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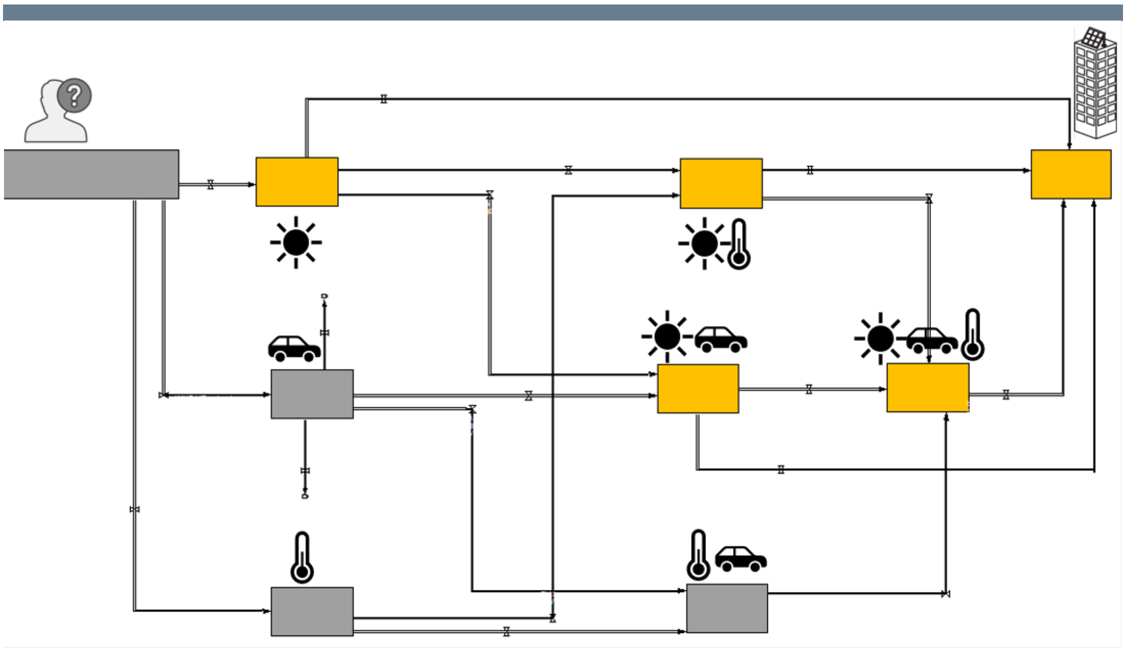

Focus report: Socio-economic Business Models for Utility Companies

Prosumer-Lab

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Abstract

This study addressed the impact of several dynamics that challenge the utility company business model of supply and sale of electricity to household customers in Switzerland. In collaboration with BKW, a major utility company in the Canton of Bern, and based on a quantified simulation model using system dynamics method, this study demonstrated how a system of prosumers, utility companies, and associated incentives or regulations develop in the Swiss electricity market over the next three decades, from 2020 to 2050. The scope of the modeling and analysis is limited to the household sector in Switzerland. The quantitative statements relate to the specifications of BKW and its supply region. However, since the values for the studied utility company are normalized, the statements are also valid for the country of Switzerland. The %-changes are calculated from the reference year of 2020 to the final year of 2050.

This report neither developed nor addressed novel business models. It focused rather on the impact of changing regulations and market developments on the existing business model. In the following, some of the findings are highlighted:

First, the increasing share of produced and stored electricity by photovoltaic and battery storage (PVB) systems will decrease the household electricity demand from the grid and the corresponding electricity sales of utility companies by -9% in 2050. These companies potentially can compensate part of the lost revenue by designing services for prosumers and penetrating the PVB and heat-pump installation markets.

Second, the increase in electric vehicles (EV) popularity potentially increases the household electricity demand from the grid by 8% in 2050.

Third, a near-flat figure of heat-pump (HP) sales indicates that the HP market currently is close to saturation in Switzerland, i.e., more yearly sales result from HP replacement by current owners and less stem from new adopters. However, if HP gets promoted compared to alternative heating systems by 30%, for instance, by putting limits on fossil-powered heating systems, the household electricity demand from the grid potentially could increase by 13% in 2050.

Finally, although the overall electricity demand from the grid per capita in Switzerland has started to fall since 2005, and the trend has continued until today, the electricity distributed to the household sector per capita has stayed relatively stable – around 2’277 kWh per person – from 2010 to 2017. This is an indication that the major reduction in electricity demand from the grid in Switzerland has occurred in sectors other than the household sector.

Disclaimer: Figures and data about utility companies in this report are not related to BKW. They are assumptions for a generic utility company in Switzerland.

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1 Summary

Focus question: From a business model perspective, how does a system of prosumers, utility companies, and associated incentives or regulations develop in the Swiss electricity market?

Utility companies currently face a new, multifaceted situation in Switzerland. First, the consumption of self-produced electricity from photovoltaic (PV[1]) systems occurs in the household sector and is incentivized nationally. Second, the topic of self-consumption has evolved further, and some household consumers have become electricity producers and suppliers. The increasing number of these so-called prosumers – who can cover a significant part of their required electricity with PV-systems and draw the remaining demand from the grid – causes irregularities in the supply and distribution of electricity and fluctuations in the grid. The combined effect can further affect electricity prices in wholesale-electricity market of power supply companies. Furthermore, the synergy of the increased prosumage and the economic-technical feasibility of battery storage potentially shifts the degree of autarky, a measure of energy self-sufficiency. As a result, the demand for electricity from prosumers decreases, which in turn increases the cost of grid usage for the remaining consumers and threatens the utility profitability. Finally, liberalization of the electricity market is on the horizon, targeting large utility monopolies in the supply of electricity[1-16].

Such dynamics make the conventional model of supply and selling of electricity to end-user customers less effective and attractive for utility companies. Thus, utility companies must undergo a transition, not only in their production and the management of that production, but also in the development of innovative, more resilient business models that includes the dynamics and uncertainties of electricity supply and demand. Such a transition improves the economic sustainability of the utility business in this industry and the electricity demand fulfillment in the long run.

In the existing business model of large utility companies in Switzerland, such as BKW, the dominant and primary activity regarding household customers is distributing electricity to the regional households. Providing and selling electricity to end-user customers is the activity that generates revenue. The cost structure of such companies consists of variable and fixed costs. Variable costs usually change relative to the volume of the produced electricity. Fixed costs, on the other hand, stays the same within specific levels of production. A realizing vulnerability of this type of business model is that a decrease in household electricity demand from the grid – as a result of acquiring more photovoltaic systems by household customers – increases the cost of grid usage for the remaining consumers and threatens the profitability of utility companies [10].

This report addressed the existing business model of BKW – a major utility company in the Canton of Bern. From a business model perspective, BKW is representative of a conventional utility company. The study aimed to explain the business dynamics of the growth in PV and battery storage installations, diffusion of electric vehicles and heat pumps, and hence the impact on the conventional business model. The analysis includes different likely market developments of the mentioned technologies. Furthermore, it indicates how adaption of these technologies will change the household customer-portfolio of the utilities. Most important, the analysis addresses the impact of these developments on the household electricity demand from the grid of BKW, as a representation of other large utility companies.

In the end, this study did not develop aspects of novel or disruptive business models but tried to provide insights on the upcoming challenges and on how to adapt and make the current business model more resilient. The study analyzed the implications of embracing new ways of revenue generation, which are close to the core business of utilities. Although the model was developed based on the inputs from BKW, other Swiss utility companies can benefit from the insights that the study provided. Such companies might be more interested to focus on their current business model, rather crafting a new business model from scratch. This is because new business models entail unforeseen risks such as not being accepted by household customers.

To achieve such objectives, the system dynamics simulation method was employed. System Dynamics is a top-down simulation modeling method, which accounts for the integral of changes during each time step or delta-time in a modeled system. The study further opted for the participatory approach of group model building, which enables inclusions of expert knowledge and perspectives from different stakeholders. The model was extended, enriched and validated at each step by referring to content experts of BKW.

[1] For a list of acronyms and abbreviations, refer to the Glossary section.

Data regarding technology-products (PVs and battery storages, heat-pumps, and electric cars) were fed to the model according to today's standard – based on an expected gradual, continuous development similar to the past trends, not according to disruptive technology developments. Nonetheless, extreme scenarios of disruptions in the diffusion of the mentioned products and corresponding impacts on the total electricity demand from the grid were analyzed.

To answer the focus research question, the modeling was concentrated on the current state of the electricity market in which BKW interacts with its household customers – consisting of both consumers and prosumers. From an energy perspective, household customers of utility companies can be categorized as prosumers and consumers. Prosumers possess photovoltaic (PV) or photovoltaic and battery (PVB) systems[2] to produce solar electricity. Consumers are those customers who do not obtain such systems for a variety of reasons. Heat pumps (HPs) and electric vehicles (EVs)[3], as two products which can significantly change the electricity consumption of household customers, were also considered in the model.

A normal customer – as defined in this study – is a private household consumer without any of the three main technology products. Most customers adopt technology products gradually, starting from the phase of being a normal customer. It is expected to see them moving toward the prosumer side through different paths and acquire PVBs, HPs, and EVs in different orders – from the utility company or its competitor installation companies – as depicted in Figure 1. For instance, a normal customer of BKW may decide to first acquire an HP, then buy an EV, and a PVB module afterwards. Such customers are considered household customers if their annual electricity consumption is less than 100 MWh. Furthermore, prosumers can be suppliers, and consumers possibly become demanders if they join a self-consumption organization (SCO).

A large utility company, such as BKW, faces at least two types of competition: Type 1 competition is product sales, in the form of selling PVBs, HPs, and EV chargers/modules[4]. The potential revenue-stream there is derived from providing after sales service to customers who buy such products from the utility company. This type of competition is already in effect in the BKW supply region (Figure 1). Type 2 competition is electricity sales. If BKW extends its operating region to the rest of Switzerland when the electricity market is liberalized, the competition will then be on both products (type 1) and electricity sales (type 2).

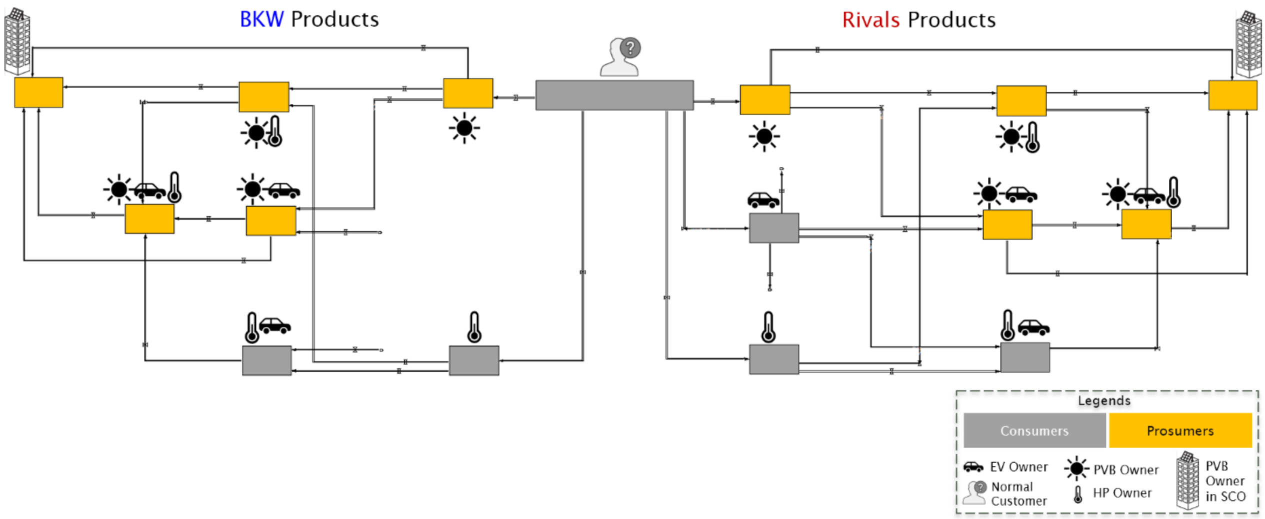

Figure 1: The current strategic business area of a major utility company, such as BKW.

[2] For the simplicity of the modeling, it was assumed that customers buy photovoltaic panels and batteries at the same time.

[3] In this study, it was assumed that electric vehicles increase the electricity consumption of household customers. The potential electricity storage capacity of such cars, as extra battery storage, and probable consequent changes in the degree of autarky for the EV owner was not considered in the modeling.

[4] Selling EVs is not part of the business model of utility companies. However, there is market potential in terms of providing services to EV owners or selling them EV chargers/modules.

(The copyright of icons is mentioned in the footnote[5].)

There are three notable challenges in front of the depicted business model:

1) An increase in the number of prosumers in the BKW supply region corresponds to lower electricity demanded from the grid and consequently a smaller revenue stream.
2) In a future liberalized Swiss electricity market, customers have the right to choose their electricity provider. Potentially, some customers will leave BKW, which means a smaller customer base for electricity sales.
3) The current large number of PVB and HP installer companies both in BKW supply region and the rest of the country. Winning new customers in such a market is challenging.

Figure 2 and Figure 3 present some important key performance indicator (KPIs) of the electricity market and product installations and services at the Swiss national level, under the base run of the simulation. It is foreseeable that the number of prosumers is on the rise, as depicted in Figure 2 (line 2 in red), and reaches approximately 906'000 by 2050. In the larger picture, more prosumers correspond to more PVB-produced electricity and reduced electricity demand from the grid, approximately by 14% in 2050, compared to 2020. Under such conditions, the revenue share of electricity sales, as the core revenue stream in the existing business model shrinks gradually.

In addition to selling electricity, there are two potential sources of revenue from the product and services perspective. One revenue stream could stem from providing services to PVB, HP and EV owners, because of an increase in the number of customers who possess any combination of PVBs, HPs, and EVs. For instance, there could be monthly or yearly subscription revenue from providing services to the growing number of prosumers (Figure 2). Another revenue stream could originate from installing such products for the first-time owners. Figure 3 presents the market potential of the studied products. The figure indicates how the market potential of selling PVBs and HPs as well as EV-related products and services in the household sector declines over time[6]. The decline can best be explained if the market development of each product (Figure 9 to Figure 11, presented in the main report) is taken into consideration. The relatively constant sales in HP market suggests that the market is saturated. Thus, the window of opportunity for HP installers and remaining potential number of HP buyers are limited. In the absence of any significant market disruption or promotion, the approximate 20% HP market potential will almost be depleted by 2050.

On the other hand, there is significant market potential in service and products related to PVBs and EVs, because these products are at the early stages of their diffusion. This study estimates that the market potentials of PVB- and EV-related products in the Swiss household sector will be approximately 60% and

[5] Courtesy of icons: the man with a question mark from www.payfort.com; the tower with a PV panel from www.vectorstock.com; the Sun, the car, and the thermometer from MS Word.

[6] Not every household customer is willing, interested, or has the possibility of acquiring the studied technology products in this study. Under the base run of the simulation model, and according to content expert knowledge in PVB, HP, and EV markets, some assumptions were made for 2010:

- PVB market potential: based on content expert knowledge, 40% of households in Switzerland are not willing or able to install PVBs. Some significant obstacles to install photovoltaic panels are initial investments, necessary refurbishments on rooftops, as well as the angle of some roofs toward the sun.
- HP market potential: based on expert knowledge and calibrating the model with actual data on HP sales in Switzerland, approximately 80% of households in Switzerland are not willing or able to install HPs. Having access to cheaper sources of energy, especially after the sharp drop in oil prices before 2010; non-suitability of HP with climate areas which face extreme freezing; high investment costs; the required refurbishing and drilling; noises that HPs causes and the ban on noise-making devices in urban areas, are among the reasons that why HP market potential is limited.
- EV market potential: based on calibrating the model with actual data on private EV sales and ownerships, it was assumed that approximately 60% of household customers in Switzerland are not willing or able to buy EVs. Not everyone on the streets is a potential EV buyer. Currently, there are feasible alternatives to EV cars, such as diesel or hybrid vehicles, as well as public transport in many cities. Furthermore, oil prices are relatively low. Besides, charging EVs, and the distance that can be driven with each charging session is a concern for new buyers. Thus, incentives to turn to EVs is not very strong.

40% in 2020, and 40% and 25% in 2050 respectively[7]. Thus, Swiss utility companies can design new revenue streams based on appropriate services and installations.

Utility companies are facing many uncertainties. Developments occur in the market, and changes are being imposed by regulatory authorities, that may significantly affect those companies and their revenue sources. Several scenarios were devised based on probable future development in the market and the simulation model. The aim was to depict what would happen to the key performance indicators of utility companies under each scenario. Scenarios were triggered in 2020 to investigate their impact on household electricity demand from the distribution grid until 2050. In one set of scenarios, the parameters of adoption and acquisition of PVBs, HPs, and EVs were modified separately in the range of ±25%, as well as extreme cases of zero adoption and acquisitions of technology.

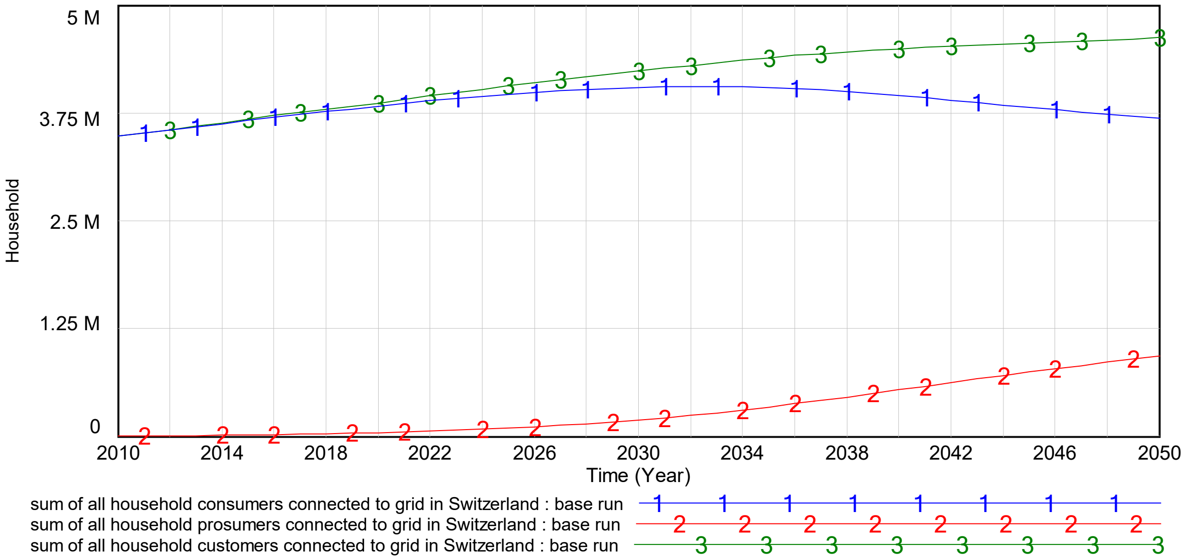

Figure 2: Portfolio of household customers connected to the grid in Switzerland.

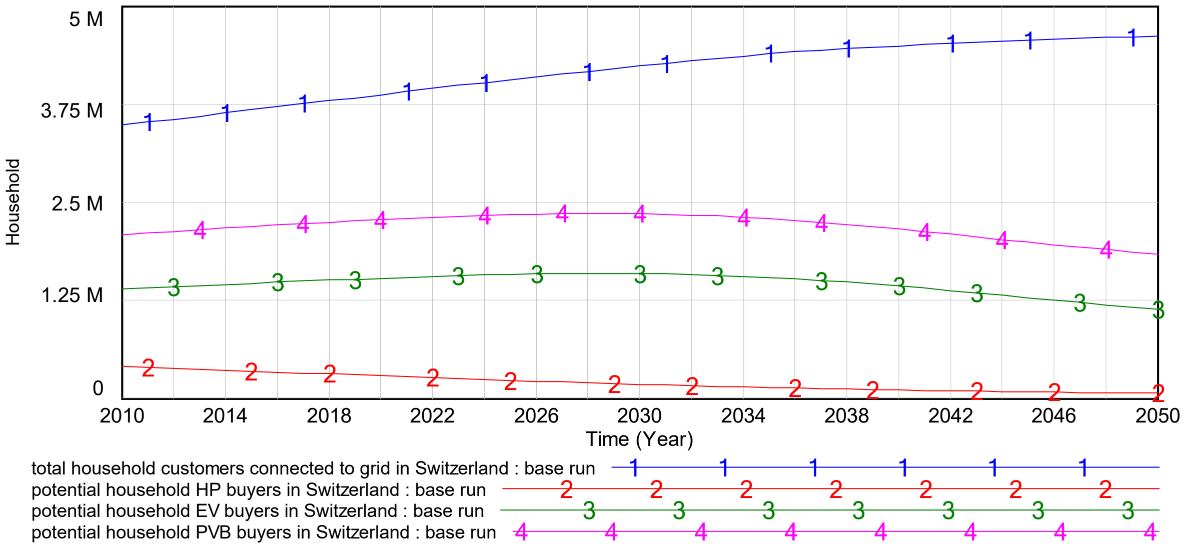

Figure 3: Changes in the market potential of service and installations in the Swiss electricity market.

The simulation model of this study also allows one to make a comparison with the Swiss Energy Strategy 2050[8], as depicted in Figure 4 and Figure 5. This study interpreted "Elektrizitätsnachfrage nach

[7] Changes in the demographics of households in Switzerland were also considered in these estimates. Assumptions on demographic are documented under "Considerations on Data: Swiss Demographic" in Appendix of this report.

[8] Source in German language: Energieperspektiven 2050. Zusammenfassung. p. 14, Tabelle 11: Elektrizitätsnachfrage nach Wirtschaftssektoren, Szenarien „Weiter wie bisher", „Massnahmen Bundesrat" und „Neue Energiepolitik", in PJ.

Wirtschaftssektoren" in Swiss Energy Strategy 2050 as electricity demand from the grid, which is the primary concern of utility companies and Swiss regulatory entities. Electricity consumption can be higher than electricity demand from the grid (as depicted in Figure 5). The difference between the two could be covered by self-produced electricity, e.g. by means of PVB-systems. Table 1 summarizes and Figure 4 presents the result of scenario analyses at the Swiss national level.

No.	Test scenarios	Changed Variables	Changed Values	Impacts on electricity demand from the Swiss grid in 2050
S1	Scenario PVB	all "expected adoption fractions" and "expected buying fractions" for PVBs	±25% in 2020	if PVB Popularity↓: +3% if PVB Popularity↑: -3%
S2	Scenario HP	all "expected adoption fractions" and "expected buying fractions" for HPs	±25% in 2020	negligible (around ±0.2%)
S3	Scenario EV	All "expected adoption fractions" and "expected buying fractions" for EVs	±25% in 2020	if EV Popularity↓: -2% if EV Popularity↑: +2%
S4	Impact of Technology Diffusion	"expected adoption fractions" and "expected buying fractions" of technology products	set to zero, in 2020	only EV diffusion: +8% only HP diffusion: +5% only PVB diffusion: -9%
S5	Scenario Degrees of Autarky	"expected increase in degree of autarky due to batteries ownership" ¦ "Change in degree of autarky"	+25% from 2020 over a period of 5 years ¦ -25% from 2020 onwards	if degree of autarky ↓: +5% if degree of autarky ↑: -5%
S6	SCOs	"interest in turning to SCOs by prosumers"	+50% from 2020	-1%
S7	Efficiency in Electricity Consumption	"changes in efficiency of electricity consumption"	1% per year (instead of assumed 0.75%), from 2020, over 30 years	-8%
S8	HP Market Potential	"fraction of households with possibility of buying HPs"	+30% from 2020, over 5 years.	+13%

Table 1: Summary of scenarios and their impacts on electricity demand from the grid.

Different scenarios can occur in the business environment. It depends on companies on how to prepare in advance, to react wisely and promptly to the changes in the market, or to take the initiative by devising and running policies that bring the best benefit for them. Table 2 summarizes the result of some policies based on the simulation model[9] and demonstrates how the ratio between two major sources of revenues – i.e., electricity sales and installations and services – for a utility company such as BKW may change in 2050.

available at: https://www.bfe.admin.ch/bfe/en/home/policy/energy-strategy-2050/documentation/energy-perspectives-2050.html

Abbreviations:

WWB: „Weiter wie bisher" | POM: „Massnahmen Bundesrat" | NEP: „Neue Energiepolitik"

Translated abbreviations:

WWB: "Continue as before" | POM: "Measures of Federal Council" | NEP: "New Energy Policy"

[9] This project resulted in a simulation tool. Additional scenarios can be devised based on it upon request.

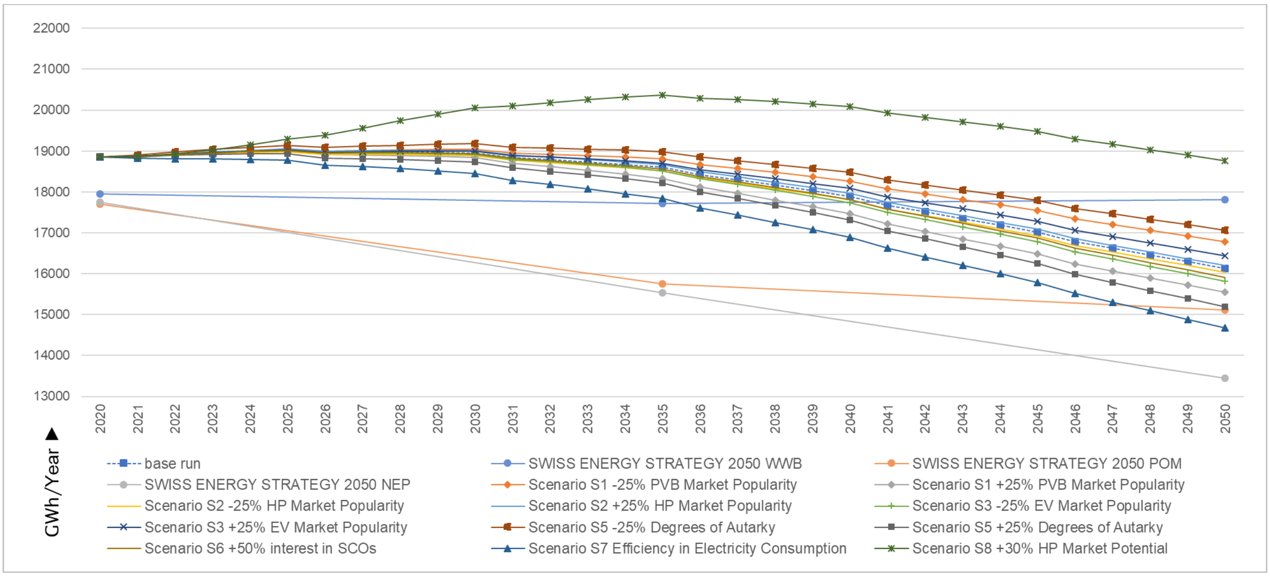

Figure 4: Household electricity demand from the grid in Switzerland under different scenarios.

The "relative" revenue share from electricity sales is defined as the fraction of revenue from electricity sales over the total revenue from electricity sales, and installation and services. The "potential" revenue share from installations and services demonstrates the maximum possible revenue that a utility company, such as BKW, could reap under normal conditions. It does not necessarily mean that the potential revenue from installation and services can be fully realized (Figure 15 in the main report demonstrates the relation of the two main revenue shares over time).

No.	Policy	Changed Variables	Changed Values	Some Impacts on BKW's Revenue Shares *
Base Run	Business as usual	-	-	Do nothing ▶ 62%:38% in 2050
P1	Increasing market share on tech-products within home supply region	relative attractiveness of BKW HP and PVB over Rivals in BKW supply region	10% increase from 2020 over 5 years.	Impact of P1 ▶ 60%:40% in 2050
P2	Extending market presence on tech-product installation and services to other Cantons	relative attractiveness BKW HP / PVB over Rivals rest of Switzerland	10% increase from 2020 over 5 years.	Impact of P2 ▶ 36%:64% in 2050
P3	Free Market win / lose	"change in average sales price per kWh" of BKW	BKW enters Free Market with CHF ±0.02 per kWh (compared to the probable market price of CHF 0.189 per kWh), from 2025 for 2 years.	If BKW wins ▶ 64%:36% in 2050, also, +8% customers for electricity. If rivals win ▶ 61%:39% in 2050, also, -8% customers for electricity

Table 2: Summarized list of policies.

(* Note: To publicly release the report and to protect BKW's data, it is hypothetically assumed that the ratio of revenue from electricity sales vs. revenue from installations and services for BKW would be 85%:15% in 2020.)

Rather than linear projections of Swiss Energy Strategy 2050 (such as scenario “WWB, Continue as Before”, pink line number 4, Figure 5), this study provides a more realistic projection of the future household electricity demand in Switzerland. The model of this study was fed and calibrated by the measured data on the average electricity demand of households in Switzerland from 2010 to 2018. That data was obtained from official data on electricity distributed to the household sector in Switzerland[10] for the mentioned period (blue line number 1, Figure 5).

The model differentiates between the “household electricity consumption” (red line number 2) and the “household electricity demand from the grid” (green line number 3). The gap between the two stems from the covered or compensated produced PVB-electricity in the household sector. It could potentially be as large as 2’300 GWh per year in 2050. Obstacles in diffusion of PVB among household customers cause a higher electricity demand of households from the grid, which makes the depicted gap smaller.

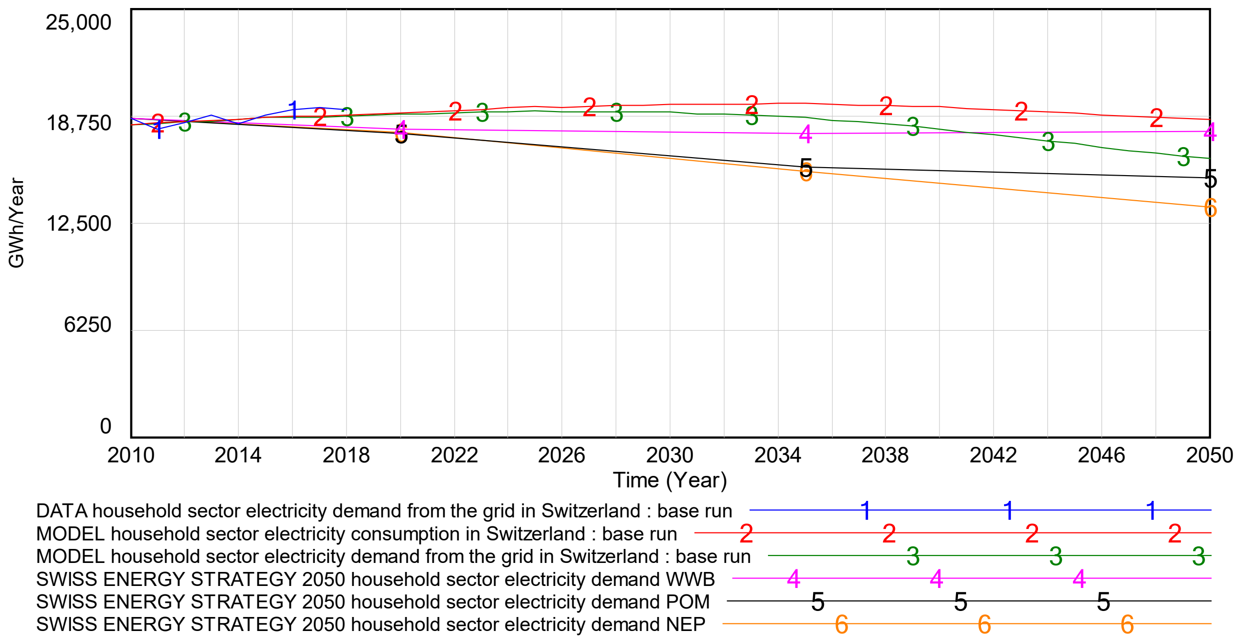

Figure 5: Electricity consumption; Current study vs. Energy Strategy 2050.

Limitations on the access to disaggregated data for the household sector and lack of reliable data on the ownership of different combinations of PVBs, HPs and EVs in the country (as elaborated in "Considerations on data: Access to data", in Appendix) mandated the parameter values were calibrated step by step, based on the available data. Modifying those parameters can change the projected behavior of the modeled system significantly. For example, the combined sensitivity analysis of “expected adoption fractions” of PVB, HP, and EV technology by normal customers indicates that the value for the “household electricity demand from the grid per capita” in 2050, under the base run of simulation, varies approximately between 1’500 and 1’750, i.e. a difference of 250 kWh (%17) per person per year.

[10] Source: Electricity statistics; Aufteilung des Endverbrauchs nach Verbrauchergruppen; Published on 21.06.2019, by Swiss Federal Office of Energy (Retrieved from https://www.bfe.admin.ch/bfe/en/home/supply/statistics-and-geodata/energy-statistics/electricity-statistics.html)

2 Position of this work package within the ProsumerLab project

This focus report is part of the larger ProsumerLab project. Research areas which were dealt with in this report are highlighted in orange, and the relevant inputs from other work packages are highlighted in blue in Figure 6.

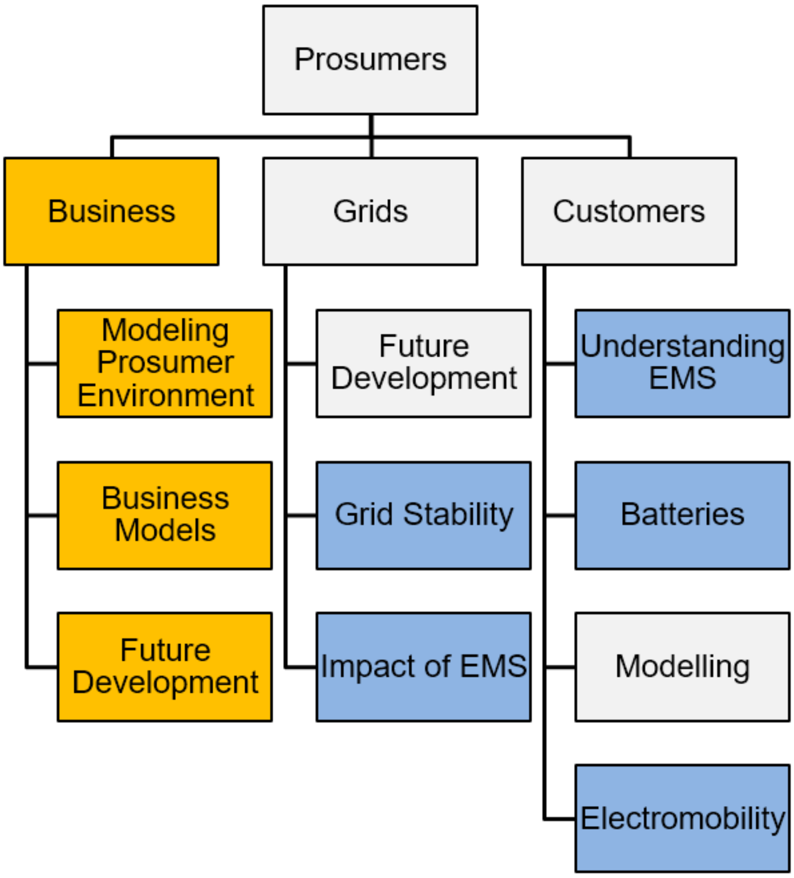

Figure 6: Position of this work package in the ProsumerLab project.

3 Introduction

This study addressed a forthcoming challenge for utility companies in Switzerland and tried to elaborate its impact on the existing business models in an evolving market. Swiss utility companies are confronted with a new, multifaceted situation. Firstly, the consumption of self-produced electricity occurs and is incentivized in Switzerland. "Self-consumption can be described as the local use of PV electricity in order to reduce the purchase of electricity from other producers." [7]. Secondly, self-consumption has evolved further, and household consumers have become decentralized electricity producers and suppliers. These so-called prosumers can cover a major portion of their electricity needs with installed PV-Systems. During peak production – often at times of low demand – they can supply the distribution grid with the excess electricity produced. On the other hand, during peak electricity demand – often at times with low production – the prosumers must cover their electricity needs by obtaining electricity from the same distribution grid. These kinds of irregularities not only cause fluctuations in the grid and call for flexibility in production and storage capacity, but also affect electricity prices on the wholesale market. Unless these irregularities can be addressed effectively, they may cause customer dissatisfaction and invoke penalties from regulatory authorities. Furthermore, the number of prosumers is sharply on the rise, accelerating the mentioned problems [1-4]. Third, the price of batteries has decreased and storage capacities have increased significantly during past decade, promising both the economic feasibility and technical capability to store the produced electricity from green sources on a larger scale [5, 6]. Fourth, the synergy of the increased prosumage and the enhanced battery storage potentially shifts the degree of autarky – a measure of energy self-sufficiency – for those who acquire the new technology [8, 9]. As a result, the electricity demand of prosumers from the distribution grid decreases, which in turn increases the cost of grid usage for the remaining consumers and threatens utility profitability [10]. Finally, liberalization of the electricity market is on the horizon, targeting monopolies in supply of electricity through large utility companies [11-15]. In a free market, consumers exercise "their ability to choose a utility provider" [14].

Such dynamics make the existing business model of providing and selling electricity to end-user customers less effective in generating revenue and causes inefficiencies in the electricity market. Thus, utility companies must undergo a transition, not only in their production and in the production management, but also in the development of an innovative, resilient business model that includes the dynamics and uncertainties of supply and demand. A successful transition ensures the sustainability of their business in this industry and the electricity demand fulfillment in the long run.

The research in this work package had two objectives. First, to explain the business dynamics of the growth in PV systems, battery storage technology and their effect on the customer portfolio of a major utility company in Switzerland. The research accounted for future changes in the market and evolution in the type of customers the utility has. Second, to project developments in key performance indicators of the household electricity market in Switzerland in the long term. Achieving these objectives will allow one to answer the focus research question:

> *From a business model perspective, how does a system of prosumers, utility companies, and associated incentives or regulations develop in the Swiss electricity market?*

Five subordinate research questions were defined to answer the focus question (Sections 4 to 8), which are as follows.

4 RQ-3027 Modeling of prosumer environment

How is the existing business model impacted by the current developments (e.g., prosumers, and self-consumption organizations)?

In the existing business model of utility companies, the primary activity regarding household customers is selling and distributing electricity to households in the supply region. Providing and selling electricity to end-user customers is the activity that generates revenue. The cost structure of such companies consists of variable and fixed costs. Variable costs usually change relative to the volume of the produced commodity. Fixed costs, on the other hand, stay the same within specific levels of production. A realizing vulnerability of such business models is that a decrease in household electricity demand from the grid – as more household customers acquire and use photovoltaic (PV) systems – increases the cost of grid usage for the remaining consumers and threatens the profitability of the utility companies.
From an energy perspective, household customers of utility companies can be categorized as prosumers and consumers. Prosumers possess photovoltaic (PV) or photovoltaic and battery (PVB) systems[11] to produce and store solar electricity [cf. 17, 18]. Consumers are those customers who do not have access to such modules for variety of reasons, e.g. not being persuaded to acquire the technology or living in houses where installing such modules is neither possible, nor cost-efficient. In this investigation, heat pumps (HPs) and electric vehicles (EVs) are also considered, since they can significantly change the electricity consumption of household customers. This study does not account variations within these technologies.
In this study, a normal customer is a household consumer without any of the three technologies, i.e., PVB, HP or EV. It has been observed that most customers adopt technologies from that initial stage. It is expected to see that they move toward the prosumer side through different paths, acquiring different technologies, as depicted in Figure 7. Furthermore, prosumers can also play the role of suppliers, and consumers can become demanders if they join a self-consumption organization (SCO). For instance, a normal customer may first buy a PVB, then an EV, and finally acquire a HP. This customer is a potential supplier in a SCO. Another normal customer may first buy an EV, then if it is possible, he may decide to join an SCO. Since he does not have any PVB, he cannot contribute as an electricity producer and is a potential SCO demander.

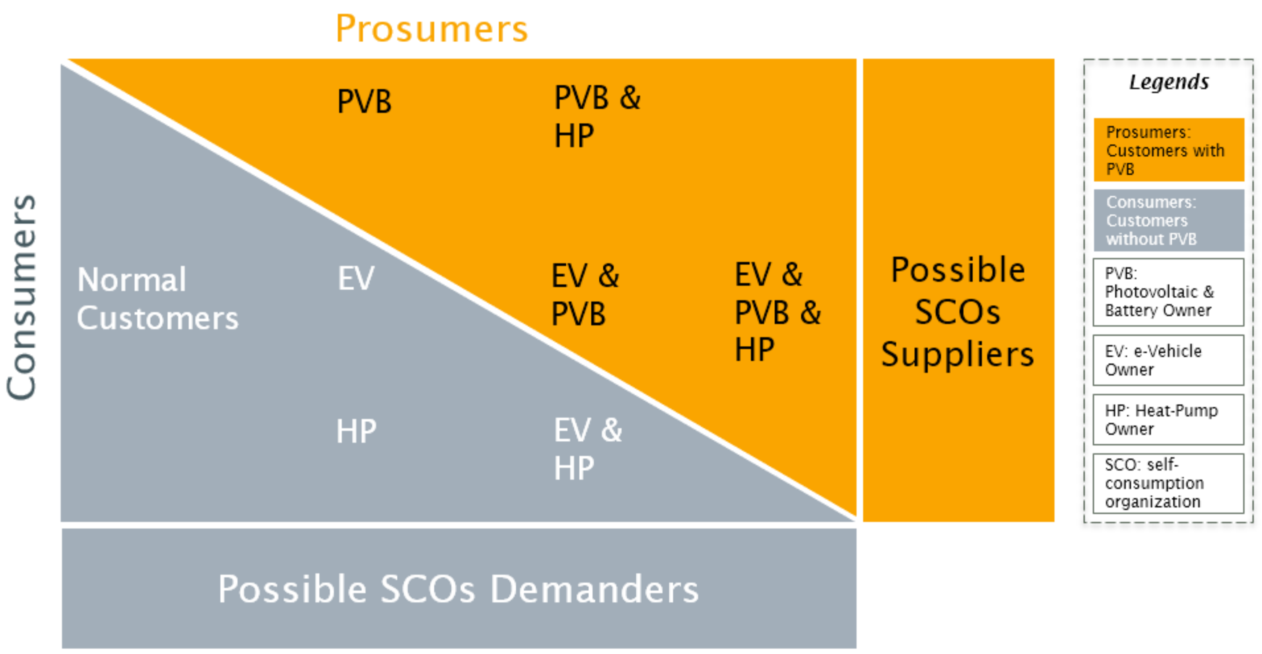

Figure 7: Supply and demand of electricity (detailed view).

[11] For the simplicity of the modeling in this study, it was assumed that customers buy photovoltaic panels and batteries at the same time. PV-owners are basically prosumers as well and their presence will lead to a decrease in the electricity demand from utility companies – even when no battery is installed.

In summary, household customers may acquire HPs, EVs, and PVBs in a different order, which considerably affects the electricity demand from the grid. HPs can replace fossil-powered heating systems similarly as EVs replace gasoline- or diesel-powered engines. These two electrical devices increase the electricity demanded from the grid. In contrast, installing PVBs helps customers to cover part of their electricity needs which consequently lowers electricity demanded from the grid. The first question and the core model developed for this study tries to capture the dynamics of the depicted current environment.

4.1 Method

The question addressed in this section has specific characteristics and behavior. For instance, the transition process from being a normal customer to becoming a prosumer – potentially incentivized by direct intervention and/or through a word-of-mouth (WOM) effect [cf. 19] – is a gradual one and takes place over time. So is the transition process of customers who choose a rival utility, either for electricity or for products/services. Turning to rivals also, for instance, can be incentivized by legal changes in selecting electricity providers or rivals' attractive deals and a consequent WOM effect. In this example, a reinforcing WOM process leads to winning more customers, and a larger customer base makes that WOM process stronger. A consequence of such dynamics can be observed through the accumulated number of prosumers and the reduced number of consumers over time.
Furthermore, there are uncertainties in technological developments, which affect important parameters such as the degree of autarky in solar electricity production and storage. Finally, if utility companies fail to build capacity in providing services to their customers, not only they will not retain their current customers, but also, they will fail to acquire new ones. However, the effect of changes in capacity on keeping or winning customers is not usually linear. For example, while 10 new units of capacity may win a company 10 new customers, 20 new units of the same type of capacity may not necessarily win the company 20 new customers. A similar argument is also valid for losing customers due to lack of capacity. From a modeling perspective, this is an example of a non-linearity that companies typically face.
In summary, the question addressed is typically governed by delays, originating from underlying accumulation processes, reinforcing and balancing feedback processes, nonlinearities, and uncertainties. System Dynamics modeling is the method of choice in this study because it addresses the characteristics and behavior of a system as outlined above [cf. 20, 21]. System Dynamics is a top-down simulation modeling method, which accounts for the integral of changes during each time step or delta-time in a modeled system. The method is particularly well-suited in in this research as it has been widely applied in the energy/electricity sector [22, 23], as well as in environmental and sustainability sciences [24].

4.1.1 Data gathering

Data for this study are obtained primarily from the Internet (in the form of reports, articles, and case studies) as well as statistical data from various Swiss Federal offices and public databases. In some cases, such data is adjusted to correspond to the specific circumstances of BKW. Additional data were obtained during workshops with BKW.

4.1.2 Expert interviews, workshops and group model-building

System dynamics becomes more fruitful if it is complemented with techniques that bring in knowledge, experience and opinion of various stakeholders, especially when the topic is as complex as the transition in the electricity industry. In this study, the researchers held monthly meetings with experts from BKW, to identify key factors that affect the business of that company. On several occasions, interviews with individual experts or smaller groups were arranged to refine and validate findings before presenting the result to the larger group of stakeholders. Participatory approaches of acquiring knowledge, such as the nominal group technique, and group model building were also used. These approaches help to include opinions and inputs from various stakeholders while addressing a problem, especially in situations where the engaged parties face conflicts of interest or have different opinions [cf. 25, 26, 27]. The researchers implemented insights and inputs from the participants in the simulation model after each session. They presented the results to the participants at the beginning of each workshop to further improve the model until the participants concluded that, for example, the model would represent core functions of the topic discussed [cf. 28].

4.2 Results: Validation and Base Run of the Simulation

This section demonstrates essential key performance indicators (KPIs) for the model's base run. A base run represents the "business as usual scenario" of a system in which everything works as usual before any game-changing assumptions of possible future scenarios, imposed from the outside, are applied to the model. The time horizon for the simulation model is from 2010 to 2050, and the results depicted in this report are limited to the Swiss household sector; industry, agriculture, or other energy intensive sectors are not modelled. Wherever possible, relevant historical data is imbedded in the figures to validate the simulation results[12].
Figure 8 depicts the household electricity demand from the grid in Switzerland (line 2 in red), accompanied by real data from 2010 to 2018 (line 1 in blue). The figure also presents projected household electricity consumption in the country (line 3 in green). The difference between the household electricity demand from the grid and the household electricity consumption indicates the extent to which prosumers cover part of their electricity needs with electricity produced by PVBs.
Figure 9 to Figure 11 illustrate the past and projected sales / net-increase and ownership of the products HPs, EVs, and PVBs[13] in Switzerland[14], under the assumptions of the base run of the simulation model. Real data demonstrates a shrinking yearly net-increase of HPs in Switzerland (Figure 10, left panel, line 1 in blue). Such a figure in consecutive years – from 2010 to 2018 – indicates that more sales are the results of replacement or refurbishment for current product owners rather than from new customers acquiring a technology-product for the first time. Thus, it can be concluded that the HP market in Switzerland is nearly saturated.
On the other hand, the PVB and EV markets are becoming more attractive for customers. The results shown in Figure 9 on Household PV sales and installed base, and the projected future diffusion of PV systems are consistent with the result in Figure 8 where the difference between the household electricity demand from the grid and the household electricity consumption is growing more significant in the long run. The peak of PVB sales and PVB market saturation occurs at some point in the future; compared to a relatively small number of PVB owners nowadays. An increase in the number of PVB owners in the long term corresponds to higher amounts of self-produced electricity, which covers a higher portion of prosumers electricity consumption and lowers electricity demand from the grid.

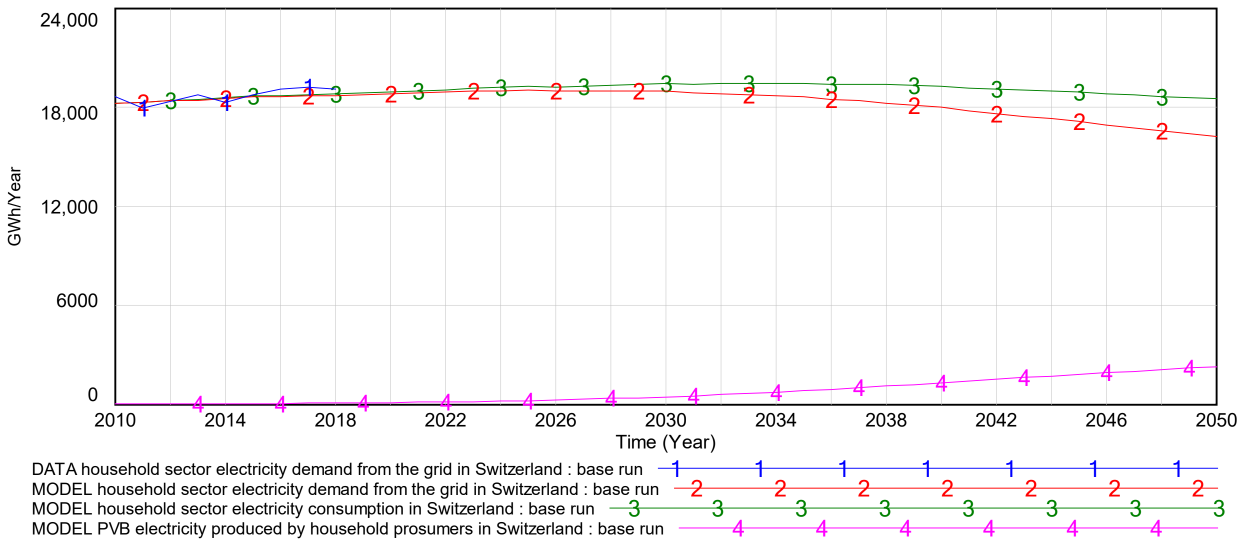

Figure 8: Household electricity demand from the grid vs. electricity consumption in Switzerland (base run).

[12] Key assumptions on parameter values are under the heading of the next research question: RQ-3028 Model Boundary

[13] Sources of historical data are documented under the section "Considerations on data: Access to data" in Appendix.

[14] In the absence of reliable data on the number of product owners in the supply region, aggregated public or Federal data are the only source to show the fit between the simulation and the real world.

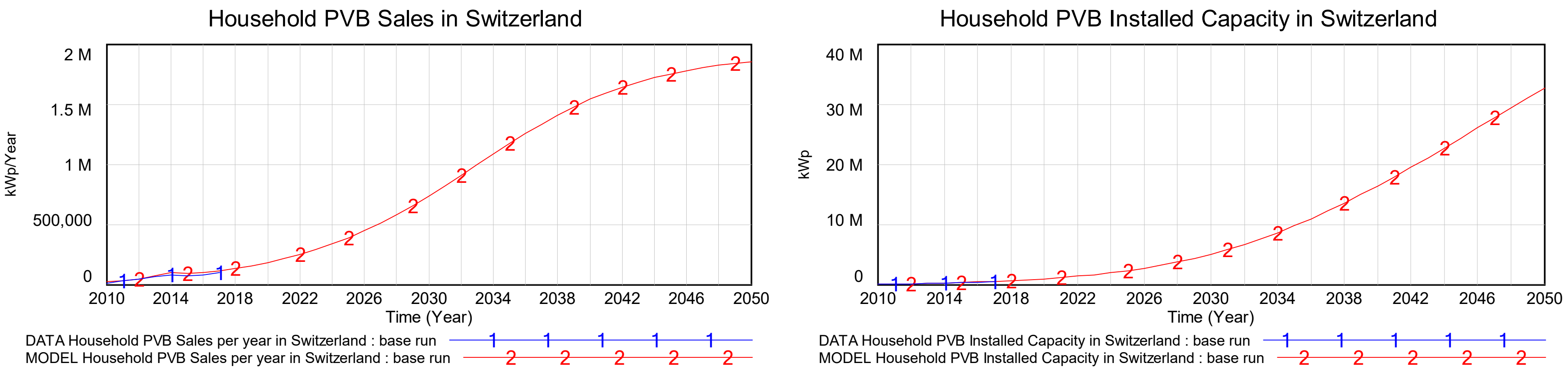

Figure 9: Swiss household PV sales (left panel) and PV installed base (right panel).

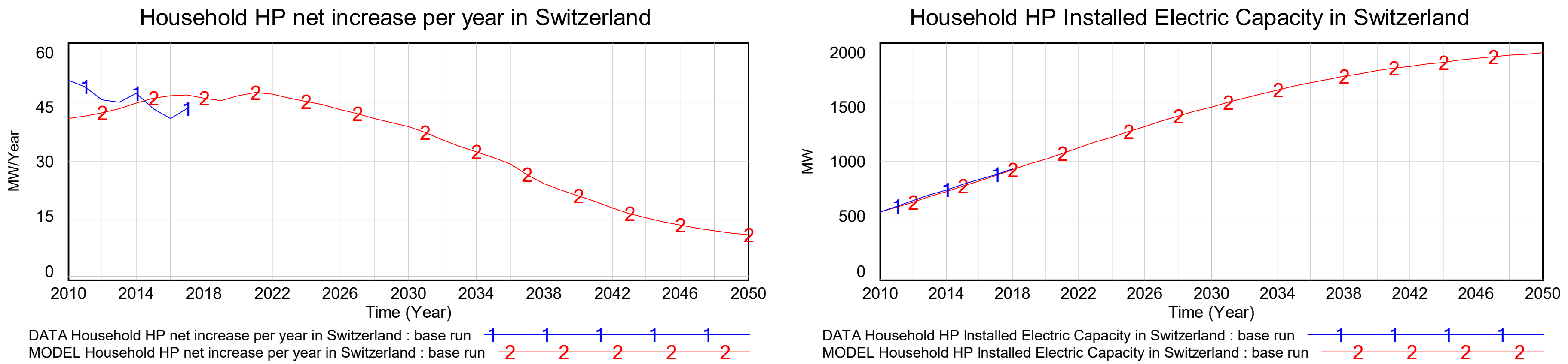

Figure 10: Swiss household HP net increase (left panel) and HP installed electric capacity (right panel).

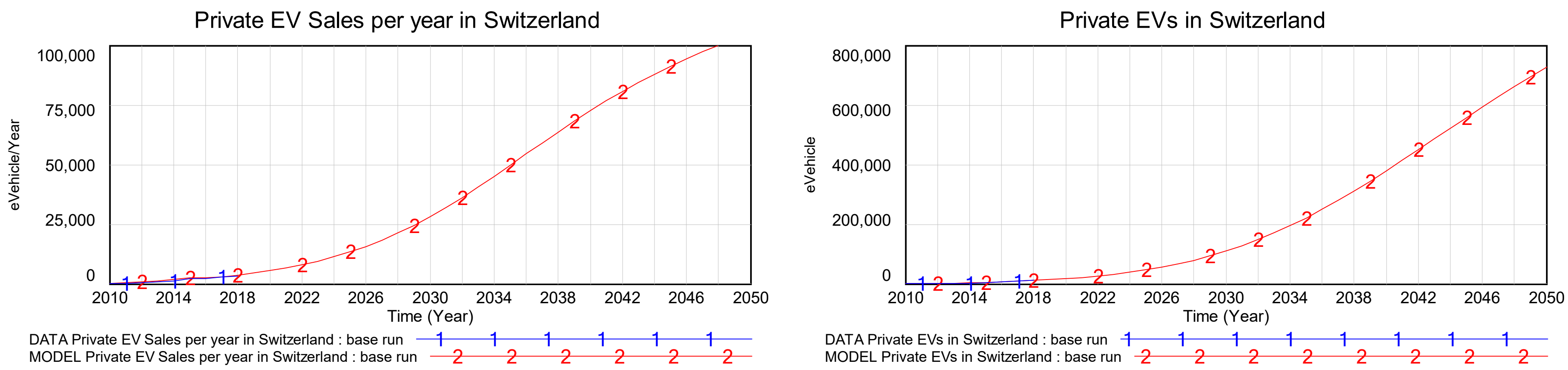

Figure 11: Swiss household e-Vehicle sales (left panel) and e-Vehicle owners (right panel).

5 RQ-3028 Model Boundary

What are the key assumptions used in the model?

For such modelling projects, it is necessary to make assumptions about which variables, and causal mechanisms are to be included, as well as parameter values to be chosen. The following summarizes the essential assumptions, which were made.

5.1 Key Assumptions

- Bundle package: Any household customer, who purchases a technology-product such as HP or PVB, acquires the next device in the future from the same company.
- BKW is the major utility company in its supply region. The main competition for the company in the region – in normal market situations – is in the selling, installation and services of PVBs and HPs to household customers.
- BKW capacity to produce electricity: BKW has a sufficient capacity for the production of electricity and can fulfill the household demand from its grid.
- From an overall perspective, total household electricity consumption is covered by PVB-produced electricity and electricity from the grid. In this study, it is assumed that prosumers try will to maximize self-consumption of produced electricity from PVBs, and if possible, not to feed back into the distribution grid.
- Customers who turn to SCOs as suppliers or demanders remain in such a self-consumption organization; they do not return to become a regular customer.
- PV panels and battery storage are considered together as a single product, referred to as PVB: the purchasing price of both products has decreased considerably in recent years. Furthermore, PV panels and battery storage can be regarded as complementary products; PVs produce electricity and batteries store this energy.
- In the modeling work done for this project, the impact of batteries on electricity demand from the grid is considered to occur as improvements in the degree of autarky over time.
- There is a zero net-exchange of household electricity-customers between BKW and its competitor, prior to a future market liberalization.
- Changes in Swiss demographics: The foreseeable decrease in the average size of the Swiss household leads to an increase in the number of them; a higher number of households, but smaller in size. Moreover, it is expected that the total population in Switzerland will increase. Relevant data were extracted from official Federal publications [cf. 29, 30-32] and were fed into the model as an input (more details are provided in Appendix, Table 7.)
- Considering averages of both single and multiple-family houses on parameter values: In this study, the parameter values corresponding to single- and multiple-family households are aggregated; wherever applicable, a weighted average of a parameter per a household in a single-family house and per a household in an apartment building or a multiple family house is calculated (ratio of single: multiple → 0.4: 0.6, where 0.4 + 0.6 = 1).
- A multi-family house refers to a house in which there is more than one household.
- The model includes two market areas: the supply region of BKW and the supply region of the rest of Switzerland (this is further explained in "RQ-3029 Meaningful Business Models", and in Figure 13)

5.2 Parameter values

Figure 12 summarizes the assumptions for the most important parameter values in the model, which are input values for the calculations and hence many of the figures in this report. More detailed parameter values are available from the authors upon approval of request. The four top panels (in blue) depict some important model inputs. The bottom panel (in grey) provides some outputs of the model. As mentioned earlier, the values in this figure represent the weighted averages of both single and multiple family houses, based on obtained real data and expert estimations.

Some model inputs for 2010 (measured data)	
average size of households in Switzerland = 2.26 People per Household	household electricity demanded per capita from the Swiss grid = 2,366 kWh/year/person
Some other model inputs for 2010 (expert knowledge and educated guess)	
average demand of a normal household customer (without PVB, EV, or HP) from the grid = 4991 kWh/year [15]	ratio of customers experiencing electricity consumption efficiency by installing HPs = 0.33
average HP electric capacity being installed per household customer = 2.4 kW/Household	electricity consumption efficiency by installing HPs = 1000 kWh/Year/Household [16]
* additional heat pump consumption = 3160 kWh/year	
average basic degree of autarky for customers	average kWp being installed (kWp/Household)
with PVB = 0.36	per normal customers buying PVB = 17.6
with EV and PVB = 0.46	per customers with EV buying PVB = 10.8
with PVB and HP = 0.56	per customers with HP buying PVB = 21.4
with PVB and HP and EV = 0.66	per customers with HP and EV buying PVB = 11.6
in SCOs = 0.56	
Some model outputs for 2010	
average demand from the grid per customer	
with EV = 6566 kWh/year	with PVB = 3194 kWh/year
with HP = 7821 kWh/year *	with EV and PVB = 3546 kWh/year
with HP and EV = 9396 kWh/year	with PVB and HP = 3441 kWh/year
	with PVB and EV and HP = 3195 kWh/year

Figure 12: Key assumptions on parameter values.

5.3 Model Boundary

The developed model is limited to the household sector. Some topics are considered in the model qualitatively and through exogenous variables. For instance, feed-in tariffs, subsidies for installing PVBS, fluctuations in PVB market, or probable future alternative technologies influence the attractiveness of PVBs. These phenomena, and many others, which affect the attractiveness of PVBs for household customers are captured qualitatively via a proxy variable, named “change in PVBs market popularity”. A similar solution for HPs and EVs is considered through their respective attractiveness. However, there are topics which are outside the scope of the project. A number of these are discussed in the following, and a summarized list is presented in Table 3.

[15] Detailed assumptions are documented in Table 7 and Table 8, section “Considerations on Data: Swiss Demographic” in Appendix.

[16] Expert opinion from BFH: Many existing customers in Switzerland use electric boilers, which are simple resistance heaters. Thus, to generate 1000 kWh worth of hot water, they use 1000 kWh of electric energy. A rough estimate is that a Swiss household needs about 500 to1500 kWh worth of hot water per person per year. If such customers switch to heat pumps for the entire building, then they typically also use such heat pumps to replace old boilers. A typical heat pump operates with a Coefficient of Power (COP) of 3. Therefore, the household will only need 333 kWh of electric energy to generate 1000 kWh worth of warm water.

If the above argument is being overlooked, most probably there will be a double-counting regarding the electricity consumption for the warm-water heating. However, the number of electric resistance-heated boilers is unknown in the calculations. Therefore, a rough heuristic to be used is as follows: approximately, one third to half (50%) of all households have boilers. If they switch to heat pumps, then a three-person-household could save as much as 2000 kWh/year. This works out to an average of 1000 kWh per year per household (note: the figures mentioned are educated guess and therefore are subject to a precise calculation).

- The electricity production capacity of BKW: This topic is related to one of the main assumptions in considering sufficient capacity in electricity production for BKW.
- The electricity fed into the grid by prosumer households: The quantity of electricity that such prosumers potentially feed into the grid of utility companies is negligible compared to the production capacity of large utility companies, and therefore was not modeled.
- The distribution grid: The distribution grid is regulated and therefore was not considered as part of the existing business model of BKW.
- PVB or HP manufacturers capacity and their supply chains: it is assumed that the availability of PVBs and HPs is sufficient in in the market, i.e., it holds no constraints in production lines of PVBs and HPs.
- The impact of the sharing economy on EVs[17], as well as the introduction of autonomous cars/electric vehicles to the market.

5.4 Result

Table 3 summarizes the above constraints and demonstrates the boundary of this research. Endogenous variables or topics are those that are calculated and projected within the simulation model. Among those is the diffusion of products such as PVBs and HPs within the household customer market. Exogenous variables or topics are also important to understand the model and its boundaries. However, their corresponding parameter values are fed to the model as an input (or a given). For example, various degrees of autarky for different categories of PVB owners are important to calculate the demand from the utility grid, however, such values are inputs to this model. Finally, excluded variables include those topics, structures, and phenomena, which are outside the scope of current research.

Excluded	Exogenous (given)	Endogenous
- Electricity demand from the grid of any sector except household sector is excluded, such as industry and agriculture. - Other types of Green electricity - BKW total capacity of electricity supply - feed-in tariffs - Sharing economy of EVs - Changing transportation behavior (e.g., autonomous cars/vehicles, public transport) - PVB or HP manufacturers' capacity and their supply chains - Emergences of new technologies instead of PVB, HP, and/or EV and their impact on electricity consumption or demand. - BKW cost structure (and profit structure) - Price elasticity of demand on product or services. - Reaction of rivals to BKW polices - Energy efficiency gains in electric vehicles mobility	- Regulations (such as free market, formation of SCOs) - Electricity price - Expected adoption (or purchase) fraction of a product - Degrees of Autarky that the combination of PV and battery storage brings (in percentage) - WACC (interest rate) to calculate the net present value of revenue streams - Average price for installation or service from utility companies - Demographics: Projected increase in the population of Switzerland	- Electricity demand of household sector. - Household PVB diffusion: Sales and Installed base - Household photovoltaic capacity installed (in kWp) - Household HP diffusion: Sales and installed base - Household HP capacity installed (in kW) - Household EV diffusion: Sales and owners - Revenue structure

Table 3: Model boundary chart.

[17] For instance: Jungblut (2017). Could Share & Charge Be the Airbnb of Electric Cars? (https://reset.org/node/28948)

6 RQ-3029 Meaningful Business Models

How can the existing business model become resilient considering current development?

BKW faces, at least, two types of competition: the first type of competition is for products, in the form of selling PVBs, HPs, and EV chargers/modules, and the potential revenue-stream that comes by providing service to customers who buy such products from BKW. This type of competition already exists in the BKW supply region. The second type of competition is for electricity sales. If BKW expands its operations to the rest of Switzerland, when the electricity market is liberalized, then there will be competition for supplying electricity inside and outside of the current BKW supply region. Figure 13 depicts an overview of the future strategic business area for BKW. Under such conditions, there will be major competition both for products and electricity sales. The top half of the figure is the current BKW supply region in which the utility company is the major electricity provider. There, the company will try to win customers for product installations and services (type 1 competition), to increase revenue streams in its “home” region. The company also can extend these market activities to the rest of the country, which is represented in the bottom half of Figure 13. This section of the figure also shows a potential growth in the electricity supply region of the company whenever the market is liberalized.
There are three notable threats to the depicted business model. The first one is the prosumage. An increase in the number of prosumers in the BKW supply region (whether as direct customers of BKW, or those who will turn to SCOs), corresponds to lower electricity demanded from the grid and a smaller revenue stream for the utility. The second threat is a competitive liberalized electricity market in which customers have the right to choose their electricity provider. There are potentially customers who will turn to or leave BKW as a supplier in such a market. A net negative number of customers joining a specific utility means a smaller customer base of selling electricity for that company. The third threat – which already exists – is from the large number of PVB and HP installation companies, both in BKW supply region and in the rest of the country. Keeping current customers and winning new customers, in a market in which many large and small installation companies operate, is challenging.

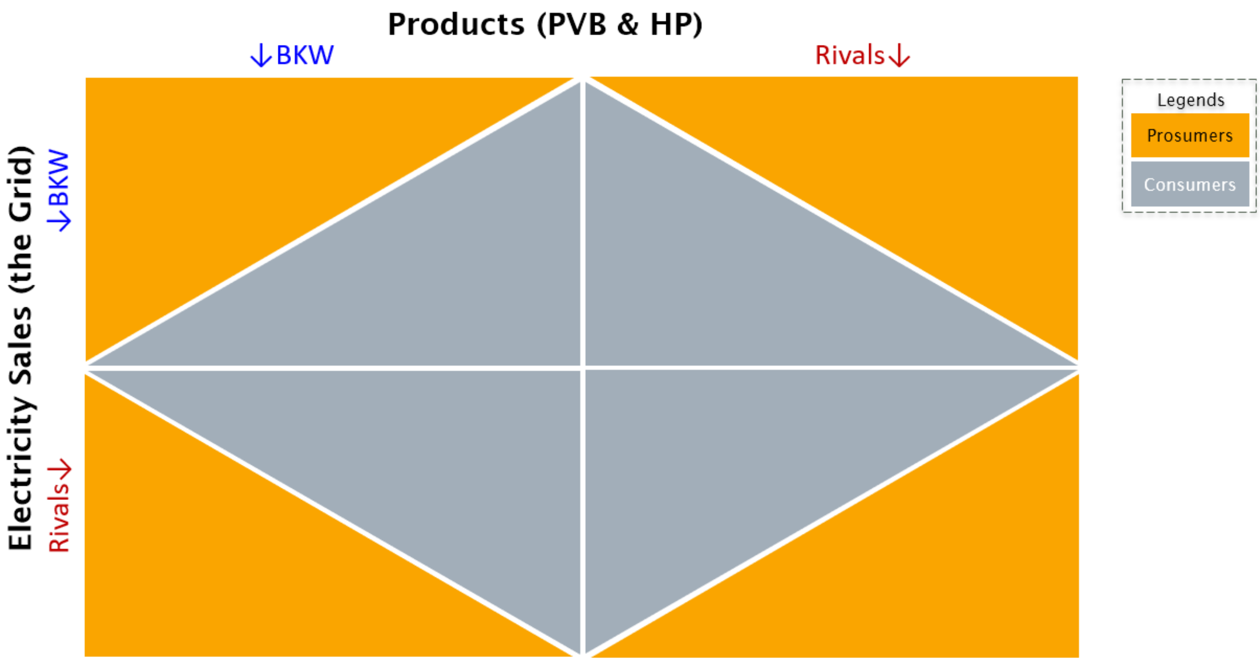

Figure 13: Possible strategic business area of BKW (overall view).

6.1 Method

Since the cost structure is a commercially sensitive topic for BKW, it is not considered as a part of the analysis, which limits the model to the revenue structure. A revenue structure for the meaningful business model consists of possible revenue streams from various parts of the BKW supply region, now and in the future. From the installation and service perspective, revenue streams mainly originate from the price considered for (1) one-time installations of tech-products, such as PVBs, HPs and EV charging modules, (2) as well as yearly service price from the owners (or users) of such products, and (3) yearly subscription for providing services (such as metering) to self-consumption organizations. From the electricity sales perspective, the revenue streams come from selling electricity to the different groups of customers in BKW supply region, as well as selling electricity to SCOs, which chose BKW as their supplementary electricity provider.

The discussed model in the previous research question was extended to investigate a meaningful business model in this section. The BFH team and the experts in BKW discussed plausible prices for each revenue source[18]. Including those parameters in the model enables one to compare the revenue shares for both the current and the enhanced business models.

6.2 Results

Figure 15 and Figure 16 present some important KPIs for a meaningful BKW business model in the base run of the simulation. It is foreseeable that the number of prosumers is increasing, as depicted in the Figure 15 (line 3 in green). This is the case for the supply region of any utility company: an increase in the number of prosumers leads to higher PVB-produced electricity and reduced electricity demand form the grid.

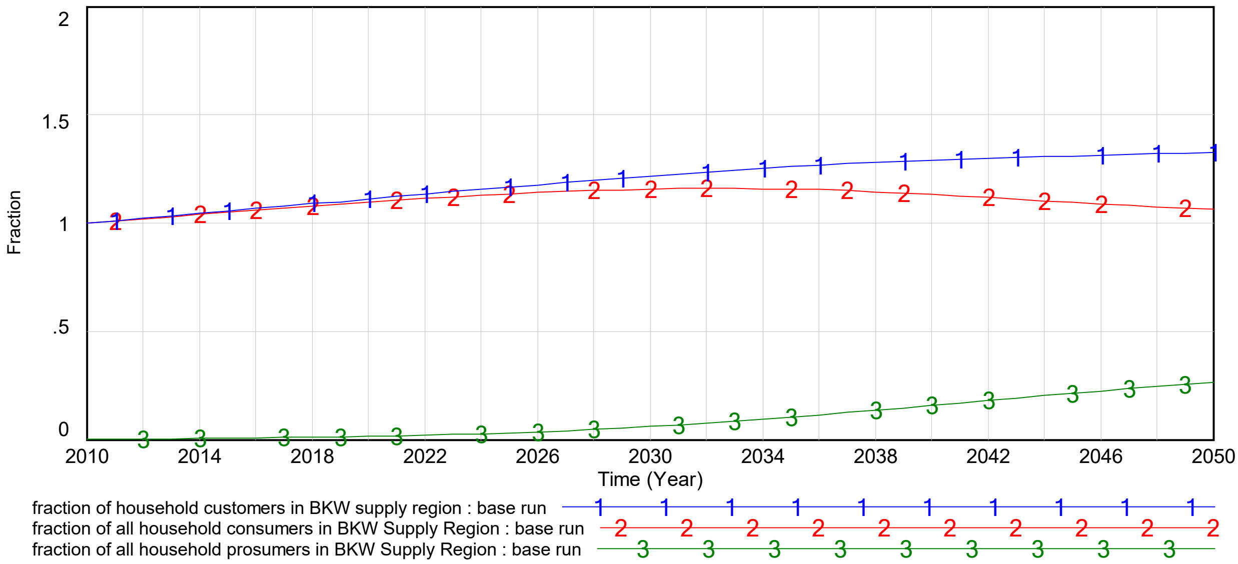

Figure 14: Changes in the portfolio of BKW customers.
(Note: The values are normalized)

Under such conditions, the revenue share of electricity undergoes interesting changes. The normalized revenue from electricity sales compared to 2010 – the fraction of yearly revenue from electricity sales compared to its value in 2010 – gradually increases to slightly less than 4% around 2025, i.e., 104% in that year. The increase is a combined effect of population growth and diffusions of EVs and HPs. Afterward, that revenue starts to decrease. It happens because of the increasing dominance of PVB diffusion and efficiency in household electricity consumption. Consequently, the discussed revenue from electricity sales drops to 87% in 2050, as depicted in Figure 15 (line 1 in blue).

The “relative” revenue share from electricity sales – the fraction of revenue from electricity sales over the total revenue from electricity sales and the potential revenue from installations and services, a term coined in this study – gradually decrease from the outset and drops to 62% in 2050, as depicted in Figure 15 (line 2 in red).

In parallel, another dynamic is occurring: the potential revenue from services and products (line 3 in green) increases to 38% in 2050, due to an increase in the number of customers who possess a various

[18] Those prices are omitted from this report on purpose to protect BKW’s sensitive data.

combinations of PVBs, HPs, and EVs (depicted in Figure 28 in Appendix, section "Technology perspective"). The potential revenue from installations and services demonstrates the maximum possible revenue that a utility company such as BKW could reap under normal condition. It does not necessarily mean that the "potential" revenue from installation and services can be fully realized.

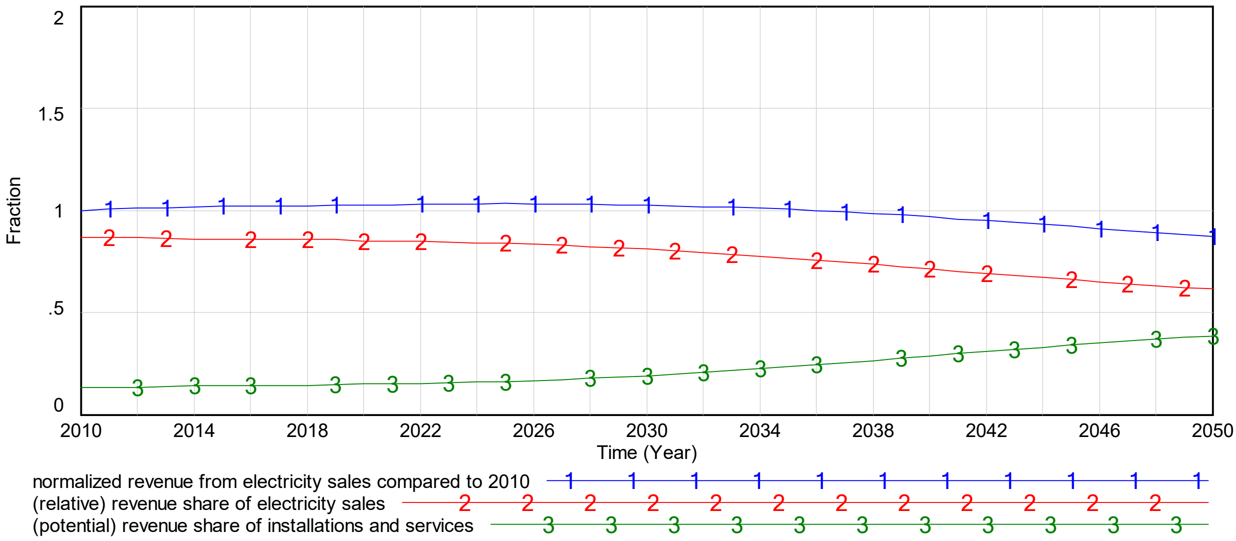

Figure 15: The impact of changes in the portfolio of customers on BKW revenue streams.
(Note: The values are normalized)

Figure 16 presents the market potential of the studied products in the BKW supply region. The figure indicates how the market potential of selling PVBs and HPs as well as EV-related products and services declines over time. The decline can best be explained by the market development of each product depicted in Figure 9 to Figure 11. The HP market is near to its saturation level in Switzerland, i.e. more of the yearly sales are a result of HP replacement by current owners and less is from new adopters. Thus, the remaining number of potential HP buyers is limited. However, there are large market potentials on service and products related to PVBs and EVs because these products are at the early stages of their diffusion. If the company is diligent, those potential buyers may become direct technology-product customers and the utility company can potentially develop new revenue streams based on these services. Potential solutions on how the situation may be improved, to align more with the interests of a utility company such as BKW, will be discussed in the section "RQ-3031 Plausible Policies".

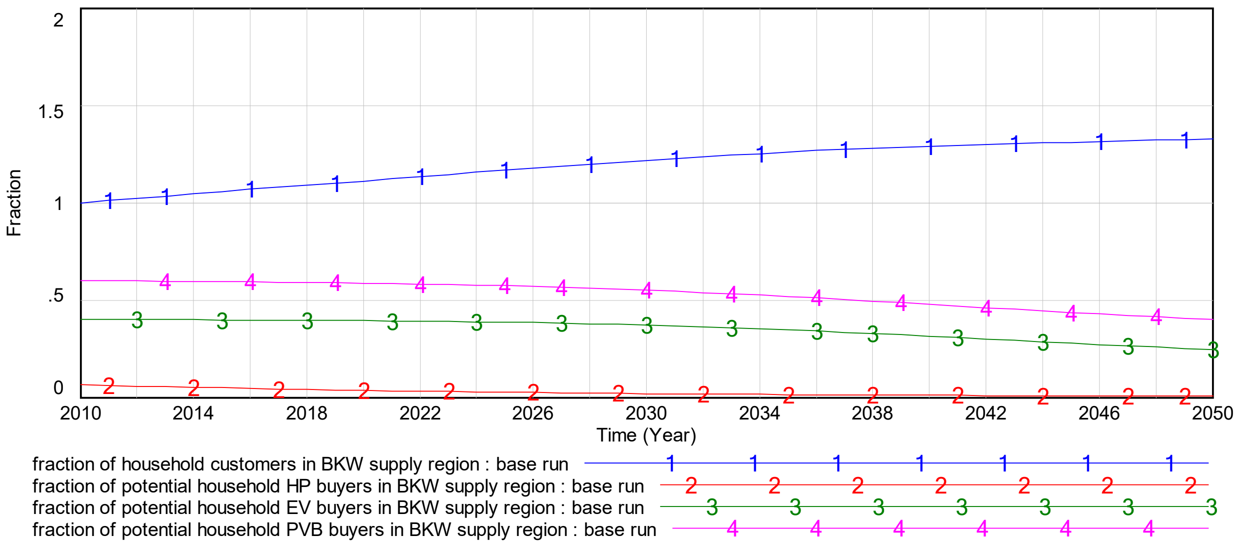

Figure 16: Market potential of HP, EV and PVB in BKW supply region (under the base run of simulation).
(Note: The values are normalized)

7 RQ-3030 Possible Scenarios

What are the plausible scenarios that significantly impact the business model of utility companies?

Utility companies are facing many uncertainties. Developments are happening in the market and regulatory authorities are imposing changes that may significantly affect those companies and their revenue sources. In this section, the results of some scenarios based on the developed simulation model are presented. The aim is to depict what would happen to the important KPIs of utility companies under each scenario.

7.1 Method

To answer this research question, a list of probable scenarios for the industry was postulated and discussed with the BKW experts to validate their plausibility. To create the refined list, several additional modules were implemented in the model with the possibility of turning them on or off to study the impact of various scenarios separately or jointly.

7.2 Results

Scenarios were triggered in 2020 to investigate their impact on household electricity demand from the grid in 2050. Figure 17 and Figure 18 presents results of scenarios tested with the model. Table 4 provides an overview of those scenarios and details the percentage changes in electricity demand from the grid. The reported rounded percentages are based on the parameter values that were fed to the model, and uncertainty still exists as it is discussed in the sensitivity analysis section in the Appendix.

In one set of scenarios, the parameters of adoption and acquisition of PVBs, HPs, and EVs were modified separately in the range of ±25%. For instance, an increase in the PVB market popularity by 25% potentially impacts PVB adoption and leads to higher self-produced electricity. The result inevitably would be a decrease in electricity demand from the grid by -3%, with a negative impact on the total revenue of utility companies[19]. In comparison, a decline of PVB popularity among existing potential buyers by -25% hinders PVB acquisition, which in turn increases electricity demand and the corresponding total utility revenue approximately by 3% in 2050.

In contrast, higher HP and/or EV popularity increases the installed base of such tech-devices and increases electricity demand from the grid as well. However, changes in the EV market have a larger impact on customer demand, compared to changes in the HP market. This is mainly because the HP market is near saturation, and the EV market is growing. For instance, while a 25% increase in HP sales to the current HP potential buyers has a negligible impact, the same percentage of increase in EV sales to the existing potential EV buyers leads to 2% increase in the demand of electricity in 2050.

An increase in degree of autarky for various categories of prosumers by 25%, also potentially leads to a reduced electricity demand from the grid by -5% and a reduced total utility revenue. This is because a higher autarky in electricity production enables prosumers to cover higher fraction of their electricity consumption by PVB-produced electricity and draw less electricity from the grid. Similarly, an extra improvement efficiency in household electricity consumption by 0.25% per year – because of more efficient household devices – has a negative impact on the demanded electricity from the grid by 13%.

7.2.1 Impact of Technology Diffusion

A special group of scenarios analyzes the extreme conditions of technology diffusion and its impact on electricity demand. The base run in Figure 18 (line 1 in blue) is what a normal transition to technology-products contributes to the change in electricity demand from the distribution grid, such as that of BKW. For the scenario of "no diffusion" (line 2 in red), all expected diffusion and adoption fractions are set to zero. In this scenario, it is assumed that all new sales of HP, EV, and PVB is stopped. Thus, the combination of product owners stays intact (all other assumptions such as efficiency in electricity consumptions remain unchanged, same as the base run).

[19] Figures about revenues are not addressed in this report. The developed simulation model has capability to provide figures on such business objectives.

Figure 17: Household electricity demand from BKW under different scenarios.
(Note: The values are normalized)

The rest of the scenarios depict how the mono-diffusion of a single technology would contribute to an increase or decrease in total demand of electricity from the grid. For instance, in the extreme case of "only PVB diffusion", the diffusions of the other two products are stopped. A reduction in total demand is more visible (by almost -9% in 2050) because PVB-produced electricity increases, while the installed base of the other two products, which consume electricity, will not change. This scenario shows what it would look like if customers would become prosumers without turning to electricity-based heating and mobility. Finally, the HP market is relatively mature. Thus, "only HP diffusion" will not add drastically to the electricity demand. However, since the EV market is growing, the "only EV diffusion" scenario significantly contributes to the total electricity demand from the grid in the long term. The difference between "only EV diffusion" and "only PVB diffusion" would be approximately 15%.

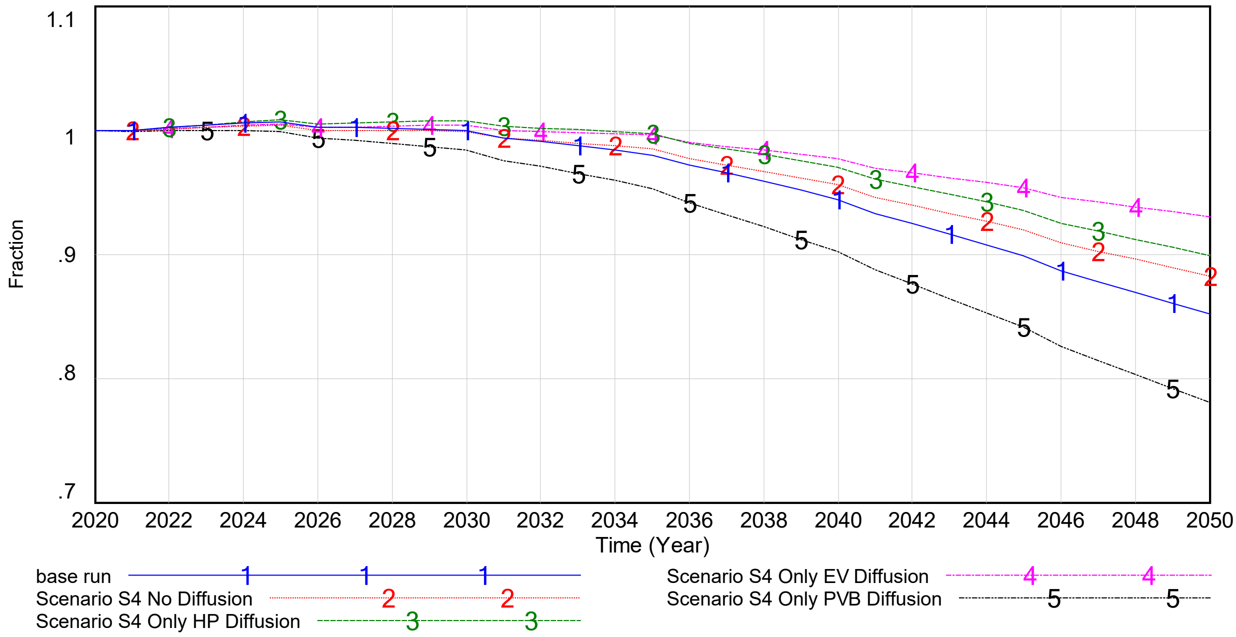

Figure 18: Household electricity demand from BKW under the extreme cases of diffusion of products.
(Note: The values are normalized)

No.	Test scenarios	Changed Variables	Changed Values	Motivation	Impacts on electricity demand from the Swiss grid in 2050
S1	Scenario PVB	all "expected adoption fractions" and "expected buying fractions" for PVBs	±25% in 2020	Changes in PVBs popularity among the existing potential buyers for different reasons.	if PVB Popularity↓: +3% if PVB Popularity↑: -3%
S2	Scenario HP	all "expected adoption fractions" and "expected buying fractions" for HPs	±25% in 2020	Change in HPs popularity among the existing potential buyers for different reasons.	negligible (around ±0.2%)
S3	Scenario EV	All "expected adoption fractions" and "expected buying fractions" for EVs	±25% in 2020	Change in EVs popularity among the existing potential buyers for different reasons.	if EV Popularity↓: -2% if EV Popularity↑: +2%
S4	Impact of Technology Diffusion	"expected adoption fractions" and "expected buying fractions" of technology products	set to zero, in 2020	Analyzing the extreme conditions (a hypothetical situation) on technology diffusion and their impact on the KPIs, such as electricity demand from the grid.	only EV diffusion: +8% only HP diffusion: +5% only PVB diffusion: -9%
S5	Scenario Degrees of Autarky[20]	"expected increase in degree of autarky due to batteries ownership" ¦ "Change in degree of autarky"	+25% from 2020 over a period of 5 years ¦ -25% from 2020 onwards	Changes in degrees of autarky: New Technologies in Energy Storages ¦ Market fluctuations	if degree of autarky ↓: +5% if degree of autarky ↑: -5%
S6	SCOs	"interest in turning to SCOs by prosumers"	+50% from 2020	Legal changes that enables forming of SCOs (Self-Consumption Organization)	-1%
S7	Efficiency in Electricity Consumption	"changes in efficiency of electricity consumption"	1% per year (instead of assumed 0.75%), from 2020, over 30 years	Potential decrease in the average demand per normal household customer due to an improved efficiency in electricity consumption of devices[21]	-8%
S8	HP Market Potential	"fraction of households with possibility of buying HPs"	+30% from 2020, over 5 years.	Federal mandates, changes in oil price, or other reasons which force / persuade household customer to switch from legacy fossil-powered boilers and/or heaters to HPs.	+13%

Table 4: List of scenarios and their impacts on electricity demand from the Swiss grid.

[20] It is highly likely that changes in the degree of autarky cause changes in PV popularity as well. Thus, various impacts are plausible for the latter. For the simplicity of presentation, such confounding effects are avoided here. However, a gamification feature is implemented in the developed model. Users are encouraged to consider such possibilities.

[21] From BFH Experts: On average, it is expected that the improved efficiency in electricity consumption will be 1% per year, over 10 to 15 years; however, it is difficult to determine the type of the slope of such curve (linear, exponential growth, or exponential decay). The assumed yearly-improved efficiency in the base run of the model for this study is 0.75% year. This value is based on calibrating the model with historical data on the volume of electricity distributed to the household sector in Switzerland, from 2010 to 2018 (Table 7, in Appendix).

8 RQ-3031 Plausible Policies

What are the plausible policies that significantly improves key performance indicators for utility companies?

Different scenarios can occur in the business environment. It depends on companies on how to prepare in advance, to react wisely and promptly to the changes in the market, or to take the initiative by devising and running policies that bring the best benefit. This section discusses some plausible policies that a utility company may run in such an environment.

8.1 Method

A similar method to that of the previous research question, RQ-3030 Possible Scenarios, has been employed here. A list of probable policies applicable for BKW has been devised. Afterwards, the most significant ones were implemented in the model with the possibility of turning them on or off to study the impact of each separately or jointly.

8.2 Results

An increase in yearly market share of a product that BKW supplies, reflects itself in the long-term acquisition of customers, translated in terms of installed base. The installed base of a product or service – in simple words – is the total number or the unit of a specific product or service, which is being utilized by customers, usually in the supply region of the manufacturer of that product or the service provider. The first policy is a relatively modest one and targets the BKW home or supply region. The second policy is a relatively ambitious one, which targets the rest of Switzerland. Figure 19 demonstrates the impact of these two policies on revenue shares of BKW for electricity sales, as well as installations and services. If the company wants to lower its dependence on electricity sales, it is recommended to penetrate the market of installations and services for PVBs, HPs and EVs. Both regional and national policies will lead to a higher revenue share of installations and services for BKW. However, since the second policy targets a larger customer base, i.e. the rest of Switzerland, it generates higher total revenue (Figure 21).

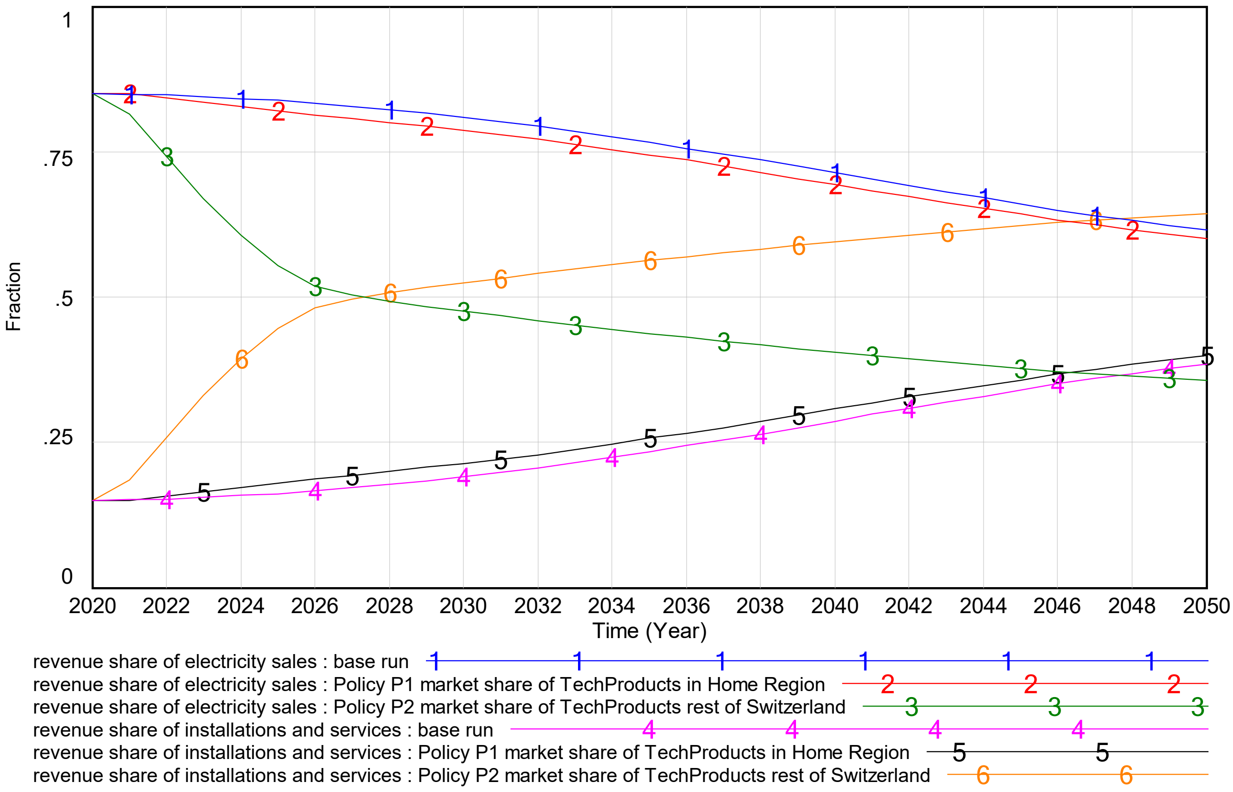

Figure 19: Impact of policies on the two major revenue shares (the utility company level).

The third policy is applicable when the market liberalization comes into effect. Legal changes will allow household customers to select their electricity provider. When the free market commences, one highly probable scenario is that sensitivity to electricity price will play an important role. Depending on how sensitive customers are to such prices, utility companies such as BKW, win or lose a fraction of customers and its consequent revenue streams[22].

Within this hypothetical setting, it is assumed that CHF 0.189 per kWh will be the market price in a Free Market. Then, a utility company such as BKW enters the Free Market with CHF ±0.02 per kWh, from 2025 and offers those prices for the following two years. If it is assumed that BKW is flexible in pricing and have financial capacities to implement the policy and outperform its rivals, it is foreseeable that BKW will win a fraction of customers in the open market. In such conditions, offering lower prices compared to the market price brings approximately 8% new customers. On the other hand, charging higher prices deters household customers and 8% of them will turn to the rivals. Figure 20 presents the magnitude of the impacts pictured for these scenarios. The take away message from this policy is that lower revenues in the short run will be compensated by higher revenues in the long run, as depicted in Figure 21, because of a higher customer base that the company potentially acquires.

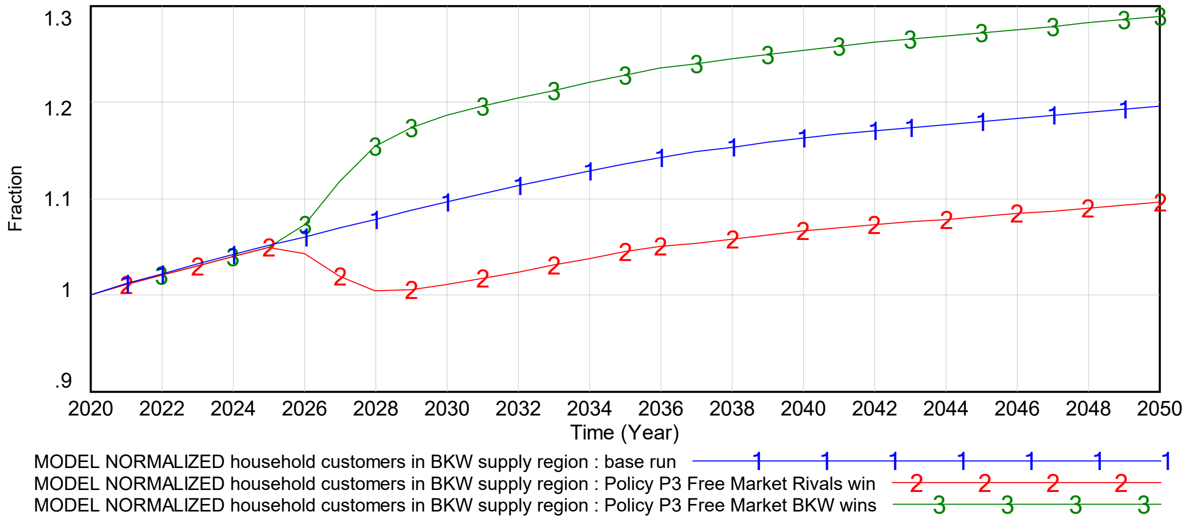

Figure 20: Impact of BKW's policies on its number of household customers in Free Market.
(Note: The values are normalized)

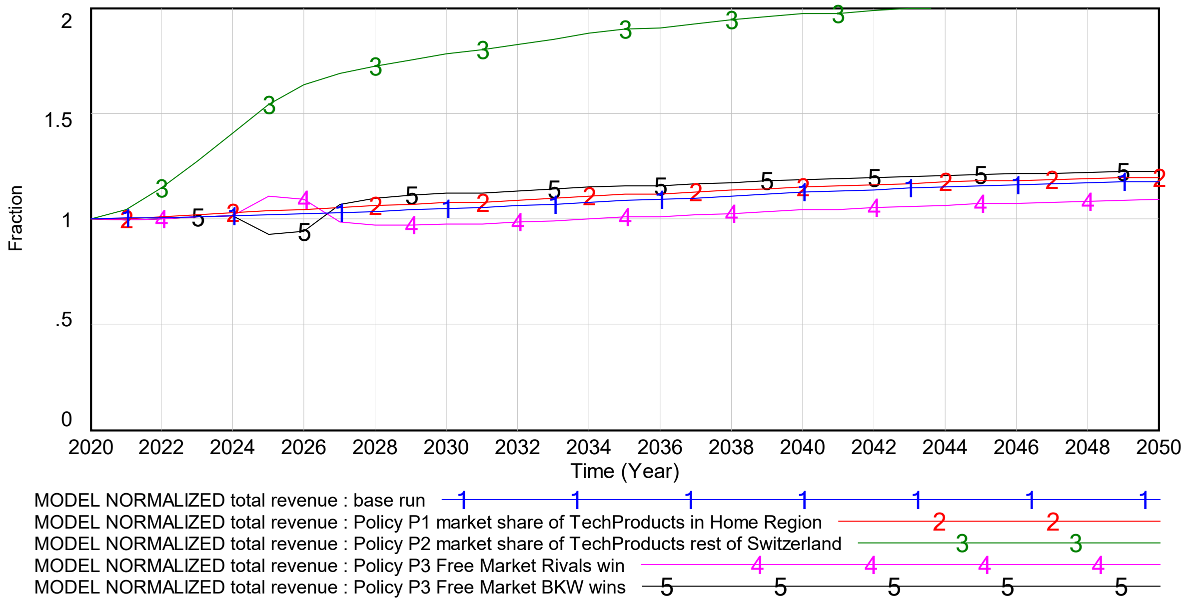

Figure 21: Impact of different policies on BKW's total revenue.
(Note: The values are normalized)

[22] Extra details on price sensitivity are in the Appendix, Considerations on Free Market .

Table 5 demonstrates the result of some policies, based on the simulation model. **Figures and data about utility companies are assumptions made for a generic utility company in Switzerland.**

No.	Policy	Changed Variables	Changed Values	Motivation	Some Impacts on BKW's Revenue Shares *
Base Run	Business as usual	-	-	The bases of the comparison.	Do nothing ► 62%:38% in 2050
P1	Increasing market share on tech-products within home supply region	relative attractiveness of BKW HP and PVB over Rivals in BKW supply region	10% increase from 2020 over 5 years.	To leverage BKW resources and expertise to penetrate the market of installation and services in BKW's supply region	Impact of P1 ► 60%:40% in 2050
P2	Extending market presence on tech-product installation and services to other Cantons	relative attractiveness BKW HP / PVB over Rivals rest of Switzerland	10% increase from 2020 over 5 years.	To make the business model more resilient by diversifying sources of revenues	Impact of P2 ► 36%:64% in 2050
P3	Free Market win / lose	"change in average sales price per kWh" of BKW	BKW enters Free Market with CHF ±0.02 per kWh (compared to the probable market price of CHF 0.189 per kWh), from 2025 for 2 years.	Legal changes in freedom of selecting electricity provider[23], and customers' sensitivity to electricity price. Hypothetical setting: CHF 0.189 per kWh will be the market price in Free Market.	If BKW wins ► 64%:36% in 2050, also, +8% customers for electricity. If rivals win ► 61%:39% in 2050, also, -8% customers for electricity

Table 5: List of policies.
(* Note: To publicly release the report and to protect BKW's data, it is hypothetically assumed that the ratio of revenue from electricity sales vs. revenue from installations and services for BKW would be 85%:15% in 2020.)

[23] The electricity free market (market liberalization) in Switzerland probably will commence in 2024 or 2025.

9 Conclusion

Diffusion of new technologies is an ongoing phenomenon, which affects the lifestyle and habits of people, as well as the way of doing business. Adopting PVs and battery storage by households is one such phenomenon, which changes the electricity consumption habits of household customers, and inevitably impacts the business of utility companies and other players in the energy sector.

Today, the number of prosumers and their more advanced form, i.e. electricity self-consumption organizations, are increasing. This study has tried to explain the impact that prosumage as well as the diffusion of three major technologies – PVs and battery storage, heat pumps, and electric vehicles – could have on household electricity demand from the grid and electricity sales of utility companies. The results indicate how the revenue from electricity sales of utility companies shrinks as the installed base of PVBs increases over time in the household energy sector. In contrast, popularity of HPs and EVs will serve to increase household electricity consumption.

In a realistic scenario, which is indicated by the base run of analysis in this study, the impact of a larger installed base of PVBs – that leads to a lower household electricity demand from the grid – will be larger than the impact of HPs and EVs sales growth among the existing potential buyers – which corresponds to higher electricity demand. Thus, the overall household electricity demand from the grid drops by almost 9% in 2050 compared to 2020 under normal assumptions.

In such a dynamic market, utility companies need to diversify their revenue streams. A vertical extension in the scope of activities to services and installations is a promising solution. Utility companies can do this both in their home supply regions and in the rest of the country. The PVB and EV markets potentially look attractive. Electric vehicles are not a core business of utility companies, however potential services could be designed for owners of these vehicles. Finally, historic data on HP market indicates a saturated market and hence and a relatively small market potential. However, it is highly probable that the market potential increases if the alternative home heating and hot water solutions, such as fossil fuel-powered boilers, will become less attractive financially. This is potentially foreseeable in an uncertain and volatile oil market. The other highly probable scenario is a federal mandate to ban fossil fuel-powered heating devices to reduce CO_2 emissions. As a result, more households will become potential HP buyers and users.

Self-service and self-consumption are the reality of today's energy business environment. Customers, their capabilities, their needs, and what they consider as value have evolved. Similar change is occurring in other markets and businesses. For example, the Swiss Post is removing some of its branches because fewer letters are being physically sent, and more customers are becoming digital. Some of the supermarket chains in Switzerland have implemented self-checkouts, which let shoppers process their purchases. In the current case of the electricity market, prosumers and self-consumption organizations can cover a part of their electricity needs. Legal changes or new technologies influence market development significantly. To survive in such a constantly changing electricity market –which will soon become liberalized and highly competitive– utility companies need to focus on selling *solutions*, in addition to selling electricity as their classic product. They should diversify their products and solutions and be more responsive to the market. Such an approach will help diligent utility companies to differentiate themselves from the competition and to win customers.

10 Outlook

10.1 Robustness of key performance indicators

The resilience of a business model can be assessed if both the "revenue" and "cost" structures are considered. This study had to drop the cost structure from the modeling effort because of its commercial sensitivity and data security importance for the study partner. As already mentioned, when demand of electricity from the grid drops, the unit cost of each kWh increases. Such increase in cost will gradually shrink the profit margin of utility companies over time. In theory, the profit margin drops even more in a competitive environment such as a liberalized electricity market. Thus, at a certain point in time, utility companies may no longer be able to cope with the cost pressure. For the reason mentioned earlier, the model could not be extended to capture both revenue and cost structures and project a probable "breaking-point" under each scenario. The current modeling effort needs to be extended according to the needs and specifications of interested utility companies to represent their key performance indicators more realistically.

10.2 Relation to the Energy Strategy 2050 Perspective

According to the Swiss Energy Strategy 2050, the average electricity consumption per person compared to the year 2000 shall be reduced by 3% in 2020, and by 13% by 2035 [33, 34]. Before discussing the relevance of this study to the Swiss Energy Strategy 2050, two aspects of the model and the referenced data need to be mentioned:

- First, some important specifications of the developed simulation model are as follows: 1) the time horizon is from 2010 to 2050. 2) The focus of the model is only on the household sector. 3) The model distinguishes between the "household electricity demand from the grid" from the "household electricity consumption".
- Second, in this study, the data on electric power consumption – i.e., kWh per capita – is interpreted as the electricity demand per capita from the grid (the pink line number 4 in Figure 22). That data – which is an aggregation of all sectors of the Swiss electricity market such as industry, transportation, agriculture, and household – indicates a gradual decrease from 2005 to 2014[24].

The blue line number 1 in Figure 22 depicts data on the per capita **household** electricity demand from the grid in Switzerland from 2010 to 2017. The figure shows a slight decrease in household demand per capita[25]. The projected future of household electricity demand and household electricity consumption are also marked in the same figure, with line number 2 in red and line number 3 in green, respectively.

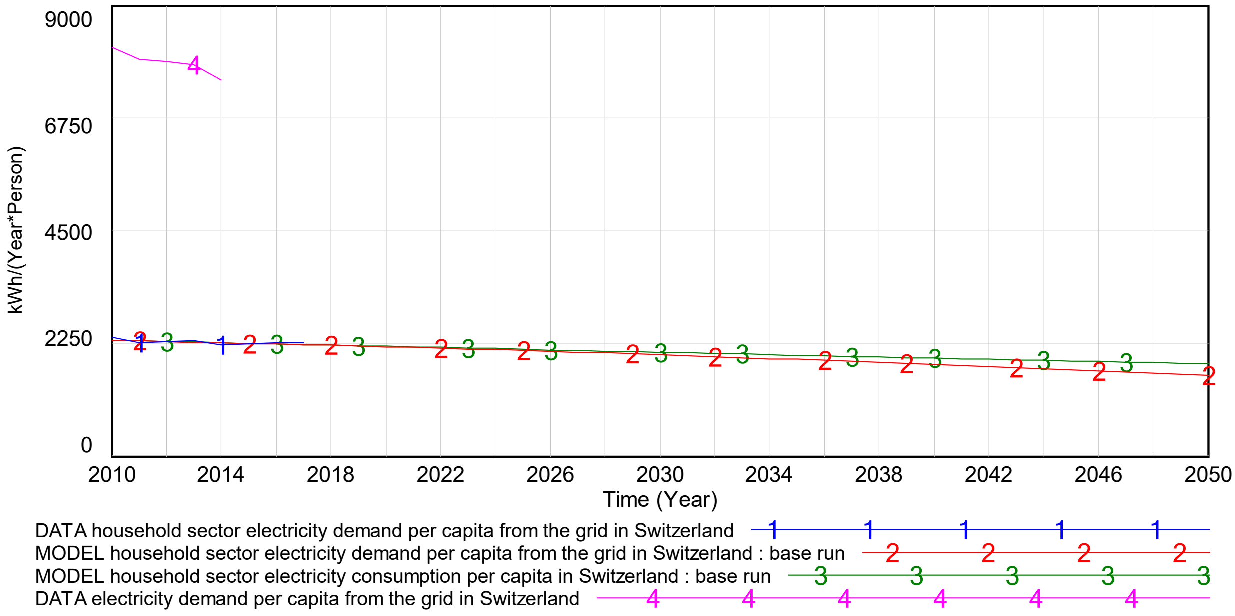

Figure 22: Household sector vs. all sectors electricity demand from the grid per capita in Switzerland.

According to the analysis of this study, the per capita household electricity consumption will be higher than the per capita household electricity demand from the grid, by 240 kWh per year in 2050. The gap

[24] The Word Bank data, Electric power consumption (kWh per capita) for Switzerland (Retrieved from https://data.worldbank.org/indicator/EG.USE.ELEC.KH.PC?cid=GPD_28&locations=CH)

[25] This data series is calculated by dividing the electricity distributed to households (Source: Electricity statistics; Aufteilung des Endverbrauchs nach Verbrauchergruppen; Published on 21.06.2019, by Swiss Federal Office of Energy. Retrieved from https://www.bfe.admin.ch/bfe/en/home/supply/statistics-and-geodata/energy-statistics/electricity-statistics.html) by permanent resident population in Switzerland (Source: Permanent resident population by age, canton, district and commune, 2010-2017; Published on 31.08.2018, by Swiss Federal Statistical Office. Retrieved from https://www.bfs.admin.ch/bfs/en/home/statistics/population/effectif-change.assetdetail.5886149.html)

– between the projected household electricity consumption and demand from the grid – will be covered or compensated by PVB-electricity produced in the household sector.

Finally, the historical data on the per capita overall electricity demand from the grid (pink line number 4) is also depicted in Figure 22. When one compares the significant negative slope of the per capita overall electricity demand and the per capita household electricity demand, it can be inferred that the major decrease in total electricity demand from the grid in Switzerland has occurred in sectors other than the household sector. However, a potential further reduction in household electricity demand from the grid may originate from a combination of different scenarios, as discussed in the section "RQ-3030 Possible Scenarios".

10.3 Next steps for this study

The next planned step for this study is publishing in a scientific journal in the field of energy. For this purpose, a generalized version of the model with additional features will be used. The model will not contain any company-specific data. One possible avenue to advance this study is to analyze in detail the substitution effect which household-based electricity storages and additional electricity demand have on the conventional fossil-fuel-based demand in the household sector and how to accelerate this conversion.

11 List of Figures

12 List of Tables

13 Glossary

Throughout this report, some terms and abbreviations have been used frequently. Abbreviations particularly demonstrate their effectiveness to avoid redundancy in the report and the developed model. The mentioned terms and abbreviations are as follows:

Abbreviation	Description
BKW	A major utility company in Switzerland.
BKWe	Customers connected to BKW grid for electricity.
EV	Electric Vehicle
HP	Heat Pump
kWp	Kilowatt peak: it indicates the power of a Photovoltaics system under standard working conditions.
PVB	Photovoltaics and Batteries
SCO	Self-Consumption Organization
Ue	Customers connected to Rivals grid for electricity.
WACC	Weighted Average Cost of Capital: it is considered as the discount rate to calculate the net present value (NPV) of the future stream of revenues
WOM	Word-of-Mouth

Table 6: Abbreviations

Customer: Any household who is in the supply region of BKW or its rivals or has acquired a product from these companies.

Prosumer: Any customer owning and operating photovoltaics and battery (PVB) module (this is a simplified assumption for this study. In reality, a prosumer could also only have photovoltaic panels without any battery storage.)

Consumer: Any electricity customer without any PVB module.

Base run: A base run represents the "business as usual scenario" of a system in which everything works as usual before any game-changing assumptions of possible future scenarios or probable policies are being applied to a model.
Business model: "A business model describes the rationale of how an organization creates, delivers, and captures value" [35].
Degree of autarky: in this study, the degree of autarky is a measure of electric energy self-sufficiency for the owners of PVBs. A higher autarky percentage corresponds to a lower electricity demand from the grid by PVB owners, and vice versa.
(Expected) adoption fraction: "The proportion of contacts that are sufficiently persuasive to induce the potential adopter to adopt the innovation is termed … the adoption fraction" [20].
Installed base: the installed base of a service or a product refers to the total number or capacity of that service or that product which are already in the field and being used by customers [36].
Policy (i.e., strategy): A policy is a decision rule that is under the direct control of the organization being modelled. The terms policy and strategy are used interchangeably in the report and the simulation results.
Prosumage: Producing electricity with PV panels and storing that in battery storage by prosumer households to increase self-consumption of electricity, is named prosumage [1, 3].
Revenue share: Assuming X and Y as two different activities that generate revenue streams for a company, the monetary value earned from X divided by the total monetary value earned from X and Y – in the form of percent – is the revenue share of the company from X.
Scenario: A scenario is a change in the environment that is not under the control of the studied organization. For instance, a change in the federal regulations or a significant behavior shift in the customer base is among scenarios for businesses and firms.
Word-of-Mouth (WOM): the process through which a customer tells other people what he or she knows about a product or service. It can be in the form of communicating positive or negative aspect of that product or service, in order to encourage or discourage others to use or acquire them [37].

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*   Sorted by surname
** BFH: Bern University of Applied Sciences / Berner Fachhochschule / Haute école specialisée bernoise
BFS: Swiss Federal Statistical Office / Bundesamt für Statistik / Office fédéral de la statistique
FWS: Fachvereinigung Wärmepumpen Schweiz

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16 Appendix

16.1 Considerations on data: Access to data

Data plays a critical role in simulation models and calibration of results with real data. One of the major hindrances of this project was lack of disaggregated data for the household sector and the excluded sectors (such as industry and business) on HPs[26], EVs[27], and PVs[28]. For example, the data on PV sales per year and PV installed base in Swiss household sector are available. That data was transformed to reach an educated guess on the number of households possessing PVs. However, there was not similar reliable data on HPs in the household sector. Moreover, no data source could indicate how many households own a different combination of PVBs, HPs, and EVs, as elaborated in Figure 23. For instance, there are some public data on new plate registrations and ownership of EVs. However, when the EVs data set is compared with the PV data set, it is impossible to infer how many private owners possess EVs and PVBs at the same time. Thus, to find such common denominators on the owners of various technology-product, calibration of the model according to mentioned data sets was used as a workaround.

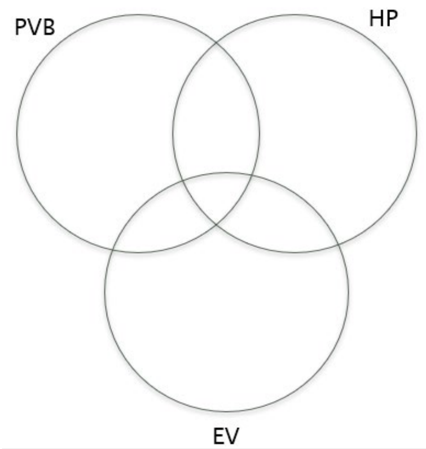

Figure 23: Challenge of finding common denominators on the ownership of different products in various data sets.

[26] HP data sources:
- Schweizerische Elektrizitätsstatistik 2018. Published by Bundesamt für Energie / Office fédéral de l'énergie. (Retrieved from https://www.bfe.admin.ch/bfe/en/home/supply/statistics-and-geodata/energy-statistics/electricity-statistics.html)
- Statistik, 2010 to 2018. Published by Fachvereinigung Wärmepumpen Schweiz FWS. (Retrieved from https://www.fws.ch/unsere-dienstleistungen/statistiken/)

* Note: The obtained data does not distinguish between household and non-household sectors in HP installations. According to the content expert knowledge, HPs with capacities in the category of 13–20 kW and lower are being installed in the household sector (in some cases, the category of 20–50 kW are also fit with the need of households). This study assumes the categories of 20–50 kW and lower for the household sector, which approximately accounts for 80% of yearly statistics on HPs in Switzerland.

[27] EV historical data was obtained partially,
1) by contacting Swiss Federal Office of Statistics (Bundesamt für Statistik BFS).
2) from BFS publications on Mobilität und Verkehr → Strassenfahrzeuge, on years 2011, 2014, 2016, and 2018. (Retrieved from https://www.bfs.admin.ch/bfs/de/home/statistiken/mobilitaet-verkehr.html)
Note: BFS data on EVs indicates new (plate) registrations per year. It does not exactly mean same as EV yearly sales.
3) from statista.com, n.a.. Anzahl der Pkw-Neuzulassungen mit Elektroantrieb in der Schweiz von 1997 bis 2018. (Retrieved from https://de.statista.com/statistik/daten/studie/287632/umfrage/neuzulassungen-von-elektroautos-in-der-schweiz/).

[28] PV data sources: Markterhebung Sonnenenergie, 2010 to 2018. Published by Bundesamt für Energie BFE and Swissolar (Retrieved from https://www.swissolar.ch/ueber-solarenergie/fakten-und-zahlen/markterhebungen/).

It is essential to differentiate customers who have various products because each category of customers consumes a different amount of electricity, which in turn impacts the overall electricity consumption and demand from the grid.

16.2 Considerations on data: types of data

Three types of data were fed to the simulation model. First, single data points of the best available data for PVs, private electric cars, and estimates of heat pumps in the household sector, to parameterize the model as of the year 2010. Second, data series on Swiss demographics based on official reports (from the Swiss Federal Statistical Office). Third, assuming a continuous development like past trends and based on experts' opinion, this study also considers expected gradual changes in technology-related parameters – such as a decrease in household primary electricity consumption due to the improved efficiency in electricity consumption of devices.

16.3 Considerations on data: the impact of Swiss demographic on electricity demand

The average household electricity demand from the grid in Switzerland in this study (Table 7) is calculated based on the volume of electricity distributed to the household sector in Switzerland divided by multiple of "household electricity demand per capita from the grid in Switzerland" and the "average size of households in Switzerland. Any transmission system losses – as acknowledged generally by Swissgrid[29], or estimated by some studies around 7% [cf. 38] – is not included or considered to calculate the average household electricity demand from the grid.
Table 8 is based on Table 7 and presents assumptions that lead to estimate parameter value of the average electricity demand of normal customer (a household customer without any PVB, HP, or EV), as an input of the model.

16.4 Considerations on Data: Sensitivity Analysis

Related to the previously mentioned challenge, there is no reliable data on the acquisition fraction of the studied technology-products. Thus, In the absence of reliable data, the workaround was to start with "educated guesses" on such fractions and calibrate the parameter values step by step. Those parameters can change the projected behavior of the model significantly.
Figure 24 to Figure 26 present the sensitivity analysis of expected adoption fractions of individual PVB, HP, and EV technology by normal customers. The target variables are the Swiss household-kWp PV installed base, the Swiss household-HP installed capacity, and EV owners in Switzerland, respectively. Each graph shows the confidence bounds of 50%, 75%, 95%, and 100% on the analyzed variable. "The outer bounds of uncertainty (100 %) show maximum values … and minimum values at the end of the simulation"[30].

For example, Figure 24 shows that if the expected adoption fraction[31] of PVB technology by normal customers varies by ±0.002, then the outer bound of uncertainty (100%) varies approximately between 18 and 35 Million kWp of PV capacity installed. Similarly, Figure 25 indicates that if the expected adoption fraction of HP technology by normal customers varies by ±0.002, then the outer bound of uncertainty varies approximately between 1'700 and 2'000 MW HP electric capacity. Besides, Figure 26 suggests that if the expected adoption fraction of EV technology by normal customers varies by ±0.002, then the outer bound of uncertainty changes approximately between 400'000 and 900'000 EV owners.
Figure 27 combines the above-mentioned parameters and analyses the impact on the household electricity demand from the grid per capita. Thus, if the adoption fraction of PVB, HP, and EV is analyzed simultaneously by ±0.002, then the household electricity demand from the grid per capita varies approximately between 1'500 and 1'750 kWh per year.

[29] Swissgrid Website: Grid operation > Grid data >Transmission > Transmission system losses. Retrieved from https://www.swissgrid.ch/en/home/operation/grid-data/transmission.html (accessed August 2019)

[30] The Vensim software manual: Confidence Bounds. (Retrieved from https://www.vensim.com/documentation/index.html?21115.htm)

[31] Fraction = Percent

Year	[A] Permanent resident population of Switzerland at the end of the year (Unit: People)[32]	[B] (Approximate) net change in permanent resident population of Switzerland at the end of the year (Unit: People per Year)	[C] Average size of households in Switzerland (Unit: People per Household)[33]	[D] (Approximate) net increase in the number of households in Switzerland (Unit: Households per Year)	[E] Average number of households in Switzerland based on a shrinking household size (Unit: Households)	[F] Distribution of final consumption in Switzerland according to the main consumer groups: Household (Unit: GWh/ year)[34, 35]	[G] Household electricity demand per capita from the grid in Switzerland (Unit: kWh/year/person)	[H] Average household electricity demand from the grid in Switzerland (Unit: kWh/year/ household)
2010	7'870'100 ●		2.26 ◙		3'482'345 ◙	18'618 ●	2'366 ■	5'346 ◙
2011	7’954’700 ●	84'600 ■	2.26 ◙	37'434 ◙	3'519'779 ■	17'942 ●	2'256 ■	5'098 ◙
2012	8'039’100 ●	84'400 ■	2.26 ●	37'345 ■	3'557'124 ■	18'333 ●	2'280 ■	5'154 ■
2013	8'139’600 ●	100'500 ■	2.25 ●	44'667 ■	3'617'600 ■	18'768 ●	2'306 ■	5'188 ■
2014	8'237’700 ●	98'100 ■	2.25 ●	43'600 ■	3'661'200 ■	18'287 ●	2'220 ■	4'995 ■
2015	8'327’100 ●	89'400 ■	2.25 ●	39'733 ■	3'700'933 ■	18'762 ●	2'253 ■	5'070 ■
2016	8'419’600 ●	92'500 ■	2.24 ●	41'295 ■	3'758'750 ■	19'078 ●	2'266 ■	5'076 ■
2017	8'484’100 ●	64'500 ■	2.23 ●	28'924 ■	3'804'529 ■	19'228 ●	2'266 ■	5'054 ■
2018	8'542’300 ●	58'200 ■	2.23 ◙	26'099 ■	3'830'628 ◙	19'085 ●	Average from 2010 to 2017, as a basis to project household electricity demand from 2018 onward = 2'277 ■	
2019	8'649'950 ◙	107'650 ◙	2.23 ◙	48'274 ◙	3'878'901 ◙			
2020	8'757’600 ●	107'650 ◙	2.23 ◙	48'274 ◙	3'927'175 ◙			
2030	9'541’500 ●	72’483 ◙	2.21 ◙	32’798 ◙	4’317’421 ◙			
2040	10'044’300 ●	36’604 ◙	2.19 ◙	16’714 ◙	4’586’438 ◙			
2050	10'310’332 ◙	26’987 ◙	2.17 ◙	12’437 ◙	4’751’305 ◙			

Table 7: Household demographic and its impact on electricity demand in Switzerland.

Source: ● official data/forecasts; ■ measured based on official data; ◙ extrapolation based on official data; □ educated guess / calibration; ▲expert opinion

[32] Source: Permanent residant population by age, canton, district and commune, 2010-2017, Published on 31.08.2018, Observation period 2010-2017, Published by Federal Statistical Office, FSO number su-e-01.02.03.06

+ Statistical Data on Switzerland 2012 (No. 025-1200), 2013 (No. 025-1300), 2014, (No. 025-1400), 2015 (No. 025-1500), 2016 (No. 025-1600), 2017 (No. 025-1700), 2018 (No. 025-1800), 2019, (No. 025-1900)

+ Website of Federal Statistical Office > Population > Current situation and change. Retrieved from https://www.bfs.admin.ch/bfs/en/home/statistics/population/effectif-change.html (accessed July 2019)

+ Szenarien zur Bevölkerungsentwicklung der Kantone der Schweiz 2015-2045 (12.05.2016), Nr. 0350-1605-00

[33] Source: Private households by canton and household size, 2010-2017. Published on 04.10.2018, by Federal Statistical Office, FSO number cc-e-01.02.02.02.

[34] Source: Swiss Electricity statistics; Aufteilung des Endverbrauchs nach Verbrauchergruppen. Published on 21.06.2019, by Swiss Federal Office of Energy. Retrieved from https://www.bfe.admin.ch/bfe/en/home/supply/statistics-and-geodata/energy-statistics/electricity-statistics.html

[35] Transmission system losses

			Direct Inputs to the model		J * K by the model
Year	[H, from Table 7] Average household electricity demand from the grid in Switzerland (Unit: kWh/year/ household)	[I] [Calibrated and Smoothed] Average household electricity demand from the grid in Switzerland (Unit: kWh/year/ household)[36]	[J] [Calibrated] Average electricity demand of normal customer (no PVB, no HP, no EV) from the grid in Switzerland (Unit: kWh/year/ household), without considering efficiency in electricity consumption[37]	[K] [Assumption] development trend in basic household electricity consumption (Unit: fraction)[38]	[L] Average electricity demand of normal customer (no PVB, no HP, no EV) from the grid in Switzerland (Unit: kWh/year/ household), considering efficiency in electricity consumption
2010	5'346 ◙	5'145 ◙	4'991 ◙ □	1.00 ▲□	4’991
2011	5'098 ◙	5'145 ◙	4'991 ◙ □		4’953
2012	5'154 ■	5'145 ◙	4'991 ◙ □		4’916
2013	5'188 ■	5'122 ◙	4'969 ◙ □		4’857
2014	4'995 ■	5'122 ◙	4'969 ◙ □		4’820
2015	5'070 ■	5'122 ◙	4'969 ◙ □		4’782
2016	5'076 ■	5'100 ◙	4'947 ◙ □		4’724
2017	5'054 ■	5'077 ◙	4'925 ◙ □		4’666
2018		5'077 ◙	4'925 ◙ □		4’629
2019		5'077 ◙	4'925 ◙ □		4’592
2020		5'077 ◙	4'925 ◙ □		4’555
2030		5'031 ◙	4’880 ◙ □	0.85 ▲□	4’148
2040		4'986 ◙	4’836 ◙ □		3’748
2050		4'940 ◙	4’792 ◙ □	0.70 ▲□	3’354

Table 8: Some electricity-related inputs of the model.
Source: ● official data/forecasts; ■ measured based on official data; ◙ extrapolation based on official data; □ educated guess / calibration; ▲expert opinion

[36] The product of the average of column “G” and values of column “C”, from “Table 7: Household demographic and its impact on electricity demand in Switzerland.”

[37] 97% of values in column “I”, from the same table, based on the calibration of the model with historic data.

[38] from BFH: In average, it is expected that the improved efficiency in electricity consumption will be 1% per year, over 10 to 15 years; however, it is difficult to determine the slope of such curve (linear, exponential growth, or exponential decay.

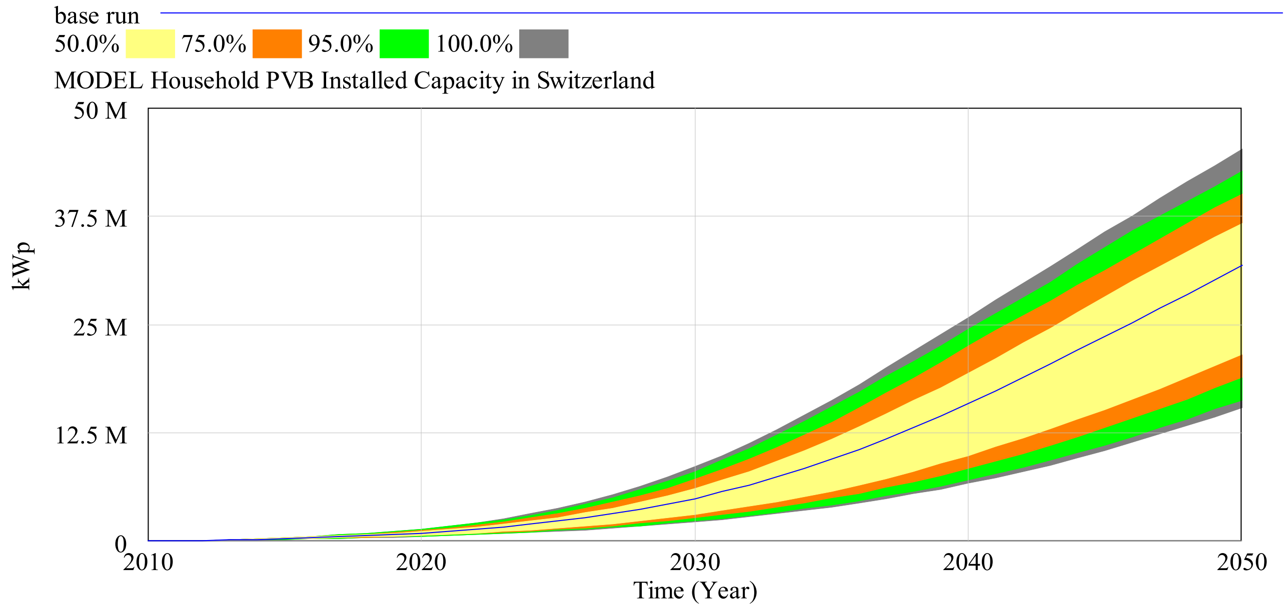

Figure 24: Sensitivity analysis of Swiss household-PV installed base (in kWp).
Specifications: 0.006 < expected adoption fraction of PVB technology by Normal Customers = 0.008 < 0.010

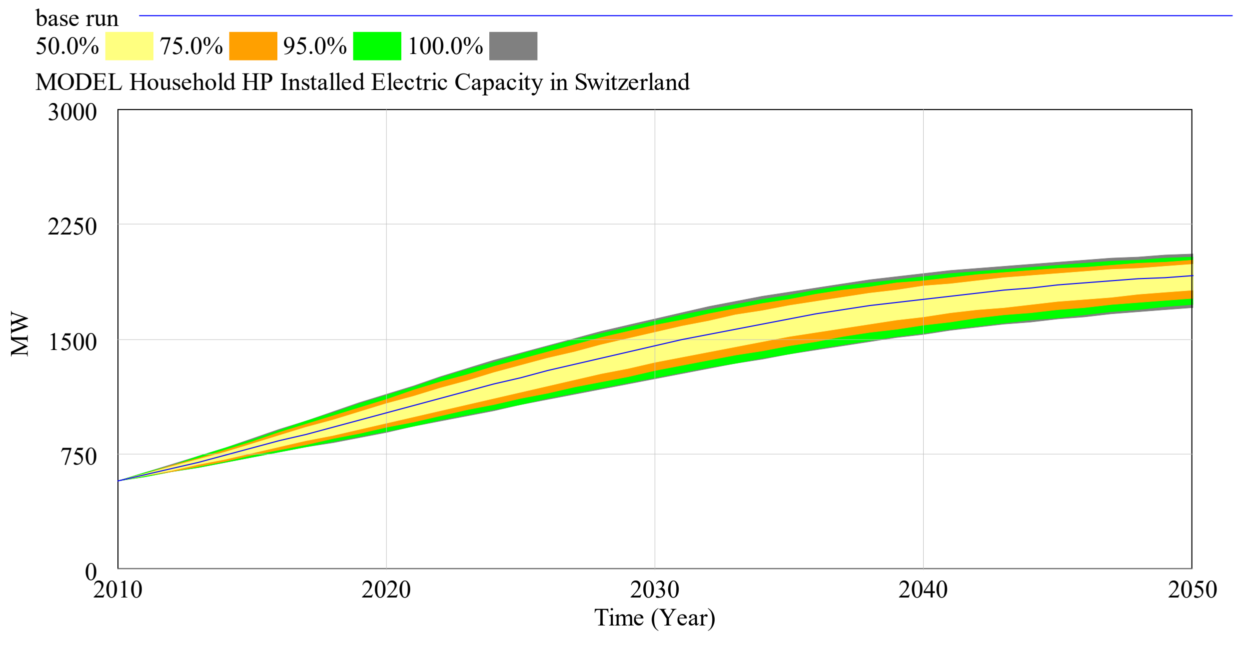

Figure 25: Sensitivity analysis of Swiss household-HP installed electric capacity.
Specifications: 0.004 < expected adoption fraction of HP technology by Normal Customers = 0.006 < 0.008

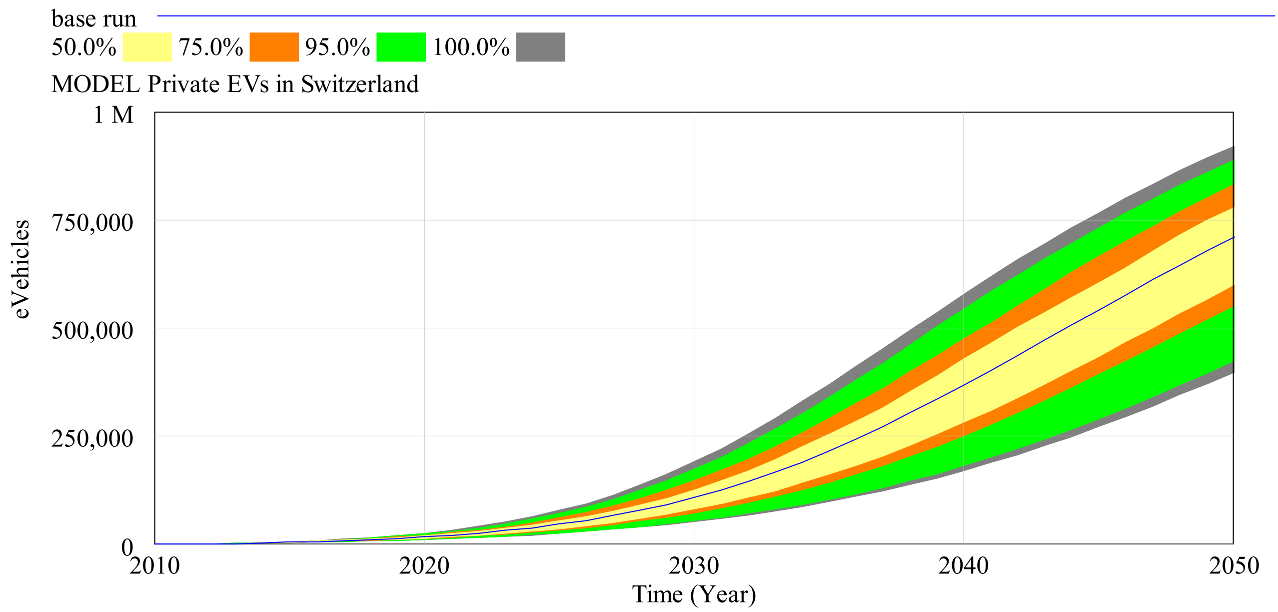

Figure 26: Sensitivity analysis of Swiss Private e-Vehicles.
Specifications: 0.006 < expected adoption fraction of EV technology by Normal Customers = 0.008 < 0.010

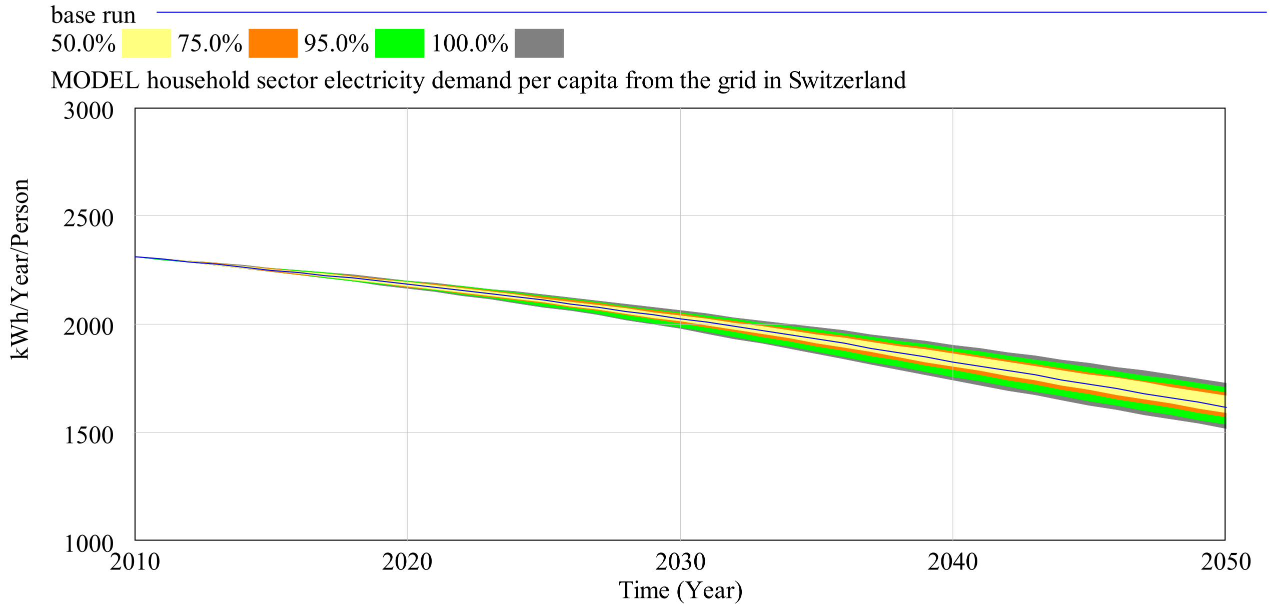

Figure 27: Combined sensitivity analysis on the household electricity demand from grid per capita.
Specifications: 0.006 < expected adoption fraction of PVB technology by Normal Customers = 0.008 < 0.010
0.004 < expected adoption fraction of HP technology by Normal Customers = 0.006 < 0.008
0.006 < expected adoption fraction of EV technology by Normal Customers = 0.008 < 0.010

16.5 Technology perspective

This study investigated the adoption of PVBs, HPs, and EVs by household customers. Figure 28 depicts how fraction of product-owners changes over time. As household customers adopt such products, the fraction of normal customers – who have not acquired any of mentioned products – decreases over time. The important things that should be noted here is that this figure tracks individual product acquisitions. For example, there could be customers who have both PVBs and HPs. Another category of customers may have EVs and HPs at the same time. Line 3, in green, tags HP owners and depicts the result. Thus, the sum of the fractions in the below figure does not add to one (=1).

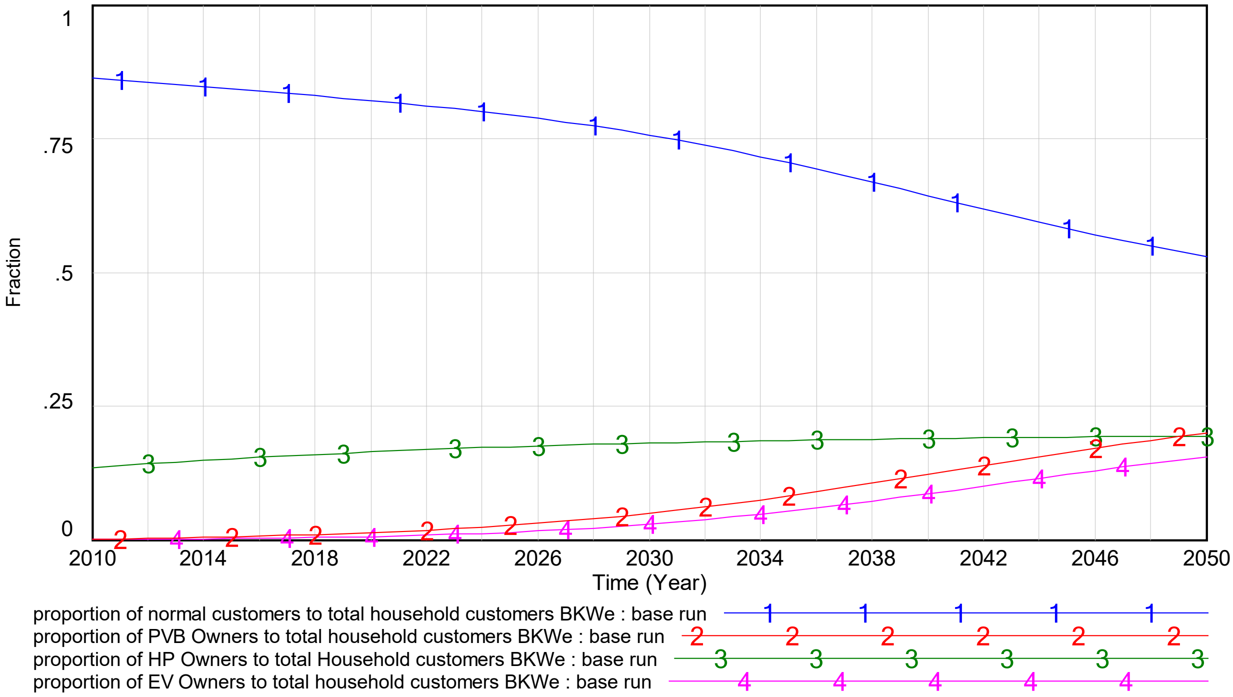

Figure 28: Fraction of Tech-Products in-use by BKW customers.

16.6 Considerations on Free Market

The postulated policy for the Free Market scenario is consistent with the forthcoming legal changes in selecting an electricity provider. However, it is also based on the assumption of electricity price sensitivity. If differences exist in the unit price of electricity sales among utility companies after market liberalization (free market), most probably a fraction of customers switch to other utility companies.

Assumptions for this scenario are as follows:

1) The basic expected annual fraction of customers turning to other utility companies in free market will be 0.1 (or 10%) per year.
2) If the relative[39] electricity price per kWh for BKW household customers compared to rivals becomes one (i.e., BKW and its rivals offer the same price), there is no incentive to change the provider. Thus, the effect of price becomes zero. If the mentioned value goes higher than one, more and more customers will leave BKW to join other utility companies (with a magnitude of three times). If the mentioned value goes lower than one, BKW will win customers over its rivals (with an opposite magnitude of three times).

Considering the above assumptions, Figure 29 depicts a situation that the household customers may react to charged prices if they differ from the assumed market price of electricity (CHF 0.189 per kWh) when the free market goes into effect. The relative electricity price (the X-axis) is the input. Customers'

[39] The relative value of A to B is being calculated by dividing the value of parameter A by the value of parameter B.

decision on staying or leaving a utility company (the Y-axis) is the output. In the pictured scenario, charging lower prices compared to the market price brings new customers. On the other hand, offering higher prices deters household customers, and a fraction of them will join rivals. The higher the difference in prices will be, the stronger the effect. If a utility company such BKW does not react and stick to a price higher than the market price in the Free Market, the company will lose customers and consequently revenues as depicted previously in Figure 20.

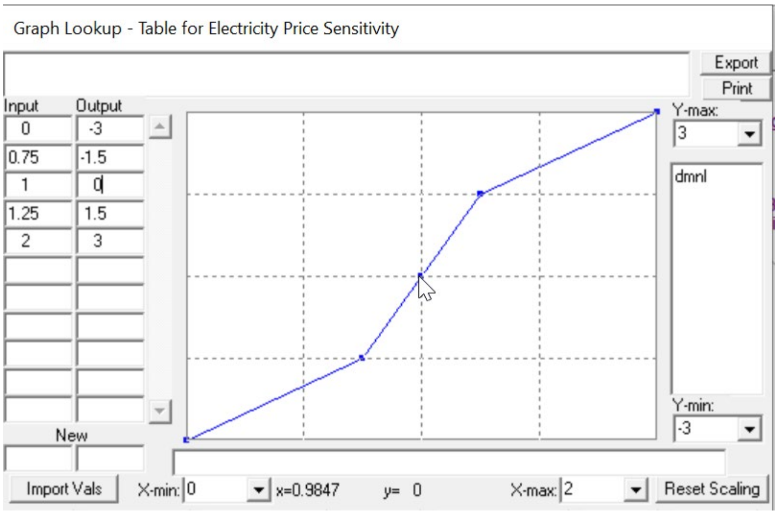

Figure 29: Electricity price sensitivity (hypothetical).

16.7 Detailed parameter values of the model

Note 1: The Sensitive data which possibly reveals BKW's trade secrets are removed from this table.
Note 2: In this study, the parameter values corresponding to single and multiple family households are aggregated; wherever applicable, a weighted average of a parameter per a household in a single-family house and per a household in an apartment building (a multiple-family house) is calculated (ratio of single: multiple → 0.4: 0.6, where 0.4 + 0.6 = 1).

Table 9: Detailed parameter values of the model.

No.	Name of Parameter	Unit	Value for Single Family Houses in 2010	Value in Multiple Family Houses in 2010	Average for the Household Sector in 2010	Description
1	(standard) kWh needed per kilometer	kWh/km			0.15	kWh needed per kilometer for electric cars. Data from BKW: 0.15 kWh/km Data from BFH: For TESLA cars, it is 0.2 kWh/km. Note: km = kilometer

No.	Name of Parameter	Unit	Value for Single Family Houses in 2010	Value in Multiple Family Houses in 2010	Average for the Household Sector in 2010	Description
2	additional heat pump consumption	kWh/Year/Household	4’000	2’600	3’160	Estimations for multiple-family houses are from BKW. Relevant information: Consumption profiles of a typical household Source: [translated from German] Federal Electricity Commission ElCom → The cantonal electricity prices in comparison → Consumption category. (Retrieved from https://www.strompreis.elcom.admin.ch/Map/ShowSwissMap.aspx?CatID=4&CantonBez=BE&View=0&Period=2019&ProdID=10) --- Assuming that a household customer has not installed any heat-pump in his building yet, how much extra electricity consumption he will see in his electricity bill per year if, a) he lives in a single-family house, b) he lives in a multiple-family house? Expert opinion from a Swiss HP installation company: A heat pump works about 2000 to 2300 hours a year (2000 hours just for heating the house, 2300 hours for heating the house as well as hot water). Calculations: 2‘000 hours per year (or 2‘300) * 12 kW (output of the heat-pump in a single-family house) = 24'000 kWh per year 24'000 kWh per year ÷ 3.5 (COP of air water heat pump) = 6'857 kWh per year 6‘857 kWh per year * 0.20 CHF per kWh (average price for electricity) = 1'371.40 CHF per year The above (approximate) calculation is being done usually to estimate the extra electricity needed for a heat pump (approximate). --- Relevant information for single-family houses: Heat pump BTU rating 15’000 → 3’525 kWh per year Heat pump BTU rating 18’000 → 4’725 kWh per year Source: Solaflect, 2016. How much more electricity will I use if I add a heat pump to my house? (Retrieved from http://www.solaflect.com/faq-how-much-more-electricity-will-i-use-if-i-add-a-heat-pump-to-my-house/).

No.	Name of Parameter	Unit	Value for Single Family Houses in 2010	Value in Multiple Family Houses in 2010	Average for the Household Sector in 2010	Description
3	average annual mobility demand per household	km/Year/ Household			15'000	Data from BKW. Note: km = kilometer
4	average annual mobility per year per EV	km/Year/ eVehicle			10'500	Data from BKW. Note: km = kilometer
5	average annual yield per kWp	kWh/KWp /Year	850	850	850	An estimate by BKW: it varies between 850 to 900 kWh/KWp/Year.
6	average demand per normal customer (before efficiency gains)	kWh/Year/Household			4'991	Calibrated based on real data (Table 7, Table 8).
7	average electricity price per kWh for household customers BKWe	CHF/kWh	0.189	0.189	0.189	0.189 CHF/kWh in 2013. Source: Schläpfer, 2015. Energy Costs in Canada and Switzerland (Retrieved from http://www.swissbiz.ca/is_article.php?articleid=2). 0.14 €/kWh in 2010. Source: Nowak et al., 2014. European Heat Pump Market and Statistics Report 2014 (Retrieved from http://www.ehpa.org/fileadmin/red/07._Market_Data/2013/EHPA_Statistics_Report_2014_ONLINE_VERSION.pdf)

No.	Name of Parameter	Unit	Value for Single Family Houses in 2010	Value in Multiple Family Houses in 2010	Average for the Household Sector in 2010	Description
8	average electricity price per kWh for household customers Rivals	CHF/kWh	0.189	0.189	0.189	0.189 CHF/kWh in 2013. Source: Schläpfer, 2015. Energy Costs in Canada and Switzerland (Retrieved from http://www.swissbiz.ca/is_article.php?articleid=2). 0.14 €/kWh in 2010. Source: Nowak et al., 2014. European Heat Pump Market and Statistics Report 2014 (Retrieved from http://www.ehpa.org/fileadmin/red/07._Market_Data/2013/EHPA_Statistics_Report_2014_ONLINE_VERSION.pdf)
9	average HP electric capacity being installed per household customer in kW	kW/Household	4	1.33	2.4	Expert opinion: The average kW HP capacity being installed per single-family household is 12 and per multiple-family household is 4. Geothermal heat-pump (drilling) COP: 4 – 4.8. Air-Water heat-pump COP: 3.5 – 3.9. Ground-Water heat-pump COP: 5.5 – 5.8. The temperature of the source is an important reason for the variations in COP. The higher the temperature of the source, the higher the COP. -- A simplistic assumption: The average electric input, assuming a COP of 3, per single-family household is 4 kW (12 ÷ 3) and per multiple-family household is 1.33 kW (4 ÷ 3). -- Other relevant sources: Source: Evans, 2018. The heat-pump Guide (Retrieved from https://theengineeringmindset.com/heat-pump-guide/). Source: EnerGuide, 2004. Heating and Cooling with a Heat Pump (Retrieved from https://www.nrcan.gc.ca/sites/oee.nrcan.gc.ca/files/pdf/publications/infosource/pub/home/heating-heat-pump/booklet.pdf)

No.	Name of Parameter	Unit	Value for Single Family Houses in 2010	Value in Multiple Family Houses in 2010	Average for the Household Sector in 2010	Description
10	average kWp being installed per customers with EV buying PVB	kWp/Household	12	10	10.8	Estimates from BKW: The average kWp being installed per customers with EV who is buying PVB in single-family houses is 12 kWp. That value for a multiple family house with three households is 30 kWp (30 ÷ 3 = 10 per household).
11	average kWp being installed per customers with HP and EV buying PVB	kWp/Household	14	10	11.6	Estimates from BKW.
12	average kWp being installed per customers with HP buying PVB	kWp/Household	10	29	21.4	Estimates from BKW.
13	average kWp being installed per normal customers buying PVB	kWp/Household	8	24	17.6	Estimates from BKW.
14	average kWp being installed per normal	kWp/ Househ	10	29	21.4	An assumption: it equals to the "average kWp being installed per customers with HP buying PVB."

No.	Name of Parameter	Unit	Value for Single Family Houses in 2010	Value in Multiple Family Houses in 2010	Average for the Household Sector in 2010	Description
	customers buying PVB HP Package					
15	average lifetime of EVs	Year			10	An assumption: 10 years. Relevant information: Depending on the model, the life expectancy of EVs differs. Moreover, similar to regular cars, some components of an EV such as its battery may need to be replaced earlier. At some point, replacement of parts may no longer be feasible, and it is wise to scrap the car and replace it with a new one. Source: Kukreja, 2018. Life Cycle Analysis of Electric Vehicles (Retrieved from https://sustain.ubc.ca/sites/default/files/2018-63%20Lifecycle%20Analysis%20of%20Electric%20Vehicles_Kukreja.pdf)
16	average lifetime of HPs	Year	16	16	16	Estimates from Kansas City Power & Light = 15 years. National Association of Home Builders (2006) = 16 years. Source: Amerman, 2018. Heat Pump Life Expectancy (Retrieved from https://www.hunker.com/13415875/heat-pump-life-expectancy). "Heat pumps are considerably long-lasting. In the past, their average life expectancy was around 15 years, but thanks to several technological developments, modern units currently last around 20-25 years before they need replacing." Source: Evergreenenergy, n.a.. How Long Do Heat Pumps Last? (Retrieved from (https://www.evergreenenergy.co.uk/heat-pumps/how-long-do-heat-pumps-last/)
17	average lifetime of PVBs	Year	25	25	25	- Solar panels last about 25-30 years. Source: Energysage, n.a. How long do solar panels last? (Retrieved from https://news.energysage.com/how-long-do-solar-panels-last/, accessed July 2019) - 25 years (or longer) Source: Rothenberg, 2018. How Long Do Solar Panels Last? (Retrieved from https://www.wholesalesolar.com/blog/how-long-do-solar-panels-last/) - "Photovoltaic (PV) modules typically come with 20-year warranties that guarantee that the panels will produce at least 80% of the rated power after 20 years of use."

No.	Name of Parameter	Unit	Value for Single Family Houses in 2010	Value in Multiple Family Houses in 2010	Average for the Household Sector in 2010	Description
						Source: Lombardo, 2014. What Is the Lifespan of a Solar Panel? (Retrieved from https://www.engineering.com/DesignerEdge/DesignerEdgeArticles/ArticleID/7475/What-Is-the-Lifespan-of-a-Solar-Panel.aspx) - "Battery Type: Li-Ion; theoretical useful life: 500 - 800 charging cycles; theoretical lifetime in years: 10-15 years Akkuredakteur, 2014. Was? Wo? Wie? – So laden Sie Ihren Akku richtig! [Translated from German -> What? Where? As? - How to charge your battery correctly!] (Retrieved from https://www.akku.net/magazin/so-laden-sie-ihren-akku-richtig/)
18	average number of consumers per SCO	Household/ SCO	3	3	3	Estimates from BKW.
19	average number of people per household	people/ Household			2.23	The average size of the private households (number people per household) in 2018 = 2.23. Source: Private households by canton and household size, 2010-2017. Published on 04.10.2018, by Federal Statistical Office, FSO number cc-e-01.02.02.02. Note: The increase in the number of people per household does not necessarily increase the average consumption of a household linearly. Most probably, the increase happens non-linearly. For instance, two children can take a bath with the same water which fills a bathtub.
20	average number of prosumers a.k.a customers with PVB per SCO	Household/ SCO	1	1	1	Estimates from BKW.

No.	Name of Parameter	Unit	Value for Single Family Houses in 2010	Value in Multiple Family Houses in 2010	Average for the Household Sector in 2010	Description
21	average number of PVB installations per customer	PVB/ Household	1	1	1	Data from BKW. This parameter multiplied by the “average sales price per PVB installation” gives a monetary value for each installation.
22	basic degree of autarky for customers with EV and PVB	Fraction	0.4	0.5	0.46	Estimates from BKW.
23	basic degree of autarky for customers with PVB	Fraction	0.3	0.4	0.36	Estimates from BKW.
24	basic degree of autarky for customers with PVB and HP	Fraction	0.5	0.6	0.56	Estimates from BKW.
25	basic degree of autarky for customers with PVB and HP and EV	Fraction	0.6	0.7	0.66	Estimates from BKW.

No.	Name of Parameter	Unit	Value for Single Family Houses in 2010	Value in Multiple Family Houses in 2010	Average for the Household Sector in 2010	Description
26	basic degree of autarky for SCOs	Fraction	0.5	0.6	0.56	Estimates from BKW.
27	complexity of joining SCOs from BKW	Fraction	0.9	0.9	0.9	The value is an assumption. This variable is an estimation of the complexity of joining SCOs, and ranges from 0 to 1, meaning zero to 100% of the complexity. The maximum value halts the flow of joining SCOs.
28	complexity of joining SCOs from rival utility companies	Fraction	0.9	0.9	0.9	The value is an assumption. This variable is an estimation of the complexity of joining SCOs, and ranges from 0 to 1, meaning zero to 100% of the complexity. The maximum value halts the flow of joining SCOs.
29	contact frequency of people	1/Year	52	52	52	The value is an assumption: "People in the relevant community come into contact at a rate of c people per person per day." [20]

No.	Name of Parameter	Unit	Value for Single Family Houses in 2010	Value in Multiple Family Houses in 2010	Average for the Household Sector in 2010	Description
30	electricity consumption efficiency by installing HPs	kWh/Year/Household	1’000	1’000	1’000	Expert opinion from BFH: Many existing customers in Switzerland use electric boilers, which are simple resistance heaters. Thus, to generate 1000 kWh worth of hot water, they use 1000 kWh of electric energy. A rough estimate is that a Swiss household needs about 500 to1500 kWh worth of hot water per person per year. If such customers switch to heat pumps for the entire building, then they typically also use such heat pumps to replace old boilers. A typical heat pump operates with a Coefficient of Power (COP) of 3. Therefore, the household will only need 333 kWh of electric energy to generate 1000 kWh worth of warm water. If the above argument is being overlooked, most probably there will be a double-counting regarding the electricity consumption for the warm-water heating. However, the number of electric resistance-heated boilers is unknown in the calculations. Therefore, a rough heuristic to be used is as follows: approximately, one third to half (50%) of all households have boilers. If they switch to heat pumps, then a three-person-household could save as much as 2000 kWh/year. This works out to an average of 1000 kWh per year per household (note: the figures mentioned are educated guess and therefore are subject to a precise calculation).
31	expected adoption fraction of EV technology by Normal Customers	Fraction	0.008	0.008	0.008	The value is based on the calibration with past-periods data Note: This means the fraction of normal customer being persuaded by EV owners to adopt EVs.
32	expected adoption fraction of HP technology by Normal Customers	Fraction	0.006	0.006	0.006	based on the calibration with past-periods data.

No.	Name of Parameter	Unit	Value for Single Family Houses in 2010	Value in Multiple Family Houses in 2010	Average for the Household Sector in 2010	Description
33	expected adoption fraction of PVB HP package by Normal Customers	Fraction	0.0004	0.0004	0.0004	based on the calibration with past-periods data.
34	expected adoption fraction of PVB technology by Normal Customers	Fraction	0.00835	0.00835	0.00835	The value is based on the calibration with past-periods data. Note: This means the fraction of households being persuaded by household PVB owners to adopt the PVB technology.
35	expected annual fraction EV and HP owners switching to SCOs	1/Year	0.001	0.001	0.001	based on the calibration with past-periods data.
36	expected annual fraction EV and PVB owners buying HP	1/Year	0.1	0.1	0.1	based on the calibration with past-periods data.
37	expected annual fraction EV and PVB owners	1/Year	0.02	0.02	0.02	An assumption.

No.	Name of Parameter	Unit	Value for Single Family Houses in 2010	Value in Multiple Family Houses in 2010	Average for the Household Sector in 2010	Description
	turning to SCOs					
38	expected annual fraction EV owners buying HP	1/Year	0.005	0.005	0.005	based on the calibration with past-periods data.
39	expected annual fraction EV owners buying PVB	1/Year	0.05	0.05	0.05	based on the calibration with past-periods data.
40	expected annual fraction EV owners switching to SCOs	1/Year	0.005	0.005	0.005	An assumption.
41	expected annual fraction HP and EV owners buying PVB	1/Year	0.009	0.009	0.009	based on the calibration with past-periods data.
42	expected annual fraction HP owners buying EV	1/Year	0.001	0.001	0.001	based on the calibration with past-periods data.

No.	Name of Parameter	Unit	Value for Single Family Houses in 2010	Value in Multiple Family Houses in 2010	Average for the Household Sector in 2010	Description
43	expected annual fraction HP owners buying PVB	1/Year	0.0025	0.0025	0.0025	based on the calibration with past-periods data.
44	expected annual fraction HP owners switching to SCOs	1/Year	0.001	0.001	0.001	An assumption.
45	expected annual fraction normal customers turning to SCOs	1/Year	0.02	0.02	0.02	An assumption.
46	expected annual fraction of turning to other utility company in Free Market	1/Year	0.1	0.1	0.1	Note 1: An assumption. Note 2: This parameter is for the gamification and a hypothetical scenario on the price sensitivity in Free Market.
47	expected annual fraction PVB and HP owners buying EV	1/Year	0.08	0.08	0.08	based on the calibration with past-periods data.

No.	Name of Parameter	Unit	Value for Single Family Houses in 2010	Value in Multiple Family Houses in 2010	Average for the Household Sector in 2010	Description
48	expected annual fraction PVB and HP owners turning to SCOs	1/Year	0.02	0.02	0.02	An assumption.
49	expected annual fraction PVB HP EV owners turning to SCOs	1/Year	0.05	0.05	0.05	An assumption.
50	expected annual fraction PVB owners buying EV	1/Year	0.15	0.15	0.15	based on the calibration with past-periods data.
51	expected annual fraction PVB owners buying HP	1/Year	0.15	0.15	0.15	based on the calibration with past-periods data.
52	expected annual fraction PVB owners turning to SCOs	1/Year	0.02	0.02	0.02	An assumption.

No.	Name of Parameter	Unit	Value for Single Family Houses in 2010	Value in Multiple Family Houses in 2010	Average for the Household Sector in 2010	Description
53	expected increase in degree of autarky due to batteries ownership	Fraction	0.2	0.2	0.2	Estimates from BKW: It is expected in all categories of this degree.
54	fraction of households not interested in or without the possibility of buying EVs	Fraction	0.6	0.6	0.6	Not everyone on the streets is a potential EV buyer. Based on calibrating the model with actual data on private EV plate registration and ownerships, it was assumed that approximately 60% of household customers in Switzerland are not willing or able to buy EVs. Currently, there are feasible alternatives to EV cars, such as diesel or hybrid vehicles, as well as public transport in many cities. Furthermore, oil prices are relatively low. Besides, charging EVs, and the distance that can be driven with each charging session is a concern for new buyers. Thus, incentives to turn to EVs is not very strong. The situation will most probably change in the future by planned restrictions on diesel cars. Sources: Dieselinformation, n.a.. Where in Europe can I drive my diesel car? (Retrieved from https://dieselinformation.aecc.eu/where-in-europe-can-i-drive-my-diesel-car/) Boffey, 2019. Amsterdam to ban petrol and diesel cars and motorbikes by 2030 (Retrieved from https://www.theguardian.com/world/2019/may/03/amsterdam-ban-petrol-diesel-cars-bikes-2030)
55	fraction of households not interested in or without the possibility of buying PVBs	Fraction	0.4	0.4	0.4	Based on the content expert knowledge, 40% of households in Switzerland are not willing or able to install PVBs. Some significant obstacles to install photovoltaic panels are initial investments, necessary refurbishments on rooftops, as well as the angle of some roofs toward the sun.

No.	Name of Parameter	Unit	Value for Single Family Houses in 2010	Value in Multiple Family Houses in 2010	Average for the Household Sector in 2010	Description
56	fraction of households not interested in or without the possibility of turning to SCOs	Fraction	0.5	0.5	0.5	Estimates from BKW.
57	fraction of households not interested in or without the possibility of buying HPs	Fraction	0.8	0.8	0.8	Based on expert knowledge and calibrating the model with actual data on HP sales in Switzerland, approximately 80% of households in Switzerland are not willing or able to install HPs. Having access to cheaper sources of energy, especially after the sharp drop in oil prices before 2010; non-suitability of HP with climate areas which face extreme freezing; high investment costs; the required refurbishing and drilling; noises that HPs causes and the ban on noise-making devices in urban areas, are among the reasons that why HP market potential is limited.
58	fraction of HP replacement for current HP owners	1/Year	0.050	0.050	0.050	Expert knowledge: In average, 5% of HP owners refurbish their HPs mainly because of having a more efficient HP (with a higher COP). Other relevant information: refer to “average lifetime of HPs”
59	fraction of PVB replacement for current PVB owners	1/Year	0.05	0.05	0.05	Estimates from BKW.
60	fraction of SCOs for electricity with BKW	Fraction	0.9	0.9	0.9	Estimates from BKW: It could change from 0 to 1 (i.e., 0 to 100%).

No.	Name of Parameter	Unit	Value for Single Family Houses in 2010	Value in Multiple Family Houses in 2010	Average for the Household Sector in 2010	Description
61	fraction of SCOs for electricity with other utility companies in the rest of Switzerland	Fraction	0.9	0.9	0.9	Estimates from BKW: It could change from 0 to 1 (i.e., 0 to 100%).
62	initial Households EV Owners in Switzerland (in 2010)	Household			399	Based on past-periods data of EV in 2010 (under section Considerations on data: Access to data).
63	initial Households PVB Owners in Switzerland	Household			1’786	An educated guess based on past-periods data of PV in 2010 (under section Considerations on data: Access to data) and the “average kWp being installed per … ” various category of customers buying PVB in this table.
64	initial Households with EV and HP in Switzerland	Household			20	An educated guess based on EV and HP past-periods data in 2010 (under section Considerations on data: Access to data), and the “average HP capacity being installed per household customer in kW” in this table.
65	initial Households with EV and PVB and HP in Switzerland	Household			10	An educated guess based on PV, HP, and EV past-periods data in 2010 (under section Considerations on data: Access to data), the “average kWp being installed per … ” various category of customers buying PVB, and the “average HP capacity being installed per household customer in kW” in this table.

No.	Name of Parameter	Unit	Value for Single Family Houses in 2010	Value in Multiple Family Houses in 2010	Average for the Household Sector in 2010	Description
66	initial Households with HP in Switzerland	Household			239’199	An educated guess based on HP past-periods data in 2010 (under section Considerations on data: Access to data) and the “average HP capacity being installed per household customer in kW” in this table.
67	initial Households with PVB and EV in Switzerland	Household			100	An educated guess based on PV and EV past-periods data in 2010 (under section Considerations on data: Access to data), and the “average kWp being installed per … ” various category of customers buying PVB in this table.
68	initial Households with PVB and HP in Switzerland	Household			200	An educated guess based on PV and HP past-periods data in 2010 (under section Considerations on data: Access to data), the “average kWp being installed per … ” various category of customers buying PVB, and the “average HP capacity being installed per household customer in kW” in this table.
69	initial Total Households in Switzerland	Household			4’452’916	- The permanent resident population of Switzerland at the end of the year 2010: 7'870'100 People (Source: Statistical Data on Switzerland 2012, Federal Statistical Office, Report No. 025-1200, p. 4) - The average size of households in Switzerland in 2010 is not available. Consequently, the value for 2012 was used: 2.26 people per household (Source: Private households by canton and household size, 2010-2017, Federal Statistical Office, No. cc-e-01.02.02.02) Thus, the approximate number of households in Switzerland in 2010: 7'870'100 People ÷ 2.26 People per Household = 3'482'345 Households. Note: It cannot necessarily be concluded that the number of households equals the number of households connected to the grid.
70	number of chargers per EV	charger/ eVehicle	0.5	0.5	0.5	Data from BKW: in average, one charger for two cars.

No.	Name of Parameter	Unit	Value for Single Family Houses in 2010	Value in Multiple Family Houses in 2010	Average for the Household Sector in 2010	Description
71	number of EV per household	eVehicle/ Househol	1	1	1	Estimates from BKW.
72	percent of capacity being added by replacing an old with new HP	Fraction	0	0	0	In the case of refurbishment/replacement, do the HP output capacity of 12 kW per single-family household and 4 kW capacity for multiple-family household change (refer to “average HP capacity being installed per household customer in kW”)? Expert opinion: If a household already had a heat-pump, then he usually finds the working hours on the regulator (attached on the heat-pump). If hours are around 2‘000 – 2‘300 per year, then the power of the heat pump was calculated very good. Thus, the new heat-pump will have a similar capacity. If the number of hours is below (for instance, 1‘300 – 1‘800 hours per year), then a smaller heat-pump can be selected. If the working hours are over 2‘500 per year, the heat pump capacity was small. Note: This parameter is for the gamification of the model.
73	probability of EV owners turning to either BKW PVBs or Rivals PVBs SCOs	Fraction	0.5	0.5	0.5	An Assumption = 50%
74	probability of normal customers turning to either BKW PVBs or Rivals PVBs SCOs	Fraction	0.5	0.5	0.5	An Assumption = 50%

No.	Name of Parameter	Unit	Value for Single Family Houses in 2010	Value in Multiple Family Houses in 2010	Average for the Household Sector in 2010	Description
75	ratio of customers experiencing electricity consumption efficiency by installing HPs	Fraction	0.33	0.33	0.33	One third (i.e., 0.33) to 50%, according to BFH experts. (please refer to “electricity consumption efficiency by installing HPs”)
76	WACC	Fraction/ Year	0.038	0.038	0.038	WACC = Weighted Average Cost of Capital (here, discount rate). Data from BKW.