E1

Raphael Klein

January 3, 2020

Contents

Chapter 1

Introduction

Chapter 2

Modelling

2.1 The electricity model

The model presented in this chapter is a transposition of the model created by Paul van Baal and Reinier Verhoog and first created by Paul van Baal for his master thesis (van Baal, 2016). The model has also been further improved to look into the effect of a strategic reserve in a hybrid system dynamics - agent based model version (van Baal and Finger, 2019). In this report, the model, which was a system dynamics model and then a hybrid model, is turned into an agent based model. This report is the ODD presentation of that model (Grimm et al., 2010). All equations and additional details are in the appendices.

2.1.1 Purpose of the model

The purpose of this model is to simulate the Swiss electricity system. This includes the spot market, international trade with neighbouring countries, and investments. This constitutes what is considered to be the simplest electricity model (SMel). In future iterations of the model, depending on the goals of the research, the model can be extended to consider the presence of demand side management, batteries, prosumers or a strategic reserve.

2.1.2 Entities, state variables and scales

There are four types of agents within the model: the market operator, the firms (or investors), the supply agents and the demand agents. The market operator is the agent that is in charge of the spot market, making sure everything is going well. The firms are the agents that own the power plants and other assets present in the model. They are in control of the power plants. The demand agents are the agents that buy electricity. This includes the inflexible demand (which is based on a historical scenario), and demand created by hydro-pumping power and international trading.

The firms are characterised by the following attributes: assets owned, electricity supplied, planned assets, retired assets and constructed assets. The supply agents can either be the power plants (assets), they can be long term contracts with France, or they can be the net transfer capacities from the different border countries. Each has a different set of attributes. The assets are characterised by the following attributes: owner, technology type, installed capacity, age, lifespan, capital costs, annual fixed costs, variable costs and utilisation factor. Additionally, depending on the technology type, some power plants have more parameters. For example, the thermal power plants, the nuclear power plants and the waste power plants all have a fuel cost. The thermal power plants also have an emission attribute. The nuclear power plants have attributes related to their maintenance requirements: maintenance month and maintenance time. Waste, hydro and hydro-pumping assets have attributes related to their reservoirs: reservoir level and maximum reservoir level. Hydro-pumping assets have an efficiency attribute related to their pumping efficiency.

The technology types are limited to: solar, wind, hydro power, hydro-pumping power, run of river, thermal, nuclear and waste. The firms can only invest in solar, wind and thermal technologies as it is considered that other technologies are already maxed out in Switzerland or they cannot be used to produce significantly more electricity.

2.1.3 Process overview and scheduling

The model runs along two different scales, highlighting two parts of the model. The first part is the spot market, running on an hourly basis. It consists of all the actions related to the spot market including all of the inputs, the calculation of the demand, the calculation of the spot price, the distribution of the money and electricity when the equilibrium is found and the update of the NPV for all of the agents (that is later used for investments).

The second part is related to the investments that the firms can perform. This happens monthly. These are actions that are related to the firms. They decide whether to invest in new assets. They also decide whether they should reinvest in their current assets by extending their lifetimes or shuttering them temporarily or definitively. Then there are additional measures that include the end of life actions that occurs when an asset has reached its lifetime. It also includes scenario based events such as the closing of nuclear power plants according to a politically determined timeline.

2.1.4 Design concepts

Basic principles The model is, in essence, a simple supply and demand model where electricity is demanded and supplied. The main added element is that instead of resolving this supply and demand every week or year as it has been done in past models, it is done on an hourly basis.

Emergence The main outputs of the model relate to the energy mix that is needed to meet the Swiss electricity demand. The investments, their type and amount are also of interest for the purpose of the study and should emerge from the needs to supply electricity.

Adaptation There is no real adaptation programmed in this model beyond agents deciding on whether to discontinue their current assets and whether to invest in current or new ones.

Objectives The objectives for the market operator is that there be a balanced spot market. The objective for the firms is to make as much money as possible. The objective of the supply agents is to supply as much energy as possible. The objective of the demand agents is to have their demand met.

Prediction The firm agents have to use prediction for the investments. They forecast the price of electricity for the next year, two years and five years based on historical data for each technology considered. This is then used in the profitability check and the Net Present Value (NPV) by the firms for their respective assets or future investments.

Sensing The sensing of the actors is limited. Only the firms have sensing. They have a clear and full understanding of the performance of their assets. This includes the costs involved, the electricity generated and sold, and for some technologies, the reservoir related values. For investments, actors only inform their investment potential based on what assets are present in the system and the overall price of electricity. They do not have knowledge of other firm's assets in construction or planned. This can therefore lead to periodical supply surplus.

Stochasticity Most of the model is deterministic. Some outages can occur randomly for each of the plants. Scenarios also provide some stochasticity to the simulation.

Observation The model produces a large amount of data. Not all of it is necessary for testing, understanding and analysis. Some of the data needs to be collected to feed the policy process model. The agents in the policy process based their decision based on what is going on with a set of key performance indicators in the electricity model. Beyond this, the interest for understanding and analysis is mostly focused on the electricity prices, the number of outages (if any), the supply mix, and the trade with foreign countries. Depending on the study being performed, the amount of investment is also of interest along with the type of investment and measures related to the goals of the Energy Strategy 2050.

2.1.5 Initialisation

The model is initialised with values from 2018 for all of the assets that are present in the model. This includes the 2018 Swiss electricity power plants distribution and costs. The initialisation state is always the same for all simulations. All the values considered are informed on the Swiss electricity sector directly.

2.1.6 Input data

There are a lot of input data required to simulate the electricity system. The data used to run the model is given below:

- Asset investment (type, sizes and costs)
- The gas prices for thermal power plants (scenario based)
- The emission prices for thermal power plants (scenario based)
- The water inflow in Swiss reservoirs for hydro power plants yearly and hourly (scenario included)
- The waste inflow in Swiss waste management facilities yearly (scenario based)
- The price of nuclear fuel (scenario based)

- The amount of solar radiation hourly (based on the years 2015, 2016 and 2017)
- The amount of wind hourly (based on the years 2015, 2016 and 2017)
- The amount of run of river water (based on the years 2010, 2011, 2012, 2013 and 2014)
- The average hourly electricity price in France, Germany and Italy (based on the years 2015, 2016 and 2017)
- The average border capacity (import and export) with France, Germany and Italy (based on the years 2015, 2016 and 2017)

2.1.7 Submodels

There is a large number of submodels that are used to simulate the Swiss electricity market. They are all detailed qualitatively within this section. The equations used are present in the appendix for each submodel.

1. The spot market
2. The electricity price forecast
3. The profitability calculation
4. The NPV calculation
5. The end of life actions
6. The international trading
7. The demand aspect of storage in the model

The spot market The spot market is at the centre of the model. Its role is to match supply with demand. Some of the demand is inelastic and always has to be met. Some of it is elastic and will be met depending on the supply price. The spot market includes all of the assets (supply and demand wise) and the international trading. It is cleared on an hourly basis using a merit order curve.

The spot price is calculated using the merit order curve. The cheapest technologies are first selected and then depending on demand, the price moves up to account for other technologies. In the cases where there is not enough supply, the Value of Lost Load (VOLL) is set at 3000 CHF per MWh.

There are two parts for the supply of energy. There is the installed capacity and the available capacity at any point of time. The market is cleared every hour.

The supply that is considered for the spot market is made of: hydropower (including run-of-river, reservoir and pumped storage), nuclear power, CCGT, solar and wind power, long term French nuclear import contracts, interruptible contracts (dischargeable generation option), and thermal power (including green CHP, waste burning power plants, other thermal).

The electricity price forecast The electricity price forecast is used by the firms to gain an understanding of the market and help them assess whether future investments are worth the expenses. This price forecasts consists of estimating a linear relation for the future in the form $y = mx + p$. Therefore finding a slope (m) and a constant (p) for future prices based on prices from the previous four years. This is done using a weighted average of the last three years of prices and is updated throughout the simulation based on the evolution of the price of electricity for each technology.

The profitability calculation Towards the end of life of an asset, within ten years of the end of life, the one year and five profitability of the assets are assessed monthly by the owners. Then several options present themselves. If the one year profitability is negative and the asset has reached its lifetime, then it is decommissioned. If the five year profitability is higher than zero but the one year profitability is negative, then the asset is mothballed. If the one year profitability is positive and the asset has been renovated less than twice, it is renovated. If not, it is decommissioned when it reaches its final age.

The NPV calculation The NPV calculation is used by the actors to assess potential new power plants for their portfolios. The NPV is used to assess the profitability of a future plant. If that profitability is higher than the hurdle rate of the actor, then the actor will consider investing in the plant.

The investment pipeline The firms can invest in three main technologies: solar, wind and thermal power plants. These investments are discrete in capacity. Only one option per technology is provided as an option to the investors. Every month, each firm is provided with the opportunity of investing in one of the three technologies. They test the NPV of each of the plants and the most positive, if there is one, is approved by the firm. Approval at this stage means that a permit is demanded. This is a process that takes a different amount of time depending on the technology. Its rate of success also depend on the technology with the rate of success of solar being affected by land scarcity and the rage of success of wind being affected by land scarcity and social acceptance.

Once the permit has been approved, the firms will once again assess the NPV of the investment on a monthly basis. If the NPV has changed and is now negative, the firm keeps the permit without building the plant. If it becomes positive, then construction is started. The plant then comes online only after the building period has been completed.

The international trading International trading of electricity is introduced in the model. The import and export prices of the electricity are known from historical data for Germany, Italy and France. The supply of this electricity is then limited by the inter-connections to these different countries.

This international trading is supplemented by the long term contracts that Switzerland has with France. Such contracts take a part of the capacity on the interconnections between France and Switzerland, limiting the potential for international trading.

The demand aspect of storage in the model Demand is mostly present in the model through the inelastic demand of Swiss consumers. One can also consider the demand of foreign countries and the demand of storage technologies such as hydro-pumping. All these aspects are taken into account in the spot market to make sure demand is met by supply. In the future, prosumers and their batteries could also be considered as demand agents.

2.2 The policy process model

The policy emergence model uses concepts taken from the policy process theories as mentioned in the introduction. It follows work performed in Klein (2017) and to be presented in forthcoming papers. This model has also been presented at a number of conference with the goal of obtaining feedback. This includes the International System Dynamics conference, the Social Simulation Conference, the International Conference on Energy Research and Social Science and the International Conference on Public Policy. The model is presented here using the ODD framework (Grimm et al., 2010).

2.2.1 Purpose of the model

The purpose of the model is to simulate the policy process according to the Advocacy Coalition Framework (ACF) (Sabatier and Weible, 2007). By this, it is meant that the simulation should accommodate agents from a policy subsystem that can interact with one another based on their perception of the policy context - an electricity model in this case - and their respective interests. It should then enable these agents to decide whether to implement a policy instrument and if so, which one and at what time.

2.2.2 Entities, state variables and scales

The policy process simulation takes place at the policy subsystem level (Sabatier and Weible, 2007). The subsystem is selected based on the policy context of interest, represented here as the Swiss electricity market. This allows for the selection of the agents and the creation of specific structures within the model such as the agents' belief system.

Four different types of agents, in two categories, populate the model. The truth agent and the electorate are part of the passive agent family. The **truth agent** passes information from the policy context onto the policy subsystem agents. This role has no equivalent in the real world, it is purely computational. The role of the **electorate** is to influence the goals of the policy makers. Each electorate represents a political affiliation. They help shape the political field depending on their affiliation and goals (Laver and Sergenti, 2011). The model accommodates one electorate agent per political affiliation with a certain percentage of representativeness, corresponding to the amount of political support per affiliation.

The policy entrepreneurs and policy makers are part of the active agent category. Every active agent is a **policy entrepreneur**. This grants them the right to advocate for their interests. Some agents are also **policy makers**. This grants them, additional decision making powers at a key step within the policy making process. They help select the agenda and they select the policy to be implemented.

All active agents have a number of attributes: a belief system composed of a **problem tree**, **resources**, and a **policy** and **affiliation network**.

The problem tree is a three-tiered hierarchy composed of problems from the policy context following the ACF belief system (Sabatier, 1987). The highest tier is composed of deep core beliefs which are normative values, the second tier is composed of policy core problems directly related to the policy context main problems while the lowest tier is composed of secondary problems related to details within the policy context. For each problem, the agents have a goal, a belief and, as a result of the difference between their goal and belief, a preference. This preference helps them select a specific problem of importance such that they can focus their limited attention on it. Finally, the problems are connected vertically with one another using causal relations. For example, more thermal power production can be perceived by the agents as having a negative impact on the investments into renewable energy. Overall, the problem tree provides a simplified representation of the policy context and its mechanisms within the mind of the agents.

Each agent has resources reflecting not only their financial resources but also the political resources (Nohrstedt and Weible, 2010). These are used to interact with other agents.

Finally, all agents are connected through a policy network and an affiliation network. The policy network defines whether agents know each other and how much they trust one another. The affiliation network helps define the relations between the different political affiliations. This has an impact on the agents they talk to in the policy process.

Within the policy process, the agents can assemble into like-minded **coalitions**. These coalitions are used by the agents to pull resources together to be more effective in their interactions with other agents. Such coalitions are created early in the policy process and remain stable throughout the process (Weible and Ingold, 2018). They are created with agents sharing similar policy core goals and beliefs. For example, in the present case two main coalitions will be formed: one focused on the environment and one focused on the economy (Markard et al., 2016).

2.2.3 Process overview and scheduling

The policy process considered is a two step process made of the **agenda setting** and the **policy formulation** step. This process is in part based on the theory of the policy cycle (Simmons et al., 1974). Note that in the full hybrid simulation, the process is complemented by a simulation of the policy context, effectively adding one step to the policy process.

Before the start of the policy process, the agents are made aware of developments in the policy context. The indicators from the policy context simulation are calculated and fed to the truth agent which collects them unchanged. Then, these are passed on onto the active actors.

Once informed, agents select a problem that they consider to be most important in furthering their interests. These are the problem or policy they will advocate for throughout the entire process due to their limited attention span (Baumgartner et al., 2014). During the agenda setting step, a policy core problem is selected. For the policy formulation step, a secondary problem and a policy instrument are selected.

In the agenda setting step, the agents interact with one another on their goals, beliefs, and understanding of the policy context (causal relations). The aim of these interactions is to align other agents with their own interests. Once they have completed their interactions, the agenda is selected. It is created if a majority of the agents agree on the same policy core problem. If no agenda is agreed upon, then the simulation skips the policy formulation and heads into the simulation of the policy context directly. If an agenda is created, the interactions between the agents continues on a narrower set of problems - secondary problems - in the policy formulation step.

The policy formulation step is slightly different. It ends with the selection, or lack thereof, of a policy instrument. This selection is performed by the policy makers only. If a majority of policy makers approves the same instrument, then it is selected and implemented within the policy context. If not, the status quo is maintained and the simulation continues undisturbed. Note that in this step as well, policy makers can be influenced by all other actors.

2.2.4 Design concepts

Basic principles The basic principles highlighted within this model is that through interaction, policy learning will be emulated. Policy learning is one of the pathways to policy change (Sabatier, 1988). It comes as a result of the agents' changes in their belief system which is, in turn, a result of their reaction to the evolution of the policy context and their interactions with one another.

Emergence There are a number of emergent behaviours present in the policy emergence model. The main emergence behaviour is related to policy learning. Just as policy learning is an emergent phenomenon in real policy subsystems, it is also so within the simulation. It results from the interactions of the agents with one another but also from the reaction of the agents to the policy context.

Coalitions are another emergent phenomenon. Coalitions are created by agents with same-minded policy core interests. They are created to speed up the policy learning in the direction of the coalition's interests. These coalitions are expected to remain stable throughout the simulations considering the low speed at which policy core problems change. Coalitions can lead to a significant drive of the policy learning process, and lead to policy change.

Finally, the agenda and the policy instrument implementation can also be seen as emergent phenomena. They are the results of agents converging over and over in their beliefs on certain problems and policies. This convergence is the result of policy learning, the interactions between agents, the influence of the coalitions, and what is going on in the policy context.

Adaptation The agents have no strategy for say and therefore no adaptation possibilities. They follow rules which dictate that they can only select one problem at at time. They adapt their interests based on their understanding of the policy context, their goals, and the influence of other agents. Any change in their beliefs, goals or understanding will lead to a change in their preferences and therefore the interests they advocate for. This can effectively be seen as a change in their strategy as what they advocate will change over time.

Objectives The objectives of the agents are to bridge the gap between their goals and beliefs for all problems and above all else, their deep core problems. They do this principally through the implementation of policy instruments that will affect the policy context. This gap can also be influenced by other agents. Overall, and this relates to the core of the policy making process, and the agents are never able to reach their objectives fully. This can be due to unattainable objectives, the presence of unlimited and unexpected external events, a dynamic and unstable policy context or their flawed understanding of the policy context.

Learning The agents have only one learning possibility: interactions. Every interaction they perform allow them a brief peak within the belief system of the agents they have interacted with. This allows them to be better informed on other agents and perform better informed interactions in the future. Agents do not have a memory and cannot inform their future decisions based on past interactions.

Sensing All agents are provided with information on the policy context, through the truth agent. This information can be imperfect. The agents have virtually no way of establishing whether the information is correct or not beyond interacting with one another.

Interaction All interactions between the agents are explicit and relate to efforts that can be seen as lobbying, influencing or pressuring other agents on their belief system. Agents interact with one another to push their respective interests onto other agent's belief systems. The ultimate aim being to implement policy instruments they think are best.

Stochasticity Stochasticity plays only a small role in a number of parts of the model. For example, agents are called upon in a random order when they perform interactions. Additionally, the knowledge they gain about other agent's belief system from their interactions is not exact. It is dependent on a small level of uncertainty. Finally, most of the inputs to the model, when it comes to the agent's belief systems, are introduced with a small dose of uncertainty.

Collectives The agents can assemble into coalitions. The main effect of these coalitions is the ability to create what can be seen as "super-agents". They behave like agents with a lot more resources to push their respective interests forward and using what is effectively a greater policy network.

Observation A lot of data can be observed from the simulation. Amongst other things, there is the potential to observe all of the beliefs of all of the agents at all points in time throughout the simulation. However, this would lead to an enormous amount of data, and difficulty for analysis. Instead, the focus is placed on observing the agendas, the policy instruments selected and the different preferences for all agents. This allows the tracking of policy change. Then, depending on the focus of specific studies and the research questions selected, certain parts of the model can be observed such as the evolution of the network, the evolution of the coalitions or the influence of partial knowledge on the decision making of the agents. More details are provided on this later on.

2.2.5 Input data

Both empirical data and modeller generated data can be used as inputs. This depends on the case being studied. In the present case where the model is coupled to an electricity model, the data used is empirical data obtained in other studies.

2.2.6 Submodels

Two submodels are detailed: the influence of the electorate on policy makers and the active agent interactions.

Electorate influence At the beginning of the policy process, the electorate influences the goals of the policy makers. Their goals follow those of their respective electorate in an effort to satisfy their electorate and remain in power (Laver and Sergenti, 2011). This happens throughout the simulation and is one of multiple ways that the goals of the policy makers evolve over time.

Agent interactions The active agents can interact with one another. Such interactions can be performed on all other active agents and their belief system. An agent decides on specific actions based on the expected impact of the action. For this, the agent will be grading all actions possible. This grading takes into account the conflict level that s/he has with the other agent based on his/her understanding of the other agent's belief system and their mutual trust. It also accounts for the type of agent being influenced. Policy makers are preferred as they have more decision making power for example. The expected best action is selected. When an action has been selected, it is implemented by the agent.

Policy network maintenance To perform actions and interactions, agents must have a robust policy network. To keep that network robust, they need to maintain it. They do so by spending resources to interact with other agents and maintain their level of trust with them. Resources spent on network maintenance are resources that cannot be spent on problems actions and interactions.

Coalition creation Advocacy coalitions are created based on similarity of policy core problems goals. Agents that have similar goals will converge into a coalition.

Coalition actions and interactions The coalitions can be seen as super-agents. They have a policy network and resources. They can also perform similar actions to the agents. The main difference is that the coalition actions are decided by the leader of the coalition. Furthermore, the actions can be performed on the members of the coalition themselves as an exercise of coalition strengthening, or they can be performed on agents outside the coalition as a way to push forward their interests.

2.3 The hybrid model

The hybrid model is the a model that is composed of both the electricity market model and the policy process model. These two models are connected with the goal of having policy agents influence what is going on in the electricity market. The policy agents will react to what is going on in the electricity market and will attempt to influence what is going on in the electricity market model. They will do so by implementing policy instruments that they perceive will help them reach their goals. These goals could be a decrease in emissions or an increase in international trade with France for example.

This chapter details the module interface that needs to be built to connects both models. This both considers the bridge that needs to be constructed to exchange data between the models and considers the specification of the policy process model which is now a generic model. This means specifying the problem tree and defining a set of policy instruments.

2.3.1 The hybrid model

The hybrid model is presented in Figure 2.1. The diagram outlines the two models and how information is transmitted from one to the other. The key performance indicators from the electricity market model are used to inform the truth agent which then relays the information to the active agents (policy makers and policy entrepreneurs) to inform their beliefs. At the end of the policy emergence model, if a policy instrument has been selected, it is transmitted to the electricity market model through a change in the exogenous parameters. This will then affect the system's outputs. This cycle goes on until the end of the simulation. Note that the electricity market model might be run for a period of a month to six months for every run of the policy process model.

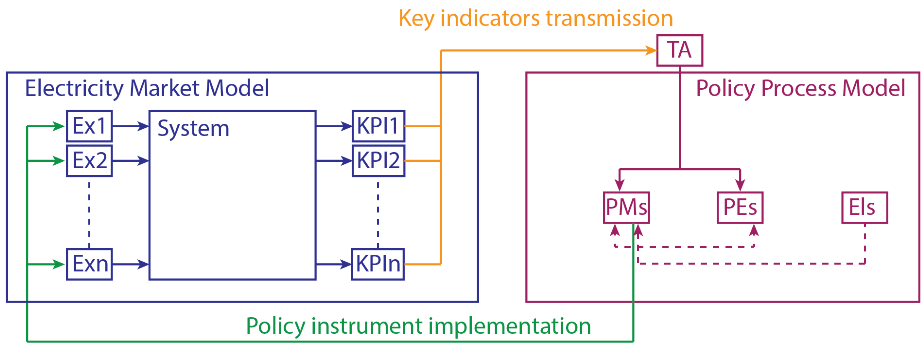

Figure 2.1: Diagram of the hybrid model.

2.3.2 The problem tree

To couple the models, the agents in the policy process need to be provided with a problem tree. This problem tree is specific to the electricity market model as it is informed by the key performance indicators from that model. This was highlighted in the previous section. Beyond this, the problems selected are also informed from previous work done by Markard et al. (2016). They identified a number of problems (they call these beliefs in their publication) that are specific to the Swiss context. These are however limited to the deep core and policy core levels. Secondary problems are not included or researched and are therefore taken from the model only.

The difficulty in the creation of the problem tree is to associate the right indicators to the right problems. The first step is to not consider the deep core problems. These are considered to be normative problems. They are beyond the boundaries of the model, out of the scope. They are not a crucial aspect of the process as it is focused on policy core problems so it does not make a big difference if deep core problems are considered or not. The next step is to consider the secondary problems. These can be found directly within the model. They are indicators that are made into secondary problems. Not all indicators are considered, only a few are selected. These are considered to be the important ones for the agents in the policy process. Finally, there is the selection of the policy core problems. These are, in general, aggregates of the secondary problems. They are calculated as a function of the main model indicators.

For the policy core problems, there is an additional aspect that needs to be considered. In work performed by Markard et al., policy core problems within the Swiss electricity market subsystem were identified. These are:

seriousness of the problem, role of the state, environment, economy and society. Several of these cannot be obtained from the model as they are outside of the boundaries of the model. However, the environment and economy can be considered. They are therefore selected as the policy core problems. Markard et al. (2016) also identified four secondary problems. They are however not suitable for the model as they are more questions than problems. Furthermore, four secondary problems is not sufficient. It is for this reason that the secondary problems are only selected from the model. Ultimately, the policy core problems are calculated using linear equations that include a number of the indicators used for the secondary problems.

Overall, the problem tree is given as follows:

- Policy core problems:
  - Economy
  - Environment
- Secondary problems:
  - Renewable energy production
  - Electricity prices
  - Renewable energy investments
  - Domestic level emissions
  - Imported emissions

The economy takes into account elements related to profits of firms along with the security of supply of the country. The environment takes into account aspects such as the emissions, the amount of renewable energy and the amount of imported emissions.

2.3.3 The policy instruments

The policy instruments within the policy tree are implemented using incremental increases and decreases in the following exogenous parameters.

1. Solar subsidies [+/- 0.04]
2. Wind turbine permit times [+/- 0.04]
3. Agent's hurdle rate [+/- 0.02]
4. Carbon tax on domestic fossil fuel [+/- 10]
5. Carbon tax on fossil fuel imports [+/- 10]

Chapter 3

Implementation

3.1 The electricity model

This section outlines the different algorithms that are used within the electricity market model.

Chapter missing key elements like the merit-order curve algorithm.

3.1.1 Electricity costs calculation per technology

The calculation of the price at which each asset sells its electricity varies depending on the technology considered. The details of the calculations for the marginal costs are presented below:

- For solar power plants:

$$MC_{solar} = VC_{solar} \tag{3.1}$$

where MC are the marginal costs and VC are the variable costs.

- For wind power plants:

$$MC_{wind} = VC_{wind} \tag{3.2}$$

- For hydro and hydro-pumping power plants:

$$MC_{hydro} = OC + VC_{hydro} \tag{3.3}$$

where OC are the opportunity costs.

The opportunity costs are calculated using the price reference and depend on the amount of water that is left in the reservoir of the hydro power plant. The price reference is calculated based on the weighted average of the previous three year electricity price on the spot market in the previous years.

$$P_{ref} = 2 \cdot \frac{3 \cdot P_{t-1} + 2 \cdot P_{t-2} + P_{t-3}}{6} \tag{3.4}$$

where P is the average price of electricity on a given year and t is the year within which the simulation is.

If the installed capacity is larger than the water left in the reservoir then, the opportunity costs are:

$$OC = (P_{ref} - VC_{hydro}) \cdot \left(1 - \frac{RL}{2 \cdot RC_{max}}\right) \tag{3.5}$$

If the opposite is true, then:

$$OC = (P_{ref} - VC_{hydro}) \cdot \left(1 - \frac{RL - IC}{RC_{max}}\right) \tag{3.6}$$

where RL is the reservoir level, IC is the installed capacity and RC is the reservoir capacity

- For run of river plants:

$$MC_{ror} = VC_{ror} \tag{3.7}$$

- For waste management power plants:

$$MC_{waste} = OC_{waste} \tag{3.8}$$

Here the costs are calculated using the opportunity costs again. These can be found using the same equations as for hydro power plants.

- For thermal power plants:

$$MC_{thermal} = FC + VC_{thermal} \tag{3.9}$$

where FC are the fuel costs. The fuel costs include both the gas price and the carbon price. This considers a price for carbon that varies over time and emissions of 0.342834 tons/MWh (NREL, 2018).

Below is the carbon prices scenario:

2017	9
2020	15
2025	22
2030	33
2035	42
2050	73

- For nuclear power plants:

$$MC_{nuclear} = FC + VC_{nuclear} \tag{3.10}$$

3.1.2 Supply amount per technology

The amount of electricity supplied per technology is given using the following equations:

- For solar power plants:

$$S_{solar} = C \cdot Solar_{conditions} * UF \tag{3.11}$$

  where S is the supply, $Solar_{conditions}$ is an input file defining how much solar electricity was produced for every hour of the year historically, UF is the potential utilisation factor. The potential utilisation factor is calculated based on a curve that helps assess the best locations for solar and the maximum theoretical amount of roof top solar in Switzerland. The curve is given below:

0	0.147
0.0367	0.1358
0.9306	0.114155
1	0.100114

- For wind power plants:

$$S_{wind} = C \cdot Wind_{conditions} * UF \tag{3.12}$$

  where $Wind_{conditions}$ is an input file defining how much solar electricity was produced for every hour of the year historically, UF is the potential utilisation factor. The potential utilisation factor is calculated based on a curve that helps assess the best locations for wind and the maximum theoretical amount of wind power in Switzerland. The curve is given below:

0	0.3196
0.181	0.2497
0.195	0.2457
0.267	0.2301
1	0.1608

- For hydro, hydro-pumping and waste power plants:

  The supply of electricity is dependent on the level of the reservoir. If the reservoir level is below the capacity of the power plant, then the reservoir level is the amount supplied, otherwise, the capacity of the power plant is the electricity supplied.

- For run of river power plants:

$$S_{ror} = flow_{ror} \cdot growth_{ror} \cdot C_{ror} \tag{3.13}$$

  where C is the installed capacity and the flow is dependent on weather input data.

  The run of river growth factor represents the growth of such production over the year. It is based on a scenario provided in Table 3.1 and can be calculated using the following equation:

$$growth_{ror} = C_{ror,scenario}/C_{ror,installed} \tag{3.14}$$

  This considers the entire run of river production within Switzerland and not just one plant.

2015	16400
2020	16700
2025	16933
2035	17533
2050	18333

Table 3.1: Expected total production for all run of river power plants in GWh.

- For thermal power plants:

$$S_{thermal} = C \tag{3.15}$$

- For nuclear power plants:

$$S_{nuclear} = C \tag{3.16}$$

Note that nuclear power plants are not online throughout the year. They have a yearly planned maintenance, usually planned in the summer when the plant is offline. This is a done over a period of thirty days. Each starting month is specified as an input per asset.

3.1.3 Investment approach

The electricity price forecast is used for the investments. This price forecasts consists of estimating a linear relation for the future in the form $y = mx + p$.

The slope m is calculated using the following equation:

$$U = \frac{P_{t-0} + P_{t-1} + P_{t-2} + P_{t-3}}{4} \tag{3.17}$$

$$m = \frac{-3 \cdot (P_{t-3} - U) - (P_{t-2} - U) + (P_{t-1} - U) + 3 \cdot (P_{t-0} - U)}{2 \cdot 2015} \tag{3.18}$$

The constant p is given by:

$$p = U - t * m \tag{3.19}$$

where t is the time at which the simulation is at.

The profitability of an asset is calculated using the following equation:

$$P = \left(\sum^{t} \frac{((Y + t) \cdot m + p) - VC}{(1 + r)^{t+1}} \right) \cdot 8760 \cdot \epsilon \cdot C \tag{3.20}$$

where P are the profits, Y is the initial year, t the year for which profitability is considered after the initial year, VC the variable costs, r the discount rate, ϵ the utilisation rate and C the capacity of the asset considered.

The losses are calculated using:

$$L = \left(\sum^{t} \left[1 + \frac{1}{(1 + r)^{t+1}} \right] \right) \cdot FC \cdot C \tag{3.21}$$

where L are the losses, C is the capacity of the plant and FC are the annual fixed costs of the plant.

The profitability is then calculated as the difference between profits and losses.

For investments, the actors use the NPV and the profitability index of potential new power plants.

The following equations are used to estimate the NPV.

$$NPV = \sum_{n=0}^{N} \frac{C_n}{(1+r)^n} = \sum_{n=0}^{N} \frac{(R - MC) * \epsilon - OC}{(1 + WACC)^n} \tag{3.22}$$

where R are the revenues per year, ϵ is the utilisation factor, MC are the marginal costs, OC are the fixed operating costs. WACC is given as the sum of the risk rate and the discount rate.

3.2 The policy process model

The policy process model is composed of several key parts. The first consists of the process followed, then comes the policy arena that is considered. After that comes the identification of the agents and finally the interactions between the agents and between the agents and the environment.

3.2.1 The process

In the simplest model, we assume that the policy process followed is a two-step process. First the agenda setting step is performed, then, if an agenda has bene agreed on, comes the policy formulation step. This does not include the environment simulation that is outlined in the next section.

The steps used to mode this approach are then detailed as follows:

1. Initialisation:

   (a) *Trigger of external events:* Any event that the modeller decides to implement are activated at this stage of the model cycle.

   (b) *Update of the truth agent:* Information from the environment is used to inform the truth agent actual beliefs.

   (c) *Electorate actions on policy makers*

   (d) *Transmission of the actual beliefs:* The agents are informed about the environment from the truth agent.

2. Agenda setting step:

   (a) *Preferences calculation (issues):* Each agent calculates the preference for their deep core and policy core issues. Additionally, each agents selects an issue that (s)he will advocate for in his/her policy core issues based on the preferences.
   (b) *Agenda selection*

3. Policy formulation step:

   (a) *Preferences calculation (policy instruments):* All agents update their preferences for their secondary beliefs based on the issue on the agenda. All agents then selects a policy instrument that (s)he will be advocating for.
   (b) *Policy instrument implementation*

3.2.2 The subsystems

The policy arena is designed as a subsystem. For the present model this means the Swiss electricity sector. This mostly relate to the selection of the issues in the belief system and the actors that are simulated.

3.2.3 The agents

There are two main categories of agents in the model: the active agents that have a direct influence on the agenda and the passive agents that an indirect impact on the agenda and policy change.

Active agents The active agents are the policy makers and the policy entrepreneurs. Their attributes are given as follows:

1. The *active agent* is represented as an 5-tuple given by `agent = (ID, type, beliefHierarchy, affiliation, advocacy)` where `ID` is the agent unique ID, `type` is the agent type, `beliefHierarchy` is the agent's personalised belief hierarchy, `affiliation` is the political entity the agent identifies with, `advocacy` is the list of the issues the agent is supporting.

2. A *type* corresponds to a choice of agent. This can either be a policy maker or a policy entrepreneur.

3. The *belief hierarchy* is made of the agent's own belief hierarchy structure and associated values.

4. The *advocacy* is represented as a 3-tuple `(prob_as, prob_pf, pol_pf)` where `prob_pf` is the problem chosen by the agent during the agenda setting step, similarly for the `prob_pf`. `pol_pf` is the policy instrument selected the policy formulation step.

Passive agents The passive agents are the truth agent and the electorate.

The truth agent: The truth agent is an agent included only for programming purposes. This agent provides a link between the environment and the policy agents. It is communicated all the states in the environment and uses them to inform the actual beliefs of the active agents. The only attribute of the truth agent is the belief hierarchy composed only of actual beliefs for each of the issues.

The electorate: The electorate represents the different constituencies. There are as many electorate agents as there are political affiliations. The role of the electorate is to influence the policy makers in their aims. The following defines the attributes of the electorate:

The *electorate* can be given as a 3-tuple written as: `electorate = (ID, affiliation, beliefHierarchy)` where `ID` is the unique name of the electorate, `affiliation` is its associated affiliation and `beliefHierarchy` is the associated belief hierarchy of the electorate. The belief hierarchy of the electorate is similar in structure to the one of the truth agent.

Belief hierarchy The belief hierarchy is composed of two main parts: the issues and the causal beliefs. The issues are categorised in multiple layers: the deep core issues (the top layer), the policy core issues (the middle layers) and the secondary issues (the bottom layer). Secondary issues are linked to policy core issues through causal beliefs and similarly for policy core issues and deep core. The overall representation of this hierarchy structure is shown in Figure 3.1.

Each issue is categorised by three parameters: the actual belief, the preferred state and the preference. The actual belief defines the view of the agent of a certain issue as it is in the environment. They can take values within the interval $[0, 1]$ and where a value of 0.5 means that the agent is satisfied with the issue.

The preferred states shows where the agent would like the issue be in the future. They can also take values within the interval $[0, 1]$.

The preference which is a calculated parameter, defines the urgency that the agent places on the each issues. It is obtained depending on the actual belief, the preferred state and the causal beliefs linked to the issue. The sum

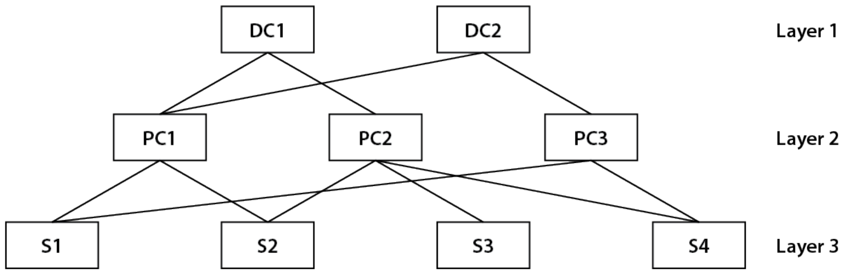

Figure 3.1: Representation of the belief hierarchy of the agents.

of all issue preferences on any single layer of the belief hierarchy have to be equal to 1.

The belief hierarchy structure also contains causal beliefs. These can be seen as causal relations. They represent the understanding of an agent about how a change in one issue will lead to a change in another on a different layer. The causal beliefs can take values within the interval $[-1, 1]$. A negative value means that an issue when growing will affect negatively another issue.

3.2.4 The actions and interactions

There are a number of actions and interactions that the agents can performed. We will first outline the actions that actors have to make for the system to work. This includes the calculation of the preferences. We will then outline the agenda and policy instrument selection for the entire policy arena. Finally, we outline how we conceptualise that the electorate influence the policy makers.

Preference calculation - deep core issues For the deep core issues, which are at the top of the belief system, the preference is calculated differently than for the policy core and secondary issues. The calculation of the preference for each issue is given by:

$$P_i = \frac{|G_i - B_i|}{\sum_{j=1}^{n} |G_j - B_j|} \tag{3.23}$$

where P is the preference, G is the preferred state - or goal, B is the actual belief - or belief, j is defined at the number of principle belief issues and i is the deep core issue.

Preference calculation - policy core and secondary issues The preference calculations for the policy core and secondary issues are adapted to include the causal beliefs that link these layers to their directly above layers.

To calculate the preference, the gap between aim and state for the issues is considered along with the impact of the causal relation on the gap of the issue on the above layers. The causal relations are not always helping bridge the gap between the aim and the state of issues on a higher layer. If this is the case, then the causal relations are not considered within the calculation as there effort is counter productive within the mind of the agent. The resulting equation that can be used to calculate the preference for these layers is given by:

$$P_k = \frac{|G_k - B_k| + \sum_{j=1}^{n} |C_j \left(G_j - B_j\right)|}{\sum_{l=1}^{p} \left[|G_l - B_l| + \sum_{j=1}^{n} |C_{j,l} \left(G_{j,l} - B_{j,l}\right)|\right]} \tag{3.24}$$

The sums only include these terms if C_j and $(G_j - B_j)$ have the same sign. If it is not the case, these terms are not considered.

Where p is defined at the number of issues on that layer, k characterises the issue being selected for the calculation, j specifies the issues above the layered considered and C represents the causal belief between k and whichever issue on the layer above is considered.

Based on these preferences obtained, the agent will select one issue to advocate. In the agenda setting, the agent will select one policy core issue and for the policy formulation, the agent will select a secondary issue.

Agenda selection The *agenda* is a 1-tuple given by `agenda = (issue)` where `issue` is the policy core issue that is placed on the agenda by all agents.

To constitute the agenda, an issue has to be chosen as a majority issue by all agents in the policy arena. If no majority is obtained on no issue, then the policy formulation cannot happen as now agenda has been selected.

Policy instruments The policy instruments are measures that can are chosen by the policy makers to impact the environment. To assess the different policy instruments, the different active agents assess the impact of these instruments on the secondary issues in their belief hierarchy. These instruments have an impact on the gap between the states and the aim of each of these issues. The policy instruments can be described as follows:

1. A *policy instrument* is represented as a 2-tuple `(ID, impact)` where `impact` is related to the impact of the policy on a specific issue.

2. There are as many *impacts* of a policy instrument as there are secondary issues. These impacts provide an information to the agents on how much the secondary issue will change if that instrument is implemented.

Preference calculation - policy instruments The policy makers have to select a policy instrument that they will advocate for. This is based on their preferences for which the calculation is detailed below:

$$P_k = \frac{\sum_{p=0}^{n} |G_p - (B_p(1 + I_{k,p}))|}{\sum_{q=0}^{m} \sum_{p=0}^{n} |G_q - (B_q(1 + I_{q,p}))|} \tag{3.25}$$

where k is the policy instrument for which the preference is calculated, n is the number of secondary issues, m is the number of policy instruments, I is the impact of the instrument on a specific secondary issue.

Once all the preferences have been calculated, the agent will select the instrument with the highest preference.

Policy instrument selection and implementation The policy makers are the agents that can selected a policy instrument at the end of the policy formulation step. This is done through a majority vote. If a majority of actors decide on one policy instrument, then that instrument is implemented.

Electorate passive action on policy makers The policy makers are passively influenced by the electorate. Each electorate has a certain affiliation to which policy makers are also related. Each policy makers' issue aim will be influenced by their respective electorate. This happens as a passive effect where the issue aims of the policy makers slowly progress towards the issue aims of the electorate. The equation to calculate the change in the aim of the policy maker is given as follows:

$$G_k := G_k + (G_{El} - G_k) \cdot C_i \tag{3.26}$$

where El stands for electorate of same affiliation of the policy maker, k is a policy maker, C_i is a the constant influence that allows variation in the speed of the change of the goals of the actors.

3.3 The hybrid model

There are a number of aspects that need to be added when considering the hybrid model. These are relations that help connect the electricity and the policy process model.

3.3.1 KPI calculations

The KPIs are calculated within the electricity model but they are only used for the hybrid model. There are five secondary indicators that are calculated and two policy core indicators. The secondary indicators are calculated directly from the data that is obtained from the model while the policy core indicators are calculated based on the secondary indicators. Each of the indicators are also normalised as they are to be used within the belief system of the actors within the policy process model. All indicators are calculated for data that is obtained for the year prior to the policy making round. The data considered does not include all of the years between negotiating rounds.

The secondary indicators are the following: renewable energy production (S1), electricity prices (S2), renewable energy investment level (S3), domestic level emissions (S4) and imported emissions (S5).

The renewable energy production (S1) indicator is calculated as follows. The total supply of electricity is given by: (note we only consider domestic production and no imports or exports)

$$S_{total} = S_{solar} + S_{CCGT} + S_{wind} + S_{nuclear} + S_{hydro} + S_{hydrop} + S_{waste} + S_{ROR} \tag{3.27}$$

The renewable supply is given by:

$$S_{RES} = S_{solar} + S_{wind} S_{hydro} + S_{hydrop} S_{ROR} \tag{3.28}$$

The indicator is then normalised using:

$$S1 = S_{RES} / S_{total} \tag{3.29}$$

The electricity prices (S2) indicator is calculated based on the average electric price of the previous year. It is then normalised using an expected maximum electricity price ($P_{elec,max}$). The normalisation equation is given by:

$$S2 = \frac{P_{elec}}{P_{elec,max}} \tag{3.30}$$

$P_{elec,max}$ is selected to be equal to 150 but can be tuned depending on the outcome of simulation such that the values of S2 are always between 0 and 1.

The renewable energy investment level (S3) indicator is calculated using the investment performed by all the investors in solar, wind and CCGT assets.

$$I_{total} = I_{wind} + I_{solar} + I_{CCGT} \tag{3.31}$$

$$I_{RES} = I_{wind} + I_{solar} \tag{3.32}$$

The indicator is normalised using:

$$S3 = I_{RES}/I_{total} \tag{3.33}$$

The domestic level emissions (S4) is calculated based on the CCGT emissions. The normalisation of this indicator is once again done using an assumed maximum for the emissions which is given as five times the emissions for year 1 of the simulation. This is an arbitrary value that can be tuned to make sure that the indicator is always between 0 and 1.

$$S4 = S_{CCGT}/S_{CCGT,max} \tag{3.34}$$

The imported emissions (S5) indicator is calculated based on the imports and the policy mixes of the countries from which Switzerland imports. The policy mixes are scenarios that are obtained from technical report and goals for the different countries. For each country, the percentage of coal and gas production is considered to calculated the imported emissions.

$$E_{FR} = (S_{FR,NTC} + S_{LTC}) \cdot (M_{FR,CCGT} \cdot E_{CCGT} + M_{FR,coal} \cdot E_{coal}) \tag{3.35a}$$

$$E_{DE} = Ss_{DE,NTC} \cdot (M_{DE,CCGT} \cdot E_{CCGT} + M_{DE,coal} \cdot E_{coal}) \tag{3.35b}$$

$$E_{IT} = S_{IT,NTC} \cdot (M_{IT,CCGT} \cdot E_{CCGT} + M_{IT,coal} \cdot E_{coal}) \tag{3.35c}$$

where E are the emissions per type of technology and where M is the share of the mix for a specific technology in the country.

To normalise this indicator, we once again select a maximum amount of emissions. This is calculated as being 5% higher than the initial imported emissions in year 1 of all these countries. Considering the emissions should decrease in the scenarios, this means that the indicator should remain within the $[0, 1]$ interval.

$$S5 = \frac{E_{FR} + E_{DE} + E_{IT}}{E_{total}} \tag{3.36}$$

where $E_{total} = E_{FR,init} + E_{DE,init} + E_{IT,init}$

The policy core issues are given as the economy (PC1) and the environment (PC2). They are calculated using weighted averages of a number of secondary indicators. The equations used can be tuned but the ones implemented are given below:

$$PC1 = \frac{3}{4} \cdot S2 + \frac{1}{4} \cdot S3 \tag{3.37}$$

$$PC2 = \frac{1}{4} \cdot S1 + \frac{1}{4} \cdot S3 + \frac{1}{4} \cdot S4 + \frac{1}{4} \cdot S5 \tag{3.38}$$

Chapter 4

Code documentation

4.1 The electricity model

This is the detailed documentation, file by file of the Swiss electricity market model.

4.1.1 run_elec.py

This is the file that is used to the electricity model. It has for input the duration of the runs in years. It then initialise the electricity model.

The script is using a loop where each iteration is one year. This is the `step()` function of the `model_elec.py` file.

For checks, some of the results can be plotted every five years.

Once the simulation has ended, the data is extracted from the `datacollector` and save as a `.csv` file.

4.1.2 model_elec.py

This script is composed of two main parts: the `get_supply` functions at the beginning and the `class Electricity(Model)`. The functions are there for the datacollector. They are used to collect the data that needs to be saved from the model. They are outside of the class and only called by the datacollector following the architecture provided by mesa. Each of the functions returns what needs to be recorded and only that.

The `class Electricity(Model)` begins with the initialisation of all the parameters that are needed for the simulation of the electricity model. This is detailed within the python file itself and is not detailed here.

The functions:

- `policy_implementation()`

  This function is used exclusively for the hybrid model. It implements whichever policy has been chosen by the policy makers through a modification of a number of pre-defined parameters. This function is not used when the electricity model is run alone.

- `step()`

  This function is used to simulate one year of the policy process. It includes the implementation of the policies, the iteration over 8760 hours and the calculation of the KPIs needed for the hybrid model at the end. The function returns the KPIs.

- `step_hourly()`

  This is the main function of the electricity model. It does whatever needs to be run over an hour. This includes the merit-order curve construction and the selection of the point of supply and demand, it includes the investment of the actors and it includes all of the recording of the data points within the model.

  For the merit order curve: first the supply list is built, this is followed by the construction of the demand list. The point at which these cross is then calculated. Once it has been found, the electricity supplied is allocated to the different assets along with the amount of electricity. This is also true for the demand for the asset that have a certain demand.

  The first part of the merit curve is to construct the supply list. This list is composed of all of the assets and the supply they can provide and at what price. This calculate for each asset depending on the technology considered. The list is then sorted by prices which the assets that offer supply at the lower price at the front of the list and the most expensive ones at the end. This also includes a probability that certain assets will go offline due to unexpected maintenance.

  The same is then done for the demand list. But the list is ordered in the opposite sense with the highest demand prices at the front of the list and the lowest at the back. The demand list is only made of the inelastic demand, the demand from bordering countries and the demand from hydro power plants.

  Then, there is a need to find at which point the two list cross. That is when the demand meets the supply at the same price. This is done using an algorithm that runs through each of the lists. Every time the supply has been allocated to demand, supply of a new asset is added and vice versa. This algorithm also takes into account that capacity allocated from France through the NTC or LTC needs to add up to the total of the border capacity and not go over that limit. This results is dynamically adjusting the supply and demand lists as supply and demand are allocated.

In some instances, when there is not enough supply to meet the inelastic demand, it is possible for there to be a blackout.

Once the point where supply meets demand has been found, the algorithm stop and the electricity price for that specific hour has been defined. The supply is allocated to the different assets along with the demand. This allows for the calculation of the utilisation factor of the different technologies later on. The revenue per assets are also attributed.

After the merit-order curve come the so-called end of step actions. This lumps all of the other actions that can be performed in a step. It includes mandatory actions along with opportunity actions (such as investments).

These include:

- Nuclear asset maintenance
- Asset ageing: simple iteration of one year for the age parameter for all assets
- Investment algorithms: investors must decide whether they want to invest in new assets or not
- End of life actions for assets: potential decommissioning, mothballing or re-investment in assets.
- Planned assets actions: assets that are already planned need to be advanced in their steps, either constructed or put on hold.

• `hydro_demand_supply_check`

This is a function that is used to reset the hydro supply or demand if it is already supplying or demanding. This is done to avoid having a hydro pumping plant both providing and supplying. This only affect hydro pumping assets.

- `end_of_life`

  This function is used to perform the so-called end of life actions. This is divided in two parts. For the long term contracts, if they come to the end of their life they are decommissioned and put off line.

  For the nuclear, wind, solar and CCGT assets, if these assets are within ten years of their end of life, it consists of checking if the asset is profitable. This calls the next function with different actions depending on the profitability of the asset. If the asset is already mothballed, then a different set of profitability checks are performed.

- `end_of_life_profitability`

  This function is used to assess the profitability of plants at their of life and perform the necessary actions based on the results of this profitability.

  First one year and five year profitability are calculated. Based on the results of these calculations, actions are taken.

  - If the one year profitability is negative and the age of the asset is past its maximum lifetime, the asset is decommissioned.
  - If the one year profitability is negative but the five year is positive and the asset is not past its lifetime, the asset is mothballed.
  - If the one year profitability is positive and the asset is not past its lifetime:
    - If the the asset has not yet been renovated, it is renovated and its life is extended by five years.
    - If the asset has already been renovated too much, it is decommissioned.

- `asset_decommissioning`

  This function remove the asset that has been decommissioned from the asset schedule. Additionally, if the asset is a solar or a wind asset, then the utilisation factor potential for these assets is recalculated.

- `asset_mothball`

  This function mothballs an asset. It puts it offline and extends its overall lifetime by one year.

- `asset_demothball`

  This function puts back online assets that have been mothballed.

- `saving_supply`

  This is the function that record the supply for each technology. This is done hourly, every time the merit-order curve has been completed.

- `saving_demand`

  This is the function that record the demand for each technology (hydro pumping and NTC. This is done hourly, every time the merit-order curve has been completed.

- `planned_assets_invest`

  This is the function that is used to deal with the assets that are planned. These are stored in a list when the investors have decided to submit a permit. Each planned asset goes through a certain number of steps.

  Each planned asset has to go through a planning time, then, if approved, it is placed in a waiting list. If the asset if planned to be profitable, it is constructed by the investor. If not, it stays there until the end of the plan lifetime. At the end of the life of the plan, the asset is removed from the list of planned assets. The actions are provided as follows:

  - If asset is in the approval process.

    If the asset has gone through the process time, check if the plan is approved. If approved, move to the waiting list for construction, if not remove asset from the planned asset list.

  - If the asset has been approved but is not in construction.

    If the asset has been too long planned and not constructed, it is removed from the list. If this is not the case, and its profitability index is higher than the hurdle rate, then the asset is placed in construction.

  - If the asset is in construction.

    If the asset has completed its construction time, it is added to the list of online assets for electricity generation.

  Not that with this loop, one assumes that the process for all technology types (solar, wind and CCGT) is the same.

- `elec_UF_elec_prices_updates`

This function is used to update the utilisation factors for solar, wind, CCGT and nuclear technology types. It is also used to update the historical price of these technologies. These prices are the ones used to extrapolate future prices for the NPV and profitability calculations. This is done yearly.

- `pp_investment_recording`

  This function is used to record the amount of investments in the different technologies. This is used to inform the policy makers within the hybrid model.

- `pp_supply_recording`

  This function is used to record all of the supply over a year for the different technologies. These are stored within a dictionary.

- `parameter_update_yearly`

  This function performs all the parameter updates that are needed yearly. This includes:

  – Update the technology parameters depending on pre-set input scenarios (emissions costs, variable costs, ...).
  – Update the utilisation factor and electricity prices for each technology type (see `elec_UF_elec_prices_updates`), the general electricity prices, the cumulative electricity prices, the run of river growth potential and the demand growth.
  – Reset revenue, and supply for all assets.
  – Calculation of the utilisation factor per asset.

- `parameter_update_hourly`

  This function performs all the parameter updates that are needed hourly. This includes:

  – Reset the hourly supply recording, the hourly demand recording, the demand met parameter and the blackout boolean.
  – Update the hydropower and waste reservoirs.
  – Update the import and export values for the NTC assets.
  – Update the ages of the assets and the planned assets.
  – Update of the wind and solar conditions.

  - Introduction of random outages.
  - Calculation of the price preference for the opportunity costs calculation.

- `calculation_solar_UF_potential`

  This function is used to determine the utilisation factor potential for solar installations. This is based on the maximum theoretical solar production in Switzerland and the total capacity already installed.

- `calculation_wind_UF_potential`

  This function is used to determine the utilisation factor potential for wind installations. This is based on the maximum theoretical wind production in Switzerland and the total capacity already installed.

- `pp_KPI_calculation`

  This function is only used as part of the hybrid model. It calculates the KPIs that are needed for the policy actors within the policy emergence model. Each KPI is calculated separately. It consists of:

  - Renewable energy production (S1)

    The calculation is made between the total supply and the total renewable supply (solar, wind, run of river, hydro and hydro pumping). Note that the total supply does not include the NTC and LTC supply. It is then normalised where 0 is no renewable production and 1 is only renewable production.
  - Electricity prices (S2)

    The electricity price average is calculated using the last year average price. It is then normalised with the assumption that the maximum average yearly electricity price cannot go above 150 CHF. If this value turns out to be too low, a warning message will de displayed to tune the model accordingly.
  - Renewable energy investment level (S3)

    The renewable energy investment level is calculating by looking at all investments (wind, solar and CCGT) and comparing it to the amount of renewable investment (wind and solar). A value of 0 means that there is no renewable investment and 1 that there is only renewable investments. Note that the investment only over the previous year are considered and not since the last time a policy was considered.

- Domestic emissions level (S4)

  The emissions are calculated using the CCGT-provided supply. They are normalised using an estimated highest amount. In this case, a value of 0 means that the domestic emissions are high and a value of 1 means that they are low.

- Imported emissions level (S5)

  The imported emissions are calculated using an estimation, based on scenarios, of the electricity mix of bordering countries, and the importations of Switzerland. The share of coal and CCGT is considered along with their respective emissions. This is normalised with an arbitrarily selected maximum level. A value of 0 means high imported emissions and a value of 1 means low emissions.

- Economy (PC1)

  The economy indicator is calculated through a weighted function that considers the electricity prices and the amount of investments only.

- Environment (PC2)

  The environment indicator is also calculated using a weighted function. It considers the amount of renewable energy, the amount of investments, the amount of domestic emissions and the amount of imported emissions.

• `get_supply`

  The `get_supply` functions are numerous and not within the main class. They are used for the datacollector. They are not used anywhere else. Each function is used to collect a specific data point of the model. This is done hourly, when the datacollector function is called.

4.1.3 asset.py

This file is used to redefine the asset class. It copies and modifies the `Asset` class from mesa (former `Agent` class) and introduces the `AssetWCost` class for as a subclass of it. The new class is introduced for assets for which costs are needed and are present in the calculations. This consists of all assets except for the `LTContract` and `NTCAsset`.

There are no functions that are used at this level of the `Asset`.

4.1.4 model_elec_agents.py

4.1.5 model_elec_assets.py

This script included each of the different technology types. Each technology type is its own class and has a number of functions that are used to determine the costs at which electricity is sold for that technology and the amount that can be supplied. Additional function are also sometimes present.

- `calculation_opportunity_cost`
- `PlannedAsset()`
- `SolarAsset(AsssetWCost)`
  - `calculation_cost`
  - `calculation_supply`
- `WindAsset(AsssetWCost)`
  - `calculation_cost`
  - `calculation_supply`
- `HydroAsset(AsssetWCost)`
  - `calculation_cost`
  - `calculation_supply`
  - `reservoir_step_update`
- `HydroPumpingAsset(AsssetWCost)`
  - `calculation_cost`
  - `calculation_supply`
  - `calculation_cost_demand`
  - `reservoir_step_update`
- `RunOfRiverAsset(AsssetWCost)`
  - `calculation_cost`
  - `calculation_supply`
- `WasteAsset(AsssetWCost)`

  - `calculation_cost`
  - `calculation_supply`
  - `reservoir_step_update`

- `CCGTAsset(AsssetWCost)`
  - `calculation_cost`
  - `calculation_supply`

- `NuclearAsset(AsssetWCost)`
  - `calculation_cost`
  - `calculation_supply`

- `LTContract(Asset)`
  - `calculation_cost`
  - `calculation_supply`

- `NTCAsset(Asset)`
  - `calculation_cost`
  - `calculation_supply`
  - `calculation_demand`

4.1.6 model_elec_agents_init.py

4.1.7 model_elec_assets_init.py

4.2 The policy process model

The following is the documentation for the policy process model.

4.2.1 model_SM.py

The `model_SM.py` is the main file fo the policy emergence model. This is where the policy process is coded and stepped through. The different functions of this files are outlined below:

- `get_agents_attributes()`

  This function is used as part of the datacollector function. This function is used to output the key attributed of the policy emergence model agents. Note that a deepcopy function is used for to avoid data rewriting over itself.

- `get_electorate_attributes()`

  This function is similar to the previous one but for the electorate attributes.

- `get_problem_policy_chosen()`

  This function is also used as part of the datacollector function. This function records the agenda selected and the policy implemented by the agents.

- `step()`

  The step function is the main core of policy emergence model. It consists of a set of steps. These are the initialisation, the agenda setting, the policy formulation and the data collection. For the initialisation, this includes the communication of the beliefs from the environment and the impact of the policy instruments to the agents.

- `module_interface_input()`

  The module interface function is used to inform the active agents of what has happened in the environment. This includes taking the indicators and feeding them to the truth agent. Taking the truth agents issue tree and informing all active agents. Finally, it includes informing the active agents about the policy instruments' impact that are recalculated for every step of the policy emergence model.

- `agenda_setting()`

  In the agenda setting step, the active agents first select their policy core issue of preference and then select the agenda. Then we check for all preferences for all agents and see whether there is a majority of one policy core issue. If that is the case, then the policy formulation can happen.

- `policy_formulation()`

  In the policy formulation step, the policy maker agents first select their policy core issue of preference and then they select the policy that is to be implemented if there is a majority of them.

- `preference_update()`

  This function is used to call the preference update functions of the issues of the active agents.

- `preference_update_DC()`

  This function is used to update the preferences of the deep core issues of agents in their respective issue trees.

- `preference_update_PC()`

  This function is used to update the preferences of the policy core issues of agents in their respective issue trees.

- `preference_update_S()`

  This function is used to update the preferences of secondary issues the agents in their respective issue trees.

- `electorate_influence()`

  This function calls the influence actions in the electorate agent class.

4.2.2 model_SM_agents.py

- `ActiveAgent` class:

  The active agent class contains the policy makers and the policy entrepreneurs. These are agents that have a say in the agenda setting and the policy formulation.

  - `selection_PC()`

    This function is used to select the preferred policy core issue for the active agents based on all their preferences for the policy core issues.

  - `selection_S()`

    This function is used to select the preferred secondary issue. First, only the secondary issues that are related, through a causal relation, to the policy core issue on the agenda are placed into an array. Then, the one with the highest preference is selected. It is then used as the issue that the agent will advocate for later on.

  - `selection_PI()`

    This function is used to select the preferred policy instrument from the policy family on the agenda. First the preferences are calculated. Then the policy family preferred is selected as the policy family with the lowest preference (this means the smallest gap after the introduction of the policy family likelihood).

- `ElectorateAgent` class:

  This is the electorate agent class. These agents are only used to influence the policy makers. They cannot be influenced by agents within the system.

  - `electorate_influence()`

    This function is used to perform the electorate influence on the policy makers.

- `TruthAgent` class:

  This is the truth agent class. It is used to transfer the indicators into beliefs for the active agents.

4.2.3 model_SM_agents_initialisation.py

- `issuetree_creation()`

  This function is used to create a skeleton issue tree. This stores all of the issues of the agents.

- `policytree_creation()`

  This function is used to create a skeleton policy tree. This stores all of the policy instruments of the agents.

- `init_active_agents()`

  This function creates all of the active agents that are specified within the inputs of the model.

- `init_electorate_agents()`

  This function creates the electorate passive agents. The electorate

- `init_truth_agent()`

  This function is used to create the truth agent. It has a limited set of attributes and a different structure for its policy tree (it does not need any causal relations).

4.2.4 model_SM_policyImpact.py

This script is used to calculate the impact of the policy instruments. It is done by simulating a separate instance of the model with a specific policy instrument and by recording the outcome. Such simulation are done using parallel processes. Two functions are considered within this script:

- `model_simulation()`

  This function is used to run the independent simulations of the model. It takes in the inputs from the model and outputs the indicators as a result from the simulation.

- `policy_impact_evaluation()`

  This function is used to estimate the impact of the policy instruments on the policy context. This is done by separately simulating every policy instruments and comparing the results with the initial states of the policy context. This is what is then used to inform the agents on the impact of the policies.

4.3 The hybrid model

The following is the documentation for the hybrid model. This includes the script files that are needed to connect the policy context model (electricity model in the present case) with the policy emergence model.

4.3.1 run_batch.py

This script is used to simulate the entire hybrid model for different scenario. To this effect, it contains the inputs for all models. This includes the inputs for the hybrid model itself (number of steps, duration of steps, number of repetitions, number of scenarios, ...), the inputs for the policy context, and the inputs for the policy emergence model (actor distribution, actor belief profiles, ...)

This is then followed by the for loop that simulate the hybrid model. This includes the simulation of a warm up round. Then the policy context is simulated n times for every policy process step simulation. Each feeds the other through indicators and policy selection. The results are all extracted using the data collector from each of the model. The files are saved within .csv files.

4.3.2 model_module_interface.py

This script is used to connect the policy context to the policy emergence model. This part of the model will change every time a new policy context is considered. For this, two functions are considered:

- `belief_tree_input()`

  This function is used to define the agent issue tree. It includes the specification of the deep core, policy core and secondary issues.

- `policy_instrument_input()`

  This function is used to define the policy instruments that the agents can select.

Chapter 5

Inputs

5.1 The electricity model

This section outlines the inputs that are used to initialise the electricity market model.

5.1.1 Asset investments

Firms can invest in thermal, solar and wind technologies. The investments are discrete choices that are detailed below. Note that the costs change over time non-linearly, not all points are outlined below.

Parameters	Thermal	Solar	Wind
Size [MW]	250	100	100
Permit time [months]	36	0.5	6
Construction time [months]	36	12	36
Plant lifetime [years]	55	30	25
Rejection rate [%]	20	20	60
Annual fixed costs [CHF/kWh-year][2018]	10.4	49.3	8.8
Annual fixed costs [CHF/kWh-year][2035]	10.4	38.8	4.7
Variable costs	2.7	0	0
Utilisation factor [%]	0	20	20
Investment costs [CHF/kWh] [2018]	1 051.5	940.5	1 396.9
Investment costs [CHF/kWh] [2035]	983.8	553.2	672.1

5.1.2 Gas and emission prices

The carbon prices are set based on a scenario provided by Demiray et al. (2018). The gas prices are taken from NREL (2018). They are given in the table below:

Year	Gas prices	Emission prices [CHF/ton$_{CO_2}$]
2017	47.333	9
2020	54.906	15
2025	58.693	22
2030	62.479	33
2035	70.053	42
2050	92.773	73

5.1.3 Water inflow

The yearly water inflow is provided as a scenario from VSE (2012):

Year	Inflow
2015	18 733 000
2020	18 767 000
2025	18 767 000
2035	18 83 3000
2050	18 933 000

There is also a hourly profile in percentage of water per year that is obtained from four reference years. These are the years 2010 to 2014. These are obtained from Demiray et al. (2018). They are used in a loop throughout the simulation to calculate the hourly inflow in litter into the reservoirs.

5.1.4 Waste inflow

The average waste inflow in Switzerland is of 233 MW per hour over the entire year. Within the model, it is assumed that this remains constant throughout the year. This is based on electricity statistics for 2016 (2041 GWh per year).

5.1.5 Nuclear fuel price

The price of nuclear fuel is set at 7 $/MWh (NREL, 2018).

5.1.6 Solar radiation and wind capacity

The average Swiss solar radiation is obtained from the years 2015 to 2017. These are then used in a loop for the rest of the simulation. This is similar for the wind and for the same year (SFOE, 2018).

Solar theoretical maximum is 19 702 MW, wind theoretical maximum is 2 282 MW. The lookups used for the code are provided below. Note that currently in the code these are implemented as step function and not as linear continuous functions.

Lookup solar	
0	0.147
0.0367	0.1358
0.9306	0.114155
1	0.100114

Lookup wind	
0	0.3196
0.181	0.2497
0.195	0.2457
0.267	0.2301
1	0.1608

5.1.7 Run of river

For the run of river capacity, an hourly profile is used as input. It is based on data from the years 2010 to 2014 that is looped through for the simulation. The source for this data is Demiray et al. (2018).

This needs to be checked (the data is not obtained where the reference indicates) - what is used in the code is placed in the table.

Year	Inflow [kWh]
2015	16 400 000
2020	16 700 000
2025	16 933 000
2035	17 533 000
2050	18 333 000

5.1.8 Foreign capacity

The foreign aspect of the model is also dealt with input data. For the prices, they are obtained based on average prices in France, Germany and

Italy between 2015 and 2017. Similarly for the average border capacity both for imports and exports, this is used hourly from the input data of the years 2015 to 2017. This data is obtained from the ENTSO-E transparency platform (ENTSO-E, 2018).

5.2 The policy process model

There are no inputs to be considered within the policy process model. Most parameters need to be intialised and are therefore detailed in the initialisation.

5.3 The hybrid model

Chapter 6

Model simulation

6.1 The steps for model integration

This section presents the steps that are needed to connect a policy context model, in this case the predation model, to the policy process model.

1. Before any coding, define what the belief tree and the policy instruments will be for the predation model.

2. Copy the policy emergence model files into the same folder.

3. In `runbatch.py`, replace the policy context items by the predation model.

4. In `runbatch.py`, make sure to initialise the predation model appropriately.

5. Change the `input goalProfiles` files to have the appropriate belief tree structure of the predation model.

6. In `model module interface.py`, construct the belief tree and the policy instrument array.

7. Make sure that the step function in the `model predation.py` returns the KPIs that will fit in the belief system in the order DC, PC and S. If no DC is considered, then include one value of 0 at least. All KPIs need to be normalised.

8. Modify the step function of the `model predation.py` to include a policy implemented.

9. Introduce the changes that a policy implemented would have on the model in `model predation.py`.

6.2 The steps for model simulation

This section presents the steps that are needed to connect a policy context model, in this case the electricity model, to the policy process model.

1. For the policy process:
   (a) Define a set of hypotheses to be tested
   (b) Define scenarios that will be needed to assess the hypotheses
   (c) Choose the agent distribution based on the scenarios constructed
   (d) Set the preferred states for the active agents and the electorate along with the causal beliefs to be used. This should all be based on the scenarios that have been constructed.
2. For the predation model:
   (a) Define the initial values for the main parameters
   (b) Define the parameters that will be recorded
3. Save the right data from the model.

Chapter 7

Verification

7.1 The electricity model

Most of the verification of the electricity model has been performed, though it has not been documented. This might be redone in the future.

7.2 The policy process model

The following is the verification for the policy process model.

Functions	**Issues**	**Verified**
model_SM.py		Yes
get_agents_attributes	None	Yes
get_electorate_attributes	None	Yes
get_problem_policy_chosen	None	Yes
step	None	Yes
module_interface_input	None	Yes
agenda_setting	None	Yes
policy_formulation	None	Yes
preference_update	None	Yes
preference_update_DC	None	Yes
preference_update_PC	None	Yes
preference_update_S	None	Yes
electorate_influence	None	Yes
model_SM_agents.py		Yes
selection_PC	None	Yes

Continued on next page

Table 7.1 – *Continued from previous page*

Functions	**Issues**	**Verified**
selection_S	None	Yes
selection_PI	Was missing a check for the agenda - has been added	Yes
electorate_influence	None	Yes
model_SM_agents_initialisation.py		Yes
issuetree_creation	None	Yes
policytree_creation	None	Yes
init_active_agents	None	Yes
init_electorate_agents	None	Yes
init_electorate_agents	None	Yes
init_truth_agent	None	Yes
	None	Yes
model_SM_policyImpact.py		Yes
model_simulation	None	Yes
policy_impact_evaluation	Some code simplification were performed	Yes

7.3 The hybrid model

Chapter 8

Experiments

Before the simulation of the model, there is a need to plan what we want to simulate. This is based on the research question that we would like to answer. We first create a number of hypotheses that we want to prove. We then build the scenarios to test these hypotheses. These scenarios should detail the required initial parameters.

8.1 The model hypotheses

Several hypotheses are made for testing the electricity model. They are given as follows:

- H1: An increasingly environmentally conscious electorate will lead to more indigenous renewable investments regardless of the speed electrification of the energy sector.

The hypotheses should relate to the impact of actors on the unfolding of the electricity model in a range of growth scenarios.

The current hypothesis would require a variation in the electorate rate of change (scenarios for the electorate), along with a variation in the demand growth scenarios.

8.2 The scenarios

Scenarios are built to attempt to prove the hypothesis that has been outlined before. The hypothesis spans a number of parameters in both models that will need to be changed. This includes a variation in the electorate's goal evolution and a variation of the demand growth scenarios.

8.2.1 Electorate goal changes

There are three main options when looking at the changes of the preferred states of the electorates over time:

- Option 1: We can have some sort of benchmark test where both electorates start with the same preferred states.
- Option 2: We make three scenarios with one variation over time of the preferred states. Scenario 1 has the preferred states of all electorates change, scenario 2 would only see the preferred states of electorate 1 change and scenario 3 would see the same but for electorate 2.
- Option 3: The scenarios are based on the electorates' preferred states changing at different rates. This might include one electorate (economy) changing at a slower pace that the second electorate (environment)

I think we can assume that the environmental consciousness of the electorate is only going to grow over time or at least not decrease. Therefore we will select option 3 with three scenarios. These are provided below:

- S1: Affiliation 1 and 2 preferred states for environment grow quickly at same rate (see **??**).
- S2: Affiliation 1 preferred states for environment grows slowly while it grows fast for affiliation 2 (see **??**).
- S3: Affiliation 1 preferred states for environment stays constant while it grows fast for affiliation 2 (see **??**).

The changes in the preferred states happen twice within the model at regular intervals.

As a reminder, the issues are:

- S1: renewable energy production on range [0, 1].
- S2: electricity prices on range [200, 0].
- S3: renewable energy investment level on range [0, 1].
- S4: domestic level emissions on range [0, $\sim$20m].
- S5: imported emissions on range [0, $\sim$9m].

	PC1 Econ.	PC2 Env.	S1 RES	S2 Price	S3 REI	S4 Dom. em.	S5 Imp. em.
Policy makers			0.60	50 CHF/MWh	0.70	4 m [?]	60k [?]
	0.70	0.53	0.60	0.75	0.70	0.80	0.33
Electorate			100%	75 CHF/ MWh	100%	0.00 [?]	5000.00 [?]
	0.73	0.89	1.00	0.63	1.00	1.00	0.94

Table 8.1: New table - Starting preferred states for the policy makers and preferred states for the electorate agents in 2040 on a the interval [0,1].

- PC1: economy [0, 1].
- PC2: environment [0, 1].

How are the initial values selected for the different electorate affiliations? When the party is neutral on a certain issue, we assume that they favour the status quo. Therefore, the preferred states for the electorates will be those of the initial states in the simulation. When the party is not neutral, a guestimation is made based on where we would expect each affiliation would want to be in the future. The policy core values are calculated based on the preferences on the secondary issues.

Remark: One of the weakness of this approach is the need for goals for all of the beliefs. In a lot of cases, for the electricity model, agents do not necessarily have a goal when they are not interested in the topic. They are simply indifferent. This is something that should be discussed in the limitations of the model.

Remark 2: There is an irony in the way the economy KPI is calculated. Because it is only base don electricity prices and the investments, if both actors want the same prices, then the affiliation for the environment will want more economy than the economy affiliation. This is a direct consequence of the system boundaries.

8.2.2 Growth demand

The electricity demand growth needs to be varied to confirm the hypothesis. The basis behind such changes are to account for increasing efficiencies in the electricity sector while at the same time sustaining the electrification of the energy sector, including heating and mobility. Four different levels of demand growths are considered: 0%, 1%, 2% and 3%.

8.3 The initialisation of the model

8.3.1 The policy process model

The affiliations, the actor distribution and their preferred state need to be initialised for the policy process model. These elements are not part of the scenarios and are therefore constant across all simulations.

The affiliations There are two affiliations that need to be considered for the electricity sector in the policy process model. These follow the findings of Markard et al. (2016). One of the affiliation is focused on the economy (affiliation 1) while the other on the environment (affiliation 2). Their differences in beliefs outlined in Markard et al. (2016) will be reflected in their preferred states. Note that no surveys were performed for this study as this is an initial study and it is considered that the study made in Markard et al. (2016) is still sufficiently recent to apply to the model at hand here.

The actor distribution It is assumed in this approach that the actor distribution will not change over time. Only the beliefs of the electorate and the actors change. This is an assumption that could have an impact on the results obtained. This is translated in 3 policy makers and 4 policy entrepreneurs (Affiliation 1: 2 policy maker and 2 policy entrepreneurs; affiliation 2: 1 policy makers and 2 policy entrepreneurs).

Because of computational efficiency issues, not all actors that were found to have a role to play in Markard et al. (2016) can be considered. Similarly, not all of the Swiss parliament can be reflected within this study. All actors are therefore aggregated down to a size of roughly ten actors in total.

The actor preferred states The actor preferred states are given in Table 8.2. They are identical to the preferred states of their respective electorate at that point in time. Their causal beliefs are given in Table 8.3. The causal beliefs are equivalent to the ones used within the model. This assumes that the agents have a perfect understanding of the inner workings of the system. It is not in the scope of the present research to understand the effect of an imperfect understanding of the system by the actors and therefore, it is not studied here. This is also means that there are no negative influences on the

The causal beliefs between deep core and policy core beliefs are not present in Table 8.3 as no deep core belief is considered for this specific case.

	PC1 Eco.	PC2 Env.	S1 RES	S2 Price	S3 REI	S4 Dom. em.	S5 Imp. em.
Aff. 1	0.70	0.53	0.60	0.75 (50)	0.70	0.80 (4m)	0.33 (60k)
Aff. 2	0.65	0.78	0.75	0.75 (50)	1.00	0.95 (1m)	0.55 (40k)

Table 8.2: Preferred states for the electorate agents in both affiliation on a the interval [0,1].

	PC1	PC2
-S1	0.00	0.25
-S2	0.75	0.00
-S3	0.25	0.25
-S4	0.00	0.25
-S5	0.00	0.25

Table 8.3: Causal beliefs for the agents of both affiliations. These causal relations can be read as: the impact of S1 on PC2 is 0.25. They are all given on the interval [-1,1].

The hybrid model duration The model simulation last 27 years in total with a warmup time of three years. This considers a start of year of 2016, therefore the model runs until 2043. The interval between policy process is 3 years with the policy process model being called 9 times. The scenarios are therefore triggered at time of 9 years ($t_1 = 2025$) and 18 years ($t_2 = 2034$). The evaluation interval, that is the amount of time that is used to test the effectiveness of policies is set at 3 years, similar to the interval between which policy processes are called. (At the moment an interval of ten years is also tested to observe potential consequences of such changes).

Chapter 9

Model initialisation

Chapter 10

Results

Chapter 11

Conclusions

Bibliography

Baumgartner, F. R., Jones, B. D., and Mortensen, P. B. (2014). Punctuated equilibrium theory: Explaining stability and change in public policymaking. In Sabatier, P. A. and Weible, C. M., editors, *Theories of the policy process*, pages 59–103. Westview Press Boulder, CO, third edition edition.

Demiray, T., Weigt, H., Beccuti, G., Schlecht, I., Savelsberg, J., and Schillinger, M. (2018). Modellierung der system adequacy in der schweiz im bereich strom. Technical report, Swiss Federal Office of Energy.

ENTSO-E (2018). Transparency platform. Technical report, ENTSO-E.

Grimm, V., Berger, U., DeAngelis, D. L., Polhill, J. G., Giske, J., and Railsback, S. F. (2010). The odd protocol: a review and first update. *Ecological modelling*, 221(23):2760–2768.

Klein, R. (2017). *Policy Emergence - An Agent-based approach*. TU Delft.

Laver, M. and Sergenti, E. (2011). *Party competition: An agent-based model*. Princeton University Press.

Markard, J., Suter, M., and Ingold, K. (2016). Socio-technical transitions and policy change – advocacy coalitions in swiss energy policy. *Environmental Innovation and Societal Transitions*, 18:215 – 237.

Nohrstedt, D. and Weible, C. M. (2010). The logic of policy change after crisis: Proximity and subsystem interaction. *Risk, Hazards & Crisis in Public Policy*, 1(2):1–32.

NREL (2018). Annual technology baseline (atb) from the national renewable energy laboratory. Technical report, NREL.

Sabatier, P. A. (1987). Knowledge, policy-oriented learning, and policy change: An advocacy coalition framework. *Knowledge*, 8(4):649–692.

Sabatier, P. A. (1988). An advocacy coalition framework of policy change and the role of policy-oriented learning therein. *Policy Sciences*.

Sabatier, P. A. and Weible, C. M. (2007). The advocacy coalition framework the advocacy coalition framework - innovations and clarifications. In Sabatier, P. A., editor, *Theories of the policy process*. Westview Press.

SFOE (2018). Schweizerische elektrizitätsstatistik 2017. Technical report, Swiss Federal Office of Energy.

Simmons, R. H., Davis, B. W., Chapman, R. J., and Sager, D. D. (1974). Policy flow analysis: A conceptual model for comparative public policy research. *Western Political Quarterly*, 27(3):457–468.

van Baal, P. (2016). Business implications of the energy transition in switzerland. Master's thesis, EPFL.

van Baal, P. and Finger, M. (2019). The effectiveness of a strategic energy reserve during the energy transition: The case of switzerland.

VSE (2012). Scénarios pour l'approvisionnement électrique du futur - rapport global. Technical report, Verband Schweizerischer Elektrizitätsunternehmen.

Weible, C. M. and Ingold, K. (2018). Why advocacy coalitions matter and practical insights about them. *Policy & Politics*, 46(2):325–343.

Appendix A

Dear Diary

This section outlines some passing thoughts as the model is being developped.

A.1 22/10/2019

In the current iteration of the model, all actors of the same affiliation practically have the same beliefs. Because there is no communication and perfect knowledge and information transmission, this means that the majority affiliation always decides on what policy instruments should be implemented based on their interests. If summarise, this means that one policy maker of the majority affiliation decides what policy should be implemented. This can be seen as a problem because it effectively means that the entire policy process part of the model is pretty much useless.

However, if one were to think that we are only studying the impact of the electorate on policy change, then this is not so much of a problem. As the preferred states of the agents evolve over time, the policy selected might change. If it is limited to that then it might be fine.

One way to make this more interesting would be to change the consensus criterion to one where 2/3rd of the actors need to prefer a policy instrument for it to be implemented. This, along with a different way to counting which instruments are preferred by 2/3rd of the actors would be needed. In such a scenario, the opposition would have a say on what policy instrument is implemented. This might further better represent Switzerland which tends to be a compromise country.

A.2 23/10/2019

One of the reasons why the actors always select policy instrument 0 is that all policy instruments just have very little impact on the model. Therefore, PI0 is always the one that is selected because it is always slightly better.

There could also just be a lack of verification of the run_batch elements. This needs to be further checked. Because even when the actors had different beliefs (the ones from the predation model of all models), then they also chose PI0.

PI1 has been selected once on time step 5 for scenario 2 growth of 0%.

What about the fact that maybe the testing period of these policies is too limited, giving bad advice to the actors and therefore leading them to make bad decisions. This could be fixed by changing the amount of year checked every time. This is also very computationally inefficient.

Test the model with 9 years of check for each policy instead of the current three.

A.3 24/10/2019

Today I am running the model for an evaluation interval of ten years on the desktop to check whether the results are affected.

On a simulation with evaluation interval of 3, for scenario 2 growth 0%, step 1 has selected PI9. Overall the rest of the selection seems to remain on PI0 for the majority of the time.

On a simulation with evaluation interval of 10, for scenario 1 growth 1%, step 1 has selected PI4. Overall the rest of the selection seems to remain on PI0 for the majority of the time.

From an early look at the simulations, the evaluation interval change does not seem to affect the policy outcomes within the model.

PI4 selected again once for another simulation.

A.4 25/10/2019

Performing verification on the policy instrument selection, it appears that the preference for all of the instruments is the same (0.091) for all actors. This means that there is a problem in the selection of the policy instruments. Maybe check this with the predation model and then see how that changes in the electricity model.

Looking at the predation model, this does not appear to be a systematic issue with the policy emergence model. It seems to be a problem for the electricity model only.

A mistake was found in the core of the model where the policy are evaluated. There was an indices problems when the results were compared to the initial KPIs meaning the agents were assessing the wrong policies (basically). It has been fixed and changed in all models (that now need to be rerun as well).

One thing that still needs to be checked is, though all agents get the same information, they should have different policy instrument preferences based on their secondary goals. This does not seem to be the case for now in the electricity model. This needs to be checked.

Looking at the predation model, it seems that the root of all problems is in the selection of the policy instruments based on preferences. The preferences do not add up to 1 (which they should).