A System Dynamics model for the Cost Recovery of Residential Smart Meter Roll-Out in the Lemanic Area

Amin Dehdarian[1], Peter Racz[1]

[1] Department of Management of Technology, Ecole Polytechnique Federale Lausanne (EPFL), Switzerland

Abstract

In this paper, the effect of governance intervention on the cost allocation of residential Smart Meter roll-out among relevant actors is analyzed. Feedback structures between different dimensions of institutions, including economic, political, social and technological institutions, in energy systems cause institutional lock-in preventing change in these systems. In this paper, the dominant feedback structure between economic and political dimensions of institutional lock-in is analyzed by using a system dynamics model of cost allocation of smart meter roll out in the case of Romande Energie, a state-owned energy company in the Swiss Lemanic area. By modeling, the effect of different policy interventions on two different organizational structure for the utility company are analyzed. Based on the results, policies are proposed for ensuring the efficient cost recovery of smart meter implementation and insights for un-locking the institutional inertia in the energy system and directing transition in energy sector are discussed

1. Introduction

Electricity for households is a public need, like water. It has no substitute, it is a fundamental pillar of a city, region or a country. The electricity infrastructure is getting more and more complex, so new technologies have to be introduced in order to increase its operational efficiency and ensure its secure functionality for a sustainable future. Smart Meters are one of the enabling technologies that provide social and economic advantages for a society.

The mass implementation of Smart Meters is a capital intensive task. Investors are uncertain about the profitability of this technology as Smart Metering, in a long-term, is an enabling technology that facilitates the improvement of the electricity supply chain, so its long-term economic value is hardly measurable. Short-term gains do not provide the Distribution System Operators (DSO) sufficient incentive to undertake such a costly and risky investment. Besides the incentives of the individual actors, public interest of the investment has to be considered as well, as Smart Metering can contribute to the electricity consumption reduction.

Smart Meter integration concerns all the actors of the downstream part of the electricity supply chain so its roll out and its cost recovery has to be considered by the participation of all the relevant actors. The interaction among these actors is a key factor regarding the success of the implementation. These actors are motivated by their own financial incentives which can be contradictory. Switzerland's electricity sector is not yet completely liberalized: consumers under 100 MWh yearly consumption have no access to the market. It means that household consumers cannot choose their electricity provides freely. Most of Switzerland's electricity distributors operate according to the accounting unbundling principle: the production, the commercialization and the distribution units are financially separated even if these units belong to the same company (e.g. Groupe Romande Energie). In the case of both the accounting unbundling and vertically integration, the electricity companies can abuse of their position. ElCom, the Swiss Electricity Regulator supervises these companies in order to avoid such kind of situations. The Smart Meter implementation is not an exception; it would require the active participation of ElCom by setting up institutions for a smooth, socially and economically efficient implementation.

2. Smart Metering: Quantification of actors' short- and long-term benefits

In order to analyze the cost allocation process of Smart Meter implementation, the integration related cost and the economic value of possible benefits have to be determined in the case of each actor (consumer, DSO, Retailer) related to Smart Metering. This would require tight collaboration with the Distribution System Operators and the Retailers.

2.1 Utility

The assumptions related to Romande Energie on which this paper is based are the following:

- The company operates according to the accounting unbundling principle: retail and distribution system operation are separated in a financial way.
- Romande Energie is the owner of the infrastructure related assets.

Table 1 :Romande Energie :Characteristics

Households served	176360	Clients
Av. # of person per household	2.2	Person
Av. Consumption per household	5000	KWh/Year
Total Residential Consumption	881.18	GWh/Year
# of MV/LV Transformers serving households	2160	Pcs
# of MV/LV Transformers per household	81	Pcs

- Currently, all the households are on the "Volta Simple" tariff (Table 2).

Table 2 : Volta Simple Tariff

	Volta Simple Tariff	
Subscription	66	CHF/Year
Tariff	0.0798	CHF/KWh
Energy	0.106	CHF/KWh

- Profit margin of the distribution divisions is 10% (EBIT).
- The wholesale market electricity prices are based on the German Spot Market prices from 2010 and 2011.

- The normalized consumption profile of Swiss households is similar to the United Kingdom's profile [1] which was adapted to the Swiss yearly household consumption (Figure 1).

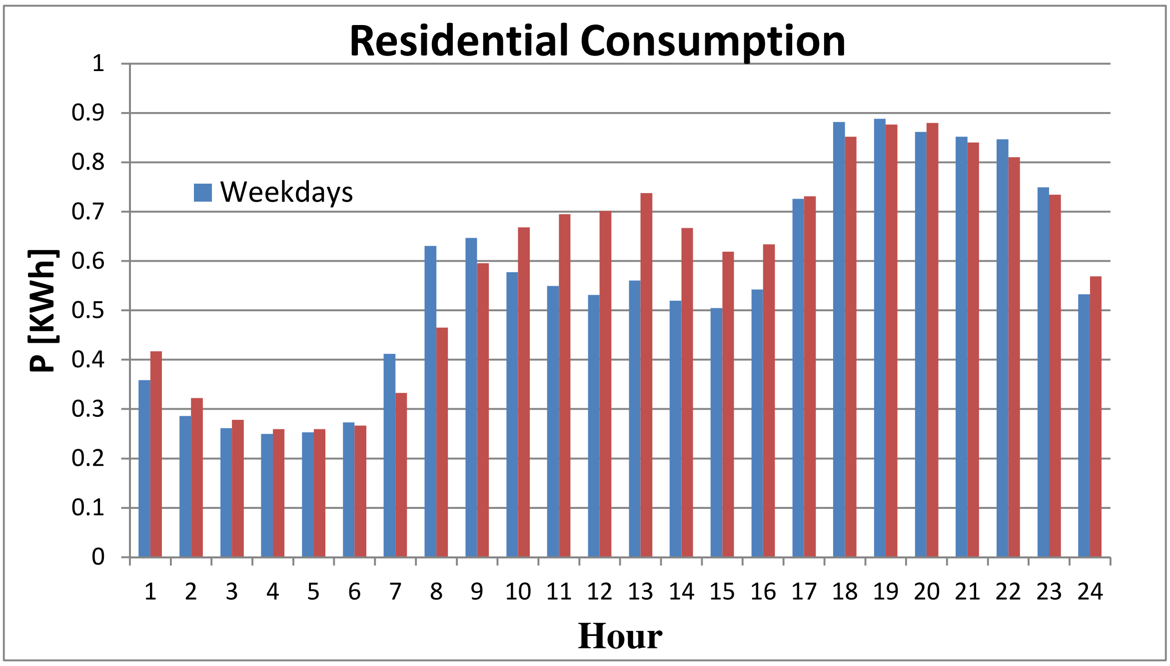


Figure 1: Consumption profile of households [1]

2.2. Consumer

The consumer is characterized by the consumption profile represented in Figure 1. During the week the consumption peaks are between 7-9am and 6-10pm. At the weekend, the consumption is higher during the afternoon as people usually stay at home and use their electronic devices more often.

The benefits of consumers would come from two sources in case of the implementation of Smart Meters by using dynamic pricing:

- Load-shifting
- Conservation Effect

The incertitude regarding the values of these effects is high. People have different lifestyles and different electronic devices, but an average value still can be estimated. Two types of results can be found in the literature: experimental values from pilot projects and estimations based on theory.

A lot of pilot programs were studied from Canada and the United Stated in order to quantify the potential benefit of these effects. The best documented results are given by the Canadian Hydro One company about the pilot project conducted from May to September 2007 [2]. The electricity consumption per capita is higher in Canada than in Switzerland but it is supposed that the Swiss households would react in a similar way in case of the implementation of the

Time-of-Use electricity prices. Besides this information the load-shifting potential is estimated by using experimental data about the household equipment's consumption and their time of use during the day and the week.

1) Hydro One Pilot Project May to September 2007

The project was conducted in order to identify the impact of Time-of-Use electricity prices as well the impact of the Real Time Monitoring (RTM) of the consumption for residential consumers. The following table summarizes the experimental results of the pilot program.

Table 3 : Hydro One Pilot Program Results

Load-Shifting (% of the total consumption)	
TOU effect	-3.7%
TOU and RTM effect	-5.5%
Conservation (% of the total consumption)	
TOU effect	-4.3%
TOU and RTM effect	-7.6%

It is assumed, that the RTM effect can be reached not only with fixed display as in the case of Hydro One, but with other enabling devices as well, such as smartphones, tablets or PCs without having a fixed device for this purpose. Based on this report, out of 5.5% shifted, 3% is from on- to off-peak and 2.5% is on- to mid-peak shift.

2) Theoretical potential for load-shifting

The potential load shift is estimated by using the penetration of different household devices in Switzerland [3] and by using the utilization profile of these devices [4]. The load of devices like washing machine, dishwasher, and clothes dryer can be shifted easily and represents a non-negligible potential of economies. The author based on this information estimates that a usual Swiss household could shift about 310 kWh per year which corresponds to 6.2% of the total yearly consumption. This estimation confirms the experimental values coming from Hydro One that are used in this paper.

2.3. Distribution System Operator (DSO)

The cost structure of Romande Energie's distribution department is estimated by using information available about European DSO's as they all are supposed to have similar cost structure characteristics.

2.3.1. Cost structure

Figure 2 shows the distribution of the Finnish DSO's costs. It can be deduced that the fixed cost is 54% while the variable cost is 46% of the total cost. These values are in the same order as the estimations of the Swiss Federal Department of Economy [6]. The cost of Romande Energie Distribution is not known so its amount is estimated from the revenue by assuming 10% of profit margin.

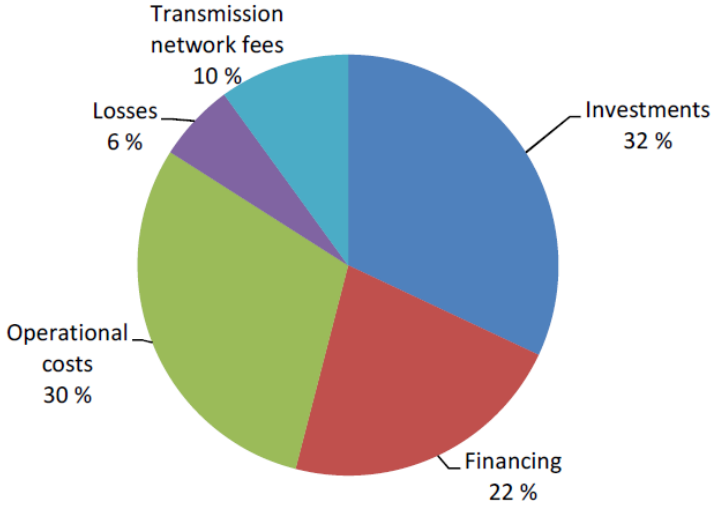


Figure 2 : Cost structure of a usual Finnish DSO [5]

It results in the following variable and fixed cost per consumer

Table 4 : Cost structure of the DSO per household

Cost structure per household	Value	Unit
Fixed	229	CHF/Year
Variable	0.039	CHF/kWh
TOTAL with 5000kWh/Year Consumption	423	CHF/Year

2.3.2. Smart Meter Implementation: OPEX and CAPEX effects

The estimation of the CAPEX and OPEX of the implementation per Smart Meter is a complex task. The Association Smart Grid Switzerland provides an estimation of these costs for a lifetime of 10 years. However, other sources, like the Impact Assessment of Smart Meter Implementation for Switzerland [7] works with 15-20 years of operation. In this paper, 15 years of operating time will be used so the respective operating cost is recalculated.

Table 5 shows the structure of these costs.

With an interest rate of 1% [9]and a lifetime of 15 years, the OPEX and the CAPEX are given by table 6.

2.3.2.1 OPEX reduction: Remote Meter Reading and Data Management

Smart Metering allows remote reading of the devices and better data management of the consumption. M.Steinmann , in charge of the energy efficiency project at the Electrical Utility of Zurich said in 2009 that the reading of conventional meters costs 10 CHF per year per unit. [10] . Thus, the possible economies would be approximately 10 CHF per Smart Meter.

Table 5 : CAPEX and OPEX per Smart Meters (life cycle 10 years) [8]

	Investment Cost [CHF]		
	Minimum	**Mean**	**Maximum**
Metering Device	178	209	286
Installation	33	122	260
IT System	13	18	24
Implementation	0	18	27
Premature Depreciation of Old Devices	10	28	72
CAPEX [per device]	**302**	**395**	**546**
OPEX Platform	23	69	98
OPEX Communication	20	52	106
OPEX [per device] 10y	**49**	**120**	**185**
TOTAL [per device] 10y	**391**	**516**	**626**

Table 6 : Annualized and total investment cost of Smart Meters

	Scenario		
	Min Cost	**Mean Cost**	**Max Cost**
Annualized CAPEX [CHF/Year]	22	29	40
OPEX [CHF/Year]	5	12	19
Total [CHF/Year]	27	41	59
Capital Required [CHF 2014]	**~54 mio**	**~70 mio**	**~95 mio**

2.3.2.2 Further OPEX and CAPEX reduction

The electricity networks, historically, were built according to the current needs of a given region, without really having a clear strategic view about the optimal network structure which could ensure both the current and the future needs. This led to the fact that nowadays, most of the electricity networks are struggling with the following problems:

- The configuration of the network is not optimal
- The losses occurring in the network are relatively high
- The equipment is not standardized

To solve these problems, one can identify two types of network planning strategies:

- Short-term (Connection of new consumer to the grid, modifications to strengthen the grid etc.)
- Long-term (Strategic network planning using an "ideal network"

Smart Metering would facilitate and would open a new horizon in the short- and long term planning as well, which gives an important economic value to the Smart Metered data.

The Low Voltage network is not as critical as the Medium Voltage (MV) network from a reliability point of view but regarding the assets, 50% of the value of the distribution network is concentrated in the Low Voltage (LV) level and in the MV/LV substations in Finland for example. [11]

2.3.3 Short-term Network Planning

According to Schneider Electric, 90% of the non-technical losses in distribution networks occur in the Low Voltage (LV) network. They estimate that these losses are between 1000€ and 10000€ per MV/LV substation per year in the European countries. Smart Metering would allow the localization of these losses by providing accurate metering data distributed all over the network, so recover these losses. [12] In this paper, 1000 CHF of non-technical losses are assumed in the case of Romande Energie per each substation that serves mainly residential consumers.

Technical losses are physical losses including load and no load losses. Non-technical losses are financial losses that concern the not invoiced but delivered energy (theft, non-metered public lightning and consumption of the equipment of the distribution network).

According to the Swiss Statistics of Electricity, the total transmission and distribution losses were 4.4TWh of 63.4TWh in 2012. [13] It corresponds to 6.94% of the distributed energy. Schneider-Electric, for 6% of average losses in the European networks, accounts 2% for the transmission network and 4% for the distribution network. Keeping the same ratio it results in 4.63% of energy loss for the Swiss distribution network. [12]

By using the information shown on Figure 3, the losses accountable for the LV network represent roughly 60% of the distribution losses, so 2.8% of the total losses in Switzerland that include technical and non-technical losses.

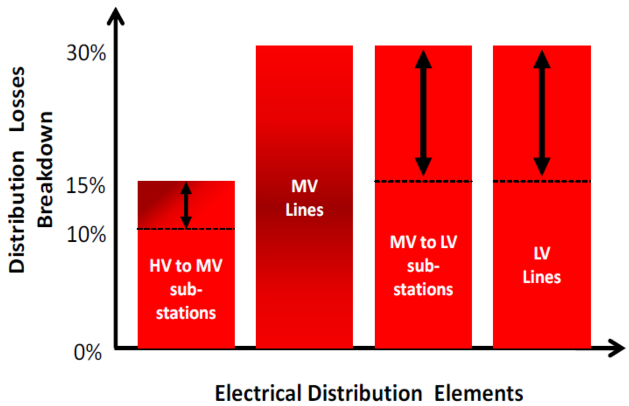


Figure 3 : Location of losses in the Distribution Network [12]

According to the French ERDF (Électricité Réseau Distribution France) [14] the losses on its network account for 3.5% as a technical and 2.5% as non-technical losses of the distributed energy. By keeping the same ratio for the 6.94% total losses in Switzerland and having in mind that 90% of the total non-technical losses occur in the LV network, it corresponds to 2.5% of the total energy distributed, so 1.585 TWh in Switzerland. It means that distribution losses could be reduced by 2.5% by taking appropriate measures (reduction of non-technical losses).

2.3.4 Long-term Network Planning

Long-term network planning is based on strategic decisions for 20-40 years, which will shape the structure and the technology of the future electricity distribution networks. In 2013, during the author's discussion with the Electrical Utilities of Lausanne (SEL), SEL highlighted the necessity of having a guideline for the network development. Smart Metering allows, by knowing the exact load at each consumer, the planning of an "ideal distribution network". This ideal network can be used for long-term strategic decisions, i.e. by supporting the network structure related important investments decision making. The mechanism is showed in Figure 4.

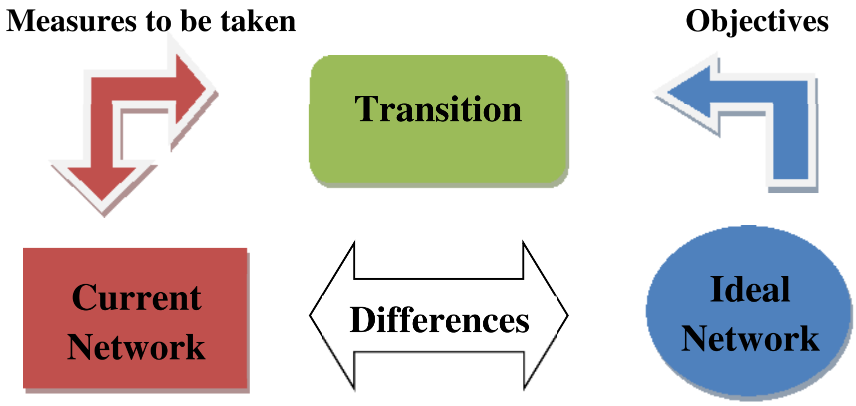


Figure 4 : Ideal Network, Investment Decision Supporting Mechanism

All in all, the analysis above shows that the potential benefits of the Distribution System Operator can be assessed as follows:

Table 7 : DSO's benefit and drawbacks

Benefit	[CHF/Year per household]	
OPEX [Remote device reading]	10	
OPEX [Reduction of Non-Technical Losses]	12.6	
CAPEX [Network Development]	++	
Conservation Effect	TOU	TOU+RTM
	-7	-16
TOTAL	**15.6+**	**6.6+**

The conservation effect due to the introduction of Time-of-Use retail pricing and the Real Time Monitoring appears as a negative benefit that the DSO should compensate. Table 8 shows that the pay-off of the Distribution System Operator would in all the cases be negative. That is the reason why the Swiss companies in the industry are still hesitating to undertake such a technical change. It is obvious that only a coordinated cooperation between the actors could lead to cost efficient integration of Smart Meters. The system dynamics simulation will provide possible solutions to recover the investment cost of DSO efficiently.

Table 8 : Financial balance of the DSO

	Scenario					
	Min Cost		Mean Cost		Max Cost	
Total Expenses [CHF/Year]	27		41		59	
Total Benefits [CHF/Year]	TOU	TOU+RTM	TOU	TOU+RTM	TOU	TOU+RTM
	15.6	6.6	15.6	6.6	15.6	6.6
TOTAL [CHF/Year]	**-12**	**-21**	**-26**	**-35**	**-44**	**-53**

2.4. Retailer

The cost structure of Romande Energie's retail department is estimated by assuming that the retail division is mainly influenced by the market price of electricity, i.e. the cost structure of the retail part of the company is supposed to be driven by the variable cost and the fixed cost associated to the sale of energy is supposed to be negligible.

2.4.1. Cost Structure

As the energy price is changing year by year, the value of the variable cost per kWh is calculated according to the market price. Without any information about Romande Energie Retail's cost structure the variable cost is estimated by using the average market price and a correction factor of 1.1, in order to take into account the different taxes and cost as well related to the trading of energy.

Therefore, the Retailer's benefit comes from the reduced consumption during peak hours however the conservation effect has a negative impact on the Retailer's revenue. The financial impact of these effects depends on the consumption conservation and market price that are normally distributed. In addition to it, the market price evolves in time so the exact amount of these financial advantages and disadvantages will be quantified in the model.

Table 9 : Retailer's benefit and drawbacks

Benefit & Drawbacks	[CHF/Year per household]	
Load Shift	TOU	TOU+RTM
	+ +	+ +
Conservation Effect	TOU	TOU+RTM
	-	- -
TOTAL	+	+

2.4.2. Wholesale Electricity Price

To assess the cost and benefits of Smart Metering, the wholesale price of electricity has to be considered. In this paper, statistical data from the German electricity spot market is used from 2010 and 2011 [15]. One can see in Figure 5 that the electricity price is about 10 CHF higher at the peak periods (lunch time and from the morning until the beginning of the afternoon). So, the goal is to smooth these peaks by shifting load to mid- or off-peak periods in order to save money and save network capacity.

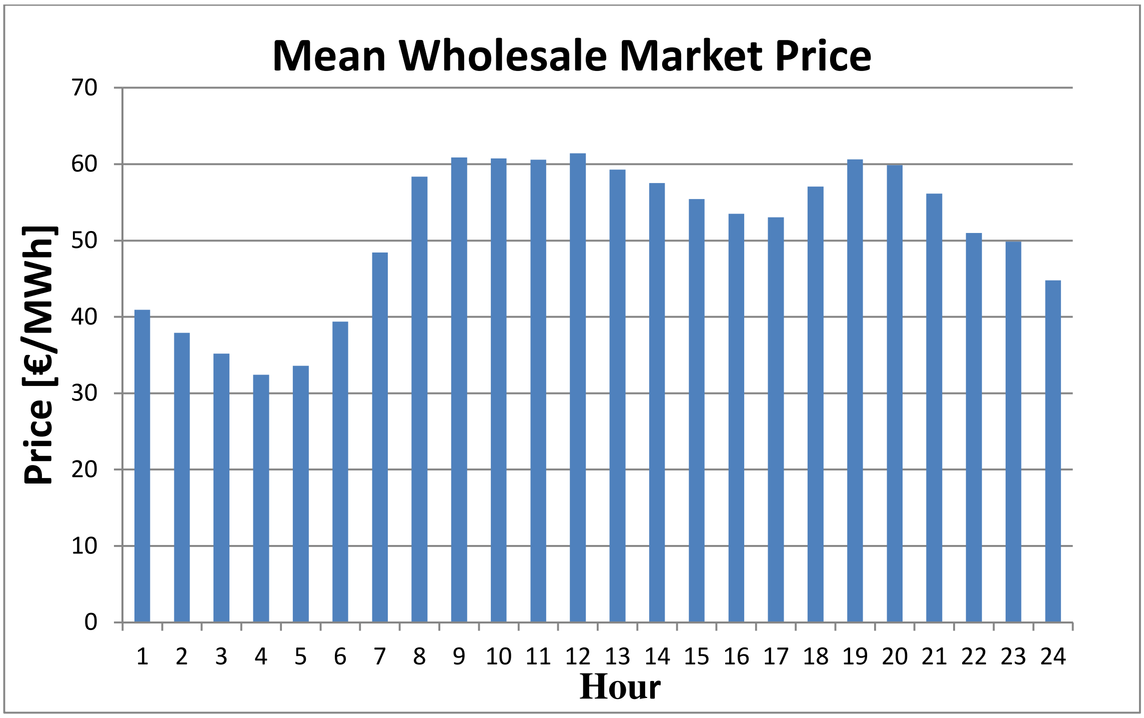


Figure 5 : Mean Wholesale Electricity Price (corrected for weekends and holidays) [15]

3. Conceptual System Dynamics Diagrams

The cost recovery of long-term infrastructure related investments is not a trivial task as the role of the actors involved in the technological change is not always clear. The financial advantages are not concentrated in the hands of one player but among all the actors. Highly profitable investments can be recovered without the participation of all the actors. It is not the case regarding Smart Metering. Traditionally, it is the Distribution System Operator who owns the metering devices, so it is up to this company to cover the investment cost. However, the DSO alone is not able to recover this cost as the benefits of Smart Meters are distributed along the electricity supply chain. The idea of this paper is that by looking at the financial incentives of the relevant actors (Retailer, DSO, consumer) the DSO can allocate the cost recovery options according to the financial incentives of the different actors. The behavior of these three actors creates a dynamic complexity that cannot be solved without modelling the problem.

System Dynamics modelling is used to simulate the cost allocation process of the residential Smart Meter implementation. This method allows identifying the different interactions between the actors concerned by the integration of the metering devices. Based on the benefit and drawbacks of Smart Metering of the three actors presented in the last chapter, first a mixed conceptual diagram is built to understand what the dynamics of the problem are.

In order to evaluate which company structure is the most adapted for the implementation, two types of structures are simulated:

1) Vertically integrated electricity distributor and retailer

2) Accounting unbundled electricity distributor and retailer

The Groupe Romande Energie operates according to the principle of accounting unbundling, so the different activities are financially separated (production, distribution, commercialization). However, in order to compare the efficiency of this structure in case of an infrastructure related investments, its behavior is compared with the one of a vertically integrated company.

3.1. Conceptual Model for a vertically integrated structure

In case of a vertically integrated structure, the two main actors concerned by the implementation of the Smart Meters are the consumer and the integrated electricity company. Their financial incentives are modelled by the electricity bill change and the profit change respectively which are represented as stocks in the model. The behavior of these actors evolves according to these stocks that have to be positive enough to provide sufficient financial motivation to undertake the investment in the case of the electricity company and to participate in the demand side management in the case of the consumer.

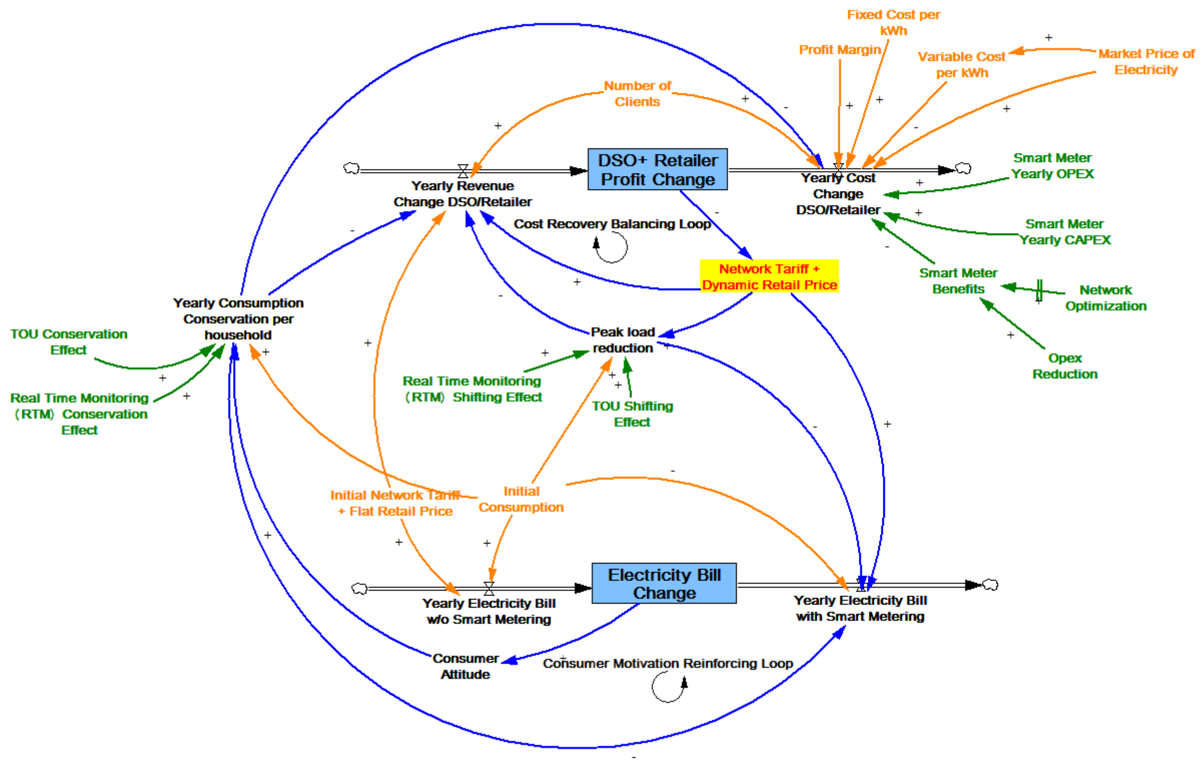


Figure 6 : Vertically Integrated Electricity Company

The model of the vertically integrated structure is shown in Figure 6. The model is centered on the two stocks, namely the profit change of the electricity company and the bill change of the consumer due to the Smart Meter implementation.

The electricity company is modelled by the variables (orange) that describe the present characteristics of the firm. These variables are mainly related to the cost and revenue structure (profit margin, fixed cost, variable cost, electricity market price) that are used to determine how the company's cost changes if the consumption is reduced by a certain amount or if a part of the load is shifted from peak periods to mid- or off-peak periods. The revenue change is assessed by looking at the difference of the present network tariffs and retail prices and the new ones used as a control variable to allocate the investment cost. The yearly consumption conservation has a mainly negative effect on the revenue, and the peak load reduction affects positively both the revenue and the cost. These variables are dependent on the initial consumption of the consumers.

Once the company structure is assessed, the Smart Meter related effects are added to the model (green). On the one side, these are benefits and drawbacks affecting the financial structure of the company and demand side response on the other side. The cost of the implementation is modelled by the Smart Meter annualized operating and capital expenditures (OPEX and CAPEX). The DSO's internal advantages are coming from the OPEX reduction, such as the meter reading cost reduction, and from the further network development such as the reduction of the non-technical losses. One can see that the financial value of these advantages depends on the company's operational excellence. Thus, the optimality of the current infrastructure and the optimality of the company structure are determinant regarding the potential financial benefit of Smart Metering. The demand side response is modelled by the effect of the Time of Use (TOU) pricing and the Real Time Monitoring (RTM) of the consumption. These variables model to what extent the consumers would reduce and shift their consumptions due to the introduction of Smart Metering.

It can be seen that the dynamics of the model is governed by two feedback loops, namely the cost recovery balancing loop and the consumer motivation reinforcing loop. Demand side management is an important chain in order to unlock the potential social and economic benefit of Smart Metering such as the consumption reduction and the load shifting. The response of consumers is based on their financial incentives which are triggered by the electricity bill change. If the consumer has enough financial incentive to participate as an active player the consumption reduction and the load shift can be realized. However, the consumption conservation is not advantageous for the electricity company who tries to recover the investment cost by charging more the consumer. One can understand that there is a conflict of interest regarding the financial incentives of the actors. Consumers need enough motivation to pay more attention to their electricity consumption but at the same time, the cost of the investment has to be recovered. The goal of the model is to analyze if it is possible to reach a trade-off between the two actors by cooperation.

3.2. Conceptual Model for an accounting unbundled structure

In case of an accounting unbundled structure, the electricity company is split in two parts: the retailer who commercializes the electrical energy and the distribution system operator who is responsible for delivering energy. The client is the consumer who consumes this energy. The financial incentives of these actors are modelled by the profit changes of the DSO and the Retailer and by the electricity bill change of the consumer.

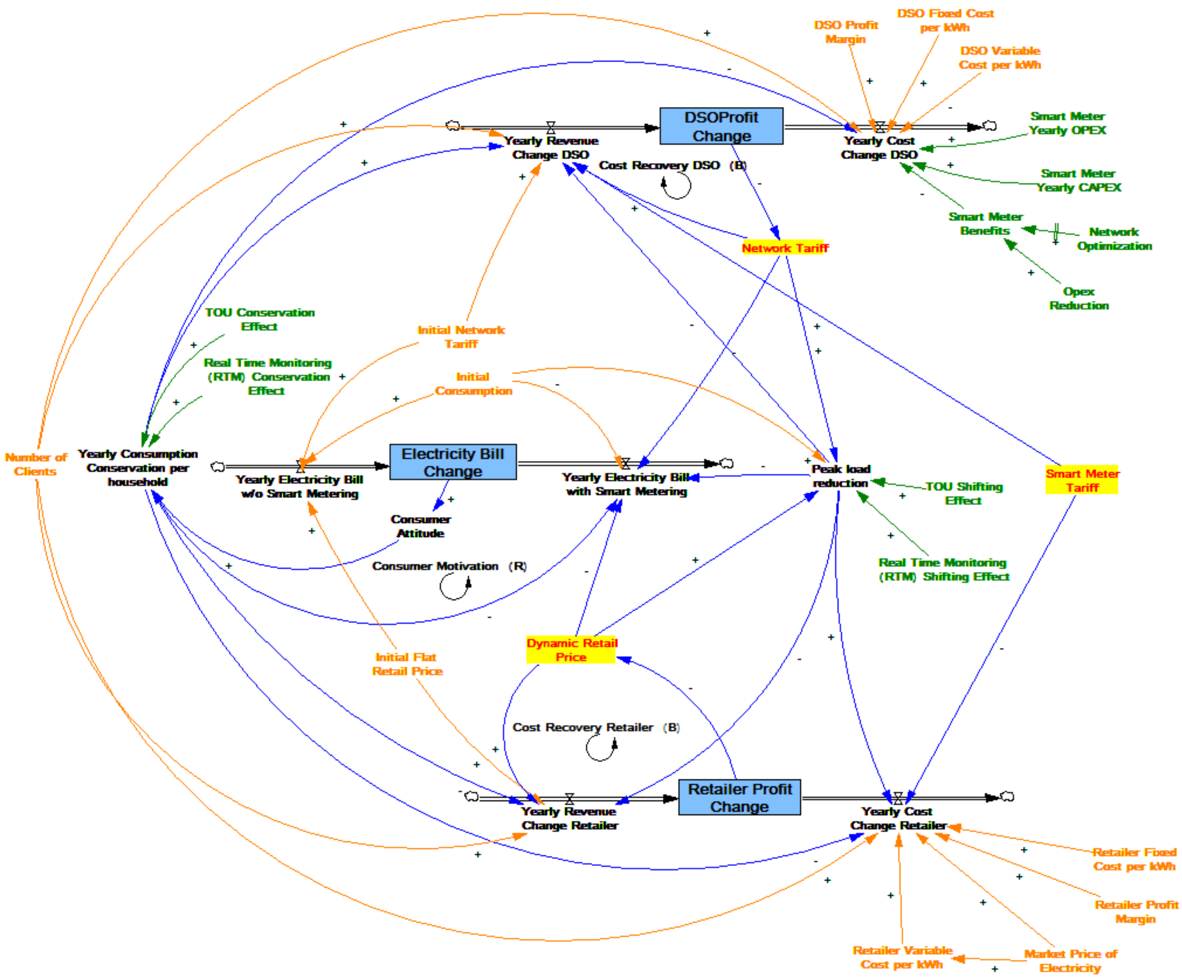


Figure 7 : Accounting Unbundled Electricity Distributor and Retailer

It can be seen in Figure 7 that the scheme is very similar to the vertically integrated company model but in case of unbundling the retail and distribution related variables are separated. The cost allocation process is centered on the three stocks of the three actors: the profit change of the DSO, the profit change of the Retailer and the electricity bill change of the consumer.

The company related variables that play a role in the cost allocation process are represented in orange. These are the variables that characterize the actors how the effects of Smart Metering (consumption conservation, load shifting) affect them financially. The DSO cost change is characterized by the profit margin, fixed cost, variable cost as well as the number of clients. Its revenue change is driven by the number of clients and the difference between the initial and the new network tariffs. The Retailer's cost change is assessed by considering the market price of electricity, the profit margin, the fixed and the variable cost as well as the number of clients. Its revenue change is associated with the number of clients and the difference of the initial flat price and the dynamic retail price. The consumer's electricity bill without Smart Metering is characterized by the initial network tariff and the flat retail price as well as by the initial consumption.

The introduction of Smart Metering has an important impact on all the three actors. The Smart Metering related variables are represented in green. They represent the investment cost and the direct and indirect benefits and effects of Smart Metering. The investment cost related variables, as the capital and the additional operational expenditures, are added to the DSO's cost change as it is the DSO who would own the metering devices. The financial amount of its directs benefits, such as the OPEX reduction due to the metering cost reduction and the further network development such as the non-technical losses reduction are highly dependent on the company. The indirect benefits of Smart Metering as the consumption conservation and the load shifting affect the three actors according to their characteristics explained above. The control variables that link the actors are the network tariff that the consumer pays to the DSO and the retail price that the consumer pays to the Retailer. In order to create a link between the DSO and the Retailer, a Smart Meter tariff is added as well as a control variable.

The dynamic of the cost allocation comes from the financial incentives of the three actors, namely the cost recovery of the DSO, the recovery of the financial disadvantages for the Retailer and the participation of the consumer on the demand side motivated by the electricity bill change. One can see that the problem is now much more complex than for a vertically integrated company. There is a conflict of interest regarding the consumption conservation which depends on the active participation of the consumer. However, the consumer's attitude is sensitive to the potential economies that depend on the profit change of the DSO and the Retailer.

3.3. Conflict of Interests

In order to understand the financial incentives of the actors, the following hypotheses have to be considered:

1) Time-of-Use pricing (TOU) would push the consumer shifts load and reduce the consumption to some extent.

2) Real Time Monitoring (RTM) of the consumption would maximize the consumption reduction in addition to the TOU prices only if enough financial benefits are given to the consumers. In other words, the effect of RTM on the consumption is zero if the consumer has no positive financial incentive (reduction of electricity bill with respect to the current situation).

The conflict of interest arises in the cost allocation process because the consumer is considered now as an active participant in the electricity supply chain. Passive so far, in order to maximize the unlocked value of the Smart Metering its active role is needed. Its active role would lead to a public interest, to the consumption reduction which is necessary in order to use more efficiently the available energy resources. It is assumed that this active participation can only by maximized by providing the consumer financial incentive to rise its awareness. However, this financial incentive reduces the cost recovery potential of the DSO and the Retailer and it creates a conflict between the public interest and the economic interest of the DSO and the Retailer.

By using System Dynamics it is possible to:

- Analyze how a compromise can be found between the three actors in order to maximize the unlocked value of Smart Metering
- Analyze to what extent the consumers are sensitive to the action of the other actors, in other words, in what extent the success of the implementation is sensitive to the action of the DSO and the Retailer

4. Cost allocation process: The Simulation Model

The simulation of the cost allocation process as a System Dynamics model requires the transformation of the conceptual diagrams into running models that include all the aspects related to the mathematical formulation of the problem. In this respect, the conceptual models are modified to be well adapted to Vensim, the software that is used for the System Dynamics simulation. The different data presented in chapter 2 are included in the model.

The general framework for both models is for 15 years, by 1 year time step. In order to model the evolution of the characteristics over time, stocks are included for some of the variables. Hypothesis are made as well that are either justified in chapter 2 based on the research or estimated based on the author's knowledge.

Time of Use Retail Pricing: The distribution of the different peak periods is shown in Table 10. It is estimated that such a configuration would create the biggest economic advantages for the retailer. The weekend is considered as off-peak period.

Table 10 : Time of Use periods during the weekdays

Hour	1	2	3	4	5	6	7	8	9	10	11	12
Mean [€/MWh]	40.92	37.91	35.19	32.43	33.59	39.37	48.42	58.37	60.86	60.74	60.59	61.41
Hour	13	14	15	16	17	18	19	20	21	22	23	24
Mean [€/MWh]	59.29	57.51	55.44	53.52	53.02	57.07	60.63	59.89	56.15	50.98	49.87	44.8

	Off-Peak Period
	Mid-Peak Period
	On-Peak Period

In order to be able to model the problem, the consumption of each peak period is aggregated during the year resulting in 43,2% off-peak, 28,9% mid-peak and 27,9% on-peak consumption.

Peak price ratios: The on-peak/off-peak price ratio is 2.85, the mid-peak/off-peak price ratio is 2.09 and are constant.

Number of Clients: The number of clients is growing over time by a mean fractional rate of 0.013 and standard deviation of 0.002. It is assumed, that Smart Meter implementation for new clients does not represent an additional cost as a conventional meter installation should anyway be done for them. Thus, it is supposed that in this case the difference of cost between the new and the old devices is negligible, given the existing communication infrastructure.

Market Price of Electricity: The market price of electricity is increasing over time by a mean fractional rate of 0.008 and standard deviation of 0.002.

TOU and RTM load shifting effect: These effects are aggregated and are constant, namely 3% on-to off-peak shift and 2.5% on to mid-peak shift.

TOU conservation effect: The effect of the dynamic pricing is 3.3% consumption reduction with a standard deviation of 0.5%.

RTM Conservation Effect: The effect of the use of the real time consumption monitoring is 4.3% consumption reduction with a standard deviation of 0.3%.

Initial Network Tariff, Retail Price: In order to assess the effect of Smart Metering, the key indicators are compared to the situation where these tariffs and prices would increase by a fractional rate of 0.008.

Further Network Optimization: The benefit coming from the value of the Smart Metering data such as the reduction of the non-technical losses is estimated to have a delay of 2 years.

Price Elasticity: It is supposed that in case of household consumption, the price elasticity on the average price has no effect on the consumption reduction as the electricity is a public need that is paid in an aggregated way.

Consumer participation: It is supposed that the consumers have financial incentive if their cumulative financial balance is positive, optimally at least 200 CHF at the end of the 15-year period (at least 1 CHF economies per month).

Based on these points the conceptual model is modified in order to simulate the cost allocation process by Vensim. The structure of the simulations is presented in Figure 8.

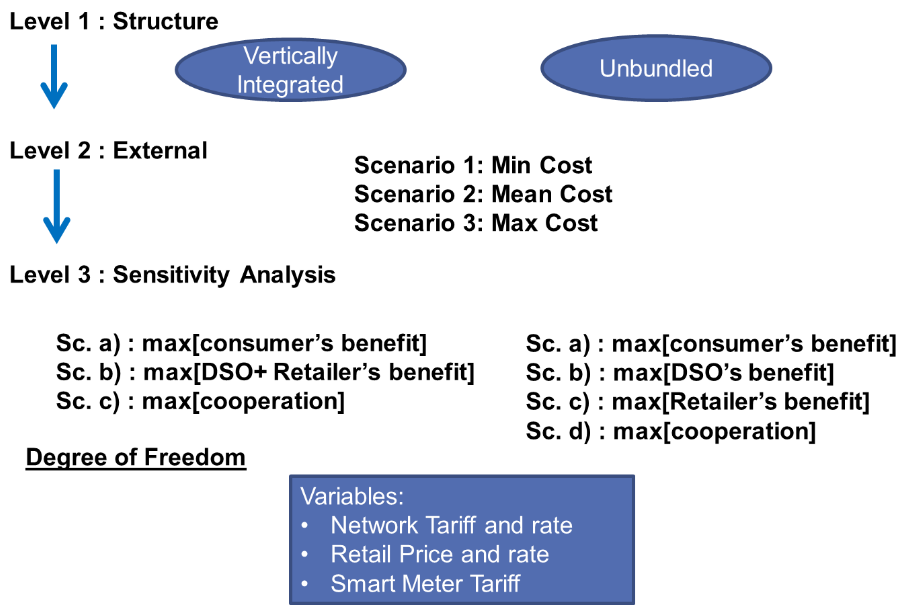


Figure 8 : Methodology for the simulations

Firstly, the two different structures are created, namely the vertically integrated and the unbundled company structure. Secondly, based on the external factors three base scenarios are simulated depending on the investment cost (min, mean, max). Thirdly, using the basic scenarios, sensitivity analysis is done by looking at the interaction between the actors i.e. how the motivation of the other actors changes if the benefit of one of them is maximized. In order to do this, the variables controlled are the network tariff, retail price and their rate of increase as well as the Smart Meter Tariff between the DSO and the Retailer.

4.1. Vertically Integrated Structure

4.1.1. Initialization

The running model of the vertically integrated structure (see Appendix A), built according to the conceptual model, is completed by the data presented in section 2 and by the hypothesis presented at the beginning of this section. The initial parameters of the control variables are presented in the following tables according to the base scenario.

Table 11: Vertically Integration- Minimum Cost Scenario, Initial Parameters

Sub Scenario	a	b	c	Unit
	Cooperation	Consumer	DSO+Retailer	
Company Variables				
Smart Meter Tariff	0	0	0	CHF/Year
Network Tariff (fixed)	70	65	65	CHF/Year
Network Tariff (per KWh)	0.085	0.085	0.0865	CHF/kWh
Fractional Tariff Increase	0.0067	0.0072	0.0072	-
Retail Price	0.062	0.0621	0.0625	CHF/kWh
Retail Price Increase	0.0067	0.0072	0.0072	-

Table 12: Vertically Integration- Mean Cost Scenario, Initial Parameters

Sub Scenario	a Cooperation	b Consumer	c DSO+Retailer	Unit
Company Variables				
Smart Meter Tariff	0	0	0	CHF/Year
Network Tariff (fixed)	84	78	80	CHF/Year
Network Tariff (per KWh)	0.083	0.084	0.085	CHF/kWh
Fractional Tariff Increase	0.0072	0.0072	0.0085	-
Retail Price	0.0621	0.0621	0.0621	CHF/kWh
Retail Price Increase	0.0072	0.0072	0.0085	-

Table 13: Vertically Integration- Maximum Cost Scenario, Initial Parameters

Sub Scenario	a Cooperation	b Consumer	c DSO+Retailer	Unit
Company Variables				
Smart Meter Tariff	0	0	0	CHF/Year
Network Tariff (fixed)	80	70	75	CHF/Year
Network Tariff (per KWh)	0.085	0.085	0.085	CHF/kWh
Fractional Tariff Increase	0.008548	0.008	0.009	-
Retail Price	0.0621	0.0621	0.06275	CHF/kWh
Retail Price Increase	0.008548	0.008	0.009	-

According to the base scenario (minimum, mean and maximum cost) the integrated electricity company has to adjust its tariffs and price in order to recover the investment cost. An increase is observable regarding the average values as the investment cost increases.

4.1.2. Analysis of the simulation results

The following tables show the evolution of the financial benefit of all the actors according to the cooperative sub-scenario which provides a compromise between the actors. It is only the cooperative sub-scenario which provides a good balance of financial benefit between the actors.

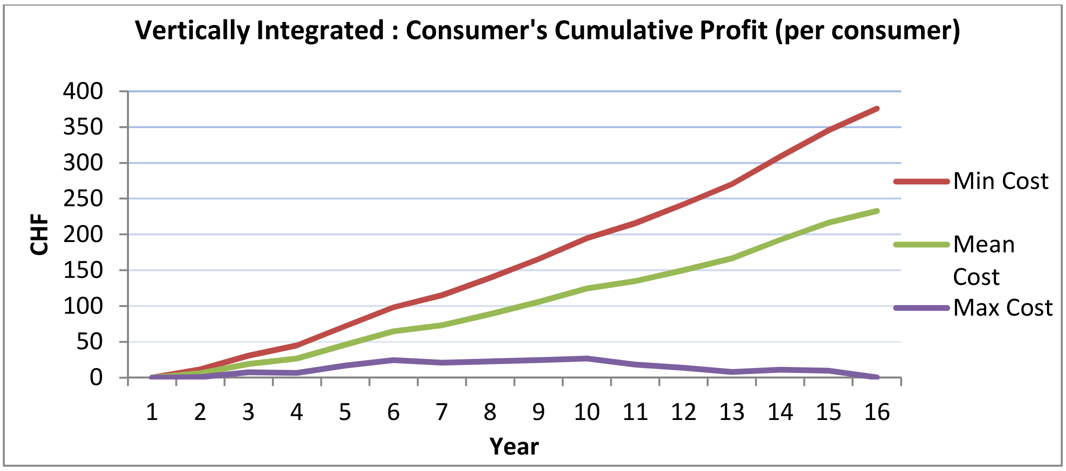


Figure 9 : Vertically Integrated structure: Consumer's cumulative profit in case of cooperative scenario

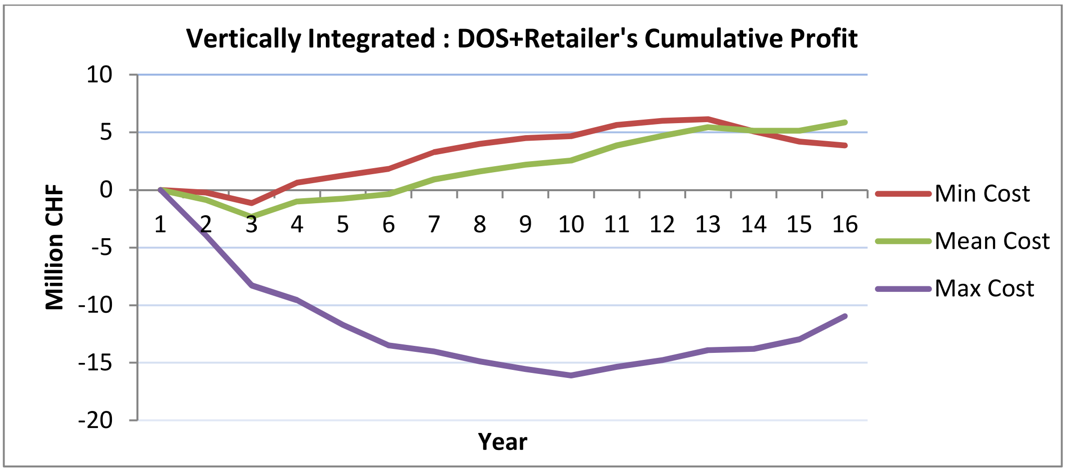


Figure 10 : Vertically Integrated structure: Electricity company's cumulative profit in case of cooperative scenario

The figures above show that in case of a vertically integrated company structure with the minimum and mean cost scenario with a cooperative sub-scenario, Smart Meters could be successfully implemented by providing the actors enough financial incentives. The electricity companies profit change is sensitive during the first two years, as the reduction of the non-technical losses cannot be realized immediately. Other sub-scenarios (DSO+Retailer, consumer) do not represent a well-balanced distribution of the financial outcomes. They are extreme cases of the Pareto frontier where the benefit of only one actor is maximized. These cases are not sustainable because of the distortion of the benefits.

Contrary to the min and the mean cost scenario, in case of the maximum investment cost scenario, the vertically integrated electricity company would end up with negative profit change with a cooperative sub-scenario. It is supposed, that the consumer cannot assume a negative bill change to help covering the investment cost. Even in the case of other sub-scenario that maximized the company's profit change (DSO+Retailer), the recovery would not possible without a high deficit of the consumer which is supposed not to be an option.

4.2. Accounting Unbundled Structure

4.2.1. Initialization

As mentioned before, inputs of the running models built on the conceptual models are based on the data collected in chapter 2 and the hypotheses, estimations presented at the beginning of this chapter. In the case of the unbundled structure (see Appendix B) initial values of the control variables used for the three base scenarios are presented in the following tables.

Table 14 : Unbundling-Minimum Cost Scenario, Initial Parameters

Sub Scenario	a	b	c	d	Unit
	Cooperation	Consumer	DSO	Retailer	
DSO Variables					
Smart Meter Tariff	5	5	6	4	CHF/Year
Network Tariff (fixed)	75	74	80	75	CHF/Year
Network Tariff (per KWh)	0.085	0.085	0.086	0.085	CHF/KWh
Fractional Tariff Increase	0.0065	0.0065	0.01	0.0065	-
Retailer Variables					
Retail Price	0.061	0.0609	0.061	0.062	CHF/KWh
Retail Price Increase	Gradual	Gradual	Gradual	0.011	-

Table 15 : Unbundling- Mean Cost Scenario, Initial Parameters

Sub Scenario	a Cooperation	b Consumer	c DSO	d Retailer	Unit
DSO Variables					
Smart Meter Tariff	5	5	5	5	CHF/Year
Network Tariff (fixed)	84	82	86	82	CHF/Year
Network Tariff (per KWh)	0.085	0.085	0.085	0.085	CHF/KWh
Fractional Tariff Increase	0.0065	0.007	0.01	0.007	-
Retailer Variables					
Retail Price	0.061	0.0609	0.0609	0.06165	CHF/KWh
Retail Price Increase	Gradual	Gradual	Gradual	0.009	-

Table 16 : Unbundling- Maximum Cost Scenario, Initial Parameters

Sub Scenario	a Cooperation	b Consumer	c DSO	d Retailer	Unit
DSO Variables					
Smart Meter Tariff	6	6	6	6	CHF/Year
Network Tariff (fixed)	80	80	87.5	87.5	CHF/Year
Network Tariff (per KWh)	0.0865	0.086	0.084	0.084	CHF/KWh
Fractional Tariff Increase	0.0093	0.009	0.011	0.011	-
Retailer Variables					
Retail Price	0.061	0.061	0.061	0.06105	CHF/KWh
Retail Price Increase	Gradual	Gradual	Gradual	Gradual	-

One can see that the average value of these variables is increasing from the minimum to the maximum cost scenario as the DSO has to recover a higher investment cost. Depending on the sub-scenario, the tariffs and prices are either in favor or against the consumer. In the case of the cooperative and the consumer scenario, these variables are advantageous for the consumer, so the demand response is supposed to be high. However, in the case of the DSO or Retailer scenario, the consumer is used to maximize the benefit of other actors, so the demand response is supposed to be lower.

4.2.2. Analysis of the simulation results

The following tables show the evolution of the financial benefit of all the actors according to the cooperative sub-scenario which provides a compromise among the actors.

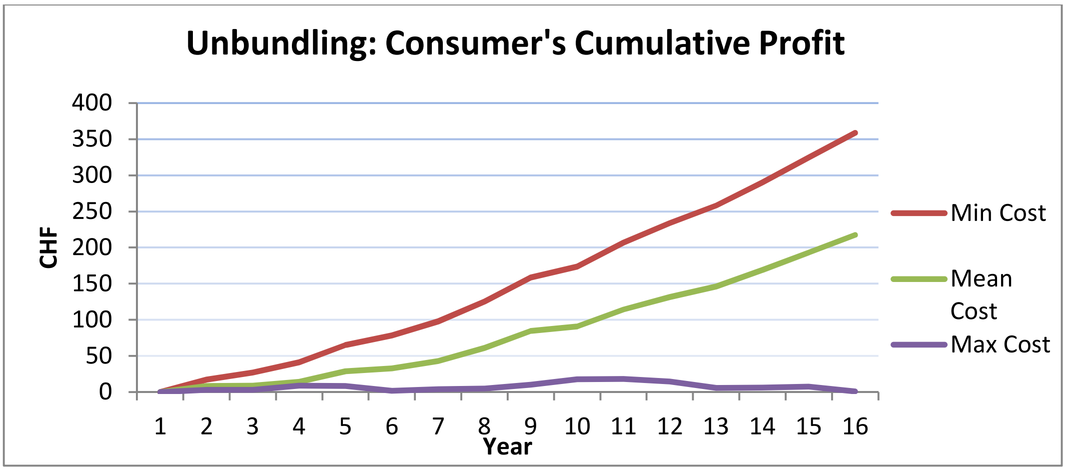


Figure 11 : Unbundled structure: Consumer's cumulative profit in case of cooperative scenario

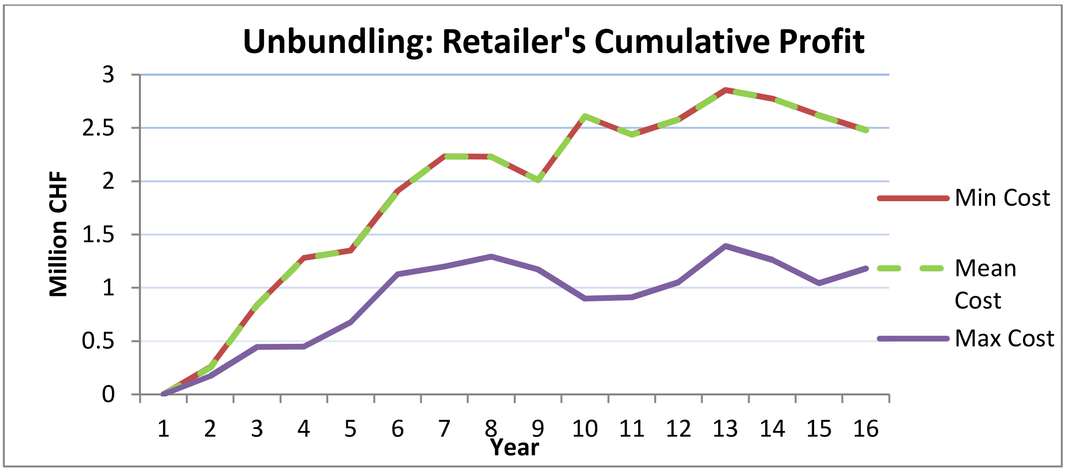


Figure 12 : Unbundled structure: Retailer's cumulative profit in case of cooperative scenario

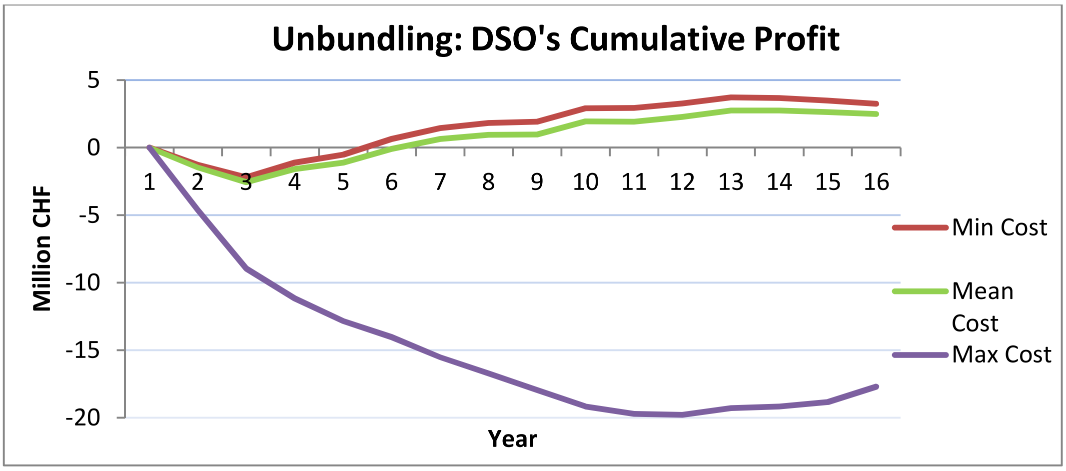


Figure 13 : Unbundled structure: DSO's cumulative profit in case of cooperative scenario

It can be seen in the figures above that the implementation of Smart Meters is possible by ensuring the profitability of the investment for the minimum and the mean cost scenario with a cooperative sub-scenario. In this case all the three actors have financial incentives to exploit all the benefits of this technology. The DSO and the Retailer end up with a positive profit change and the consumer can save money as well by participating actively from the demand side. The DSO's profit change is sensitive during the first two years, as the reduction of the non-technical losses cannot be realized immediately. Other sub-scenarios (DSO, Retailer, consumer) do not provide well balanced financial outcomes resulting from the Smart Meter implementation. The implementation still remains financially possible, but the risks and the financial incentives are not well distributed, so these sub-scenarios do not represent a sustainable solution.

In the case of the maximum cost scenario with a cooperative sub-scenario, the benefit of Smart Metering is not enough to cover all the expenses, so by the end of the 15-year investment period, the DSO ends up with a highly negative profit change while the other two actors have results around 0. It is supposed, that the consumer and the Retailer should not have a negative financial balance by the end 15-year period. Consequently, with other sub-scenarios it is not possible to cover the investment cost without the deficit of the Retailer and the consumer.

4.3. Comparison of the two structures (Vertically Integrated vs Unbundled)

The analysis showed that in both cases, the implementation for Romande Energie with positive financial incentives for all the actors are only possible in the case of the minimum and the mean cost scenario. In these scenarios in case of cooperation, independently of the structure of the company, the outcome of the investment is well balanced and positive for all the actors. Table 17 and Table 18 show that in these cases the consumers have enough financial incentive to participate actively in the demand side program. In case of both structure, the consumer pay higher tariff and price for the electricity, but thanks to the Smart Meter provided potential electricity bill economies, the consumer can even save money by an active demand side response.

However, the maximum cost scenario does not provide the actors enough financial incentive and the deficit would worsen the financial situation of the DSO in case of unbundling and of the electricity company in case of vertically integration even if the consumer is participating “for free”.

In spite of these similarities, the investment, in case of a vertically integrated structure is less risky as the number of actors is reduced to two.

Table 17 : Unbundled Structure, Cooperative Scenario, financial balance after 15 years

Unbundled Structure			
Cooperative Scenario	Actor's Benefit		
	DSO	Retailer	Consumer
Min cost	fr. 3'253'000	fr. 2'481'000	fr. 359
Mean cost	fr. 2'490'000	fr. 2'481'000	fr. 217
Max cost	fr. -17'702'000	fr. 1'180'000	fr. 1

Table 18: Vertically Integrated Structure, Cooperative Scenario, financial balance after 15 years

Vertically Integrated Structure		
Cooperative Scenario	Actor's Benefit	
	Electricity Company	Consumer
Min cost	fr. 3'844'000	fr. 376
Mean cost	fr. 5'846'000	fr. 233
Max cost	fr. -10'952'000	fr. 0

(The slight difference of the total results between the two structures is due to the randomness of certain variables)

5. Conclusion

Besides answering the research question based on the case of Romande Energie, the author extends his work by looking at possible regulatory solutions on a national level. The models and analysis presented in the previous chapters show that the paper contributes at numerous points to the transition of the energy infrastructure.

<u>1) Conceptual results</u>

The paper provides conceptual results about the modelling of a risky infrastructure related investment in the electricity distribution sector. Based on a detailed research, it quantifies the potential financial advantages of Smart Metering. The conceptual models presented in section three show how the different actors interact with each other depending on the company structure. These models help the reader to understand what the motivations of these actors are and what the important points are to take into consideration for a successful implementation of the residential Smart Meters. These are generic results that can be applied for any electricity company.

The comparison of the results based on a vertically integrated company and an unbundled company shows that the structure does not affect the financial outcome but the difficulty of the coordination between the actors. Due to the easier coordination, the vertically integrated structure is more adapted to such a risky investment.

<u>2) Investment support for Romande Energie</u>

This work also provides a running model to simulate the implementation of the residential Smart Meters for electricity companies. The case of Romande Energie is analyzed in this paper. The model is initialized by the characteristics of this company to provide results about the financial viability of such an investment.

Based on the results, the research question can be answered: In the case of Romande Energie that operates in the Lemanic area according to the accounting unbundling principle, the implementation of Smart Meters (by ensuring the necessary financial incentives of the actors) would only be profitable with the minimum and mean cost scenario. Even in this case, strong cooperation is needed among the actors to organize the cost allocation in a way that the unlocked benefit of Smart Metering could be maximized in a sustainable way.

<u>3) Characteristics of the Smart Meter implementation process</u>

Based on the case of Romande Energie, some general features can be deduced regarding the implementation process. It can be seen that such a model is really sensitive to the initial conditions i.e. to the nature of the investment such as:

<u>Cost of the investment:</u>

The cost and the risk associated with the implementation play a determining role with respect to the profitability of the Smart Metering. The two key points that have to be considered are the maturity and the standardization of this technology. A mature technologic solution and countrywide standardized features can reduce the risk and the cost of the investment.

Company structure:

The potential financial advantages of the DSO are limited by the company characteristics. The technologic and operational efficiency determine the company related cost reduction possibilities.

e.g.: If the current meter reading cost is high and the non-technical losses are high, the financial advantages of Smart Metering would by high as well.

Potential future locked benefit of Smart Metering

As Smart Metering is an enabling technology, it is a necessary pillar for other future technologies and actors related to the demand side programs or to the network optimization. However, the financial viability of these possible mass scale future solutions as Home Automation, Distributed Generation cannot be so far well assessed and confirmed. There is a potential to unlock other advantages of Smart Metering than the advantages presented in this work, but it needs mature business models from the technology side and future research about their mass implementation.

Cooperation:

The cooperation among the actors is a key factor in the cost allocation process. Every actor in the cost allocation process is motivated to reduce cost or increase revenue i.e. to have a positive profit change. However, the source of the problem from a financial point of view is the consumption reduction.

In the case of an unbundled structure, the consumer's financial incentive is against of those of the DSO and the Retailer. The consumers, in order to maximize their economies will reduce their consumption thanks to the awareness. However, it is against the financial incentives of the other actors who have the possibility to reduce the "motivation" of the consumers and increase their own profit. It is assumed that the consumers are more motivated if they are granted a money saving possibility in order to gain more than if they are forced to save money in order not to lose more. (The situation is the same in the case of the vertically integration).

The social benefit, i.e. the consumption reduction depends on the motivation of the consumer. In Switzerland up to date, the electricity market is liberalized only for consumers with a yearly consumption higher than 100 MWh. In this case, the regulator could act, to balance the financial advantages of Smart Metering between the actors by setting up institutions (rules) that could protect the consumer against abusive cost recovery. It could provide a guarantee to the policy makers that the social goals of the implementation will be reached in a sustainable way.

On the contrary, if the retail market is completely liberalized for the household consumers, there is no guarantee that the Retailer would not recover its losses abusively.

4) Possible regulations and policy implications

Based on the characteristics of the Smart Meter implementation, the paper provides the Swiss electricity regulator (ElCom) possible interventions in the field of Smart Metering.

As presented above, the cooperation is a key issue for the success of the Smart Meter implementation. As a result of this, an optimal cooperation is needed among the actors. Without an optimal cooperation the outcome of the implementation is only a financial Pareto-optimum (If one actor deviates to increase its benefit, the benefit of at least one other actor will decrease). The regulator should set up rules in order to bring the outcome to a Nash-equilibrium (Actors have no financial incentive to deviate). This requires first, the introduction of a common framework to evaluate the financial viability of the implementation of Smart Metering for each electricity distributor in Switzerland to know which companies are the ones that could implement Smart Meters in a profitable way. It could be a generalized mathematical model in order to evaluate the infrastructure related investments. Besides that, national minimum requirements are needed regarding the implementation (technical, administrative) to ensure the efficiency and the good quality of the Smart Meter integration.

a) Companies for which the implementation would be profitable

After identifying the financial viability of such an investment, ElCom should monitor that the potential cost reductions are executed at the electricity distributor and that the distribution and the retail part do not charge the consumer excessively by using the cost recovery in an abusive way.

b) Companies for which the implementation would not be profitable

After identifying that the implementation would result in deficit the regulator should suggest the company seeking after other potential, so far hidden, benefits of Smart Metering. In case the company still would like to introduce the technology, ElCom should supervise that the deficit coming from the investment does not affect the consumer negatively.

The authors' strong opinion is that as electricity is an basic everyday public need, it has no substitute, cannot be stored, the residential electricity market has not to be liberalized in Switzerland. As in the case of the Smart Metering, the infrastructure related investment concern numerous actors along the electricity supply chain, so a tight collaboration is needed between the different actors that can only be efficiently realized in a regulated, non-liberalized way.

All in all, this paper provides a guideline both for industrial and academic purposes to understand the characteristics of the energy infrastructure related investments and their policy implications for a sustainable future.

6. Bibliography

[1] UK ENERGY RESEARCH CENTRE , "Electricity user load profiles by profile class," 1997.

[2] Hydro One, "Time-of-Use Pricing Pilot Project Results," Toronto, May 2008.

[3] Association Smart Grid Switzerland VSE, "Les consommateurs d'électricité privés examinés de près," 2011.

[4] Enertech, "Campagne de mesures des appareils de production de froid et des appareils de lavage dans 100 logements," 2008.

[5] LUT Energy, "Tariff scheme options for distribution system operators [p.10]," Lappeenranta University of Technology , 4 May 2012.

[6] F. D. o. Economy, "Coûts d'exploitation imputables au réseau électrique en Suisse," Berne, 2008.

[7] SFOE, Swiss Federal Office of Energy, "Folgeabschätzung einer Einführung von «SmartMetering» im Zusammenhang mit «Smart Grids» in der Schweiz (Impact Assesment Switzerland)," 2012.

[8] Association Smart Grid Suisse, "Livre blanc Smart Grid," 2013.

[9] "Swiss National Bank," [Online]. Available: http://www.snb.ch/en/iabout/stat/statpub/zidea/id/current_interest_exchange_rates.

[10] "Le magazine clients de Hager | N° 18 |," December 2009.

[11] Niklas Löf, Marko Pikkarainen,Sami Repo,Pertti Järventausta, "UTILIZING SMART METERS IN LV NETWORK MANAGEMENT," Tampere University of Technology, 2011.

[12] Michel Clemence, Renzo Coccioni, Alain Glatigny, "How Utility Electrical Distribution Networks can Save Energy in the Smart Grid Era".

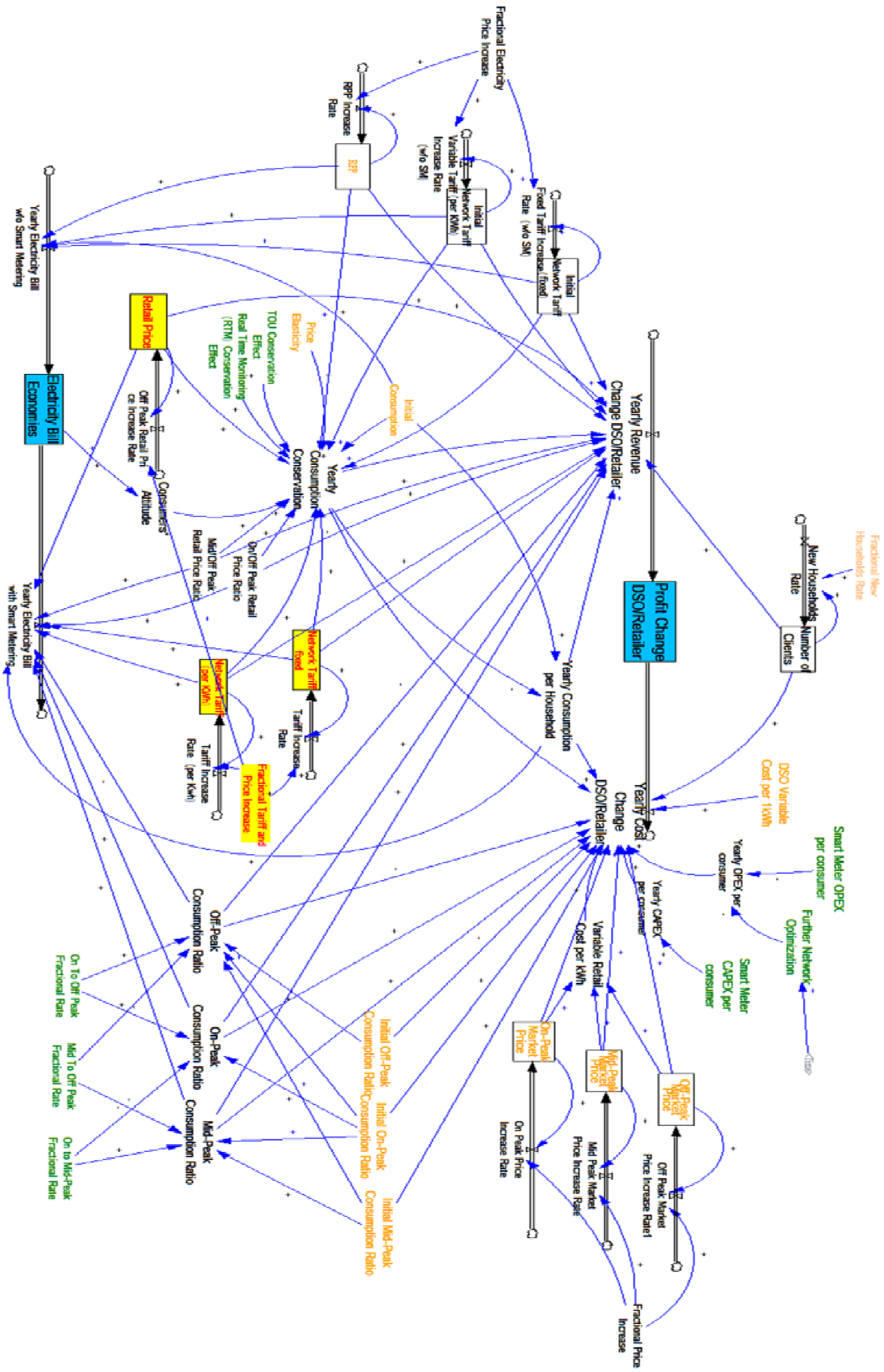
[13] SFOE, Swiss Federal Office of Energy, "Statistique suisse de l'électricité (Swiss statistics of Electricity)," 2012.

[14] Philippe Deschamps, Michel Clemence and Sivakumaran Govindarajan, "Power Today," [Online]. Available: http://www.powertoday.in/News.aspx?nId=I32C0qsuy48JxWHdXLgnhg==.

[15] David Erni, "Day-Ahead Electricity Spot Prices -Fundamental Modelling and the Role of ExpectedWind Electricity Infeed at the European Energy Exchange," University of St. Gallen, 2012.

7. Appendices

Appendix A: Running Model: Vertically Integrated Structure



Appendix B: Running Model: Accounting Unbundled Structure