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Federal Department of the Environment, Transport, Energy and Communication DETEC

Swiss Federal Office of Energy SFOE
Energy Research and Cleantech

Final report dated 20.11.2019

Prosumer-Lab

Influence of novel strategies and components of the energy management of grid-integrated, smart buildings on the stability and quality of the house and distribution grids.

Date: 20.11.2019

Location: Nidau

Subsidiser:
Swiss Federal Office of Energy SFOE
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Co-financing
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SFOE contract number: SI/501434-01

Zusammenfassung

Im Rahmen dieses Projektes werden Grundlagen, Strategien und Komponenten erforscht, entwickelt und unter kontrollierten Bedingungen verglichen, um den Eigenverbrauch in intelligenten Gebäuden mittels Energiemanagementsystemen unter Berücksichtigung des gesamten Netzverhaltens so zu optimieren, dass eine optimale Integration von Prosumenten in Verteilnetze ermöglicht wird. Zudem werden die sozio-ökonomischen Auswirkungen des Verhaltens einer grösseren Gruppe von Prosumenten mit ihren individuellen Optimierungsalgorithmen auf das Verteilnetz und auf die bestehenden Geschäftsmodelle von Verteilnetzbetreibern identifiziert und analysiert. Im BFH-Zentrum Energiespeicherung in Biel wurde ein Hardware-In-The-Loop (HIL) Prüfstand eingerichtet, welcher es ermöglicht, das Zusammenspiel verschiedener Hardwarekomponenten eines Prosumenten in einer realistischen Umgebung zu testen. Der Prüfstand unterstützt die Analyse, den Vergleich und die Entwicklung von Systemkomponenten unter kontrollierten und reproduzierbaren Bedingungen.

Dedizierte Tests an drei Energiemanagementsystemen (EMS) für typische Einfamilienhäuser zusammen mit Heimspeicherlösungen verschiedener Hersteller wurden durchgeführt und bewertet, um Verbesserungspotenziale zu identifizieren. Es wurde festgestellt, dass aus rein wirtschaftlicher Sicht der Einsatz von Energiemanagement-systemen zur Erhöhung des Eigenverbrauchs für Einfamilienhäuser nicht sinnvoll erscheint. Eine korrekte Planung und Dimensionierung von Anlagenkomponenten oder die Implementierung effizienter Algorithmen zur Wärmepumpenregelung könnte bestehende Optimierungspotenziale besser ausschöpfen. Darüber hinaus würde die Standardisierung der Steuerungsschnittstellen für Wärmepumpen wesentlich dazu beitragen, das vorhandene Optimierungspotenzial zu nutzen. Bei stationären Batteriesystemen reichen einfache Regelalgorithmen, wie sie heute direkt in Haushaltsspeicherlösungen integriert sind, völlig aus, um den Eigenverbrauch zu erhöhen.

Mit Hilfe von Simulationen und Labormessungen wurde untersucht, wie EMS dazu beitragen können, die Stabilität des Verteilnetzes zu erhalten oder zu verbessern und unter welchen Anforderungen dies erreicht werden kann. Dazu wurde ein Teilnetz der BKW simuliert und ausgewertet. Die Simulationen haben gezeigt, dass der Anstieg der Spannung durch die PV-Leistung mit Hilfe eines EMS zur Erhöhung des Eigenverbrauchs (im Vergleich zur Situation ohne EMS) um fast 6% gedämpft werden kann. Bei einem EMS zur Verbesserung der Netzstabilität kann die maximale Spannung jedoch je nach Konfiguration des EMS nur um bis zu 3% reduziert werden.

Die sozioökonomischen Auswirkungen einer Vielzahl von Prosumenten wurden durch dynamische Modellierung identifiziert. Das Modell zeigt, dass der steigende Anteil von Photovoltaik- und Batteriespeichersystemen den Strombedarf der Haushalte aus dem Netz bis 2050 um 9% senken wird. Darüber hinaus wird gezeigt, dass der Anstieg der Elektrofahrzeuge (EV) den Stromverbrauch der Haushalte aus dem Netz bis 2050 um 8% erhöhen könnte.

Weitere Informationen zum Projekt Prosumer-Lab, zum Prüfstand oder zu den beteiligten Partnern sind unter www.prosumer-lab.ch oder www.prosumerlab.ch verfügbar.

Résumé

Ce projet vise à rechercher, développer et comparer les connaissances fondamentales, les méthodes et les systèmes dans le cadre d’une plateforme de démonstration R&D. L'objectif principal est d'optimiser la consommation propre et d'évaluer avec précision le comportement du réseau dans l'intérêt d'une intégration optimale des consommateurs décentralisés. De plus, les impacts socio-économiques d'un grand nombre de prosommateurs appliquant des stratégies d'optimisation individuelles sur le réseau de distribution ainsi que sur les modèles économiques existants des gestionnaires de réseaux de distribution seront identifiés et analysés. Au centre de recherche sur le stockage d'énergie de la BFH à Bienne, un environnement de test Hardware-In-The-Loop (HIL) a été mis en place permettant de tester l'interaction des différents composants d'un prosommateur dans un environnement réaliste. Le banc d'essai permet l'analyse, la comparaison et le développement de composants du système dans des conditions contrôlées et reproductibles.

Des essais spécifiques sur trois gestionnaires d'énergie (EMS) disponibles dans le commerce pour des maisons unifamiliales typiques comportant des système de stockage provenant de différents fabricants ont été effectués et évalués afin d'identifier des améliorations potentielles. Il a été constaté que d'un point de vue purement économique, l'utilisation de systèmes de gestion de l'énergie pour augmenter le taux d’autoconsommation n'est pas raisonnable pour les ménages unifamiliaux. Une planification et un dimensionnement corrects des composants du système ou la mise en œuvre d'algorithmes efficaces pour la commande des pompes à chaleur permettrait de mieux exploiter les potentiels d'optimisation existants. En outre, la standardisation des interfaces de commande des pompes à chaleur contribuerait grandement à exploiter le potentiel d'optimisation disponible. En ce qui concerne les systèmes de batteries stationnaires, des algorithmes de commande simples, tels que ceux qui sont intégrés directement dans les solutions de stockage domestiques actuelles, sont pleinement suffisants pour augmenter la consommation propre.

Des simulations et des mesures en laboratoire ont permis d'étudier comment l’EMS peut contribuer au maintien ou à l'amélioration de la stabilité du réseau et selon quelles exigences elle peut être réalisé. Pour ce faire, un sous-réseau des BKW a été simulé et évalué. Les simulations ont montré que l'augmentation de la tension due à la production PV peut être amortie de près de 6 % à l'aide d’un EMS conçu pour augmenter l'autoconsommation (par rapport à la situation sans EMS). Dans le cas d'un EMS conçu pour améliorer la stabilité du réseau, la tension maximale ne peut toutefois être réduite que de 3 %, selon la configuration de l’EMS.

Les impacts socio-économiques d'un grand nombre de prosommateurs ont été identifiés au moyen d'une modélisation dynamique. Le modèle montre que la part croissante des systèmes photovoltaïques et des systèmes de stockage réduira la demande d'électricité provenant du réseau des ménages de 9% en 2050. De plus, il est démontré que l'augmentation du nombre de véhicules électriques (EV) augmente potentiellement la demande d'électricité des ménages sur le réseau de 8% en 2050.

De plus amples informations sur le projet Prosumer-Lab, le banc de test et les partenaires associés sont disponibles aux adresses www.prosumer-lab.ch et www.prosumerlab.ch.

Summary

This project seeks to research, develop and compare fundamental knowledge, methods and products in a R&D-demonstration platform. The main aim is to optimize the own consumption and to accurately assess the grid behavior in the interest of an optimized integration of decentralized prosumers. In addition, the socio-economic impacts from a large number of prosumers applying individual optimization strategies on the distribution grid as well as the existing business models of distribution grid providers will be identified and analyzed. At the BFH Energy Storage Research Centre in Biel, a Hardware-In-The-Loop (HIL) test environment was set up which allows the interaction of various hardware components of a prosumer to be tested in a realistic environment. The test bench supports analysis, comparison and development of system components under controlled and reproducible conditions.

Dedicated testing on three commercially available energy management systems (EMS) for typical single-family houses together with home storage battery solutions from different manufacturers was done and evaluated in order to identify potential improvements. It was found that from a purely economic point of view, the use of energy management systems to increase the rate of own consumption is not sensible for single-family households. A correct planning and dimensioning of system components or the implementation of efficient algorithms for heat pump control could better exploit existing optimization potentials. Moreover, the standardization of control interfaces for heat pumps would greatly contribute to exploit the available optimization potential. As far as stationary battery systems are concerned, simple control algorithms such as those integrated directly into household storage solutions today, are fully sufficient to increase own consumption.

Simulations and laboratory measurements were used to investigate how EMS can contribute to maintain or improve the stability of the grid and under which requirements this can be achieved. To achieve this, a BKW sub-grid was simulated and evaluated. The simulations have shown that the rise of the voltage due to the PV power can be damped by almost 6 % with help of the EMS designed for increasing self-consumption (compared to the situation without EMS). With an EMS designed to improve grid stability however, the maximum voltage can be reduced only by up to 3%, depending on the configuration of the EMS.

The socio-economic impacts from a large number of prosumers have been identified by means of dynamic modelling. The model shows that the increasing share of photovoltaic and battery storage systems will decrease the household electricity demand from the grid by 9% in 2050. Furthermore, it is shown that the increase in electric vehicles (EV) potentially increases the household electricity demand from the grid by 8% in 2050.

Further information regarding the Prosumer-Lab project, test bench and the involved partners can be found at www.prosumer-lab.ch or www.prosumerlab.ch.

Take-home messages

- Energy management systems do what they are meant to do, however high hardware costs coupled to the current electricity tariffs make them not economically interesting (yet). Improvements in user friendliness are desirable. Continuous heat pump control brings an additional self-consumption increase (2%) for a low cost. Batteries significantly increase SCR and autarky, but investment costs are still high.
- Energy management systems could be a useful tool for distribution system operators in the future to manage grid instabilities, which are occurring due to the continuous increase in the number of prosumers. The simulations done in this project revealed that – depending on the grid topology and prosumer-basis – there is a clear potential for an EMS to help and even improve the stability of the grid.
- The socio-economic model shows that especially the increasing share of photovoltaic, battery storage systems and electric vehicles may significantly affect electricity demand and consequently current revenue models of utility companies.

Contents

Glossary

Abbreviation	Description
SFOE	Swiss Federal Office of Energy (Bundesamt für Energie, BFE)
BFH-TI	Bern University of Applied Sciences – Department Engineering and Information Technology
BKW	A major utility company in Switzerland.
CSEM	Centre Suisse d’Electronique et de Microtechnique
DSO	Distribution System Operator
EMS	Energy Management System
EPV	Energy Performance Value
EV	Electric Vehicle
HIL	Hardware in the loop
HP	Heat Pump
KPI	Key Performance Indicator
p.u.	Per unit
PV	Photovoltaic
PVB	Photovoltaics and Battery
SCE	Self-consumed Energy
SCR	Self-Consumption Rate
SCO	Self-Consumption Organization
SG-Ready	Smart-Grid-Ready
STIM	Laboratory for Strategy, Technology and Innovation Management, BFH
ZEV	Merger for own consumption (Zusammenschluss zum Eigenverbrauch)

1 Introduction

1.1 Initial situation and motivation

The share of decentralized energy producers within the distribution grid that both feed (produce) and consume electricity, so-called prosumers, has risen sharply in recent years. This trend will also continue in the future due to falling acquisition costs of PV systems and battery storages and the possibility of own consumption. So-called Energy Management Systems, or EMS for short, promise to increase the self-consumption rate by controlling heat pumps and batteries, where existing temporal flexibilities and thermal and electrical storage capacities are exploited. In addition, decentralized power feeds, electrical energy storage, controllable loads and various algorithms with which these devices are controlled pose new demands on distribution networks. Energy management systems that are geared to optimizing own consumption could control load flows fundamentally different than algorithms that are designed to grid-compatible operation.

The task of energy supply companies (EVU) is to identify such integration measures both in their role as energy service providers and in the role of distribution network operators, to assess their suitability and to create both the technical and the economic prerequisites for their use.

It is particularly important for energy supply companies and component suppliers in Switzerland to address challenges at an early stage by increasingly integrating intelligent buildings into the distribution network. Strategies must be developed that allow intelligent buildings to be integrated into the distribution grid, while keeping the distribution grid load and thus the expansion of the distribution grid as efficient as possible. This guarantees that the trend towards the integration of decentralized energy producers (with or without energy storage) will not be weakened.

At the start of the project, BKW had already begun developing an energy management system to increase own consumption by controlling a heat pump during PV production. The methods and algorithms resulting from this development work should also be tested and validated.

1.2 Project goals

To investigate the influence of novel strategies and components of the energy management of grid-integrated smart buildings on the stability and quality of the house and distribution grids, a three-fold focus was defined for the project.

- **Focus Energy Management in the Building**: How do commercial EMS and battery systems operate and what are their performance limitations? What is the performance of commercial EMS, battery and EV charging systems? How can these systems be improved in order to achieve an optimal balance between self-consumption, energy efficiency and grid integration?
- **Focus Distribution Grid Integration**: From the point of view of the distribution grid, what are the requirements of smart energy management systems in buildings to guarantee or even improve grid stability?
- **Focus Socio-economic Business Models**: From a business model perspective, how does a system of prosumers, utility companies, and associated incentives or regulations develop in the Swiss electricity market?

During the project - in addition to the present report - an individual report was produced for each of the three focus areas, which explains the methodology, the data used, the individual research questions as well as analyses and results in more detail.

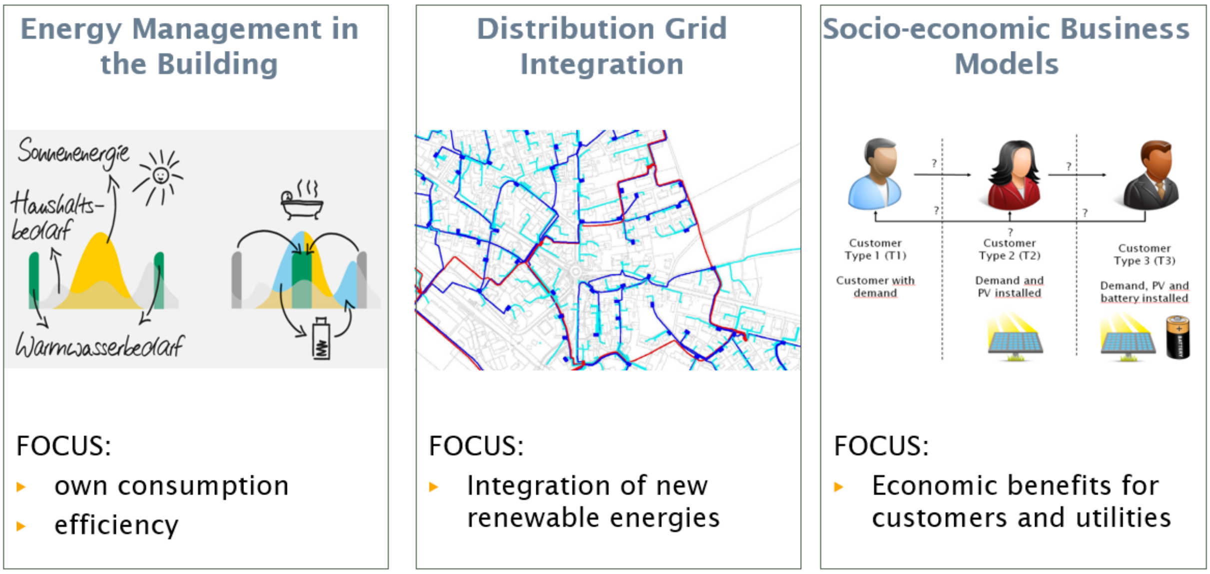

Figure 1: The three focus points of the project

Within the framework of this project, the BFH Energy Storage Research Centre of the Bern University of Applied Sciences together with the industrial partner BKW would like to promote the development of technical solutions as well as economically profitable win-win strategies for prosumers and distribution network operators and component manufacturers.

2 The Prosumer-Lab test bench

To answer the main research questions, a laboratory test bench has been realized, which allows to evaluate the impact of different prosumer production and load situations under given and reproducible boundary conditions. It models a single to multifamily apartment house through emulation devices, simulation as well as end-customer products in the laboratory. This test bench is called Prosumer-Lab. The test bench consists of 1) emulation devices, which recreate controlled real currents and voltages of devices such as PV systems in a laboratory environment, 2) simulation software for calculating room temperatures, hot water demand or thermal losses in storage tanks, and 3) consumer products such as two different battery home storage systems as well as three commercially available EMS. The test bench can emulate a prosumer with photovoltaic, inverters, storage batteries and loads up to 50 kVA. In the electric scheme shown in Figure 2 one possibility of a setup is represented. At each plug connection, devices can be individually connected, depending on the scenario to be used. Current sources are highlighted in yellow, inverters shown in blue, storage batteries in orange and the load emulator or plugs are highlighted in red. With the load emulator any household load or accumulation of those can be emulated, like heat pumps, cooking stove, fridge, light, etc. All these devices are controlled by the real-time system MicroLabBox (dSPACE) which is programmed in Matlab Simulink. The test scenarios with all the necessary profiles for PV-profiles, loads, weather information or thermal behavior of the house are provided via a connection to a scenario manager with a web interface. The control unit defines the scenarios and controls all devices together with an energy management system which accesses a heat pump through a Smart-Grid-ready signal or controls the charging or discharging behavior of a battery.

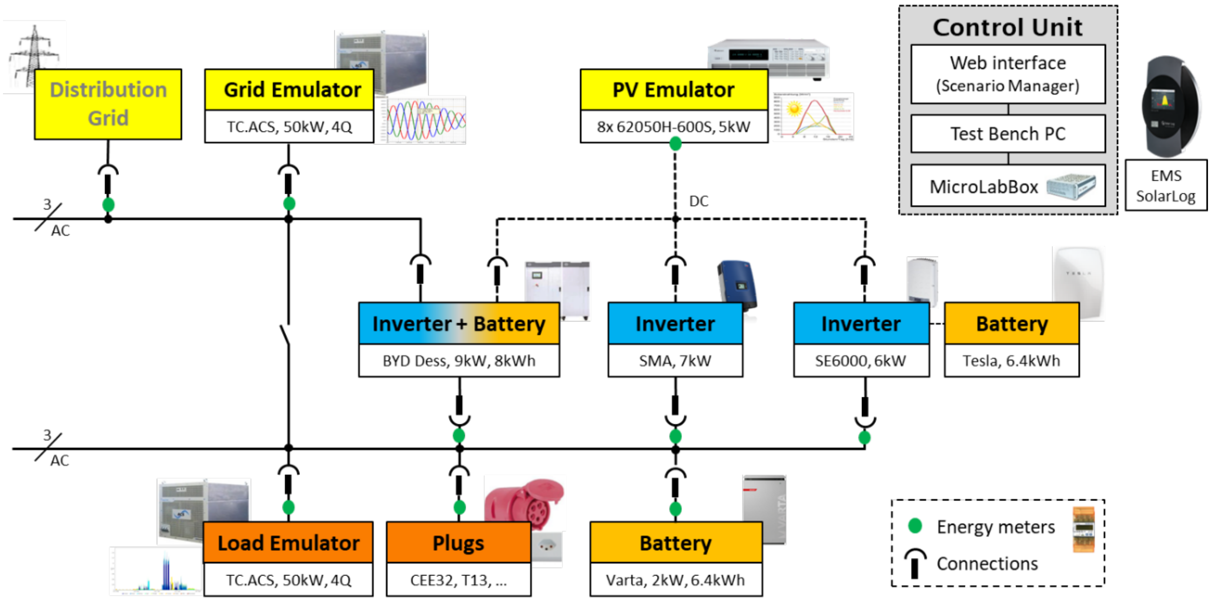

Figure 2: Electric scheme of the test bench set up. Yellow: current sources, blue: inverters, orange: storage batteries, red: loads. The green points represent energy meters, which log current and voltage every second. The control unit defines the scenarios and controls all devices.

3 Focus Energy Management in the Building

This is a summary of the Focus Energy Management in the Building. It recalls the objectives, details the used approach and discusses the results and findings obtained within this focus study. More detailed information can be found in the Focus Report Energy Management in the Building [1].

Prosumers are end customers who produce energy themselves in addition to normal electricity consumption. In households, this is usually done through a PV system. Electricity production and consumption seldom occur at the same time, which is why the self-consumption rate is correspondingly low. The resulting surplus electricity must then be fed into the grid, whereby the feed-in tariff in many places in Switzerland is already well below the electricity procurement costs. The increase in the self-consumption rate is therefore economically interesting for prosumers. So-called Energy Management Systems, or EMS for short, promise to increase the self-consumption rate by controlling heat pumps and batteries, where existing temporal flexibilities and thermal and electrical storage capacities are exploited. Within the Prosumer-Lab project three commercially available energy managers for typical single-family houses were evaluated together with home storage battery solution from different manufacturers in order to identify potential improvements.

This summary recalls the objectives linked to this evaluation, details the used approach and discusses the results and findings obtained for this domain within the Prosumer-Lab project.

3.1 Objectives

For the evaluation of the interaction between EMS, battery and electric vehicle (EV) charging systems in general as well as the performance that can be achieved with commercial systems, twelve research questions have been identified at project start. The objective of the project was to answer these research questions, which can be categorized into the following three categories:

- ***How do commercial EMS and battery systems operate and what are their performance limitations?***
- ***What is the performance of commercial EMS, battery and EV charging systems?***
- ***How can these systems be improved in order to achieve an optimal balance between self-consumption, energy efficiency and grid integration?***

3.2 Approach

To evaluate the above research questions, two methods have been used: hardware tests on a dedicated test bench for the commercial components and software simulations to obtain yearly performance figures. The hardware test environment that was set up as part of the project allows the interaction of various hardware components of a prosumer to be tested in a realistic environment. Individual components are emulated so that different devices can be compared in a reproducible manner by the generation of generation and load profile by software. When standard weather data was used to reproduce PV production profiles, the Load Profile Generator [2] generated realistic electric load curves and the Polysun software was used to model the entire thermal system of the building and the interaction with the heat pump. Different user and building categories are possible via parameter variations.

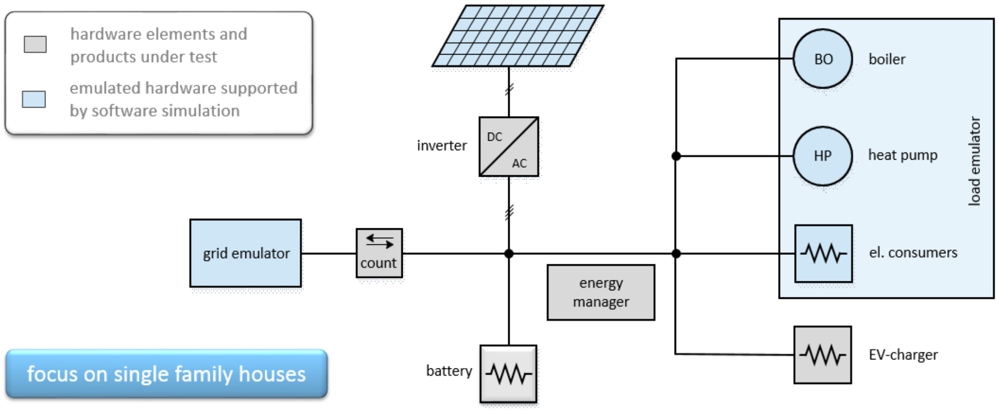

Figure 3 : The Prosumer-Lab hardware test environment.

For both, the hardware test bench and the software evaluations, two different user categories and three building types have been considered: good (Energy Performance Value of 35 kWh/m^2), average (EPV of 70 kWh/m^2) and poorly insulated building types (EPV of 150 kWh/m^2) with either a family with two adults and two children or a working couple without kids. Air-to-water heat pumps adapted to the heat demand were used, and the PV system was dimensioned so that the PV energy produced corresponded to the annual electrical energy demand. This is referred to as the 1:1 rule, whereby a solar system with a rated output of 1 kW is installed per MWh of annual consumption. For the average annual consumption without heat pump, the Swiss mean value of approx. 5 MWh was assumed. The properties of the buildings examined resulting from these assumptions for the family with two adults and two children are summarized in Table 1.

scenario	EPV	therm. cons.	el. cons.	PV production	HP power (th./el.)	PV size
S1	35 kWh/m^2	7‘667 kWh	7'352 kWh	8’531 kWh	4.8/2.3 kW	7.4 kW
S3	70 kWh/m^2	11’208 kWh	8’756 kWh	8’208 kWh	6.4/2.5 kW	7.2 kW
S5	150 kWh/m^2	21'318 kWh	11‘962 kWh	12‘806 kWh	10.9/5.5 kW	11.1 kW

Table 1 : Overview of electrical and thermal characteristics of investigated building configurations.

3.3 Results

3.3.1 How do commercial EMS & battery systems operate and what are performance limitations?

The three investigated commercial EMS communicate with heat pumps either via a simple digital signal that allows to switch the heat pump on or off or via the co-called SG-Ready interface, that is a two-wire digital connection that is available via an additional switching box. The two-wire SG-Ready interface, which was specified by the German Heat Pump Association, allows for four different modes: a) *normal* operation mode, b) *two-hour inhibition period* mode (used to reduce consumption in peak times), c) *use-if-you-can* mode and d) *forced* mode. For the latter two modes the heat pump will try to increase its power consumption by exploiting thermal storage capacities, e.g. overheating of buffer tanks. The implementation of these modes is, however, not further specified and is left to choice of heat pump manufacturer. In general, implementations simply increase the buffer or storage tank temperature by e.g. 5°C for the *use-if-you-can* mode and 10°C for the *forced* mode, but this is mostly not well or inconsistently documented. Dedicated feedback if and when activation will occur is not foreseen with the SG-Ready interface. On the EMS side, simple rule-based logic based on predefined power levels and timing is used for the activation of the latter to SG-Ready modes. Continuous power control is only supported by one of the analyzed EMS via a 0-100 mA analogue output. Power consumption was verified to be within the specified values from the data sheets and are in the range from 3 W to 7 W, which is resulting in an annual EMS power consumption around 40 kWh. The price for the hardware of the investigated EMS systems was around 800 CHF but does not include additional costs for required smart meters or the additional switching boxes. One EMS – the one with the continuous power control – stands out as a fully integrated solution that does not require additional equipment.

Similarly, three different home storage batteries from two brands with storage capacities ranging from 5 kWh to 48 kWh and maximum power levels from 2 kW to 24 kW were investigated. Standby power up varied largely from 16 W to maximum values observed of 65 W, corresponding to nearly 600 kWh annually.

3.3.2 What is the performance of EMS, battery and EV charging systems?

For the configurations from Table 1 an average of approx. 20 % to 30 % of local PV production can be consumed directly on site on an annual basis. Configurations with smaller PV systems - such as scenario S3, where PV production is lower than annual consumption - logically have higher self-consumption rates. By including a simple heat pump control by the energy manager EMS 1, the self-consumption rate can be increased on average by approx. 2 % to 4 %, see Table 2, which means that around 300 kWh more can be consumed directly on site. EMS 1 supports only a simple control logic, where the heat pump is activated via SG-Ready signal as soon as PV production exceeds a predefined level. The other two commercial solutions extend this simple threshold switching with further options that allow more energy to be stored. This is achieved with EMS 2 by a hysteresis function and with EMS 3 by an additional measurement of the heat pump output. These options make it possible to further increase the internal consumption rate by up to 1%. In general, it can be said that the systems differ only marginally in their performance, with EMS 2 being the most economically attractive solution because it does not require any additional meters or accessories. From a financial point of view, however, it is not worth it: a low feed-in tariff of 4 ct/kWh - as practiced in Eggiwil in 2017 - would save just 30 to 50 CHF per year, depending on the type of building and equipment. This corresponds to an amortization period of at least 16 years.

The situation is different with the additional use of a battery, which normally operate on their own and without EMS intervention. The self-consumption rates of a 10 kWh[1] battery are more than doubled here and on average 3 MWh more can be consumed directly on site. The influence of the battery capacity on the self-consumption rate is shown in the figure on the right for scenario S3. It can be seen that with capacities above 10 kWh, the increase in self-consumption quickly flattens out. In analogy to the dimensioning criterion for the PV system, the following design criterion can therefore be established: for each MWh of annual consumption, a battery capacity of maximum one kWh is installed. From a financial point of view, however, the battery does not yet really pay for itself. With the 10 kWh battery, financial savings of between 300 and 400 CHF per year can be achieved, which – with current purchase prices of at least 5’000 CHF and an expected service life of approx. 13 years (5’000 full cycles) – is just enough for amortization over the service life.

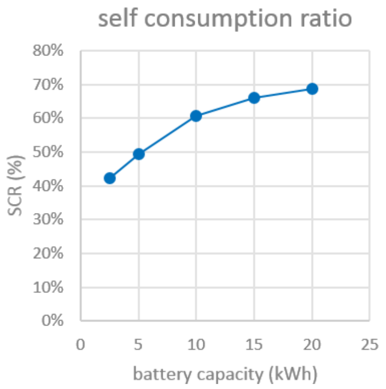

Table 2: Evolution of self-consumption rate as function of battery size, illustration for scenario S3.

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[1] The same battery size as the one used for the evaluation on the hardware emulation platform was used for yearly evaluation (done by simulation and based on standard model from Polysun library).

scenario	reference	EMS 1	EMS 2	EMS 3	max. EMS	battery
S1	22.2 %	26.1 %	26.9 %	26.7 %	29.9 %	56.4 %
S3	29.2 %	33.1 %	33.8 %	33.5 %	38.4 %	60.6 %
S5	21.2 %	23.0 %	24.1 %	24.1 %	31.8 %	44.2 %

Table 3 : Self-consumption ratios (SCR) for reference scenario, the three investigated commercial EMS and the theoretical maximum together with SCR for system also including a battery.

As batteries are currently not economically beneficial for end users, their usage in the context of emergency and stand-alone operation was investigated using the Fronius solar battery system. The tested systems work as expected, but it must be emphasized that it takes almost one minute to restore the electric power (after grid failure), a hierarchy between the loads is to be done and that only small loads shall be targeted as otherwise the battery is empties too fast.

As cars have relatively large batteries, they could be perfect candidates to increase SCR at a reasonable cost, as the battery comes with the car and not as an additional item. In that context, and EMS connected to a KEBA-charging station was tested. The three charging modes of the EMS were tested, namely full charge (i.e. charge at maximal rate as soon as possible), solar charge (charge only with the PV) and mixed charge. As expected, doing so could greatly increase SCR, if the car is available and plugged in during PV production.

3.3.3 How can these systems be improved?

By assuming that the heat pump can always be operated when PVs are producing energy, then the theoretical maximum energy that can be consumed directly on site can be determined. On a yearly basis this optimization potential was evaluated to be in the order of 3 to 8 % with regard to current EMS, which equals to at least doubling the performance of current systems (see also Table 2). This potential can be exploited especially at the beginning and end of the heating period - when the heat pump runs less than 50 % of the day. Theoretically, for scenario S3, instead of the 300 kWh, with optimum heat control up to 1300 kWh - i.e. at least four times more - could be consumed directly on site.

There are various ways of exploiting this potential. For example, the size of the buffer storages can be increased. The simulations showed that with tanks 2 times larger the annual self-consumption rate can be further increased by 2 % - 500 kWh instead of 300 kWh are now consumed directly on site. It is worth pointing out that less than 20% of this SCR increase is lost in thermal losses at tank level. When compared to the total heat generated by the heat pump, the tank losses represent 5% in the case of the large tank and 3% in the original tank configuration. Note that, the tank losses increase (10kWh elec.) linked to using EMS1 instead of the reference controller, with the original tank size in both cases, is small with respect to the SCR increase (300kWh). A similar effect can be achieved by increasing the tank temperatures. Heat pumps are usually limited to approx. 60°C and a further increase can be achieved with heating rods. Another method is to continuously adjust the output power of the heat pump to the excess PV power. It has been shown that this solution is almost as efficient as the larger buffer tanks, with an increase in self-consumption rate of approx. 1.5%, but without any additional installation costs. Modern frequency-controlled heat pumps support this power adjustment in principle but cannot be exploited with the SG-Ready interface available today. Further optimization potential can then be exploited via model-based algorithms that predict the development of thermal consumption and PV production, which have been shown to approach the theoretical performance limits. Such solutions are also very suitable for the effective use of the thermal storage potential of larger buildings, where excess energy can also be stored in the building directly. Thermal storage capacities are much higher for such cases, e.g. about 60 kWh of thermal energy can be stored in a 300 m^2 concrete ceiling by overheating up to 2°C whereas only 6 kWh can be stored when overheating a 500 l buffer tank by 10°C. It is however difficult to exploit such theoretical capacity values in practice because of large time constants above 10 hours and as it requires individual room control. But the biggest hurdle to size the available improvement potential is the lack of standardization efforts of the heat pump industry in order to facilitate optimum heat pump activation and control in combination with local PV production.

On the battery side, simple control systems such as those integrated today directly in the home storage solutions are quite sufficient to increasing self-consumption. Finally, in order to make batteries more attractive, a charging strategy that does not fully charge the battery was investigated. The last 10-20% of charge are suboptimal for the lifetime, based on cell tests. It was shown that this also applies to battery systems. But in the system test the energy loss per discharged kWh went down the more fully the battery was utilized. This shows that using oversized batteries and then only partially charging them seems not to be an optimal strategy from an efficiency standpoint.

Many different factors influence the system performance of a PV-Battery-system, such as charging efficiency, discharging efficiency, response time, maximum and minimum power, standby power, the weather, the load profile and much more. To accurately compare two systems, the impact for an entire year in a real system needs to be evaluated. But due to practicality and cost reasons carrying out year-long tests on the test bench is not feasible. To work around the problem, a detailed battery model was developed together with other partners in order to facilitate detailed analysis. It was shown that on average the error between this model and the real battery is ~16%. The model is documented in detail in the «Effizienzleitfaden für PV-Speichersysteme 2.0» of the HTW Berlin [3].

3.4 Discussion

From a purely economic point of view, the use of energy managers to increase the rate of private consumption is not sensible for single-family houses. Existing improvement potentials can be achieved by the correct planning and dimensioning of the system components or the implementation of efficient algorithms for heat pump control. The latter option, although economically more interesting as it requires lower investment costs in hardware, can today not easily be sized due to the absence of uniform ways to activate and efficiently control heat pumps, e.g. the current SG-Ready interface is not suitable to allow for the continuous adaptation of the heat-pump power to the available surplus PV power. The standardization of such interfaces would greatly contribute to exploit the available optimization potential (see also Recommendations below). Today, the integration of batteries makes sense from a technical point of view, but not from an economic point of view. Simple control systems for battery storage systems such as those integrated today directly in the home storage solution have been identified to be quite sufficient to increase self-consumption. However, they are not suitable for grid stability, see investigations done in the Focus Distribution Grid Integration.

Whenever the focus of this study was on single family houses, the results and conclusions also apply qualitatively for larger buildings, such as multi-apartment as well as commercial and office buildings or self-consumption communities (ZEV). The fundamental differences lie in the fact that bigger thermal storage capacities can be exploited – which however increases system complexity, as direct interaction with the building management system is required – and that the economic viability can be achieved much more quickly. Future development effort and support should therefore be put in this domain. In the frame of the Prosumer-Lab hardware infrastructure, the evaluation of units with power levels up to 50 kVA is possible, which is sufficient for single family houses and small self-consumption communities, e.g. multi-home buildings with up to nine apartments[2]. For bigger entities or industrial sites, creating or extending current evaluation platforms to higher power levels in the range of up to 200 kVA should be considered.

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[2] In Switzerland the working practice from VSE for multi-apartment buildings with 4 and up to 9 apartments foresees overcurrent level of 63 A, which corresponds to a connection power of ~44 kW. [18]

The soft- and hardware test bench is maintained at BFH Energy Storage Research Centre and available for interested parties to evaluate and validate their product improvements.

3.5 Recommendations

Within the project it was shown that the current SG-Ready interface is not efficient to exploit the available optimization potential with respect to the control of the heat pump and associated thermal storage assets. For the investigated single family houses it was shown via four day lasting hardware evaluations as well as yearly simulations that only 50% of the available optimization potential for increasing self-consumption and autarky can be exploited at best. It is therefore recommended to extend the SG-Ready interface or to define a new standard, that allows to access the available potential in a uniform and cost-efficient manner, e.g. similar to the way the SunSpec Alliance standardized the data interface to access and control PV inverters. The minimum requirement for such a standard is the possibility to adapt the heat pump power continuously and the provision of an information of the current storage status of the system, e.g. via tank temperatures. Additional features, like for instance the possibility to directly control the required inflow temperature of the heating circuit, would be beneficial, especially for bigger buildings.

Important note: when referring to SCR or SCE increase, unless otherwise specified, the increase is to be understood as **absolute**. Accordingly, a SCR of 20% increased by 3% results in a SCR of 23%. This convention was chosen to prevent the extensive use of formulations such as “an absolute increase with the unit of percent”.

4 Focus Distribution Grid Integration

This is a summary of the Focus Distribution Grid Integration. It recalls the objectives, details the used approach and discusses the results and findings obtained within this focus study. More detailed information can be found in the Focus Report Distribution Grid Integration [4].

Stabilization of the low voltage grid has increasingly become a challenge for the distribution system operators (DSO) due to the considerable increase in the number of prosumers. Nowadays many of those prosumers are not just feeding the energy of their PV system back into the grid, but rather trying to increase their self-consumption rate. Thus, up to a certain level, they become independent from the grid. To achieve this, the prosumer needs a storage system in combination with an intelligent energy management system (EMS). The focus question of this report is to identify in which ways these EMS can contribute to maintain or improve the stability of the grid and under which requirements this can be achieved. The term “grid stability” in this context refers to a grid where no lines are overloaded, and the voltage does not exceed the limits of +10%/-15% of the nominal voltage (required by the EN50160).

4.1 Objective

In order to identify in which ways EMS can contribute to maintain or improve stability of the grid and under which requirements this can be achieved, seven research questions have been identified at project start. The overarching focus question is this:

From the point of view of the distribution grid, what are the requirements of smart energy management systems in buildings to guarantee or even improve grid stability?

4.2 Approach

To answer this focus question, together with BKW the low voltage grid of Schüpfenried was chosen as a basis for a simulation model, using the power system analysis software PowerFactory from DIgSILENT. For the simulations, a part of the grid of Schüpfenried, consisting of ten customers, was considered. This section of the grid is connected via an overhead line to the transformer station. The end customers are predominantly single-family households and farms, which offer large rooftop areas for potential PV systems. The load profiles of the customers used for the simulations were generated by the load-profile generator by Noah Pflugradt [2]. Due to privacy concerns, the measured load profiles were not available and therefore could not be used. Based on the annual consumption, which results from the synthetic load profiles, a potential PV and battery storage system for those ten customers was dimensioned according to the rule of thumb (1 MWh consumption per year = 1 kW nominal PV power = 1 kWh storage capacity). The PV profiles are based on a measurement of a 660-kW_P-PV-system in Thun from October 2018 and are scaled accordingly. Therefore, it is important to mention that the obtained result could slightly change if the PV profiles would be based on a measurement of another season of the year. The mounting angle and orientation of the PV-system were not considered.

Furthermore, a simulation model of an EMS has been implemented for all the customers in the simulation model of Schüpfenried. Unlike the EMS developed by CSEM, which is controlling the heat pump, this EMS considers only the control of a battery storage system. It has been implemented in such a way that it allows a power-controlled and a voltage-controlled mode. Power-controlled means that the charging or discharging power of the battery is defined by the difference in the power of the PV system and the load. If this value exceeds a given upper or lower threshold (in this document referred to as dead band), the battery system is either charged or discharged. Voltage-controlled mode on the other hand means that the charging- or discharging-power of the battery is defined by the voltage at its connection point. To answer the focus question several scenarios are compared:

Scenario	Description
1	No one has installed a battery storage system with EMS.
2	Everyone has a battery storage system with EMS in power-controlled mode with a dead band of ±1kW
3	Everyone has a battery storage system with EMS in power-controlled mode with an upper dead band of ½ the nominal PV power and a lower dead band of – 1 kW.
4	Same as Scenario 3 but with doubled storage capacity
5	Everyone has a battery storage system with EMS in voltage-controlled mode

Table 4: Description of the scenarios investigated using the power system analysis software PowerFactory from DIgSILENT.

4.3 Results & Discussion

The simulations have shown that if all the PV systems are being operated without EMS and battery storage, the maximal voltage in the grid increases by 7% over the nominal value. If the PV systems are operated in combination with a storage unit and an EMS with a dead band of ±1 kW, the first part of the voltage increase can be intercepted by charging the storage with the excess PV power. In the afternoon, however, the storages are fully charged under this configuration, which forces the EMS to feed the PV power back into the grid, which then results in a strong increase of the voltage. The loading of the overhead line shows a very similar behavior. In the early afternoon, when most of the storages are fully charged, the loading increases up to 35%. To counteract this, it would be reasonable to adjust the power dead band of the EMS depending on the weather to store just the peak power of the PV systems. Therefore, for the next simulation the upper dead band of all of the EMS is set to 50% of the nominal installed PV power. This means that on a sunny day the EMS waits longer before it starts to store the PV energy. This allows the EMS to store the peak power of the PV system (peak shaving) and thus reducing the high peak voltage in the afternoon. As the simulations have shown, the situation can be further improved if in addition the battery storage capacity is doubled. Another solution would be to further increase the dead band (Figure 4). The power-controlled EMS are primarily orientated in increasing the self-consumption rate of the customers rather than stabilizing the grid.

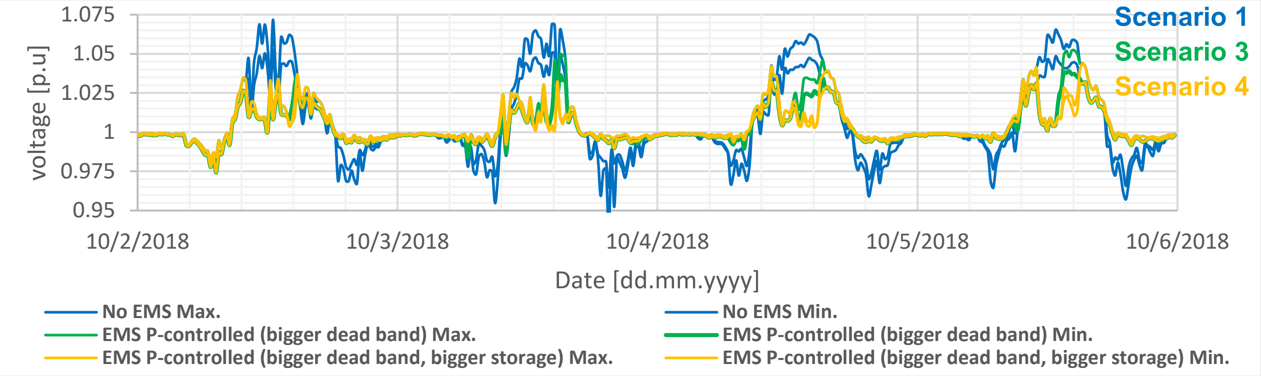

Figure 4: Envelope of the voltages of all simulated grid points when all the EMSs are operating in power-controlled mode.

In the next scenario, the behavior of a voltage-controlled EMS is investigated. The main goal of a voltage-controlled EMS is not to increase the self-consumption rate of the customer, but to increase the grid stability. It is therefore more interesting for the DSO rather than the customer. The voltage-controlled EMS sets the charge or discharge power of the battery storage depending on how much the voltage at the connection point is outside the dead band limit. If the EMS would just set a constant charge or discharge power whenever the voltage is outside of the dead band, the system would start to oscillate. For this reason, the EMS must have a droop assigned. The droop determines how sensitive the EMS sets the battery storage power, depending on a specific voltage change.

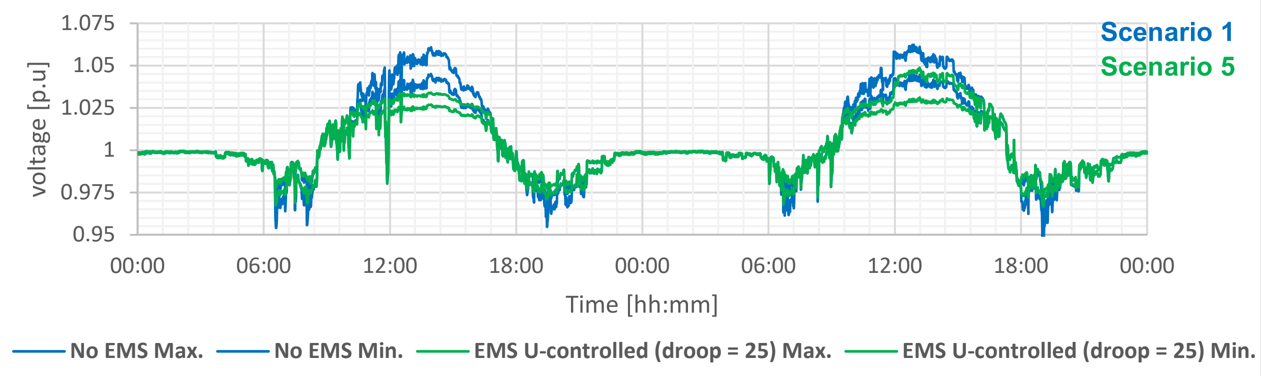

Figure 5: Envelope of the voltages of all simulated grid points when all the EMSs are operating in voltage-controlled mode.

As can be seen in Figure 5, in this case the maximum voltage can be reduced by up to 3%. The voltage increase during the day caused by the PV power is smoothly cut off in this operating mode. The optimal droop for each voltage-controlled EMS in the grid depends on the maximal and minimal voltage at its connection point and must be defined for each EMS individually. To determine the optimum droop value, a simulation was first carried out with all the EMS deactivated. Then the obtained maximum voltage was set as reference for the parameterization.

To quantify all the simulation results in terms of the potential to stabilize the grid, the following procedure was chosen. The situation where no customers have an EMS was defined as a reference scenario. Then the difference in percent between the voltage occurring in the reference scenario and the voltage occurring during the various configurations of the EMS is calculated. As shown in Figure 6, the rise of the voltage due to the PV power can be damped by almost 6% with help of the EMSs. The problem with the configuration of the power-controlled EMS with a dead band of ±1 kW is that the voltage can be stabilized only in the first half of the day. After that, all the battery storages in the grid are mostly fully charged and the potential to stabilize the grid decreases to zero (red curve in Figure 6). The increase of the dead band as soon as the weather forecast predicts sunny weather results in a longer period of the day where the voltage can be reduced with the EMSs (green and yellow curve in Figure 6). It can be seen that the power-controlled EMSs are in general more effective than the voltage-controlled EMSs. This is due to the fact, that the stabilization potential of the voltage-controlled EMS is connected to its droop value, which determines how sensitive the charging power of the battery storage is set, according to a certain change in the voltage. The simulations were done for a period of four days, however Figure 6 just shows one single day.

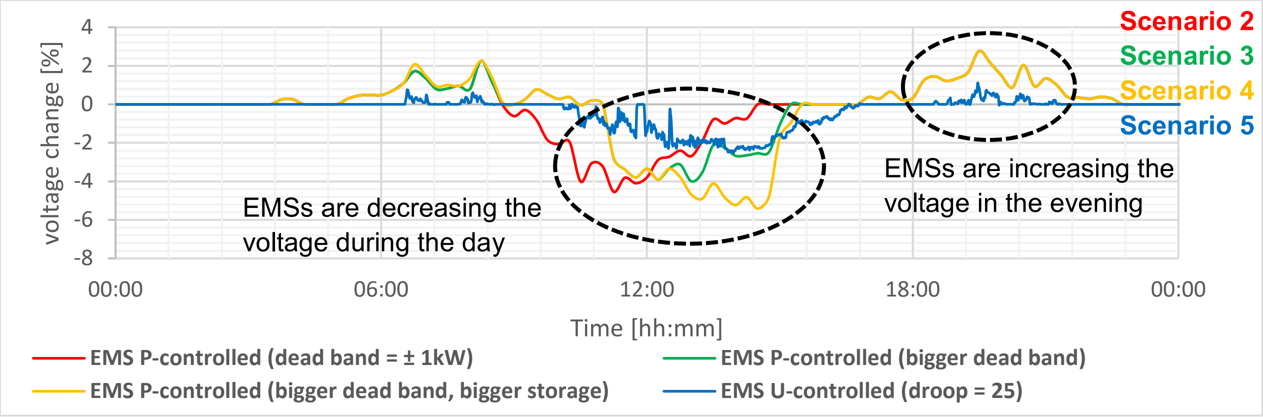

Figure 6: Change of voltage in percent between the reference scenario and the various configuration of the EMS.

To conclude, in the terms of grid stabilization the power-controlled EMSs seem to be more effective than voltage-controlled EMSs, but only for the ones with a bigger dead band (Scenario 3 and 4). It is important to add, that this is not a general statement. In Scenario 3 and 4, the power-controller EMS are more effective compared to the voltage-controlled EMS. But this is only because of the fact, that the EMS and the storage are parametrized accordingly, in order to store the complete peak of the PV power. Therefore, they are able to damp the voltage increase more efficiently than the voltage-controlled EMS. In Scenario 2 on the other, the power-controlled EMS with the dead band of ±1 kW won't decrease the voltage throughout the whole day, since the storage is fully charged around noon and the PV power is fed into the grid. From point of view of the DSO this configuration is therefore not desirable.
The most efficient configuration in this particular simulation would be to run the EMS in power-controlled mode with an increased dead band and a bigger storage (Scenario 4). This configuration allows the EMS to cut the complete peak of the PV-power and therefore reduce the voltage increase in a most efficient way.
To conclude, if the power-controlled EMS and the storage are dimensioned in a way that they are able to store the peak of the PV power, they can be more efficient than the voltage-controlled EMS in terms of grid stabilization. However, the voltage-controlled EMS will still be a more reliable solution, since it charges the battery depending on the voltage, whereas the power-controlled EMS does not consider the voltage. The voltage-controlled EMS however has the downside that the utilization of the storage might not be optimal. Meaning, the EMS will charge the battery only if the voltage reaches a critical level, while during the rest of the time, the storage is not used.

To answer the focus question: in order to guarantee or even improve grid stability, an EMS must fulfil the following conditions:

- The dead band (i.e. threshold) at which the EMS starts to charge the battery storage must be set high enough in order to store the peak of the PV power (at least 50% of the nominal PV power).
- Storage must be dimensioned big enough (at least 1 kWh capacity for each kW_P PV power).
- Regarding the voltage-controlled EMS: A correct parameterization is crucial.

To give a more general statement: To improve the grid stability, it is important to store the peak of the PV power. However, the ideal value for the dead band is strongly correlating to the storage capacity. In other words, the lower the dead band the bigger the storage must be in order to store the peak of the PV power and vice versa. Therefore, depending on the dead band value and the storage capacity the power-controlled mode of the EMS is a mix between self-consumption and improvement of the grid stability, while the voltage-controlled mode is generally just focused on improving the grid-stability.

Furthermore, it could be shown that the load flow in the overhead line in the morning and evening is significantly higher when all the EMSs are in voltage-controlled mode (Scenario 5) compared to scenario 2, where the EMSs are in power-controlled mode with a dead band of ±1kW (Figure 7). This is because scenario 2 is focused only on the improvement of the self-consumption. In other words, the main goal of those EMSs is to store as much PV power as possible and use all the stored power later in the evening. Compared to the situation without EMS (Scenario 1), the load flow, i.e. the consumption from the grid, can be reduced in the evening by up to 20 kW with the power-controlled EMS. That means all the customers are using the power from their own storages. While with the voltage-controlled EMS the load flow can only be reduced by around 6 kW (black mark in Figure 7). Therefore, the customers still have to buy energy from the grid in order to cover their consumption. This shows that the improvement of the grid stability and the increasing of self-consumption are rather conflicting goals.

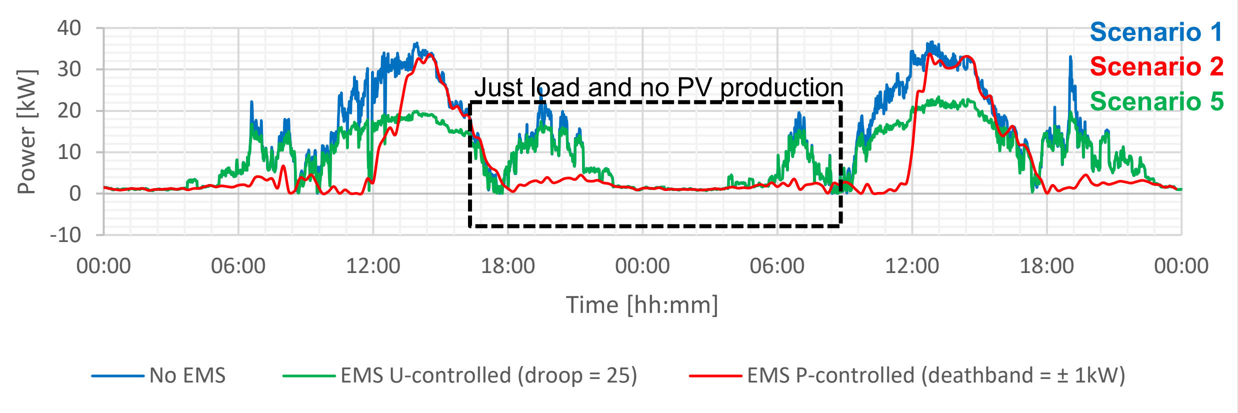

Figure 7: Power flow in the overhead line when all the EMS are operating either in voltage-controlled mode or in power-controlled mode.

Furthermore, the situation regarding the PV growth predicted by the «Energiestrategie 2050» has been investigated. The most extreme scenario of the «Energiestrategie 2050» requires a total of 11 TWh energy per year produced by PV systems. This leads to the conclusion that a total of 45 of the available roof spaces of every house in Switzerland needs to be covered by a PV system. In the analyzed part of the Schüpfenried grid a lot of the houses are farmhouses with very large roofs. In such a case an EMS controlled storage-system for every single household would be obsolete, since the consumption of the house is very small compared to the resulting PV production. As the simulation has shown, the increase of the voltage during a sunny day, as well as the loading of the overhead line in such a case, would be severe. The voltage would increase up to 1.2 p.u, which is a clear violation of the given limit of +10% required by the EN50160, and the overhead line would reach a loading of about 170% and could thus not be operated any longer. In this scenario a central storage combined with a central EMS has proven itself a good solution, in order to keep the voltage and line loading in an acceptable range. Since in terms of loading, the main supply line, i.e. the overhead line, is the most critical point in this grid, it is best to place the central storage at the end of the overhead line.
This simulation considers only the technical aspect of the central storage. The economic aspects were not part of the study. From an economically point of view a central storage might not be the most efficient solution. Furthermore, the investigated grid was a very rural area, with buildings with large roofs, which leads to a high PV power according to the Energiestrategie 2050. The same simulation in an urban area with buildings with smaller roofs would probably lead to a different conclusion. In an

urban area it might be more efficient to install multiple small decentral storages in every house rather than one big central storage in the transformer station.

Furthermore, the implemented EMS model of the power-controlled EMS has been verified using the Prosumer-Lab and a Varta battery system, which includes its own power-controlled EMS. The simulated power-profile of the battery shows a difference of max. 10% compared to the measured one. However, since the whole simulation is based on synthetic load profiles instead of measurements, the results of the simulations can only answer the focus question in a qualitative way, rather than quantitative. Nonetheless, the obtained results give a good impression of the potential to stabilize the grid, which is possible with an EMS. However, it is important to mention that these simulations are based on the specific grid of Schüpfenried, which is very a rural grid. The effect of an EMS on the grid stability however can change, depending on the grid topology, as well as the load profiles of the customers in the grid. For example, in an urban grid it would be expected that the voltage changes due to PV power would be less significant, since the lines are in general shorter and the short circuit power is higher. Therefore, the effect of an EMS would also be less significant. It is therefore strongly recommended that before the DSO relies on EMSs as a solution to maintain or improve grid stability, a simulation for the particular grid should be carried out.

Furthermore, it is important to add, that the simulations were all done on a quasi-dynamic basis. This means the simulation consists of a series of discreet independent timesteps. Therefore, the variables in the quasi-dynamic simulations are independent of time. In a dynamic simulation on the other hand, all the variables, e.g. the voltages are time-dependent. Meaning the simulations are done in a continuous way, which could lead to a slightly different behavior of the EMS. For example, if the droop-value for the voltage-controlled EMS was chosen too high, the quasi-dynamic simulation would show an oscillating behavior of the EMS. This is however only because the quasi-dynamic simulation considers only discreet independent timesteps, which does not represent reality. In a dynamic simulation this system would not oscillate. Therefore, to further analyze the subject of the voltage-controlled EMS, it is recommended to also consider using a dynamic simulation.

4.4 Recommendations

The control algorithm of a voltage-controlled EMS requires a droop-value. This value needs to be determined by a simulation for the particular grid where the EMS is used. The overall investigation of those control parameters for different grids could be the subject of a following project.

Although nowadays the grids are in general very well developed, if the penetration of PV systems required by the Energiestrategie 2050 will be the case for the future, measures must be taken e.g. EMS, reinforcement of lines or others.

A failure of the EMS could impact the stability of the grid. This must be taken into account when assessing the grid security.

5 Focus Socio-economic Business Models

This is a summary of the Focus Socio-economic Business Models. It recalls the objectives, details the used approach and discusses the results and findings obtained within this focus study. More detailed information can be found in the Focus Report Socio-economic Business Models [5].

Utility companies currently face a new, multifaceted situation in Switzerland. First, the consumption of self-produced electricity from photovoltaic (PV[3]) 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 [2-13].

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.

5.1 Objective

To study the socio-economic business models of utility companies, five research questions have been identified at project start to answer the following 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?

5.2 Approach

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 [15].

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.

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

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.

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[4] 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)[5], 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 8. 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

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

[5] 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.

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[6]. 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 8). 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).

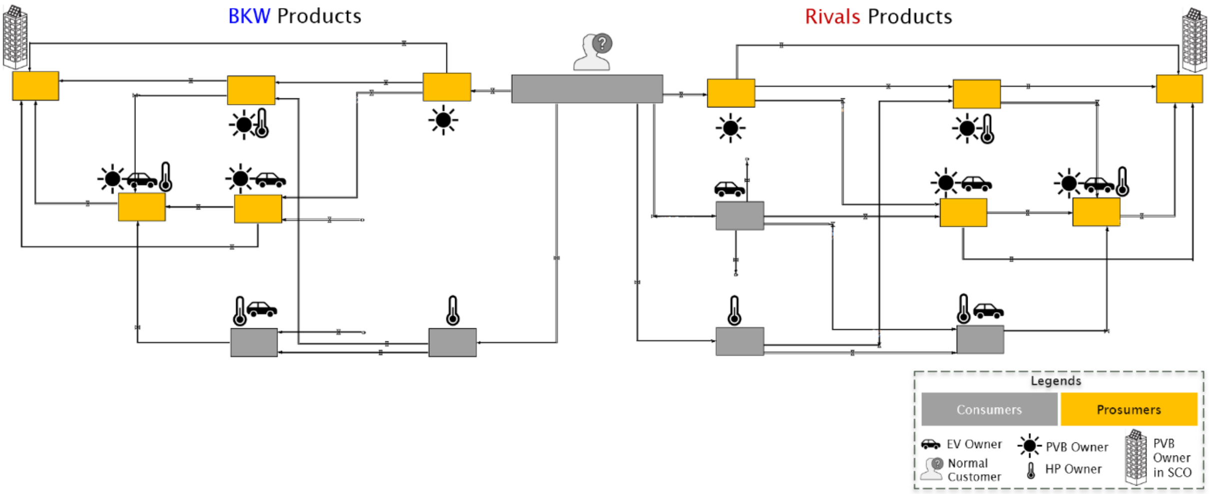

Figure 8: The current strategic business area of a major utility company, such as BKW. (The copyright of icons is mentioned in the footnote[7].)

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.

5.3 Results and Discussion

Figure 9 and Figure 10 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 9 (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%

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[6] 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.

[7] 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.

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 9). Another revenue stream could originate from installing such products for the first-time owners. Figure 10 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[8]. The decline can best be explained if the market development of each product (Figure 9 to Figure 11, presented in the Focus Report Socio-economic Business Models [5]) 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 40% in 2020, and 40% and 25% in 2050 respectively[9]. 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.

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[8] 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.

[9] 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.

The simulation model of this study also allows one to make a comparison with the Swiss Energy Strategy 2050[10], as depicted in Figure 11 and Figure 12. This study interpreted “Elektrizitätsnachfrage nach 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 12). The difference between the two could be covered by self-produced electricity, e.g. by means of PVB-systems.

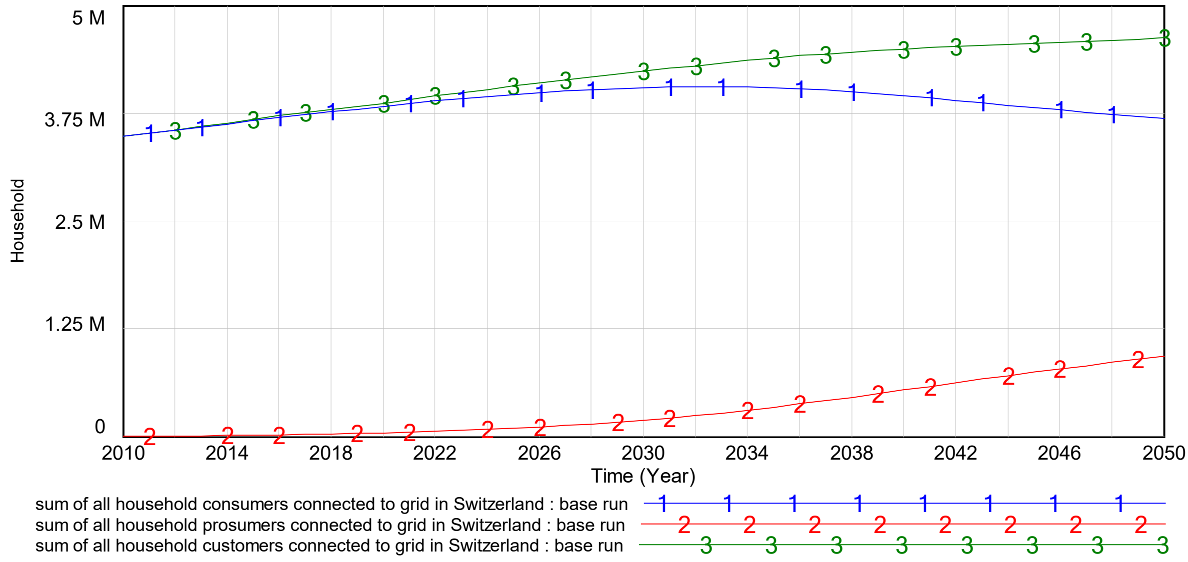

Figure 9: Portfolio of household customers connected to the grid in Switzerland.

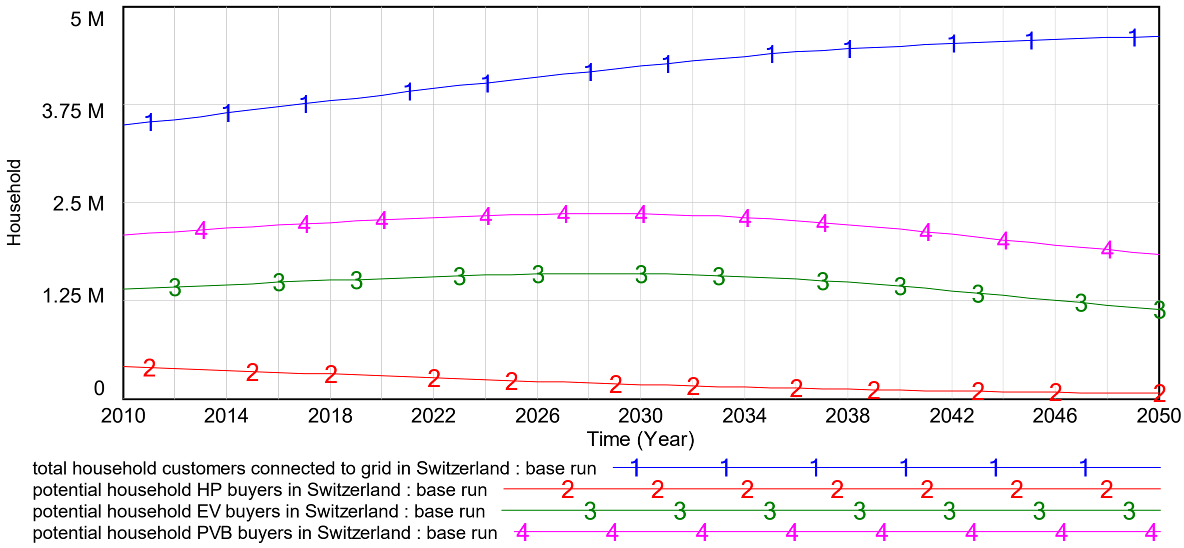

Figure 10: Changes in the market potential of service and installations in the Swiss electricity market.

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[10] 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. 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"

Table 5 summarizes and Figure 11 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 5: Summary of scenarios and their impacts on electricity demand from the grid.

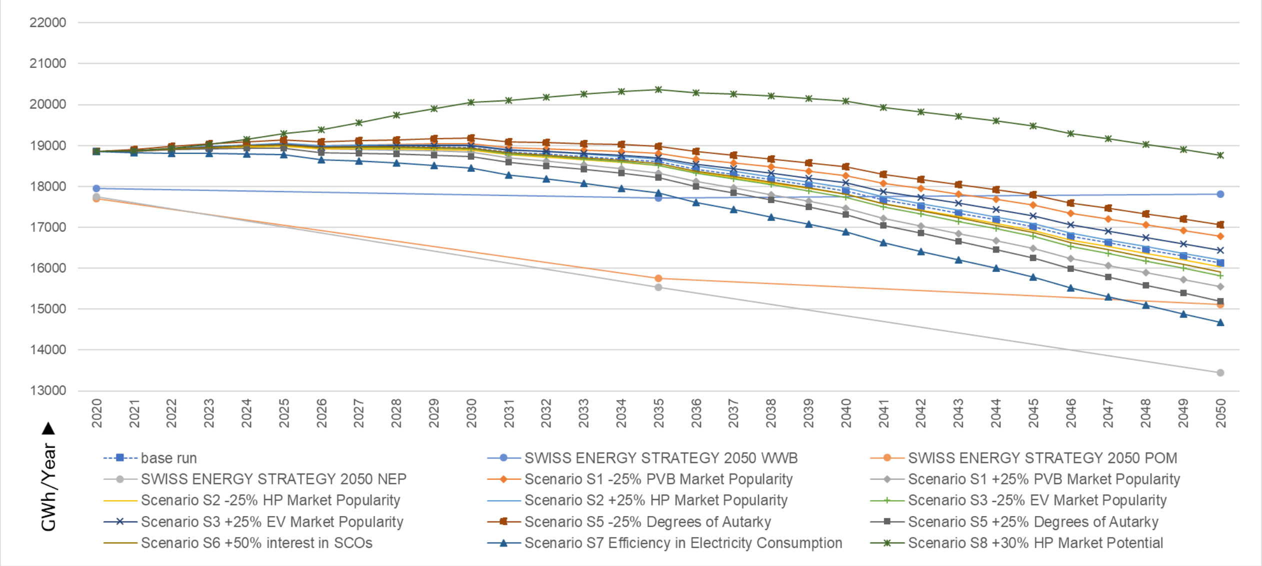

Figure 11: Household electricity demand from the grid in Switzerland under different scenarios.

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 6 summarizes the result of some policies based on the simulation model[11] 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.

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 Focus Report Socio-economic Business Models [5] 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	relative attractiveness BKW HP / PVB over Rivals rest of Switzerland	10% increase from 2020 over 5 years.	Impact of P2 ▶ 36%:64% in 2050

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

	services to other Cantons			
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 6: 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 12), 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[12] for the mentioned period (blue line number 1, Figure 12).

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.

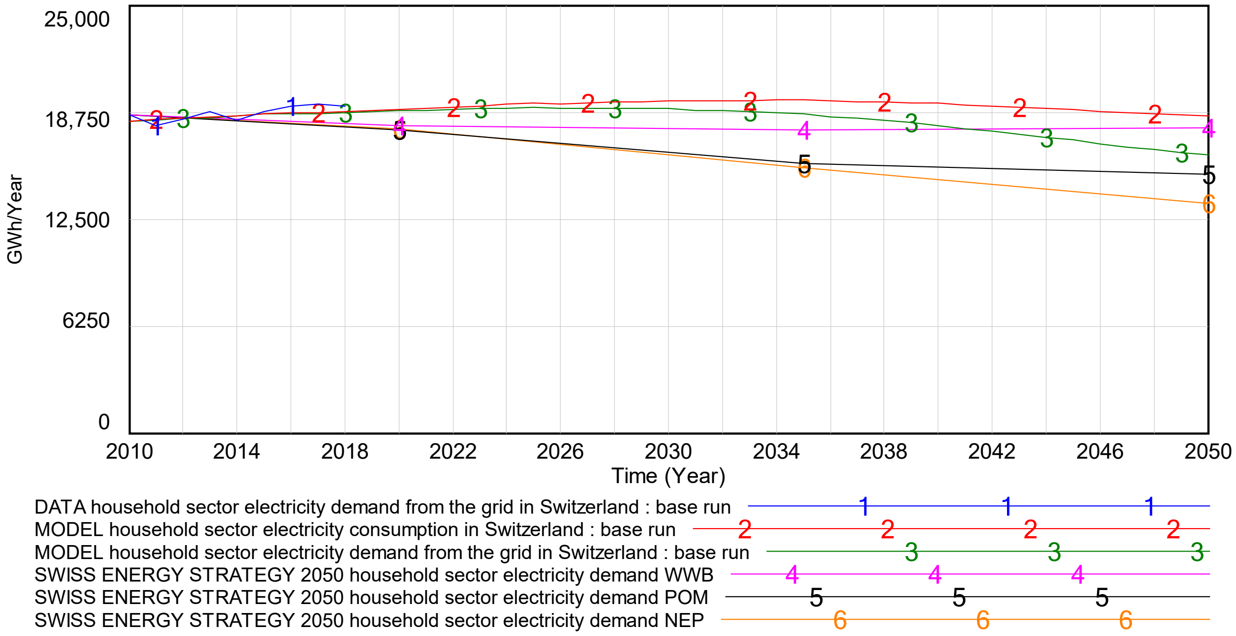

Figure 12: Electricity consumption; Current study vs. Energy Strategy 2050.

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[12] 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)

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 the Focus Report Socio-economic Business Models [5]) 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.

6 Outlook

The overall project could be carried out as planned. The objectives were achieved.

It has been shown that the SCR achieved by EMS could even be increased with simple improvements, for example by implementing a continuous control of the heat pump. Moreover, correct planning and dimensioning of the system components can further increase the SCR. The biggest hurdle to size the available improvement potential is the lack of standardization efforts of the heat pump industry in order to facilitate optimum heat pump activation and control in combination with local PV production. A standardization of such interfaces could greatly enhance optimization potentials. On the other hand, heat pump manufacturers could already integrate algorithms, e.g. for increasing their own consumption, into the heat pump itself in order to be able to offer interested prosumers a higher-quality product. In addition, to be effective, access to the heat distribution control (i.e. mixing valve and thermostats) should be available.

This study has shown that the EMS could be a useful tool for DSOs in the future to manage grid instabilities, which are occurring due to the continuous increase in the number of prosumers. The simulations done in this project revealed that there is a clear potential for an EMS to help and even improve the stability of the grid. The effect of an EMS on the grid stability however can change, depending on the grid topology, as well as the load profiles of the customers in the grid. It is therefore strongly recommended that before the DSO relies on EMS as a solution to maintain or improve grid stability, a simulation for that particular grid should be carried out.

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 the socio-economic study is to analyze in detail the substitution effect which household-based electricity storages and additional electricity demand have on the demand for conventional fossil-fuel based demand in the household sector and how to accelerate this conversion.

The soft- and hardware test bench is maintained at BFH Energy Storage Research Centre in Biel and available for interested parties to evaluate and validate their product improvements. A website for further information on the project, the test bench, publications and contact information is currently under construction. Further information regarding the Prosumer-Lab project, test bench and the involved partners can be found at www.prosumer-lab.ch or www.prosumerlab.ch.

Finally, it is planned to further study the design and technical implementation for grid-friendly operating strategies at the Prosumer-Lab test bench. Together with interested distribution network operators, a project is currently being developed to quantify the advantages of decentralized, customer-side battery storage for the distribution network. Among other things, incentive systems for grid-compatible operating strategies and their design and technical implementation are to be identified and evaluated with the help of the Prosumer-Lab test bench.

7 Communication & Publications

Within the framework of this project, several communication measures have already been taken to discuss the subject of prosumers in a professional audience as well as to make it accessible to a wider public. Further communication measures are already planned for the future. In addition, publications have been published in specialist journals. Many of these publications were offered in several languages (German, French, English) in order to achieve greater coverage.

Furthermore, the BFH Energy Storage Research Centre offers regular visits and guided tours through the Prosumer Lab for companies and associations, as well as special events such as the «Digitaltag» for the public.

Date	Type	Medium	Description
03/2016	Online Article	BKW Blog	Forschen am Gebäude der Zukunft
06/2016	Periodical	Efficience 21	Häuser sind nicht nur zum Wohnen da
07/2016	Newsletter	Spirit Biel/Bienne	Häuser sind nicht nur zum Wohnen da
08/2016	Periodical	VSE Bulletin 08/16	Bald Netzparität bei Batterien? PV-Anlagen und Speicher als Grundlage des Smart-Energy-Building
06/2017	Periodical	Asut Bulletin	Prosumenten als dezentrale und smarte «Powerstation»
06/2018	Conference	Powertage Zürich 2018	Prüfstand für den Test von Batterien, Energiemanagementsystemen und mehr!
07/2018	Newsletter	Newsletter BFH Energy Storage Research Centre	Prosumer-Lab Test Bench in Betrieb
09/2018	Conference Talk	EuroSun 2018 2nd SIGES conference	Quantifying the potential of smart heat pump control to increase the self-consumption of photovoltaic electricity in buildings
09/2018	Conference Article	EuroSun 2018 2nd SIGES conference	Quantifying the potential of smart heat pump control to increase the self-consumption of photovoltaic electricity in buildings
09/2018	Conference Poster	EuroSun 2018 2nd SIGES conference	Integrating Polysun Into a Test Bench for Prosumer Hardware
09/2018	Conference Article	EuroSun 2018 2nd SIGES conference	Integrating Polysun Into a Test Bench for Prosumer Hardware
10/2018	Seminar	VSE Zertifikatslehrgang «Prosumer-Lab – zwischen Erzeugung und Verbrauch»	- Produzent und Konsument – der Prosumer - Prosumer im Verteilnetz - Einspeise- und Lastgänge

			- Lastprofiloptimierung - Prosumer-Lab BFH-Zentrum Energiespeicherung
10/2018	Public Exhibition	Digitaltag 2018	Prosumer-Lab Prüfstand
10/2018	Periodical	VSE Bulletin 10/18	Energiemanagement auf dem Prüfstand
11/2018	Conference Talk	Symposium Energiespeicher	Elektrische Energiespeicherung beim Prosumer
01/2019	Periodical	VSE Bulletin 01/19	Zwischen Erzeugung und Verbrauch
06/2019	Periodical	dSPACE Magazin 02/2019	Geben und Nehmen – Lastflussmanagement für Prosumer-Haushalte im Labor nachgebildet
08/2019	Online Article	Swiss Engineering STZ www.ee-news.ch Phase 5 bfe.admin.ch/ec-strom	Wenn Algorithmen den PV-Verbrauch steuern
08/2019	Periodical	VSE Bulletin 08/19	Effizienz von Prosumern steigern
Upcoming	Website	Prosumer-Lab Website	Collecting all information regarding the Prosumer-Lab
Planned	Public Display	Foundation Science et Cité	Bewerbung Agora «smart und solar» to organize a public stand to learn about Prosumers in a playful environment

8 References

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9 Appendix

- Focus Report – Energy Management in the Building [PDF]
- Focus Report – Distribution Grid Integration [PDF]
- Focus Report – Socio-economic Business Models [PDF]