (1.10, 1.00), (1.20, 1.00), (1.30, 1.00), (1.40, 1.00), (1.50, 1.00), (1.60, 1.00), (1.70, 1.00), (1.80, 0.997), (1.90, 1.00), (2.00, 1.00)

capacity_utilisation[gas] = GRAPH(received_price/(production_costs+0.0000000000001))
(0.00, 0.00), (0.1, 0.00), (0.2, 0.00), (0.3, 0.00), (0.4, 0.00), (0.5, 0.0188), (0.6, 0.117), (0.7, 0.315), (0.8, 0.911), (0.9, 0.977), (1.00, 1.00), (1.10, 1.00), (1.20, 1.00), (1.30, 1.00), (1.40, 1.00), (1.50, 1.00), (1.60, 1.00), (1.70, 1.00), (1.80, 1.00), (1.90, 1.00), (2.00, 1.00)

capacity_utilisation[river] = GRAPH(received_price/(production_costs+0.0000000000001))
(0.00, 0.901), (0.1, 0.901), (0.2, 0.901), (0.3, 0.898), (0.4, 0.902), (0.5, 0.902), (0.6, 0.902), (0.7, 0.905), (0.8, 0.908), (0.9, 0.924), (1.00, 0.956), (1.10, 0.984), (1.20, 0.997), (1.30, 1.00), (1.40, 1.00), (1.50, 1.00), (1.60, 1.00), (1.70, 1.00), (1.80, 1.00), (1.90, 1.00), (2.00, 1.00)

capacity_utilisation[dam] = GRAPH(received_price/(production_costs+0.0000000000001))
(0.00, 0.00), (0.1, 0.00), (0.2, 0.00), (0.3, 0.00), (0.4, 0.00), (0.5, 0.00), (0.6, 0.00), (0.7, 0.00), (0.8, 0.103), (0.9, 0.493), (1.00, 0.911), (1.10, 0.981), (1.20, 1.00), (1.30, 1.00), (1.40, 1.00), (1.50, 1.00), (1.60, 1.00), (1.70, 1.00), (1.80, 1.00), (1.90, 1.00), (2.00, 1.00)

capacity_utilisation[thermal] = GRAPH(received_price/(production_costs+0.0000000000001))
(0.00, 0.00), (0.1, 0.00), (0.2, 0.00), (0.3, 0.00), (0.4, 0.00952), (0.5, 0.0444), (0.6, 0.127), (0.7, 0.311), (0.8, 0.454), (0.9, 0.619), (1.00, 0.902), (1.10, 0.987), (1.20, 1.00), (1.30, 1.00), (1.40, 1.00), (1.50, 1.00), (1.60, 1.00), (1.70, 1.00), (1.80, 1.00), (1.90, 1.00), (2.00, 1.00)

capacity_utilisation[biomass] = GRAPH(received_price/(production_costs+0.0000000000001))
(0.00, 0.00), (0.1, 0.00), (0.2, 0.00), (0.3, 0.00), (0.4, 0.00), (0.5, 0.00), (0.6, 0.00), (0.7, 0.00), (0.8, 0.019), (0.9, 0.178), (1.00, 0.483), (1.10, 0.886), (1.20, 1.00), (1.30, 1.00), (1.40, 1.00), (1.50, 1.00), (1.60, 1.00), (1.70, 1.00), (1.80, 1.00), (1.90, 1.00), (2.00, 1.00)

capacity_utilisation[batteries] = GRAPH(received_price/(production_costs+0.0000000000001))
(0.00, 0.00), (0.1, 0.00), (0.2, 0.00), (0.3, 0.00), (0.4, 0.00), (0.5, 0.00), (0.6, 0.00), (0.7, 0.00), (0.8, 0.00), (0.9, 0.00), (1.00, 0.00), (1.10, 0.867), (1.20, 0.962), (1.30, 0.984), (1.40, 0.994), (1.50, 0.994), (1.60, 0.994), (1.70, 0.997), (1.80, 0.997), (1.90, 1.00), (2.00, 1.00)

capacity_utilisation[pumped] = GRAPH(received_price/(production_costs+0.0000000000001))
(0.00, 0.00), (0.1, 0.00), (0.2, 0.00), (0.3, 0.00), (0.4, 0.00), (0.5, 0.00), (0.6, 0.00), (0.7, 0.00), (0.8, 0.00), (0.9, 0.206), (1.00, 0.603), (1.10, 0.883), (1.20, 0.962), (1.30, 0.984), (1.40, 1.00), (1.50, 1.00), (1.60, 1.00), (1.70, 1.00), (1.80, 1.00), (1.90, 1.00), (2.00, 1.00)

construction_time[Photovoltaic] = 3
construction_time[Wind] = 3
construction_time[nuclear] = 5
construction_time[gas] = 2
construction_time[river] = 3
construction_time[dam] = 3
construction_time[thermal] = 3
construction_time[biomass] = 3
construction_time[batteries] = 3
construction_time[pumped] = 3

data_electricity_production_hydro_total = GRAPH(TIME)
(2006, 32557), (2007, 36373), (2008, 37559), (2009, 37136), (2010, 37450), (2011, 33795), (2012, 39906), (2013, 0.00), (2014, 0.00), (2015, 0.00), (2016, 0.00), (2017, 0.00), (2018, 0.00), (2019, 0.00), (2020, 0.00), (2021, 0.00), (2022, 0.00), (2023, 0.00), (2024, 0.00), (2025, 0.00), (2026, 0.00), (2027, 0.00), (2028, 0.00), (2029, 0.00), (2030, 0.00), (2031, 0.00), (2032, 0.00), (2033, 0.00), (2034, 0.00), (2035, 0.00), (2036, 0.00), (2037, 0.00), (2038, 0.00), (2039, 0.00), (2040, 0.00), (2041, 0.00), (2042, 0.00), (2043, 0.00), (2044, 0.00), (2045, 0.00), (2046, 0.00), (2047, 0.00), (2048, 0.00), (2049, 0.00), (2050, 0.00)

data_electricity_production_thermal_and_others = GRAPH(TIME)
(2006, 3340), (2007, 3199), (2008, 3276), (2009, 3239), (2010, 3597), (2011, 3526), (2012, 3768), (2013, 0.00), (2014, 0.00), (2015, 0.00), (2016, 0.00), (2017, 0.00), (2018, 0.00), (2019, 0.00), (2020, 0.00), (2021, 0.00), (2022, 0.00), (2023, 0.00), (2024, 0.00), (2025, 0.00), (2026, 0.00), (2027, 0.00), (2028, 0.00), (2029, 0.00), (2030, 0.00), (2031, 0.00), (2032, 0.00), (2033, 0.00), (2034, 0.00), (2035, 0.00), (2036, 0.00), (2037, 0.00), (2038, 0.00), (2039, 0.00), (2040, 0.00), (2041, 0.00), (2042, 0.00), (2043, 0.00), (2044, 0.00), (2045, 0.00), (2046, 0.00), (2047, 0.00), (2048, 0.00), (2049, 0.00), (2050, 0.00)

data_nuclear_installed_cap = GRAPH(TIME)
(2006, 3.28), (2007, 3.28), (2008, 3.28), (2009, 3.28), (2010, 3.28), (2011, 3.28), (2012, 3.28), (2013, 3.28), (2014, 0.00), (2015, 0.00), (2016, 0.00), (2017, 0.00), (2018, 0.00), (2019, 0.00), (2020, 0.00), (2021, 0.00), (2022, 0.00), (2023, 0.00), (2024, 0.00), (2025, 0.00), (2026, 0.00), (2027, 0.00), (2028, 0.00), (2029, 0.00), (2030, 0.00)

data_nuclear_production = GRAPH(TIME)
(2006, 26244), (2007, 26344), (2008, 26132), (2009, 26119), (2010, 25205), (2011, 25560), (2012, 24345), (2013, 0.00), (2014, 0.00), (2015, 0.00), (2016, 0.00), (2017, 0.00), (2018, 0.00), (2019, 0.00), (2020, 0.00), (2021, 0.00), (2022, 0.00), (2023, 0.00), (2024, 0.00), (2025, 0.00), (2026, 0.00), (2027, 0.00), (2028, 0.00), (2029, 0.00), (2030, 0.00), (2031, 0.00), (2032, 0.00), (2033, 0.00), (2034, 0.00), (2035, 0.00), (2036, 0.00), (2037, 0.00), (2038, 0.00), (2039, 0.00), (2040, 0.00), (2041, 0.00), (2042, 0.00), (2043, 0.00), (2044, 0.00), (2045, 0.00), (2046, 0.00), (2047, 0.00), (2048, 0.00), (2049, 0.00), (2050, 0.00)

data_pumped_installed_cap = GRAPH(TIME)
(2006, 1.38), (2007, 1.38), (2008, 1.38), (2009, 1.38), (2010, 1.38), (2011, 1.38), (2012, 1.84), (2013, 0.00), (2014, 0.00), (2015, 0.00), (2016, 0.00), (2017, 0.00), (2018, 0.00), (2019, 0.00), (2020, 0.00), (2021, 0.00), (2022, 0.00), (2023, 0.00), (2024, 0.00), (2025, 0.00), (2026, 0.00), (2027, 0.00), (2028, 0.00), (2029, 0.00), (2030, 0.00)

data_PV_installed_cap = GRAPH(TIME)
(2006, 0.029), (2007, 0.034), (2008, 0.045), (2009, 0.071), (2010, 0.111), (2011, 0.192), (2012, 0.43), (2013, 0.73), (2014, 0.00), (2015, 0.00), (2016, 0.00), (2017, 0.00), (2018, 0.00), (2019, 0.00), (2020, 0.00), (2021, 0.00), (2022, 0.00), (2023, 0.00), (2024, 0.00), (2025, 0.00), (2026, 0.00), (2027, 0.00), (2028, 0.00), (2029, 0.00), (2030, 0.00)

data_runoff_river_installed_cap = GRAPH(TIME)
(2006, 3.65), (2007, 3.66), (2008, 3.67), (2009, 3.71), (2010, 3.77), (2011, 3.81), (2012, 3.84), (2013, 0.00), (2014, 0.00), (2015, 0.00), (2016, 0.00), (2017, 0.00), (2018, 0.00), (2019, 0.00), (2020, 0.00), (2021, 0.00), (2022, 0.00), (2023, 0.00), (2024, 0.00), (2025, 0.00), (2026, 0.00), (2027, 0.00), (2028, 0.00), (2029, 0.00), (2030, 0.00)

data_seasonal_storage_installed_cap = GRAPH(TIME)
(2006, 7.96), (2007, 8.06), (2008, 8.07), (2009, 8.07), (2010, 8.07), (2011, 8.08), (2012, 8.08), (2013, 0.00), (2014, 0.00), (2015, 0.00), (2016, 0.00), (2017, 0.00), (2018, 0.00), (2019, 0.00), (2020, 0.00), (2021, 0.00), (2022, 0.00), (2023, 0.00), (2024, 0.00), (2025, 0.00), (2026, 0.00), (2027, 0.00), (2028, 0.00), (2029, 0.00), (2030, 0.00)

data_thermal_installed_cap = GRAPH(TIME)
(2006, 0.335), (2007, 0.336), (2008, 0.332), (2009, 0.358), (2010, 0.358), (2011, 0.349), (2012, 0.00), (2013, 0.00), (2014, 0.00), (2015, 0.00), (2016, 0.00), (2017, 0.00), (2018, 0.00), (2019, 0.00), (2020, 0.00), (2021, 0.00), (2022, 0.00), (2023, 0.00), (2024, 0.00), (2025, 0.00), (2026, 0.00), (2027, 0.00), (2028, 0.00), (2029, 0.00), (2030, 0.00)

data_wind_installed_cap = GRAPH(TIME)
(2006, 0.012), (2007, 0.012), (2008, 0.014), (2009, 0.018), (2010, 0.042), (2011, 0.046), (2012, 0.0494), (2013, 0.00), (2014, 0.00), (2015, 0.00), (2016, 0.00), (2017, 0.00), (2018, 0.00), (2019, 0.00), (2020, 0.00), (2021, 0.00), (2022, 0.00), (2023, 0.00), (2024, 0.00), (2025, 0.00), (2026, 0.00), (2027, 0.00), (2028, 0.00), (2029, 0.00), (2030, 0.00)

DelayT = 1

demand_curve_seasonal = GRAPH(TIME)
(2006, 1.17), (2006, 1.08), (2006, 1.10), (2006, 0.937), (2006, 0.92), (2006, 0.896), (2006, 0.885), (2007, 0.89), (2007, 0.918), (2007, 0.997), (2007, 1.07), (2007, 1.14), (2007, 1.17), (2007, 1.08), (2007, 1.10), (2007, 0.937), (2007, 0.92), (2007, 0.896), (2007, 0.885), (2008, 0.89), (2008, 0.918), (2008, 0.997), (2008, 1.07), (2008, 1.14), (2008, 1.17), (2008, 1.08), (2008, 1.10), (2008, 0.937), (2008, 0.92), (2008, 0.896), (2008, 0.885), (2009, 0.89), (2009, 0.918), (2009, 0.997), (2009, 1.07), (2009, 1.14), (2009, 1.17), (2009, 1.08), (2009, 1.10), (2009, 0.937), (2009, 0.92), (2009, 0.896), (2009, 0.885), (2010, 0.89), (2010, 0.918), (2010, 0.997), (2010, 1.07), (2010, 1.14), (2010, 1.17), (2010, 1.08), (2010, 1.10), (2010, 0.937), (2010, 0.92)...

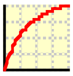
demand_exogenous = GRAPH(TIME)
(2006, 62124), (2007, 61750), (2008, 63147), (2009, 61814), (2010, 64278), (2011, 63002), (2012, 63408), (2013, 63408), (2014, 63408), (2015, 63408), (2016, 63408), (2017, 63408), (2018, 63408), (2019, 63408), (2020, 63408), (2021, 63408), (2022, 63408), (2023, 63408), (2024, 63408), (2025, 63408), (2026, 63408), (2027, 63408), (2028, 63408), (2029, 63408), (2030, 63408), (2031, 63408), (2032, 63408), (2033, 63408), (2034, 63408), (2035, 63408), (2036, 63408), (2037, 63408), (2038, 63408), (2039, 63408), (2040, 63408), (2041, 63408), (2042, 63408), (2043, 63408), (2044, 63408), (2045, 63408), (2046, 63408), (2047, 63408), (2048, 63408), (2049, 63408), (2050, 63408)

demand_in_GW = (demand_exogenous*demand_curve_seasonal)/hours_per_year
demand__supply_ratio = demand_in_GW/total_supply
economic_availability[Technology] = technical_availability_of_capacity*capacity_utilisation
effect_of_daily_price_fluctuations[Photovoltaic] = 1
effect_of_daily_price_fluctuations[Wind] = 0.85
effect_of_daily_price_fluctuations[nuclear] = 1
effect_of_daily_price_fluctuations[gas] = 1.1
effect_of_daily_price_fluctuations[river] = 1.5
effect_of_daily_price_fluctuations[dam] = 1.5
effect_of_daily_price_fluctuations[thermal] = 1.1
effect_of_daily_price_fluctuations[biomass] = 1.1

effect_of_daily_price_fluctuations[batteries] = 1.2

effect_of_daily_price_fluctuations[pumped] = 1.3

effect_of_nuclear_shut_down = GRAPH(LOOKUP(shut_down_plan_for_nuclear,TIME+5))



(0.00, 1.00), (0.0513, 1.12), (0.103, 1.19), (0.154, 1.26), (0.205, 1.32), (0.256, 1.37), (0.308, 1.42), (0.359, 1.47), (0.41, 1.51), (0.462, 1.56), (0.513, 1.59), (0.564, 1.62), (0.615, 1.64), (0.667, 1.66), (0.718, 1.68), (0.769, 1.70), (0.821, 1.73), (0.872, 1.74), (0.923, 1.76), (0.974, 1.77), (1.03, 1.79), (1.08, 1.81), (1.13, 1.83), (1.18, 1.84), (1.23, 1.85), (1.28, 1.87), (1.33, 1.88), (1.38, 1.90), (1.44, 1.91), (1.49, 1.92), (1.54, 1.93), (1.59, 1.94), (1.64, 1.95), (1.69, 1.96), (1.74, 1.97), (1.79, 1.97), (1.85, 1.98), (1.90, 1.98), (1.95, 1.98), (2.00, 1.98)

elasticity_of_price_depending_on_DS = 0.8

electricity_production_hydro_total = production_rate[river]+production_rate[dam]+production_rate[pumped]

electricity_production_nuclear = production_rate[nuclear]

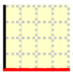
electricity_production_thermal_and_others = production_rate[Photovoltaic]+production_rate[Wind]+production_rate[thermal]+production_rate[biomass]+production_rate[batteries]

expenditures_FIT_percentage[Technology] = production_rate*FIT_percepntage_of_retail_price

expenditures_premium_FIT[Technology] = production_rate*premium_for_FIT_premium

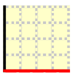
FIT[Technology] = IF(FIT_ending_time>=TIME)THEN(FIT_data)ELSE(0)

FIT_data[Photovoltaic] = GRAPH(TIME)



(2006, 620000), (2007, 620000), (2008, 620000), (2009, 620000), (2010, 508000), (2011, 422000), (2012, 349000), (2013, 269000), (2014, 220000), (2015, 220000), (2016, 220000), (2017, 220000), (2018, 220000), (2019, 220000), (2020, 220000), (2021, 220000), (2022, 220000), (2023, 220000), (2024, 220000), (2025, 220000), (2026, 220000), (2027, 220000), (2028, 220000), (2029, 220000), (2030, 220000), (2031, 220000), (2032, 220000), (2033, 220000), (2034, 220000), (2035, 220000), (2036, 220000), (2037, 220000), (2038, 220000), (2039, 220000), (2040, 220000), (2041, 220000), (2042, 220000), (2043, 220000), (2044, 220000), (2045, 220000), (2046, 220000), (2047, 220000), (2048, 220000), (2049, 220000), (2050, 220000)

FIT_data[Wind] = GRAPH(TIME)



(2006, 200000), (2007, 200000), (2008, 200000), (2009, 200000), (2010, 200000), (2011, 200000), (2012, 215000), (2013, 215000), (2014, 215000), (2015, 60000), (2016, 60000), (2017, 60000), (2018, 60000), (2019, 60000), (2020, 60000), (2021, 60000), (2022, 60000), (2023, 60000), (2024, 60000), (2025, 60000), (2026, 60000), (2027, 60000), (2028, 60000), (2029, 60000), (2030, 60000), (2031, 60000), (2032, 60000), (2033, 60000), (2034, 60000), (2035, 60000), (2036, 60000), (2037, 60000), (2038, 60000), (2039, 60000), (2040, 60000), (2041, 60000), (2042, 60000), (2043, 60000), (2044, 60000), (2045, 60000), (2046, 60000), (2047, 60000), (2048, 60000), (2049, 60000), (2050, 60000)

FIT_data[nuclear] = GRAPH(TIME)
(2006, 0.00), (2007, 0.00), (2008, 0.00), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00), (2013, 0.00), (2014, 0.00), (2015, 0.00), (2016, 0.00), (2017, 0.00), (2018, 0.00), (2019, 0.00), (2020, 0.00), (2021, 0.00), (2022, 0.00), (2023, 0.00), (2024, 0.00), (2025, 0.00), (2026, 0.00), (2027, 0.00), (2028, 0.00), (2029, 0.00), (2030, 0.00), (2031, 0.00), (2032, 0.00), (2033, 0.00), (2034, 0.00), (2035, 0.00), (2036, 0.00), (2037, 0.00), (2038, 0.00), (2039, 0.00), (2040, 0.00), (2041, 0.00), (2042, 0.00), (2043, 0.00), (2044, 0.00), (2045, 0.00), (2046, 0.00), (2047, 0.00), (2048, 0.00), (2049, 0.00), (2050, 0.00)

FIT_data[gas] = GRAPH(TIME)
(2006, 0.00), (2007, 0.00), (2008, 0.00), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00), (2013, 0.00), (2014, 0.00), (2015, 0.00), (2016, 0.00), (2017, 0.00), (2018, 0.00), (2019, 0.00), (2020, 0.00), (2021, 0.00), (2022, 0.00), (2023, 0.00), (2024, 0.00), (2025, 0.00), (2026, 0.00), (2027, 0.00), (2028, 0.00), (2029, 0.00), (2030, 0.00), (2031, 0.00), (2032, 0.00), (2033, 0.00), (2034, 0.00), (2035, 0.00), (2036, 0.00), (2037, 0.00), (2038, 0.00), (2039, 0.00), (2040, 0.00), (2041, 0.00), (2042, 0.00), (2043, 0.00), (2044, 0.00), (2045, 0.00), (2046, 0.00), (2047, 0.00), (2048, 0.00), (2049, 0.00), (2050, 0.00)

FIT_data[river] = GRAPH(TIME)
(2006, 0.00), (2007, 0.00), (2008, 0.00), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00), (2013, 0.00), (2014, 0.00), (2015, 0.00), (2016, 0.00), (2017, 0.00), (2018, 0.00), (2019, 0.00), (2020, 0.00), (2021, 0.00), (2022, 0.00), (2023, 0.00), (2024, 0.00), (2025, 0.00), (2026, 0.00), (2027, 0.00), (2028, 0.00), (2029, 0.00), (2030, 0.00), (2031, 0.00), (2032, 0.00), (2033, 0.00), (2034, 0.00), (2035, 0.00), (2036, 0.00), (2037, 0.00), (2038, 0.00), (2039, 0.00), (2040, 0.00), (2041, 0.00), (2042, 0.00), (2043, 0.00), (2044, 0.00), (2045, 0.00), (2046, 0.00), (2047, 0.00), (2048, 0.00), (2049, 0.00), (2050, 0.00)

FIT_data[dam] = GRAPH(TIME)
(2006, 0.00), (2007, 0.00), (2008, 0.00), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00), (2013, 0.00), (2014, 0.00), (2015, 0.00), (2016, 0.00), (2017, 0.00), (2018, 0.00), (2019, 0.00), (2020, 0.00), (2021, 0.00), (2022, 0.00), (2023, 0.00), (2024, 0.00), (2025, 0.00), (2026, 0.00), (2027, 0.00), (2028, 0.00), (2029, 0.00), (2030, 0.00), (2031, 0.00), (2032, 0.00), (2033, 0.00), (2034, 0.00), (2035, 0.00), (2036, 0.00), (2037, 0.00), (2038, 0.00), (2039, 0.00), (2040, 0.00), (2041, 0.00), (2042, 0.00), (2043, 0.00), (2044, 0.00), (2045, 0.00), (2046, 0.00), (2047, 0.00), (2048, 0.00), (2049, 0.00), (2050, 0.00)

FIT_data[thermal] = GRAPH(TIME)
(2006, 142000), (2007, 142000), (2008, 142000), (2009, 142000), (2010, 142000), (2011, 142000), (2012, 142000), (2013, 142000), (2014, 142000), (2015, 142000), (2016, 142000), (2017, 142000), (2018, 142000), (2019, 142000), (2020, 142000), (2021, 142000), (2022, 142000), (2023, 142000), (2024, 142000), (2025, 142000), (2026, 142000), (2027, 142000), (2028, 142000), (2029, 142000), (2030, 142000), (2031, 142000), (2032, 142000), (2033, 142000), (2034, 142000), (2035, 142000), (2036, 142000), (2037, 142000), (2038, 142000), (2039, 142000), (2040, 142000), (2041, 142000), (2042, 142000), (2043, 142000), (2044, 142000), (2045, 142000), (2046, 142000), (2047, 142000), (2048, 142000), (2049, 142000), (2050, 142000)

FIT_data[biomass] = GRAPH(TIME)
(2006, 175000), (2007, 175000), (2008, 175000), (2009, 175000), (2010, 175000), (2011, 175000), (2012, 175000), (2013, 175000), (2014, 175000), (2015, 175000), (2016, 175000), (2017, 175000), (2018, 175000), (2019, 175000), (2020, 175000), (2021, 175000), (2022, 175000), (2023, 175000), (2024, 175000), (2025, 175000), (2026, 175000), (2027, 175000), (2028, 175000), (2029, 175000), (2030, 175000), (2031, 175000), (2032, 175000), (2033, 175000), (2034, 175000), (2035, 175000), (2036, 175000), (2037, 175000), (2038, 175000), (2039, 175000), (2040, 175000), (2041, 175000), (2042, 175000), (2043, 175000), (2044, 175000), (2045, 175000), (2046, 175000), (2047, 175000), (2048, 175000), (2049, 175000), (2050, 175000)

FIT_data[batteries] = GRAPH(TIME)
(2006, 0.00), (2007, 0.00), (2008, 0.00), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00), (2013, 0.00), (2014, 0.00), (2015, 0.00), (2016, 0.00), (2017, 0.00), (2018, 0.00), (2019, 0.00), (2020, 0.00), (2021, 0.00), (2022, 0.00), (2023, 0.00), (2024, 0.00), (2025, 0.00), (2026, 0.00), (2027, 0.00), (2028, 0.00), (2029, 0.00), (2030, 0.00), (2031, 0.00), (2032, 0.00), (2033, 0.00), (2034, 0.00), (2035, 0.00), (2036, 0.00), (2037, 0.00), (2038, 0.00), (2039, 0.00), (2040, 0.00), (2041, 0.00), (2042, 0.00), (2043, 0.00), (2044, 0.00), (2045, 0.00), (2046, 0.00), (2047, 0.00), (2048, 0.00), (2049, 0.00), (2050, 0.00)

FIT_data[pumped] = GRAPH(TIME)
(2006, 0.00), (2007, 0.00), (2008, 0.00), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00), (2013, 0.00), (2014, 0.00), (2015, 0.00), (2016, 0.00), (2017, 0.00), (2018, 0.00), (2019, 0.00), (2020, 0.00), (2021, 0.00), (2022, 0.00), (2023, 0.00), (2024, 0.00), (2025, 0.00), (2026, 0.00), (2027, 0.00), (2028, 0.00), (2029, 0.00), (2030, 0.00), (2031, 0.00), (2032, 0.00), (2033, 0.00), (2034, 0.00), (2035, 0.00), (2036, 0.00), (2037, 0.00), (2038, 0.00), (2039, 0.00), (2040, 0.00), (2041, 0.00), (2042, 0.00), (2043, 0.00), (2044, 0.00), (2045, 0.00), (2046, 0.00), (2047, 0.00), (2048, 0.00), (2049, 0.00), (2050, 0.00)

FIT_ending_time = 2015

FIT_percentage = 0.6

FIT_percepntage_of_retail_price[Technology] = market_price_per_GWh*percentage_for_FIT_percentage_of_retail_price

FIT_premium = 100000

FIT_with_thermal_special[Photovoltaic] = FIT_data[Photovoltaic]

FIT_with_thermal_special[Wind] = FIT_data[Wind]

FIT_with_thermal_special[nuclear] = FIT_data[nuclear]

FIT_with_thermal_special[gas] = FIT_data[gas]

FIT_with_thermal_special[river] = FIT_data[river]

FIT_with_thermal_special[dam] = FIT_data[dam]

FIT_with_thermal_special[thermal] = FIT_data[thermal]/2

FIT_with_thermal_special[biomass] = FIT_data[biomass]

FIT_with_thermal_special[batteries] = FIT_data[batteries]

FIT_with_thermal_special[pumped] = FIT_data[pumped]

fix_production_cost_in_Mio[Photovoltaic] = GRAPH(TIME)
(2006, 85.0), (2021, 48.0), (2035, 27.0), (2050, 20.0)

fix_production_cost_in_Mio[Wind] = GRAPH(TIME)
(2006, 111), (2021, 96.0), (2035, 85.5), (2050, 85.5)

fix_production_cost_in_Mio[nuclear] = GRAPH(TIME)
(2006, 72.0), (2021, 72.0), (2035, 72.0), (2050, 72.0)

fix_production_cost_in_Mio[gas] = GRAPH(TIME)
(2006, 4.00), (2021, 4.00), (2035, 4.00), (2050, 4.00)

fix_production_cost_in_Mio[river] = GRAPH(TIME)
(2006, 41.0), (2021, 41.0), (2035, 41.0), (2050, 41.0)

fix_production_cost_in_Mio[dam] = GRAPH(TIME)
(2006, 17.0), (2021, 17.0), (2035, 17.0), (2050, 17.0)

fix_production_cost_in_Mio[thermal] = GRAPH(TIME)
(2006, 100), (2021, 90.0), (2035, 85.0), (2050, 85.0)

fix_production_cost_in_Mio[biomass] = GRAPH(TIME)
(2006, 350), (2021, 320), (2035, 295), (2050, 280)

fix_production_cost_in_Mio[batteries] = GRAPH(TIME)
(2006, 20.0), (2021, 20.0), (2035, 20.0), (2050, 20.0)

fix_production_cost_in_Mio[pumped] = GRAPH(TIME)
(2006, 20.0), (2021, 20.0), (2035, 20.0), (2050, 20.0)

fix_production_cost_in_Mio_1[Photovoltaic] = GRAPH(TIME)
(2006, 85.0), (2021, 48.0), (2035, 27.0), (2050, 20.0)

fix_production_cost_in_Mio_1[Wind] = GRAPH(TIME)
(2006, 111), (2021, 96.0), (2035, 85.5), (2050, 85.5)

fix_production_cost_in_Mio_1[nuclear] = GRAPH(TIME)
(2006, 72.0), (2021, 72.0), (2035, 72.0), (2050, 72.0)

fix_production_cost_in_Mio_1[gas] = GRAPH(TIME)
(2006, 4.00), (2021, 4.00), (2035, 4.00), (2050, 4.00)

fix_production_cost_in_Mio_1[river] = GRAPH(TIME)
(2006, 41.0), (2021, 41.0), (2035, 41.0), (2050, 41.0)

fix_production_cost_in_Mio_1[dam] = GRAPH(TIME)
(2006, 17.0), (2021, 17.0), (2035, 17.0), (2050, 17.0)

fix_production_cost_in_Mio_1[thermal] = GRAPH(TIME)
(2006, 100), (2021, 90.0), (2035, 85.0), (2050, 85.0)

fix_production_cost_in_Mio_1[biomass] = GRAPH(TIME)
(2006, 350), (2021, 320), (2035, 295), (2050, 280)

fix_production_cost_in_Mio_1[batteries] = GRAPH(TIME)
(2006, 20.0), (2021, 20.0), (2035, 20.0), (2050, 20.0)

fix_production_cost_in_Mio_1[pumped] = GRAPH(TIME)
(2006, 20.0), (2021, 20.0), (2035, 20.0), (2050, 20.0)

grid_losses = 0.07

hours_per_month = 732

hours_per_year = 8760

indicated_price = market_price_per_GWh*(demand__supply_ratio^(elasticity_of_price_depending_on_DS))

inital_flow_out[Technology] = (((received_price-production_costs-taxes)*(average_availability*hours_per_year))/1000000)-fix_production_cost_in_Mio_1

interest_rate = 0.05

investment_costs_per_GW_marginal[Technology] = investment__costs_per_GW_in_Mio*scarcity_effect_on_invest_costs

investment_per_technology_in_monrey[Technology] = investment_rate*investment_costs_per_GW_marginal

investment_relative_to_capacity[Technology] = GRAPH(NPV__per_GW_marginal_in_Mio)
(-200, 0.00), (-188, 0.00), (-176, 0.00181), (-164, 0.00542), (-152, 0.00722), (-139, 0.00722), (-127, 0.00903), (-115, 0.0108), (-103, 0.0126), (-90.9, 0.0144), (-78.8, 0.0171), (-66.7, 0.0214), (-54.5, 0.0256), (-42.4, 0.0278), (-30.3, 0.0299), (-18.2, 0.032), (-6.06, 0.0342), (6.06, 0.0363), (18.2, 0.0427), (30.3, 0.047), (42.4, 0.0512), (54.5, 0.0555), (66.7, 0.0598), (78.8, 0.0641), (90.9, 0.0683), (103, 0.0705), (115, 0.0769), (127, 0.0833), (139, 0.0854), (152, 0.0897), (164, 0.0961), (176, 0.105), (188, 0.111), (200, 0.117), (212, 0.122), (224, 0.13), (236, 0.137), (248, 0.147), (261, 0.156), (273, 0.167), (285, 0.181), (297, 0.188), (309, 0.199), (321, 0.209), (333, 0.22), (345, 0.226), (358, 0.237), (370, 0.246), (382, 0.252), (394, 0.256), (406, 0.265), (418, 0.273), (430, 0.282)...

investment__costs_per_GW_in_Mio[Photovoltaic] = GRAPH(TIME)
(2006, 8324), (2007, 6042), (2008, 5113), (2009, 4141), (2011, 3676), (2012, 3254), (2013, 2831), (2014, 2535), (2015, 2366), (2016, 2282), (2017, 2113), (2018, 2070), (2020, 1986), (2021, 1944), (2022, 1901), (2023, 1901), (2024, 1817), (2025, 1775), (2026, 1775), (2027, 1690), (2029, 1690), (2030, 1648), (2031, 1648), (2032, 1648), (2033, 1648), (2034, 1648), (2035, 1648), (2036, 1648), (2038, 1648), (2039, 1648), (2040, 1690), (2041, 1690), (2042, 1690), (2043, 1690), (2044, 1690), (2045, 1690), (2047, 1606), (2048, 1606), (2049, 1563), (2050, 1521)

investment__costs_per_GW_in_Mio[Wind] = GRAPH(TIME)
(2006, 1850), (2021, 1600), (2035, 1425), (2050, 1425)

investment__costs_per_GW_in_Mio[nuclear] = GRAPH(TIME)
(2006, 3000), (2007, 3000), (2008, 3000), (2009, 3000), (2010, 3000), (2011, 3000), (2012, 3000), (2013, 3000), (2014, 3000), (2015, 3000), (2016, 3000), (2017, 3000), (2018, 3000), (2019, 3000), (2020, 3000), (2021, 3000), (2022, 3000), (2023, 3000), (2024, 3000), (2025, 3000), (2026, 3000), (2027, 3000), (2028, 3000), (2029, 3000), (2030, 3000), (2031, 3000), (2032, 3000), (2033, 3000), (2034, 3000), (2035, 3000), (2036, 3000), (2037, 3000), (2038, 3000), (2039, 3000), (2040, 3000), (2041, 3000), (2042, 3000), (2043, 3000), (2044, 3000), (2045, 3000), (2046, 3000), (2047, 3000), (2048, 3000), (2049, 3000), (2050, 3000)

investment__costs_per_GW_in_Mio[gas] = GRAPH(TIME)
(2006, 792), (2021, 726), (2035, 726), (2050, 726)

investment__costs_per_GW_in_Mio[river] = GRAPH(TIME)
(2006, 5690), (2007, 5690), (2008, 5690), (2009, 5690), (2010, 5690), (2011, 5690), (2012, 5690), (2013, 5690), (2014, 5690), (2015, 5690), (2016, 5690), (2017, 5690), (2018, 5690), (2019, 5690), (2020, 5690), (2021, 5690), (2022, 5690), (2023, 5690), (2024, 5690), (2025, 5690), (2026, 5690), (2027, 5690), (2028, 5690), (2029, 5690), (2030, 5690), (2031, 5690), (2032, 5690), (2033, 5690), (2034, 5690), (2035, 5690), (2036, 5690), (2037, 5690), (2038, 5690), (2039, 5690), (2040, 5690), (2041, 5690), (2042, 5690), (2043, 5690), (2044, 5690), (2045, 5690), (2046, 5690), (2047, 5690), (2048, 5690), (2049, 5690), (2050, 5690)

investment__costs_per_GW_in_Mio[dam] = GRAPH(TIME)
(2006, 6339), (2007, 6339), (2008, 6339), (2009, 6339), (2010, 6339), (2011, 6339), (2012, 6339), (2013, 6339), (2014, 6339), (2015, 6339), (2016, 6339), (2017, 6339), (2018, 6339), (2019, 6339), (2020, 6339), (2021, 6339), (2022, 6339), (2023, 6339), (2024, 6339), (2025, 6339), (2026, 6339), (2027, 6339), (2028, 6339), (2029, 6339), (2030, 6339), (2031, 6339), (2032, 6339), (2033, 6339), (2034, 6339), (2035, 6339), (2036, 6339), (2037, 6339), (2038, 6339), (2039, 6339), (2040, 6339), (2041, 6339), (2042, 6339), (2043, 6339), (2044, 6339), (2045, 6339), (2046, 6339), (2047, 6339), (2048, 6339), (2049, 6339), (2050, 6339)

investment__costs_per_GW_in_Mio[thermal] = GRAPH(TIME)
(2006, 4500), (2021, 4250), (2035, 4000), (2050, 4000)

investment__costs_per_GW_in_Mio[biomass] = GRAPH(TIME)
(2006, 7000), (2007, 7000), (2008, 7000), (2009, 7000), (2010, 7000), (2011, 7000), (2012, 7000), (2013, 7000), (2014, 7000), (2015, 7000), (2016, 7000), (2017, 7000), (2018, 7000), (2019, 7000), (2020, 7000), (2021, 7000), (2022, 7000), (2023, 7000), (2024, 7000), (2025, 7000), (2026, 7000), (2027, 7000), (2028, 7000), (2029, 7000), (2030, 7000), (2031, 7000), (2032, 7000), (2033, 7000), (2034, 7000), (2035, 7000), (2036, 7000), (2037, 7000), (2038, 7000), (2039, 7000), (2040, 7000), (2041, 7000), (2042, 7000), (2043, 7000), (2044, 7000), (2045, 7000), (2046, 7000), (2047, 7000), (2048, 7000), (2049, 7000), (2050, 7000)

investment__costs_per_GW_in_Mio[batteries] = GRAPH(TIME)
(2006, 10000), (2007, 10000), (2008, 10000), (2009, 10000), (2010, 10000), (2011, 10000), (2012, 10000), (2013, 10000), (2014, 10000), (2015, 10000), (2016, 10000), (2017, 10000), (2018, 10000), (2019, 10000), (2020, 10000), (2021, 10000), (2022, 10000), (2023, 10000), (2024, 10000), (2025, 10000), (2026, 10000), (2027, 10000), (2028, 10000), (2029, 10000), (2030, 10000), (2031, 10000), (2032, 10000), (2033, 10000), (2034, 10000), (2035, 10000), (2036, 10000), (2037, 10000), (2038, 10000), (2039, 10000), (2040, 10000), (2041, 10000), (2042, 10000), (2043, 10000), (2044, 10000), (2045, 10000), (2046, 10000), (2047, 10000), (2048, 10000), (2049, 10000), (2050, 10000)

investment__costs_per_GW_in_Mio[pumped] = GRAPH(TIME)
(2006, 1500), (2007, 1500), (2008, 1500), (2009, 1500), (2010, 1500), (2011, 1500), (2012, 1500), (2013, 1500), (2014, 1500), (2015, 1500), (2016, 1500), (2017, 1500), (2018, 1500), (2019, 1500), (2020, 1500), (2021, 1500), (2022, 1500), (2023, 1500), (2024, 1500), (2025, 1500), (2026, 1500), (2027, 1500), (2028, 1500), (2029, 1500), (2030, 1500), (2031, 1500), (2032, 1500), (2033, 1500), (2034, 1500), (2035, 1500), (2036, 1500), (2037, 1500), (2038, 1500), (2039, 1500), (2040, 1500), (2041, 1500), (2042, 1500), (2043, 1500), (2044, 1500), (2045, 1500), (2046, 1500), (2047, 1500), (2048, 1500), (2049, 1500), (2050, 1500)

KEV_duration[Photovoltaic] = GRAPH(TIME)
(2006, 20.0), (2007, 20.0), (2008, 20.0), (2009, 20.0), (2010, 20.0), (2011, 20.0), (2012, 20.0), (2013, 20.0), (2014, 20.0), (2015, 20.0), (2016, 20.0), (2017, 20.0), (2018, 20.0), (2019, 20.0), (2020, 20.0), (2021, 20.0), (2022, 20.0), (2023, 20.0), (2024, 20.0), (2025, 20.0), (2026, 20.0), (2027, 20.0), (2028, 20.0), (2029, 20.0), (2030, 20.0), (2031, 20.0), (2032, 20.0), (2033, 20.0), (2034, 20.0), (2035, 20.0), (2036, 20.0), (2037, 20.0), (2038, 20.0), (2039, 20.0), (2040, 20.0), (2041, 20.0), (2042, 20.0), (2043, 20.0), (2044, 20.0), (2045, 20.0), (2046, 20.0), (2047, 20.0), (2048, 20.0), (2049, 20.0), (2050, 20.0)

KEV_duration[Wind] = GRAPH(TIME)
(2006, 20.0), (2007, 20.0), (2008, 20.0), (2009, 20.0), (2010, 20.0), (2011, 20.0), (2012, 20.0), (2013, 20.0), (2014, 20.0), (2015, 20.0), (2016, 20.0), (2017, 20.0), (2018, 20.0), (2019, 20.0), (2020, 20.0), (2021, 20.0), (2022, 20.0), (2023, 20.0), (2024, 20.0), (2025, 20.0), (2026, 20.0), (2027, 20.0), (2028, 20.0), (2029, 20.0), (2030, 20.0), (2031, 20.0), (2032, 20.0), (2033, 20.0), (2034, 20.0), (2035, 20.0), (2036, 20.0), (2037, 20.0), (2038, 20.0), (2039, 20.0), (2040, 20.0), (2041, 20.0), (2042, 20.0), (2043, 20.0), (2044, 20.0), (2045, 20.0), (2046, 20.0), (2047, 20.0), (2048, 20.0), (2049, 20.0), (2050, 20.0)

KEV_duration[nuclear] = GRAPH(TIME)
(2006, 0.00), (2007, 0.00), (2008, 0.00), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00), (2013, 0.00), (2014, 0.00), (2015, 0.00), (2016, 0.00), (2017, 0.00), (2018, 0.00), (2019, 0.00), (2020, 0.00), (2021, 0.00), (2022, 0.00), (2023, 0.00), (2024, 0.00), (2025, 0.00), (2026, 0.00), (2027, 0.00), (2028, 0.00), (2029, 0.00), (2030, 0.00), (2031, 0.00), (2032, 0.00), (2033, 0.00), (2034, 0.00), (2035, 0.00), (2036, 0.00), (2037, 0.00), (2038, 0.00), (2039, 0.00), (2040, 0.00), (2041, 0.00), (2042, 0.00), (2043, 0.00), (2044, 0.00), (2045, 0.00), (2046, 0.00), (2047, 0.00), (2048, 0.00), (2049, 0.00), (2050, 0.00)

KEV_duration[gas] = GRAPH(TIME)
(2006, 0.00), (2007, 0.00), (2008, 0.00), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00), (2013, 0.00), (2014, 0.00), (2015, 0.00), (2016, 0.00), (2017, 0.00), (2018, 0.00), (2019, 0.00), (2020, 0.00), (2021, 0.00), (2022, 0.00), (2023, 0.00), (2024, 0.00), (2025, 0.00), (2026, 0.00), (2027, 0.00), (2028, 0.00), (2029, 0.00), (2030, 0.00), (2031, 0.00), (2032, 0.00), (2033, 0.00), (2034, 0.00), (2035, 0.00), (2036, 0.00), (2037, 0.00), (2038, 0.00), (2039, 0.00), (2040, 0.00), (2041, 0.00), (2042, 0.00), (2043, 0.00), (2044, 0.00), (2045, 0.00), (2046, 0.00), (2047, 0.00), (2048, 0.00), (2049, 0.00), (2050, 0.00)

KEV_duration[river] = GRAPH(TIME)
(2006, 0.00), (2007, 0.00), (2008, 0.00), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00), (2013, 0.00), (2014, 0.00), (2015, 0.00), (2016, 0.00), (2017, 0.00), (2018, 0.00), (2019, 0.00), (2020, 0.00), (2021, 0.00), (2022, 0.00), (2023, 0.00), (2024, 0.00), (2025, 0.00), (2026, 0.00), (2027, 0.00), (2028, 0.00), (2029, 0.00), (2030, 0.00), (2031, 0.00), (2032, 0.00), (2033, 0.00), (2034, 0.00), (2035, 0.00), (2036, 0.00), (2037, 0.00), (2038, 0.00), (2039, 0.00), (2040, 0.00), (2041, 0.00), (2042, 0.00), (2043, 0.00), (2044, 0.00), (2045, 0.00), (2046, 0.00), (2047, 0.00), (2048, 0.00), (2049, 0.00), (2050, 0.00)

KEV_duration[dam] = GRAPH(TIME)
(2006, 0.00), (2007, 0.00), (2008, 0.00), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00), (2013, 0.00), (2014, 0.00), (2015, 0.00), (2016, 0.00), (2017, 0.00), (2018, 0.00), (2019, 0.00), (2020, 0.00), (2021, 0.00), (2022, 0.00), (2023, 0.00), (2024, 0.00), (2025, 0.00), (2026, 0.00), (2027, 0.00), (2028, 0.00), (2029, 0.00), (2030, 0.00), (2031, 0.00), (2032, 0.00), (2033, 0.00), (2034, 0.00), (2035, 0.00), (2036, 0.00), (2037, 0.00), (2038, 0.00), (2039, 0.00), (2040, 0.00), (2041, 0.00), (2042, 0.00), (2043, 0.00), (2044, 0.00), (2045, 0.00), (2046, 0.00), (2047, 0.00), (2048, 0.00), (2049, 0.00), (2050, 0.00)

KEV_duration[thermal] = GRAPH(TIME)
(2006, 20.0), (2007, 20.0), (2008, 20.0), (2009, 20.0), (2010, 20.0), (2011, 20.0), (2012, 20.0), (2013, 20.0), (2014, 10.0), (2015, 10.0), (2016, 10.0), (2017, 10.0), (2018, 10.0), (2019, 10.0), (2020, 10.0), (2021, 10.0), (2022, 10.0), (2023, 10.0), (2024, 10.0), (2025, 10.0), (2026, 10.0), (2027, 10.0), (2028, 10.0), (2029, 10.0), (2030, 10.0), (2031, 10.0), (2032, 10.0), (2033, 10.0), (2034, 10.0), (2035, 10.0), (2036, 10.0), (2037, 10.0), (2038, 10.0), (2039, 10.0), (2040, 10.0), (2041, 10.0), (2042, 10.0), (2043, 10.0), (2044, 10.0), (2045, 10.0), (2046, 10.0), (2047, 10.0), (2048, 10.0), (2049, 10.0), (2050, 10.0)

KEV_duration[biomass] = GRAPH(TIME)
(2006, 0.00), (2007, 0.00), (2008, 0.00), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00), (2013, 0.00), (2014, 0.00), (2015, 0.00), (2016, 0.00), (2017, 0.00), (2018, 0.00), (2019, 0.00), (2020, 0.00), (2021, 0.00), (2022, 0.00), (2023, 0.00), (2024, 0.00), (2025, 0.00), (2026, 0.00), (2027, 0.00), (2028, 0.00), (2029, 0.00), (2030, 0.00), (2031, 0.00), (2032, 0.00), (2033, 0.00), (2034, 0.00), (2035, 0.00), (2036, 0.00), (2037, 0.00), (2038, 0.00), (2039, 0.00), (2040, 0.00), (2041, 0.00), (2042, 0.00), (2043, 0.00), (2044, 0.00), (2045, 0.00), (2046, 0.00), (2047, 0.00), (2048, 0.00), (2049, 0.00), (2050, 0.00)

KEV_duration[batteries] = GRAPH(TIME)
(2006, 20.0), (2007, 20.0), (2008, 20.0), (2009, 20.0), (2010, 20.0), (2011, 20.0), (2012, 20.0), (2013, 20.0), (2014, 20.0), (2015, 20.0), (2016, 20.0), (2017, 20.0), (2018, 20.0), (2019, 20.0), (2020, 20.0), (2021, 20.0), (2022, 20.0), (2023, 20.0), (2024, 20.0), (2025, 20.0), (2026, 20.0), (2027, 20.0), (2028, 20.0), (2029, 20.0), (2030, 20.0), (2031, 20.0), (2032, 20.0), (2033, 20.0), (2034, 20.0), (2035, 20.0), (2036, 20.0), (2037, 20.0), (2038, 20.0), (2039, 20.0), (2040, 20.0), (2041, 20.0), (2042, 20.0), (2043, 20.0), (2044, 20.0), (2045, 20.0), (2046, 20.0), (2047, 20.0), (2048, 20.0), (2049, 20.0), (2050, 20.0)

KEV_duration[pumped] = GRAPH(TIME)
(2006, 0.00), (2007, 0.00), (2008, 0.00), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00), (2013, 0.00), (2014, 0.00), (2015, 0.00), (2016, 0.00), (2017, 0.00), (2018, 0.00), (2019, 0.00), (2020, 0.00), (2021, 0.00), (2022, 0.00), (2023, 0.00), (2024, 0.00), (2025, 0.00), (2026, 0.00), (2027, 0.00), (2028, 0.00), (2029, 0.00), (2030, 0.00), (2031, 0.00), (2032, 0.00), (2033, 0.00), (2034, 0.00), (2035, 0.00), (2036, 0.00), (2037, 0.00), (2038, 0.00), (2039, 0.00), (2040, 0.00), (2041, 0.00), (2042, 0.00), (2043, 0.00), (2044, 0.00), (2045, 0.00), (2046, 0.00), (2047, 0.00), (2048, 0.00), (2049, 0.00), (2050, 0.00)

KEV_duration_1[Photovoltaic] = GRAPH(TIME)
(2006, 20.0), (2007, 20.0), (2008, 20.0), (2009, 20.0), (2010, 20.0), (2011, 20.0), (2012, 20.0), (2013, 20.0), (2014, 20.0), (2015, 20.0), (2016, 20.0), (2017, 20.0), (2018, 20.0), (2019, 20.0), (2020, 20.0), (2021, 20.0), (2022, 20.0), (2023, 20.0), (2024, 20.0), (2025, 20.0), (2026, 20.0), (2027, 20.0), (2028, 20.0), (2029, 20.0), (2030, 20.0), (2031, 20.0), (2032, 20.0), (2033, 20.0), (2034, 20.0), (2035, 20.0), (2036, 20.0), (2037, 20.0), (2038, 20.0), (2039, 20.0), (2040, 20.0), (2041, 20.0), (2042, 20.0), (2043, 20.0), (2044, 20.0), (2045, 20.0), (2046, 20.0), (2047, 20.0), (2048, 20.0), (2049, 20.0), (2050, 20.0)

KEV_duration_1[Wind] = GRAPH(TIME)
(2006, 20.0), (2007, 20.0), (2008, 20.0), (2009, 20.0), (2010, 20.0), (2011, 20.0), (2012, 20.0), (2013, 20.0), (2014, 20.0), (2015, 20.0), (2016, 20.0), (2017, 20.0), (2018, 20.0), (2019, 20.0), (2020, 20.0), (2021, 20.0), (2022, 20.0), (2023, 20.0), (2024, 20.0), (2025, 20.0), (2026, 20.0), (2027, 20.0), (2028, 20.0), (2029, 20.0), (2030, 20.0), (2031, 20.0), (2032, 20.0), (2033, 20.0), (2034, 20.0), (2035, 20.0), (2036, 20.0), (2037, 20.0), (2038, 20.0), (2039, 20.0), (2040, 20.0), (2041, 20.0), (2042, 20.0), (2043, 20.0), (2044, 20.0), (2045, 20.0), (2046, 20.0), (2047, 20.0), (2048, 20.0), (2049, 20.0), (2050, 20.0)

KEV_duration_1[nuclear] = GRAPH(TIME)
(2006, 0.00), (2007, 0.00), (2008, 0.00), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00), (2013, 0.00), (2014, 0.00), (2015, 0.00), (2016, 0.00), (2017, 0.00), (2018, 0.00), (2019, 0.00), (2020, 0.00), (2021, 0.00), (2022, 0.00), (2023, 0.00), (2024, 0.00), (2025, 0.00), (2026, 0.00), (2027, 0.00), (2028, 0.00), (2029, 0.00), (2030, 0.00), (2031, 0.00), (2032, 0.00), (2033, 0.00), (2034, 0.00), (2035, 0.00), (2036, 0.00), (2037, 0.00), (2038, 0.00), (2039, 0.00), (2040, 0.00), (2041, 0.00), (2042, 0.00), (2043, 0.00), (2044, 0.00), (2045, 0.00), (2046, 0.00), (2047, 0.00), (2048, 0.00), (2049, 0.00), (2050, 0.00)

KEV_duration_1[gas] = GRAPH(TIME)
(2006, 0.00), (2007, 0.00), (2008, 0.00), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00), (2013, 0.00), (2014, 0.00), (2015, 0.00), (2016, 0.00), (2017, 0.00), (2018, 0.00), (2019, 0.00), (2020, 0.00), (2021, 0.00), (2022, 0.00), (2023, 0.00), (2024, 0.00), (2025, 0.00), (2026, 0.00), (2027, 0.00), (2028, 0.00), (2029, 0.00), (2030, 0.00), (2031, 0.00), (2032, 0.00), (2033, 0.00), (2034, 0.00), (2035, 0.00), (2036, 0.00), (2037, 0.00), (2038, 0.00), (2039, 0.00), (2040, 0.00), (2041, 0.00), (2042, 0.00), (2043, 0.00), (2044, 0.00), (2045, 0.00), (2046, 0.00), (2047, 0.00), (2048, 0.00), (2049, 0.00), (2050, 0.00)

KEV_duration_1[river] = GRAPH(TIME)
(2006, 0.00), (2007, 0.00), (2008, 0.00), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00), (2013, 0.00), (2014, 0.00), (2015, 0.00), (2016, 0.00), (2017, 0.00), (2018, 0.00), (2019, 0.00), (2020, 0.00), (2021, 0.00), (2022, 0.00), (2023, 0.00), (2024, 0.00), (2025, 0.00), (2026, 0.00), (2027, 0.00), (2028, 0.00), (2029, 0.00), (2030, 0.00), (2031, 0.00), (2032, 0.00), (2033, 0.00), (2034, 0.00), (2035, 0.00), (2036, 0.00), (2037, 0.00), (2038, 0.00), (2039, 0.00), (2040, 0.00), (2041, 0.00), (2042, 0.00), (2043, 0.00), (2044, 0.00), (2045, 0.00), (2046, 0.00), (2047, 0.00), (2048, 0.00), (2049, 0.00), (2050, 0.00)

KEV_duration_1[dam] = GRAPH(TIME)
(2006, 0.00), (2007, 0.00), (2008, 0.00), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00), (2013, 0.00), (2014, 0.00), (2015, 0.00), (2016, 0.00), (2017, 0.00), (2018, 0.00), (2019, 0.00), (2020, 0.00), (2021, 0.00), (2022, 0.00), (2023, 0.00), (2024, 0.00), (2025, 0.00), (2026, 0.00), (2027, 0.00), (2028, 0.00), (2029, 0.00), (2030, 0.00), (2031, 0.00), (2032, 0.00), (2033, 0.00), (2034, 0.00), (2035, 0.00), (2036, 0.00), (2037, 0.00), (2038, 0.00), (2039, 0.00), (2040, 0.00), (2041, 0.00), (2042, 0.00), (2043, 0.00), (2044, 0.00), (2045, 0.00), (2046, 0.00), (2047, 0.00), (2048, 0.00), (2049, 0.00), (2050, 0.00)

KEV_duration_1[thermal] = GRAPH(TIME)
(2006, 20.0), (2007, 20.0), (2008, 20.0), (2009, 20.0), (2010, 20.0), (2011, 20.0), (2012, 20.0), (2013, 20.0), (2014, 10.0), (2015, 10.0), (2016, 10.0), (2017, 10.0), (2018, 10.0), (2019, 10.0), (2020, 10.0), (2021, 10.0), (2022, 10.0), (2023, 10.0), (2024, 10.0), (2025, 10.0), (2026, 10.0), (2027, 10.0), (2028, 10.0), (2029, 10.0), (2030, 10.0), (2031, 10.0), (2032, 10.0), (2033, 10.0), (2034, 10.0), (2035, 10.0), (2036, 10.0), (2037, 10.0), (2038, 10.0), (2039, 10.0), (2040, 10.0), (2041, 10.0), (2042, 10.0), (2043, 10.0), (2044, 10.0), (2045, 10.0), (2046, 10.0), (2047, 10.0), (2048, 10.0), (2049, 10.0), (2050, 10.0)

KEV_duration_1[biomass] = GRAPH(TIME)
(2006, 0.00), (2007, 0.00), (2008, 0.00), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00), (2013, 0.00), (2014, 0.00), (2015, 0.00), (2016, 0.00), (2017, 0.00), (2018, 0.00), (2019, 0.00), (2020, 0.00), (2021, 0.00), (2022, 0.00), (2023, 0.00), (2024, 0.00), (2025, 0.00), (2026, 0.00), (2027, 0.00), (2028, 0.00), (2029, 0.00), (2030, 0.00), (2031, 0.00), (2032, 0.00), (2033, 0.00), (2034, 0.00), (2035, 0.00), (2036, 0.00), (2037, 0.00), (2038, 0.00), (2039, 0.00), (2040, 0.00), (2041, 0.00), (2042, 0.00), (2043, 0.00), (2044, 0.00), (2045, 0.00), (2046, 0.00), (2047, 0.00), (2048, 0.00), (2049, 0.00), (2050, 0.00)

KEV_duration_1[batteries] = GRAPH(TIME)
(2006, 20.0), (2007, 20.0), (2008, 20.0), (2009, 20.0), (2010, 20.0), (2011, 20.0), (2012, 20.0), (2013, 20.0), (2014, 20.0), (2015, 20.0), (2016, 20.0), (2017, 20.0), (2018, 20.0), (2019, 20.0), (2020, 20.0), (2021, 20.0), (2022, 20.0), (2023, 20.0), (2024, 20.0), (2025, 20.0), (2026, 20.0), (2027, 20.0), (2028, 20.0), (2029, 20.0), (2030, 20.0), (2031, 20.0), (2032, 20.0), (2033, 20.0), (2034, 20.0), (2035, 20.0), (2036, 20.0), (2037, 20.0), (2038, 20.0), (2039, 20.0), (2040, 20.0), (2041, 20.0), (2042, 20.0), (2043, 20.0), (2044, 20.0), (2045, 20.0), (2046, 20.0), (2047, 20.0), (2048, 20.0), (2049, 20.0), (2050, 20.0)

KEV_duration_1[pumped] = GRAPH(TIME)
(2006, 0.00), (2007, 0.00), (2008, 0.00), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00), (2013, 0.00), (2014, 0.00), (2015, 0.00), (2016, 0.00), (2017, 0.00), (2018, 0.00), (2019, 0.00), (2020, 0.00), (2021, 0.00), (2022, 0.00), (2023, 0.00), (2024, 0.00), (2025, 0.00), (2026, 0.00), (2027, 0.00), (2028, 0.00), (2029, 0.00), (2030, 0.00), (2031, 0.00), (2032, 0.00), (2033, 0.00), (2034, 0.00), (2035, 0.00), (2036, 0.00), (2037, 0.00), (2038, 0.00), (2039, 0.00), (2040, 0.00), (2041, 0.00), (2042, 0.00), (2043, 0.00), (2044, 0.00), (2045, 0.00), (2046, 0.00), (2047, 0.00), (2048, 0.00), (2049, 0.00), (2050, 0.00)

local_supply = SUM(economic_availability)*(1-grid_losses)

marginal_costs_per_GWh[Photovoltaic] = GRAPH(TIME)
(2006, 0.00), (2007, 0.00), (2008, 0.00), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00), (2013, 0.00), (2014, 0.00), (2015, 0.00), (2016, 0.00), (2017, 0.00), (2018, 0.00), (2019, 0.00), (2020, 0.00), (2021, 0.00), (2022, 0.00), (2023, 0.00), (2024, 0.00), (2025, 0.00), (2026, 0.00), (2027, 0.00), (2028, 0.00), (2029, 0.00), (2030, 0.00), (2031, 0.00), (2032, 0.00), (2033, 0.00), (2034, 0.00), (2035, 0.00), (2036, 0.00), (2037, 0.00), (2038, 0.00), (2039, 0.00), (2040, 0.00), (2041, 0.00), (2042, 0.00), (2043, 0.00), (2044, 0.00), (2045, 0.00), (2046, 0.00), (2047, 0.00), (2048, 0.00), (2049, 0.00), (2050, 0.00)

marginal_costs_per_GWh[Wind] = GRAPH(TIME)
(2006, 0.00), (2007, 0.00), (2008, 0.00), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00), (2013, 0.00), (2014, 0.00), (2015, 0.00), (2016, 0.00), (2017, 0.00), (2018, 0.00), (2019, 0.00), (2020, 0.00), (2021, 0.00), (2022, 0.00), (2023, 0.00), (2024, 0.00), (2025, 0.00), (2026, 0.00), (2027, 0.00), (2028, 0.00), (2029, 0.00), (2030, 0.00), (2031, 0.00), (2032, 0.00), (2033, 0.00), (2034, 0.00), (2035, 0.00), (2036, 0.00), (2037, 0.00), (2038, 0.00), (2039, 0.00), (2040, 0.00), (2041, 0.00), (2042, 0.00), (2043, 0.00), (2044, 0.00), (2045, 0.00), (2046, 0.00), (2047, 0.00), (2048, 0.00), (2049, 0.00), (2050, 0.00)

marginal_costs_per_GWh[nuclear] = GRAPH(TIME)
(2006, 20000), (2007, 20000), (2008, 20000), (2009, 20000), (2010, 20000), (2011, 20000), (2012, 20000), (2013, 20000), (2014, 20000), (2015, 20000), (2016, 20000), (2017, 20000), (2018, 20000), (2019, 20000), (2020, 20000), (2021, 20000), (2022, 20000), (2023, 20000), (2024, 20000), (2025, 20000), (2026, 20000), (2027, 20000), (2028, 20000), (2029, 20000), (2030, 20000), (2031, 20000), (2032, 20000), (2033, 20000), (2034, 20000), (2035, 20000), (2036, 20000), (2037, 20000), (2038, 20000), (2039, 20000), (2040, 20000), (2041, 20000), (2042, 20000), (2043, 20000), (2044, 20000), (2045, 20000), (2046, 20000), (2047, 20000), (2048, 20000), (2049, 20000), (2050, 20000)

marginal_costs_per_GWh[gas] = GRAPH(TIME)
(2006, 90000), (2007, 90000), (2008, 90000), (2009, 90000), (2010, 90000), (2011, 90000), (2012, 90000), (2013, 90000), (2014, 90000), (2015, 90000), (2016, 90000), (2017, 90000), (2018, 90000), (2019, 90000), (2020, 90000), (2021, 90000), (2022, 90000), (2023, 90000), (2024, 90000), (2025, 90000), (2026, 90000), (2027, 90000), (2028, 90000), (2029, 90000), (2030, 90000), (2031, 90000), (2032, 90000), (2033, 90000), (2034, 90000), (2035, 90000), (2036, 90000), (2037, 90000), (2038, 90000), (2039, 90000), (2040, 90000), (2041, 90000), (2042, 90000), (2043, 90000), (2044, 90000), (2045, 90000), (2046, 90000), (2047, 90000), (2048, 90000), (2049, 90000), (2050, 90000)

marginal_costs_per_GWh[river] = GRAPH(TIME)
(2006, 0.00), (2007, 0.00), (2008, 0.00), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00), (2013, 0.00), (2014, 0.00), (2015, 0.00), (2016, 0.00), (2017, 0.00), (2018, 0.00), (2019, 0.00), (2020, 0.00), (2021, 0.00), (2022, 0.00), (2023, 0.00), (2024, 0.00), (2025, 0.00), (2026, 0.00), (2027, 0.00), (2028, 0.00), (2029, 0.00), (2030, 0.00), (2031, 0.00), (2032, 0.00), (2033, 0.00), (2034, 0.00), (2035, 0.00), (2036, 0.00), (2037, 0.00), (2038, 0.00), (2039, 0.00), (2040, 0.00), (2041, 0.00), (2042, 0.00), (2043, 0.00), (2044, 0.00), (2045, 0.00), (2046, 0.00), (2047, 0.00), (2048, 0.00), (2049, 0.00), (2050, 0.00)

marginal_costs_per_GWh[dam] = GRAPH(TIME)
(2006, 0.00), (2007, 0.00), (2008, 0.00), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00), (2013, 0.00), (2014, 0.00), (2015, 0.00), (2016, 0.00), (2017, 0.00), (2018, 0.00), (2019, 0.00), (2020, 0.00), (2021, 0.00), (2022, 0.00), (2023, 0.00), (2024, 0.00), (2025, 0.00), (2026, 0.00), (2027, 0.00), (2028, 0.00), (2029, 0.00), (2030, 0.00), (2031, 0.00), (2032, 0.00), (2033, 0.00), (2034, 0.00), (2035, 0.00), (2036, 0.00), (2037, 0.00), (2038, 0.00), (2039, 0.00), (2040, 0.00), (2041, 0.00), (2042, 0.00), (2043, 0.00), (2044, 0.00), (2045, 0.00), (2046, 0.00), (2047, 0.00), (2048, 0.00), (2049, 0.00), (2050, 0.00)

marginal_costs_per_GWh[thermal] = GRAPH(TIME)
(2006, 10000), (2007, 10000), (2008, 10000), (2009, 10000), (2010, 10000), (2011, 10000), (2012, 10000), (2013, 10000), (2014, 10000), (2015, 10000), (2016, 10000), (2017, 10000), (2018, 10000), (2019, 10000), (2020, 10000), (2021, 10000), (2022, 10000), (2023, 10000), (2024, 10000), (2025, 10000), (2026, 10000), (2027, 10000), (2028, 10000), (2029, 10000), (2030, 10000), (2031, 10000), (2032, 10000), (2033, 10000), (2034, 10000), (2035, 10000), (2036, 10000), (2037, 10000), (2038, 10000), (2039, 10000), (2040, 10000), (2041, 10000), (2042, 10000), (2043, 10000), (2044, 10000), (2045, 10000), (2046, 10000), (2047, 10000), (2048, 10000), (2049, 20000), (2050, 20000)

marginal_costs_per_GWh[biomass] = GRAPH(TIME)
(2006, 15000), (2007, 15000), (2008, 15000), (2009, 15000), (2010, 15000), (2011, 15000), (2012, 15000), (2013, 15000), (2014, 15000), (2015, 15000), (2016, 15000), (2017, 15000), (2018, 15000), (2019, 15000), (2020, 15000), (2021, 15000), (2022, 15000), (2023, 15000), (2024, 15000), (2025, 15000), (2026, 15000), (2027, 15000), (2028, 15000), (2029, 15000), (2030, 15000), (2031, 15000), (2032, 15000), (2033, 15000), (2034, 15000), (2035, 15000), (2036, 15000), (2037, 15000), (2038, 15000), (2039, 15000), (2040, 15000), (2041, 15000), (2042, 15000), (2043, 15000), (2044, 15000), (2045, 15000), (2046, 15000), (2047, 15000), (2048, 15000), (2049, 15000), (2050, 15000)

marginal_costs_per_GWh[batteries] = GRAPH(TIME)
(2006, 150000), (2007, 150000), (2008, 150000), (2009, 150000), (2010, 150000), (2011, 150000), (2012, 150000), (2013, 150000), (2014, 150000), (2015, 150000), (2016, 150000), (2017, 150000), (2018, 150000), (2019, 150000), (2020, 150000), (2021, 150000), (2022, 150000), (2023, 150000), (2024, 150000), (2025, 150000), (2026, 150000), (2027, 150000), (2028, 150000), (2029, 150000), (2030, 150000), (2031, 150000), (2032, 150000), (2033, 150000), (2034, 150000), (2035, 150000), (2036, 150000), (2037, 150000), (2038, 150000), (2039, 150000), (2040, 150000), (2041, 150000), (2042, 150000), (2043, 150000), (2044, 150000), (2045, 150000), (2046, 150000), (2047, 150000), (2048, 150000), (2049, 150000), (2050, 150000)

marginal_costs_per_GWh[pumped] = GRAPH(TIME)
(2006, 40000), (2007, 40000), (2008, 40000), (2009, 40000), (2010, 40000), (2011, 40000), (2012, 40000), (2013, 40000), (2014, 40000), (2015, 40000), (2016, 40000), (2017, 40000), (2018, 40000), (2019, 40000), (2020, 40000), (2021, 40000), (2022, 40000), (2023, 40000), (2024, 40000), (2025, 40000), (2026, 40000), (2027, 40000), (2028, 40000), (2029, 40000), (2030, 40000), (2031, 40000), (2032, 40000), (2033, 40000), (2034, 40000), (2035, 40000), (2036, 40000), (2037, 40000), (2038, 40000), (2039, 40000), (2040, 40000), (2041, 40000), (2042, 40000), (2043, 40000), (2044, 40000), (2045, 40000), (2046, 40000), (2047, 40000), (2048, 40000), (2049, 40000), (2050, 40000)

market_price_data_adjusted = DELAY(market_price_for_electricity_data,(1.5/12+0.1))

market_price_for_electricity_data = GRAPH(TIME)
(2006, 82520), (2006, 82520), (2006, 82520), (2007, 82520), (2007, 66860), (2007, 55810), (2007, 53090), (2008, 133120), (2008, 114670), (2008, 112730), (2008, 121850), (2009, 130820), (2009, 107780), (2009, 48320), (2009, 57480), (2010, 79000), (2010, 82980), (2010, 62080), (2010, 60180), (2011, 79210), (2011, 77890), (2011, 69500), (2011, 58660), (2012, 75690), (2012, 77330), (2012, 50150), (2012, 54360), (2013, 60380), (2013, 70440), (2013, 42450), (2013, 49220), (2014, 60910), (2014, 52140), (2014, 0.00), (2014, 0.00), (2015, 0.00), (2015, 0.00), (2015, 0.00), (2015, 0.00), (2016, 0.00), (2016, 0.00), (2016, 0.00), (2016, 0.00), (2017, 0.00), (2017, 0.00), (2017, 0.00), (2017, 0.00), (2018, 0.00), (2018, 0.00), (2018, 0.00), (2018, 0.00), (2019, 0.00), (2019, 0.00)...

minimum_capacity = 0.2
monthly_electricity_production = SUM(economic_availability)*hours_per_month
monthly_electricity_production_data = GRAPH(TIME)
(2006, 4708), (2006, 4472), (2006, 4876), (2006, 4794), (2006, 5897), (2006, 5298), (2007, 6262), (2007, 4878), (2007, 5618), (2007, 5320), (2007, 4998), (2007, 5020), (2007, 5003), (2007, 4642), (2007, 4984), (2007, 4907), (2007, 5773), (2007, 6412), (2008, 7065), (2008, 5892), (2008, 5582), (2008, 5572), (2008, 5030), (2008, 5054), (2008, 5067), (2008, 4767), (2008, 4954), (2008, 4893), (2008, 6141), (2008, 6229), (2009, 6927), (2009, 5504), (2009, 6811), (2009, 5241), (2009, 5271), (2009, 5162), (2009, 5385), (2009, 4672), (2009, 5076), (2009, 5487), (2009, 6515), (2009, 6336), (2010, 7236), (2010, 5922), (2010, 5243), (2010, 5031), (2010, 4581), (2010, 5010), (2010, 5554), (2010, 4895), (2010, 5036), (2010, 4738), (2010, 5893)...

net_imports = transmission_capacity*trade_share*(1-grid_losses)
new_renewables_production = production_rate[Photovoltaic]+production_rate[Wind]+production_rate[biomass]+(0.5*production_rate[thermal])
NPV__per_GW_marginal_in_Mio[Technology] = -investment_costs_per_GW_marginal+(perceived_return*(((1+interest_rate)^time_horizon)-1)/(((1+interest_rate)^time_horizon)*interest_rate))
nuclear_phase_out_tax[Photovoltaic] = 0
nuclear_phase_out_tax[Wind] = 0
nuclear_phase_out_tax[nuclear] = 5000000*8760
nuclear_phase_out_tax[gas] = 0
nuclear_phase_out_tax[river] = 0
nuclear_phase_out_tax[dam] = 0
nuclear_phase_out_tax[thermal] = 0
nuclear_phase_out_tax[biomass] = 0
nuclear_phase_out_tax[batteries] = 0
nuclear_phase_out_tax[pumped] = 0
percentage_for_FIT_percentage_of_retail_price[Photovoltaic] = FIT_percentage
percentage_for_FIT_percentage_of_retail_price[Wind] = FIT_percentage
percentage_for_FIT_percentage_of_retail_price[nuclear] = 0
percentage_for_FIT_percentage_of_retail_price[gas] = 0
percentage_for_FIT_percentage_of_retail_price[river] = 0
percentage_for_FIT_percentage_of_retail_price[dam] = 0
percentage_for_FIT_percentage_of_retail_price[thermal] = FIT_percentage/2

- percentage_for_FIT_percentage_of_retail_price[batteries] = 0
- percentage_for_FIT_percentage_of_retail_price[pumped] = 0
- plant_life_time[Photovoltaic] = 30
- plant_life_time[Wind] = 20
- plant_life_time[nuclear] = 50
- plant_life_time[gas] = 80
- plant_life_time[river] = 80
- plant_life_time[dam] = 80
- plant_life_time[thermal] = 50
- plant_life_time[biomass] = 25
- plant_life_time[batteries] = 50
- plant_life_time[pumped] = 70
- policy[Technology] = (spot_gap_FIT*Switch_spot_gap_FIT)+(premium_for_FIT_premium* Switch_FIT_premium)+(FIT_percepntage_of_retail_price* Switch_percentage_of_retail_price_FIT)
- policy_costs_in_Mio = acc_expenditures_for_FIT_in_Mio+(sum_spot_FIT_costs_in_Mio* Switch_spot_gap_FIT)+(acc_costs_premium_FIT*Switch_FIT_premium)+ (acc_costs_FIT_percentage*Switch_percentage_of_retail_price_FIT)
- premium_for_FIT_premium[Photovoltaic] = FIT_premium
- premium_for_FIT_premium[Wind] = FIT_premium
- premium_for_FIT_premium[nuclear] = 0
- premium_for_FIT_premium[gas] = 0
- premium_for_FIT_premium[river] = 0
- premium_for_FIT_premium[dam] = 0
- premium_for_FIT_premium[thermal] = FIT_premium/2
- premium_for_FIT_premium[biomass] = FIT_premium
- premium_for_FIT_premium[batteries] = 0
- premium_for_FIT_premium[pumped] = 0
- price_abroad = 70000
- price_AT = 0.08
- production_costs[Technology] = marginal_costs_per_GWh+taxes
- production_in_KEV_time[Technology] = producing_with_FIT*total_availability*hours_per_year
- production_in_KEV_time_1[Technology] = producing_with_FIT_1*total_availability* hours_per_year
- received_price[Photovoltaic] = IF(FIT>0)THEN(FIT[Photovoltaic]+ policy[Photovoltaic])ELSE((market_price_per_GWh* effect_of_daily_price_fluctuations[Photovoltaic])+policy[Photovoltaic])
- received_price[Wind] = If(FIT>0)THEN(FIT[Wind]+policy[Wind])ELSE((market_price_per_GWh* effect_of_daily_price_fluctuations[Wind])+policy[Wind])
- received_price[nuclear] = IF(FIT>0)THEN(FIT[nuclear]+ policy[nuclear])ELSE((market_price_per_GWh*effect_of_daily_price_fluctuations[nuclear])+ policy[nuclear])
- received_price[gas] = IF(FIT[gas]>0)THEN(FIT[gas]+policy[gas])ELSE((market_price_per_GWh* effect_of_daily_price_fluctuations[gas])+policy[gas])
- received_price[river] = IF(FIT>0)THEN(FIT[river]+policy[river])ELSE((market_price_per_GWh* effect_of_daily_price_fluctuations[river])+policy[river])

received_price[dam] = IF(FIT>0)THEN(FIT[dam]+policy[dam])ELSE((market_price_per_GWh*effect_of_daily_price_fluctuations[dam])+policy[dam])

received_price[thermal] = IF(FIT[thermal]>0)THEN(0.5*FIT[thermal]+0.5*market_price_per_GWh*effect_of_daily_price_fluctuations[thermal]+policy[thermal])ELSE((market_price_per_GWh*effect_of_daily_price_fluctuations[thermal])+policy[thermal])

received_price[biomass] = IF(FIT>0)THEN(FIT[biomass]+policy[biomass])ELSE((market_price_per_GWh*effect_of_daily_price_fluctuations[biomass])+policy[biomass])

received_price[batteries] = IF(FIT>0)THEN(FIT[batteries]+policy[batteries])ELSE((market_price_per_GWh*effect_of_daily_price_fluctuations[batteries])+policy[batteries])

received_price[pumped] = IF(FIT>0)THEN(FIT[pumped]+policy[pumped])ELSE((market_price_per_GWh*effect_of_daily_price_fluctuations[pumped])+policy[pumped])

received_price_premium_price_FIT[Technology] = market_price_per_GWh*effect_of_daily_price_fluctuations+premium_for_FIT_premium

receiver_price_FIT_percentage[Technology] = (market_price_per_GWh*effect_of_daily_price_fluctuations)+FIT_percepntage_of_retail_price

receiver_price_with_spot_FIT[Technology] = (market_price_per_GWh*effect_of_daily_price_fluctuations)+spot_gap_FIT

renewables_plus_hydro = new_renewables_production+production_rate[river]+production_rate[dam]+production_rate[pumped]

scarcity_effect_on_invest_costs[Photovoltaic] = GRAPH(remaining_expansion_potential)
(0.00, 500), (0.001, 50.0), (0.002, 9.86), (0.003, 8.24), (0.004, 8.17), (0.00501, 8.03), (0.00601, 6.97), (0.00701, 6.97), (0.00801, 6.76), (0.00901, 6.27), (0.01, 6.27), (0.011, 6.13), (0.012, 5.99), (0.013, 5.99), (0.014, 5.92), (0.015, 5.85), (0.016, 5.81), (0.017, 5.56), (0.018, 5.49), (0.019, 5.46), (0.02, 5.42), (0.021, 5.28), (0.022, 5.28), (0.023, 5.07), (0.024, 5.00), (0.025, 5.00), (0.026, 4.93), (0.027, 4.79), (0.028, 4.79), (0.029, 4.79), (0.03, 4.65), (0.031, 4.61), (0.032, 4.51), (0.033, 4.51), (0.034, 4.51), (0.035, 4.51), (0.036, 4.44), (0.037, 4.44), (0.038, 4.44), (0.039, 4.30), (0.04, 4.30), (0.041, 4.23), (0.042, 4.23), (0.043, 4.19), (0.044, 4.01), (0.045, 3.94), (0.046, 3.94), (0.047, 3.94), (0.048, 3.80), (0.049, 3.80), (0.0501, 3.73), (0.0511, 3.66), (0.0521, 3.66)...

scarcity_effect_on_invest_costs[Wind] = GRAPH(remaining_expansion_potential)
(0.00, 500), (0.0101, 5.00), (0.0202, 3.73), (0.0303, 3.38), (0.0404, 3.10), (0.0505, 2.61), (0.0606, 2.32), (0.0707, 2.16), (0.0808, 2.02), (0.0909, 1.88), (0.101, 1.76), (0.111, 1.67), (0.121, 1.62), (0.131, 1.55), (0.141, 1.55), (0.152, 1.50), (0.162, 1.44), (0.172, 1.40), (0.182, 1.39), (0.192, 1.36), (0.202, 1.33), (0.212, 1.30), (0.222, 1.26), (0.232, 1.22), (0.242, 1.18), (0.253, 1.16), (0.263, 1.15), (0.273, 1.15), (0.283, 1.13), (0.293, 1.11), (0.303, 1.09), (0.313, 1.07), (0.323, 1.06), (0.333, 1.06), (0.343, 1.05), (0.354, 1.03), (0.364, 1.02), (0.374, 1.02), (0.384, 1.02), (0.394, 1.02), (0.404, 1.01), (0.414, 1.01), (0.424, 1.00), (0.434, 1.00), (0.444, 1.00), (0.455, 1.00), (0.465, 1.00), (0.475, 1.00), (0.485, 1.00), (0.495, 1.00), (0.505, 1.00), (0.515, 1.00), (0.525, 1.00)...

scarcity_effect_on_invest_costs[nuclear] = GRAPH(remaining_expansion_potential)
(0.00, 500), (0.0204, 20.0), (0.0408, 11.0), (0.0612, 8.45), (0.0816, 6.93), (0.102, 6.28), (0.122, 5.56), (0.143, 4.69), (0.163, 4.12), (0.184, 3.61), (0.204, 3.18), (0.224, 3.03), (0.245, 2.89), (0.265, 2.82), (0.286, 2.53), (0.306, 2.38), (0.327, 2.31), (0.347, 2.17), (0.367, 2.17), (0.388, 2.09), (0.408, 2.09), (0.429, 2.02), (0.449, 1.81), (0.469, 1.73), (0.49, 1.59), (0.51, 1.59), (0.531, 1.59), (0.551, 1.59), (0.571, 1.59), (0.592, 1.59), (0.612, 1.37), (0.633, 1.37), (0.653, 1.37), (0.673, 1.30), (0.694, 1.30), (0.714, 1.08), (0.735, 1.08), (0.755, 1.08), (0.776, 1.08), (0.796, 1.01), (0.816, 1.01), (0.837, 1.01), (0.857, 1.00), (0.878, 1.00), (0.898, 1.00), (0.918, 1.00), (0.939, 1.00), (0.959, 1.00), (0.98, 1.00), (1.00, 1.00)

scarcity_effect_on_invest_costs[gas] = GRAPH(remaining_expansion_potential)
(0.00, 1000), (0.0204, 20.0), (0.0408, 11.0), (0.0612, 8.45), (0.0816, 6.93), (0.102, 6.28), (0.122, 5.56), (0.143, 4.69), (0.163, 4.12), (0.184, 3.61), (0.204, 3.18), (0.224, 3.03), (0.245, 2.89), (0.265, 2.82), (0.286, 2.53), (0.306, 2.38), (0.327, 2.31), (0.347, 2.17), (0.367, 2.17), (0.388, 2.09), (0.408, 2.09), (0.429, 2.02), (0.449, 1.81), (0.469, 1.73), (0.49, 1.59), (0.51, 1.59), (0.531, 1.59), (0.551, 1.59), (0.571, 1.59), (0.592, 1.59), (0.612, 1.37), (0.633, 1.37), (0.653, 1.37), (0.673, 1.30), (0.694, 1.30), (0.714, 1.08), (0.735, 1.08), (0.755, 1.08), (0.776, 1.08), (0.796, 1.01), (0.816, 1.01), (0.837, 1.01), (0.857, 1.00), (0.878, 1.00), (0.898, 1.00), (0.918, 1.00), (0.939, 1.00), (0.959, 1.00), (0.98, 1.00), (1.00, 1.00)

scarcity_effect_on_invest_costs[river] = GRAPH(remaining_expansion_potential)
(0.00, 5000), (0.00134, 20.3), (0.00267, 10.9), (0.00401, 8.13), (0.00534, 5.83), (0.00668, 4.68), (0.00801, 3.53), (0.00935, 3.07), (0.0107, 2.38), (0.012, 2.15), (0.0134, 1.69), (0.0147, 1.46), (0.016, 1.46), (0.0174, 1.23), (0.0187, 1.00), (0.02, 1.00), (0.0214, 1.00), (0.0227, 1.00), (0.024, 1.00), (0.0254, 1.00), (0.0267, 1.00), (0.028, 1.00), (0.0294, 1.00), (0.0307, 1.00), (0.032, 1.00), (0.0334, 1.00), (0.0347, 1.00), (0.036, 1.00), (0.0374, 1.00), (0.0387, 1.00), (0.0401, 1.00), (0.0414, 1.00), (0.0427, 1.00), (0.0441, 1.00), (0.0454, 1.00), (0.0467, 1.00), (0.0481, 1.00), (0.0494, 1.00), (0.0507, 1.00), (0.0521, 1.00), (0.0534, 1.00), (0.0547, 1.00), (0.0561, 1.00), (0.0574, 1.00), (0.0587, 1.00), (0.0601, 1.00), (0.0614, 1.00), (0.0628, 1.00), (0.0641, 1.00), (0.0654, 1.00), (0.0668, 1.00), (0.0681, 1.00), (0.0694, 1.00)...

scarcity_effect_on_invest_costs[dam] = GRAPH(remaining_expansion_potential)
(0.00, 5000), (0.0204, 20.3), (0.0408, 10.9), (0.0612, 8.13), (0.0816, 5.83), (0.102, 4.68), (0.122, 3.53), (0.143, 3.07), (0.163, 2.38), (0.184, 2.15), (0.204, 1.69), (0.224, 1.46), (0.245, 1.46), (0.265, 1.23), (0.286, 1.00), (0.306, 1.00), (0.327, 1.00), (0.347, 1.00), (0.367, 1.00), (0.388, 1.00), (0.408, 1.00), (0.429, 1.00), (0.449, 1.00), (0.469, 1.00), (0.49, 1.00), (0.51, 1.00), (0.531, 1.00), (0.551, 1.00), (0.571, 1.00), (0.592, 1.00), (0.612, 1.00), (0.633, 1.00), (0.653, 1.00), (0.673, 1.00), (0.694, 1.00), (0.714, 1.00), (0.735, 1.00), (0.755, 1.00), (0.776, 1.00), (0.796, 1.00), (0.816, 1.00), (0.837, 1.00), (0.857, 1.00), (0.878, 1.00), (0.898, 1.00), (0.918, 1.00), (0.939, 1.00), (0.959, 1.00), (0.98, 1.00), (1.00, 1.00)

scarcity_effect_on_invest_costs[thermal] = GRAPH(remaining_expansion_potential)
(0.00, 500), (0.001, 47.5), (0.002, 19.2), (0.003, 12.7), (0.004, 9.51), (0.00501, 7.67), (0.00601, 7.21), (0.00701, 3.03), (0.00801, 2.16), (0.00901, 1.86), (0.01, 1.75), (0.011, 1.56), (0.012, 1.53), (0.013, 1.47), (0.014, 1.41), (0.015, 1.34), (0.016, 1.26), (0.017, 1.26), (0.018, 1.21), (0.019, 1.15), (0.02, 1.13), (0.021, 1.13), (0.022, 1.11), (0.023, 1.09), (0.024, 1.09), (0.025, 1.08), (0.026, 1.08), (0.027, 1.06), (0.028, 1.06), (0.029, 1.06), (0.03, 1.04), (0.031, 1.04), (0.032, 1.04), (0.033, 1.02), (0.034, 1.04), (0.035, 1.02), (0.036, 1.00), (0.037, 1.00), (0.038, 1.00), (0.039, 1.00), (0.04, 1.00), (0.041, 1.00), (0.042, 1.00), (0.043, 1.00), (0.044, 1.00), (0.045, 1.00), (0.046, 1.00), (0.047, 1.00), (0.048, 1.00), (0.049, 1.00), (0.0501, 1.00), (0.0511, 1.00), (0.0521, 1.00)...

scarcity_effect_on_invest_costs[biomass] = GRAPH(remaining_expansion_potential)
(0.00, 5000), (0.002, 20.0), (0.00401, 11.0), (0.00601, 8.13), (0.00802, 6.75), (0.01, 5.37), (0.012, 4.45), (0.014, 3.99), (0.016, 3.76), (0.018, 3.30), (0.02, 2.61), (0.022, 2.38), (0.024, 2.15), (0.0261, 1.69), (0.0281, 1.69), (0.0301, 1.23), (0.0321, 1.23), (0.0341, 1.00), (0.0361, 1.00), (0.0381, 1.00), (0.0401, 1.00), (0.0421, 1.00), (0.0441, 1.00), (0.0461, 1.00), (0.0481, 1.00), (0.0501, 1.00), (0.0521, 1.00), (0.0541, 1.00), (0.0561, 1.00), (0.0581, 1.00), (0.0601, 1.00), (0.0621, 1.00), (0.0641, 1.00), (0.0661, 1.00), (0.0681, 1.00), (0.0701, 1.00), (0.0721, 1.00), (0.0741, 1.00), (0.0762, 1.00), (0.0782, 1.00), (0.0802, 1.00), (0.0822, 1.00), (0.0842, 1.00), (0.0862, 1.00), (0.0882, 1.00), (0.0902, 1.00), (0.0922, 1.00), (0.0942, 1.00), (0.0962, 1.00), (0.0982, 1.00), (0.1, 1.00), (0.102, 1.00), (0.104, 1.00)...

scarcity_effect_on_invest_costs[batteries] = GRAPH(remaining_expansion_potential)
(0.00, 500), (0.0204, 20.0), (0.0408, 11.0), (0.0612, 8.45), (0.0816, 6.93), (0.102, 6.28), (0.122, 5.56), (0.143, 4.69), (0.163, 4.12), (0.184, 3.61), (0.204, 3.18), (0.224, 3.03), (0.245, 2.89), (0.265, 2.82), (0.286, 2.53), (0.306, 2.38), (0.327, 2.31), (0.347, 2.17), (0.367, 2.17), (0.388, 2.09), (0.408, 2.09), (0.429, 2.02), (0.449, 1.81), (0.469, 1.73), (0.49, 1.59), (0.51, 1.59), (0.531, 1.59), (0.551, 1.59), (0.571, 1.59), (0.592, 1.59), (0.612, 1.37), (0.633, 1.37), (0.653, 1.37), (0.673, 1.30), (0.694, 1.30), (0.714, 1.08), (0.735, 1.08), (0.755, 1.08), (0.776, 1.08), (0.796, 1.01), (0.816, 1.01), (0.837, 1.01), (0.857, 1.00), (0.878, 1.00), (0.898, 1.00), (0.918, 1.00), (0.939, 1.00), (0.959, 1.00), (0.98, 1.00), (1.00, 1.00)

scarcity_effect_on_invest_costs[pumped] = GRAPH(remaining_expansion_potential)
(0.00, 5000), (0.00503, 20.0), (0.0101, 11.0), (0.0151, 3.46), (0.0201, 3.35), (0.0251, 3.23), (0.0302, 3.18), (0.0352, 3.10), (0.0402, 2.90), (0.0452, 2.71), (0.0503, 2.62), (0.0553, 2.56), (0.0603, 2.45), (0.0653, 2.41), (0.0704, 2.35), (0.0754, 2.28), (0.0804, 2.20), (0.0854, 2.16), (0.0905, 2.15), (0.0955, 2.09), (0.101, 2.03), (0.106, 1.94), (0.111, 1.90), (0.116, 1.83), (0.121, 1.80), (0.126, 1.77), (0.131, 1.73), (0.136, 1.66), (0.141, 1.64), (0.146, 1.62), (0.151, 1.58), (0.156, 1.56), (0.161, 1.53), (0.166, 1.49), (0.171, 1.43), (0.176, 1.43), (0.181, 1.38), (0.186, 1.38), (0.191, 1.34), (0.196, 1.32), (0.201, 1.30), (0.206, 1.26), (0.211, 1.23), (0.216, 1.21), (0.221, 1.19), (0.226, 1.19), (0.231, 1.17), (0.236, 1.15), (0.241, 1.11), (0.246, 1.09), (0.251, 1.09), (0.256, 1.08), (0.261, 1.04)...

seasonal_factors[Photovoltaic] = GRAPH(TIME)
(2006, 0.0651), (2006, 0.0971), (2006, 0.14), (2006, 0.169), (2006, 0.214), (2006, 0.216), (2006, 0.218), (2007, 0.209), (2007, 0.162), (2007, 0.109), (2007, 0.07), (2007, 0.0514), (2007, 0.0651), (2007, 0.0971), (2007, 0.14), (2007, 0.169), (2007, 0.214), (2007, 0.216), (2007, 0.218), (2008, 0.209), (2008, 0.162), (2008, 0.109), (2008, 0.07), (2008, 0.0514), (2008, 0.0651), (2008, 0.0971), (2008, 0.14), (2008, 0.169), (2008, 0.214), (2008, 0.216), (2008, 0.218), (2009, 0.209), (2009, 0.162), (2009, 0.109), (2009, 0.07), (2009, 0.0514), (2009, 0.0651), (2009, 0.0971), (2009, 0.14), (2009, 0.169), (2009, 0.214), (2009, 0.216), (2009, 0.218), (2010, 0.209), (2010, 0.162), (2010, 0.109), (2010, 0.07), (2010, 0.0514), (2010, 0.0651), (2010, 0.0971), (2010, 0.14), (2010, 0.169), (2010, 0.214)...

seasonal_factors[Wind] = GRAPH(TIME)
(2006, 0.171), (2006, 0.165), (2006, 0.172), (2006, 0.153), (2006, 0.144), (2006, 0.13), (2006, 0.135), (2007, 0.126), (2007, 0.137), (2007, 0.157), (2007, 0.153), (2007, 0.168), (2007, 0.171), (2007, 0.165), (2007, 0.172), (2007, 0.153), (2007, 0.144), (2007, 0.13), (2007, 0.135), (2008, 0.126), (2008, 0.137), (2008, 0.157), (2008, 0.153), (2008, 0.168), (2008, 0.171), (2008, 0.165), (2008, 0.172), (2008, 0.153), (2008, 0.144), (2008, 0.13), (2008, 0.135), (2009, 0.126), (2009, 0.137), (2009, 0.157), (2009, 0.153), (2009, 0.168), (2009, 0.171), (2009, 0.165), (2009, 0.172), (2009, 0.153), (2009, 0.144), (2009, 0.13), (2009, 0.135), (2010, 0.126), (2010, 0.137), (2010, 0.157), (2010, 0.153), (2010, 0.168), (2010, 0.171), (2010, 0.165), (2010, 0.172), (2010, 0.153), (2010, 0.144)...

seasonal_factors[nuclear] = GRAPH(TIME)
(2006, 1.00), (2006, 1.00), (2006, 1.00), (2006, 1.00), (2006, 0.974), (2006, 0.2), (2006, 0.2), (2007, 1.00), (2007, 1.00), (2007, 1.00), (2007, 1.00), (2007, 1.00), (2007, 1.00), (2007, 1.00), (2007, 1.00), (2007, 1.00), (2007, 0.974), (2007, 0.2), (2007, 0.2), (2008, 1.00), (2008, 1.00), (2008, 1.00), (2008, 1.00), (2008, 1.00), (2008, 1.00), (2008, 1.00), (2008, 1.00), (2008, 1.00), (2008, 0.974), (2008, 0.2), (2008, 0.2), (2009, 1.00), (2009, 1.00), (2009, 1.00), (2009, 1.00), (2009, 1.00), (2009, 1.00), (2009, 1.00), (2009, 1.00), (2009, 1.00), (2009, 0.974), (2009, 0.2), (2009, 0.2), (2010, 1.00), (2010, 1.00), (2010, 1.00), (2010, 1.00), (2010, 1.00), (2010, 1.00), (2010, 1.00), (2010, 1.00), (2010, 1.00), (2010, 0.974)...

seasonal_factors[gas] = GRAPH(TIME)
(2006, 0.502), (2010, 0.502), (2015, 0.502), (2019, 0.502), (2024, 0.502), (2028, 0.502), (2032, 0.502), (2037, 0.502), (2041, 0.502), (2046, 0.502), (2050, 0.502)

seasonal_factors[river] = GRAPH(TIME)
(2006, 0.235), (2006, 0.228), (2006, 0.323), (2006, 0.484), (2006, 0.671), (2006, 0.731), (2006, 0.705), (2007, 0.612), (2007, 0.585), (2007, 0.429), (2007, 0.308), (2007, 0.309), (2007, 0.235), (2007, 0.228), (2007, 0.323), (2007, 0.484), (2007, 0.671), (2007, 0.731), (2007, 0.705), (2008, 0.612), (2008, 0.585), (2008, 0.429), (2008, 0.308), (2008, 0.309), (2008, 0.235), (2008, 0.228), (2008, 0.323), (2008, 0.484), (2008, 0.671), (2008, 0.731), (2008, 0.705), (2009, 0.612), (2009, 0.585), (2009, 0.429), (2009, 0.308), (2009, 0.309), (2009, 0.235), (2009, 0.228), (2009, 0.323), (2009, 0.484), (2009, 0.671), (2009, 0.731), (2009, 0.705), (2010, 0.612), (2010, 0.585), (2010, 0.429), (2010, 0.308), (2010, 0.309), (2010, 0.235), (2010, 0.228), (2010, 0.323), (2010, 0.484), (2010, 0.671)...

seasonal_factors[dam] = GRAPH(TIME)
(2006, 0.308), (2006, 0.344), (2006, 0.221), (2006, 0.204), (2006, 0.302), (2006, 0.354), (2006, 0.311), (2007, 0.302), (2007, 0.331), (2007, 0.286), (2007, 0.336), (2007, 0.332), (2007, 0.308), (2007, 0.344), (2007, 0.221), (2007, 0.204), (2007, 0.302), (2007, 0.354), (2007, 0.311), (2008, 0.302), (2008, 0.331), (2008, 0.286), (2008, 0.336), (2008, 0.332), (2008, 0.308), (2008, 0.344), (2008, 0.221), (2008, 0.204), (2008, 0.302), (2008, 0.354), (2008, 0.311), (2009, 0.302), (2009, 0.331), (2009, 0.286), (2009, 0.336), (2009, 0.332), (2009, 0.308), (2009, 0.344), (2009, 0.221), (2009, 0.204), (2009, 0.302), (2009, 0.354), (2009, 0.311), (2010, 0.302), (2010, 0.331), (2010, 0.286), (2010, 0.336), (2010, 0.332), (2010, 0.308), (2010, 0.344), (2010, 0.221), (2010, 0.204), (2010, 0.302)...

seasonal_factors[thermal] = GRAPH(TIME)
(2006, 0.617), (2006, 0.608), (2006, 0.545), (2006, 0.636), (2006, 0.675), (2006, 0.716), (2006, 0.716), (2007, 0.65), (2007, 0.692), (2007, 0.627), (2007, 0.681), (2007, 0.634), (2007, 0.617), (2007, 0.608), (2007, 0.545), (2007, 0.636), (2007, 0.675), (2007, 0.716), (2007, 0.716), (2007, 0.65), (2008, 0.692), (2008, 0.627), (2008, 0.681), (2008, 0.634), (2008, 0.617), (2008, 0.608), (2008, 0.545), (2008, 0.636), (2008, 0.675), (2008, 0.716), (2008, 0.716), (2008, 0.65), (2008, 0.692), (2008, 0.627), (2009, 0.681), (2009, 0.634), (2009, 0.617), (2009, 0.608), (2009, 0.545), (2009, 0.636), (2009, 0.675), (2009, 0.716), (2009, 0.716), (2009, 0.65), (2009, 0.692), (2009, 0.627), (2009, 0.681), (2010, 0.634), (2010, 0.617), (2010, 0.608), (2010, 0.545), (2010, 0.636), (2010, 0.675)...

seasonal_factors[biomass] = GRAPH(TIME)
(2006, 1.00), (2010, 1.00), (2015, 1.00), (2019, 1.00), (2024, 1.00), (2028, 1.00), (2032, 1.00), (2037, 1.00), (2041, 1.00), (2046, 1.00), (2050, 1.00)

seasonal_factors[batteries] = GRAPH(TIME)
(2006, 0.533), (2006, 0.549), (2006, 0.57), (2006, 0.585), (2006, 0.607), (2006, 0.608), (2006, 0.609), (2007, 0.605), (2007, 0.581), (2007, 0.554), (2007, 0.535), (2007, 0.526), (2007, 0.533), (2007, 0.549), (2007, 0.57), (2007, 0.585), (2007, 0.607), (2007, 0.608), (2007, 0.609), (2008, 0.605), (2008, 0.581), (2008, 0.554), (2008, 0.535), (2008, 0.526), (2008, 0.533), (2008, 0.549), (2008, 0.57), (2008, 0.585), (2008, 0.607), (2008, 0.608), (2008, 0.609), (2009, 0.605), (2009, 0.581), (2009, 0.554), (2009, 0.535), (2009, 0.526), (2009, 0.533), (2009, 0.549), (2009, 0.57), (2009, 0.585), (2009, 0.607), (2009, 0.608), (2009, 0.609), (2010, 0.605), (2010, 0.581), (2010, 0.554), (2010, 0.535), (2010, 0.526), (2010, 0.533), (2010, 0.549), (2010, 0.57), (2010, 0.585), (2010, 0.607)...

seasonal_factors[pumped] = GRAPH(TIME)
(2006, 0.8), (2010, 0.8), (2015, 0.8), (2019, 0.8), (2024, 0.8), (2028, 0.8), (2032, 0.8), (2037, 0.8), (2041, 0.8), (2046, 0.8), (2050, 0.8)

share_new_renewables = new_renewables_production/total_production_in_GWh

share_renewables = (production_rate[Photovoltaic]+production_rate[Wind]+production_rate[biomass]+(0.5*production_rate[thermal]))/SUM(production_rate) share_renewables_plus_hydro = (production_rate[Photovoltaic]+production_rate[Wind]+production_rate[biomass]+(0.5*production_rate[thermal])+production_rate[river]+production_rate[dam]+production_rate[pumped]+production_rate[batteries])/SUM(production_rate)

share_renewable_plus_hydro = renewables_plus_hydro/total_production_in_GWh

shut_down_plan_for_nuclear = GRAPH(TIME)
(2006, 0.00), (2007, 0.00), (2008, 0.00), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00), (2013, 0.00), (2014, 0.00), (2015, 0.00), (2016, 0.00), (2017, 0.00), (2018, 0.00), (2019, 0.738), (2020, 0.00), (2021, 0.365), (2022, 0.00), (2023, 0.00), (2024, 0.00), (2025, 0.00), (2026, 0.00), (2027, 0.00), (2028, 0.00), (2029, 0.985), (2030, 0.00), (2031, 0.00), (2032, 0.00), (2033, 0.00), (2034, 1.19), (2035, 0.00), (2036, 0.00), (2037, 0.00), (2038, 0.00), (2039, 0.00), (2040, 0.00), (2041, 0.00), (2042, 0.00), (2043, 0.00), (2044, 0.00), (2045, 0.00), (2046, 0.00), (2047, 0.00), (2048, 0.00), (2049, 0.00), (2050, 0.00)

spot_gap_FIT[Technology] = IF(market_price_per_GWh<FIT_data)THEN(FIT_data-market_price_per_GWh)ELSE(0)

sum_spot_FIT_costs_in_Mio = SUM(policy_costs_spot_price_gap_FIT)/1000000

Switch_FIT_premium = 1

Switch_Investments = 0

Switch_percentage_of_retail_price_FIT = 1

Switch_spot_gap_FIT = 1

taxes[Photovoltaic] = 0

taxes[Wind] = 0

taxes[nuclear] = 0

taxes[gas] = 8610

taxes[river] = 1100

taxes[dam] = 1100

taxes[thermal] = 0

taxes[biomass] = 0

taxes[batteries] = 0

taxes[pumped] = 1100

technical_availability_of_capacity[Technology] = installed__capacity*seasonal_factors

time_horizon = 20

total_availability[Technology] = seasonal_factors*capacity_utilisation

total_capacity[Technology] = projects_waiting+capacity_in__construction+installed__capacity

total_costs_on_consumers = consumer_spendings_total+policy_costs_in_Mio

total_installed_production_capacity = SUM(installed__capacity)

total_invest = SUM(investment_rate)

total_potential[Technology] = INIT(remaining_expansion_potential)+INIT(installed__capacity)+INIT(capacity_in__construction)+INIT(projects_waiting)

total_potential_constant[Photovoltaic] = 10.99

total_potential_constant[Wind] = 1.17

total_potential_constant[nuclear] = 3.28

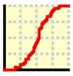
total_potential_constant[gas] = 3.85

total_potential_constant[river] = 3.97

total_potential_constant[dam] = 8.36

total_potential_constant[biomass] = 0.39
total_potential_constant[batteries] = 1
total_potential_constant[pumped] = 1.88
total_production_in_GWh = total_supply*hours_per_year
total_production_rate = SUM(production_rate)
total_remaining_potential = SUM(remaining_expansion_potential)
total_supply = (SUM(economic_availability)+(trade_share*transmission_capacity))*(1-grid_losses)

trade_share = GRAPH(market_price_per_GWh/(SINWAVE(5000,1)+price_abroad))



(0.00, -1.00), (0.0513, -0.993), (0.103, -0.993), (0.154, -0.993), (0.205, -0.972), (0.256, -0.957), (0.308, -0.943), (0.359, -0.915), (0.41, -0.879), (0.462, -0.851), (0.513, -0.829), (0.564, -0.794), (0.615, -0.744), (0.667, -0.68), (0.718, -0.623), (0.769, -0.544), (0.821, -0.473), (0.872, -0.402), (0.923, -0.302), (0.974, -0.16), (1.03, 0.00), (1.08, 0.203), (1.13, 0.302), (1.18, 0.395), (1.23, 0.488), (1.28, 0.573), (1.33, 0.63), (1.38, 0.68), (1.44, 0.765), (1.49, 0.794), (1.54, 0.843), (1.59, 0.865), (1.64, 0.9), (1.69, 0.922), (1.74, 0.957), (1.79, 0.972), (1.85, 0.972), (1.90, 0.979), (1.95, 1.00), (2.00, 1.00)

transmission_capacity = 2