Bachelor's thesis at the Lucerne School of Engineering and Architecture

Title	**Identification, Quantification and Monetisation of Multiple Benefits for Distributed Energy Systems projects in buildings**
Student	**Huta, Rossella**
Bachelor's degree program	**Bachelor in Energy Systems Engineering**
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Lecturer	**Wagner, Claas**
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Abstract German
Der Nutzen von Projekten im Bereich der erneuerbaren Energien kann in einigen Fällen nicht offensichtlich sein und behindert daher die Umsetzung des Projekts. Diese Arbeit zielt darauf ab, Projekte für dezentrale Energiesysteme in Gebäuden zu analysieren, um versteckte Vorteile aufzudecken, zu quantifizieren und zu monetisieren. Der analysierte Fall ist ein installiertes Photovoltaik- und Batteriespeichersystem im neuen Siemens-Produktionsgebäude in Zug, Schweiz. Das Endziel ist die Entwicklung einer Methodik, die auf ähnliche Projekte mit möglicherweise unterschiedlichen technischen und regulatorischen Rahmenbedingungen angewendet werden kann.

Abstract English
Benefits occurring within renewable energy projects might in some cases not be evident and therefore hinder the project's implementation. This thesis aims at analysing Distributed Energy Systems projects for buildings in order to uncover, quantify and monetise hidden benefits. The analysed case is an installed photovoltaic and battery storage system at the new Siemens production building in Zug, Switzerland. The final goal is to deliver a methodology which can be applied to similar projects in conceivably different technical and regulatory frameworks.

Place, date

Bachelor Thesis

Identification, Quantification and Monetisation of Multiple Benefits for Distributed Energy Systems projects in buildings

Rossella Huta

Lucerne University of Applied Sciences and Arts - School of Engineering and Architecture
BSc Energy Systems Engineering – Technology and Environment

Horw, Lucerne University of Applied Sciences and Arts – T&A
June 7th, 2019

Bachelor Thesis

Identification, Quantification and Monetisation of Multiple Benefits for Distributed Energy Systems projects in buildings

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Coding of the Thesis

☐ Access only possible after consultation of author

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Horw, Lucerne University of Applied Sciences and Arts – T&A
June 7th, 2019

Declaration of authorship

I declare that I have written this thesis without any help from others and without the use of documents and aids other than those indicated. All text excerpts used, quotations and contents of other authors are explicitly denoted as such.

Horw, 7th June 2019

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Rossella Huta

Abstract

Benefits occurring within renewable energy projects might in some cases not be evident and therefore hinder the project's implementation. This thesis aims at analysing Distributed Energy Systems projects for buildings in order to uncover, quantify and monetise hidden benefits. The analysed case is an installed photovoltaic and battery storage system at the new Siemens production building in Zug, Switzerland. The final goal is to deliver a methodology which can be applied to similar projects in conceivably different technical and regulatory frameworks.

The analysed technical system was first optimised to have a better comparison between demand and supply side. The regulatory framework, including incentive programmes and specific electricity tariff of the according energy utility company, was thoroughly analysed. Later, several use cases for the technical system were developed and evaluated. A cost-benefit analysis finally revealed which use cases best fit the system from an economic perspective.

The results of the analysis show that for the analysed case, photovoltaic systems in combination with production facilities are a viable option at this moment in time thanks to new business models, incentive programmes, acceptable feed-in tariffs and general costs reduction for photovoltaic systems. Monetary benefits can therefore be generated. For storage scenarios, on the other hand, high battery investment costs and low power tariffs show that the current market situation is not convenient for a system including batteries. The results of the analysis by applying the mentioned methodology are, however, dependent on the specific technical and regulatory aspects of the analysed system, which can entirely differ from one project to the other.

Kurzdarstellung

Der Nutzen von Projekten im Bereich der erneuerbaren Energien kann in einigen Fällen nicht offensichtlich sein und behindert daher die Umsetzung des Projekts. Diese Arbeit zielt darauf ab, Projekte für dezentrale Energiesysteme in Gebäuden zu analysieren, um versteckte Vorteile aufzudecken, zu quantifizieren und zu monetisieren. Der analysierte Fall ist ein installiertes Photovoltaik- und Batteriespeichersystem im neuen Siemens-Produktionsgebäude in Zug, Schweiz. Das Endziel ist die Entwicklung einer Methodik, die auf ähnliche Projekte mit möglicherweise unterschiedlichen technischen und regulatorischen Rahmenbedingungen angewendet werden kann.

Das analysierte technische System wurde zunächst optimiert, um einen besseren Vergleich zwischen Bedarf und Versorgung zu ermöglichen. Der regulatorische Rahmen, einschließlich Subventionsprogramme und spezifischer Strompreis des jeweiligen Energieversorgungsunternehmens, wurde gründlich analysiert. Später wurden mehrere Use Cases für das technische System entwickelt und bewertet. Eine Kosten-Nutzen-Analyse ergab schließlich, welche Use Cases aus wirtschaftlicher Sicht am besten zum System passen.

Die Ergebnisse der Analyse zeigen, dass für den untersuchten Fall Photovoltaikanlagen in Kombination mit Produktionsanlagen aufgrund neuer Geschäftsmodelle, Förderprogramme, akzeptabler Einspeisevergütungen und allgemeiner Kostensenkungen für Photovoltaikanlagen zum jetzigen Zeitpunkt eine sinnvolle Option darstellen. Auf diese Weise können monetäre Vorteile erzielt werden. Für Speicherszenarien zeigen dagegen hohe Batterie-Investitionskosten und niedrige Stromtarife, dass die aktuelle Marktsituation für ein System mit Batterien noch nicht geeignet ist. Die Ergebnisse der Analyse unter Anwendung der genannten Methodik sind jedoch abhängig von den spezifischen technischen und regulatorischen Aspekten des analysierten Systems, die von Projekt zu Projekt völlig unterschiedlich sein können.

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Abbreviations and acronyms

ATS	Automated Transport System
BMS	Building Management System
CBA	Cost-Benefit Analysis
CHF	Swiss Francs
CKW	Centralschweizerische Kraftwerke
DES	Distributed Energy Systems
EKZ	Elektrizitätswerke des Kantons Zürich
ES 2050	Energy Strategy 2050
EVs	Electric Vehicles
EWZ	Elektrizitätswerk der Stadt Zürich
GDP	Gross Domestic Product
GREIV	Einmalvergütung für grosse Photovoltaikanlagen
HSLU	Hochschule Luzern
KLEIV	Einmalvergütung für kleine Photovoltaikanlagen
MKF	Mehrkostenfinanzierung
PV	Photovoltaic
RES	Renewable Energy Systems
SCC	Self-Consumption Community
SES	Società Elettrica Sopracenerina
TSO	Transmission System Operator
VAT	Value-Added Tax
VPP	Virtual Power Plant
WWZ	Wasserwerke Zug

1 Introduction

Energy systems are currently experiencing several shifts such as centralisation to decentralisation and traditional fossil fuel utilisation to renewable energy generation. These were mainly influenced by a general concern regarding global warming, which lead international association and national governments to shape their energy strategies towards sustainable energy systems. Switzerland has also started participating in this energy system shift by adopting the Energy Strategy 2050, which most of all focuses on increasing renewable energy generation and energy efficiency in buildings and processes.

Distributed Energy Systems (DES) is a term which encompasses a diverse array of generation, storage, energy monitoring and control solutions. DES technologies represent a paradigm shift and offer building owners and energy consumers significant opportunities to reduce cost, improve reliability and secure additional revenue through on-site generation and dynamic load management. The identification, quantification and monetisation of additional benefits by applying DES can be uncovered and therefore create additional value for the customer.

This thesis examines a DES composed of photovoltaics (PV) and battery storage which was recently installed at the new Siemens facilities in Zug. A comprehensive analysis could uncover potential unidentified benefits from the interaction between generation and storage technologies with the main load of the system, in this case the new production building. By analysing the technical system as well as its regulatory framework, it should be possible to evaluate different use cases for the analysed DES and possibly monetise the occurring benefits.

The objective of this study is first to optimise the technical system so that it suits best the existing infrastructure. Afterwards, the goal is to identify, quantify and monetise occurring benefits in DES projects located in Switzerland as well as to provide a methodology on how to approach planning or evaluation of similar installations.

2 Methodology

This chapter aims at providing an overview on the methods used to achieve the objectives of this study. Figure 1 shows the main methods applied in the study and provides an overview of the content of the study.

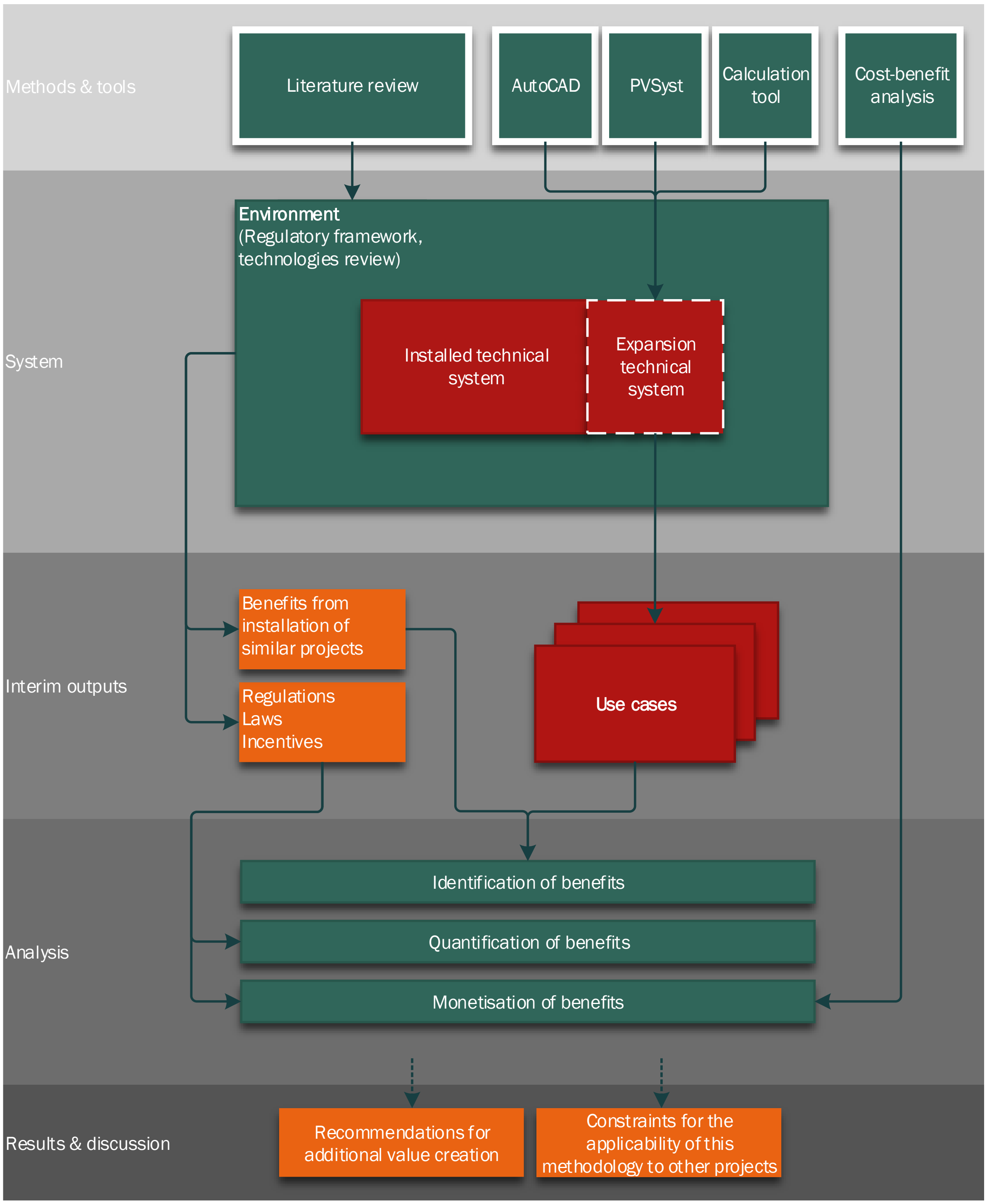

Figure 1 - Methodology overview

2.1 Literature review

This study focuses on Distributed Energy Systems (DES) for buildings with the main target in analysing PV and battery systems applications within Switzerland. Therefore, literature-based research helps in providing the knowledge background needed to understand the case study and later to perform the analysis.

In the literature review chapter, a technology review with the main focus on PV and battery storage will be provided. Reliable literature from well-established sources is available in this field of research.

Market studies, publications from the Swiss Federal Office, academic journals and scholarly books were used as the main sources for the regulatory framework. In case the required data was not found, specialised magazines as well as available material from “Swiss Solar” or “Energie Schweiz” were utilised.

A considerable amount of information for the specific case analysed was retrieved from the specific energy utility company which applies to the case.

2.2 Tools for the expansion of the technical system

An expansion of the existing technical system is required to carry out the analysis. This was achieved by using the following tools:

- AutoCAD was used to extend the existing PV system to the whole roof and therefore to estimate the amount of PV modules that could fit the rooftop;
- PV Syst provided a complete simulation with PV generation hourly data for the specific location;
- An Excel calculation tool, developed specifically for this thesis project, was used to estimate possible battery sizes for the extension of the system as well as providing approximate battery simulation results. Due to time-constraints, some parameters were not taken into consideration, therefore the results can be taken as indications but not as absolute results. An additional Siemens calculation tool was used for the charging and discharging behaviour of the battery.

Several use cases were derived for the extended technical system and later evaluated.

2.3 Cost-Benefit Analysis

A cost-benefit analysis (CBA) was selected as the main method to compare and evaluate different use cases. A CBA allows the comparison of the benefits of a system with the costs associated to it, as well as an evaluation of financial consequences of certain decisions. It gives the possibility to examine certain alternatives on a long-term rather than evaluating the system from a limited perspective. (Wagner, 2019)

According to Wagner, the main steps of a CBA are the followings:

- Definition of scope and assumptions;
- Identification of alternatives and quantification of costs and benefits for each alternative;
- Selection of an appropriate discount rate and calculation of the net present value;
- Selection and application of measure for comparing alternatives;
- Discussion of uncertainties and risks.

3 Literature review

This chapter aims at providing background information regarding the technologies relevant for this study.

Furthermore, the regulatory framework in Switzerland was analysed to provide the relevant information for the study.

3.1 Technology review

Renewable energy systems (RES) are expected to be a key component in future energy systems due to the global concern on climate change and global warming. Many countries are developing strategies and goals towards carbon neutrality.

Figure 2 shows the comparison between reserves availability of fossil and nuclear fuels and renewable energy yearly potentials. As it can be seen, the annual solar energy yield on Earth is by far the most abundant.

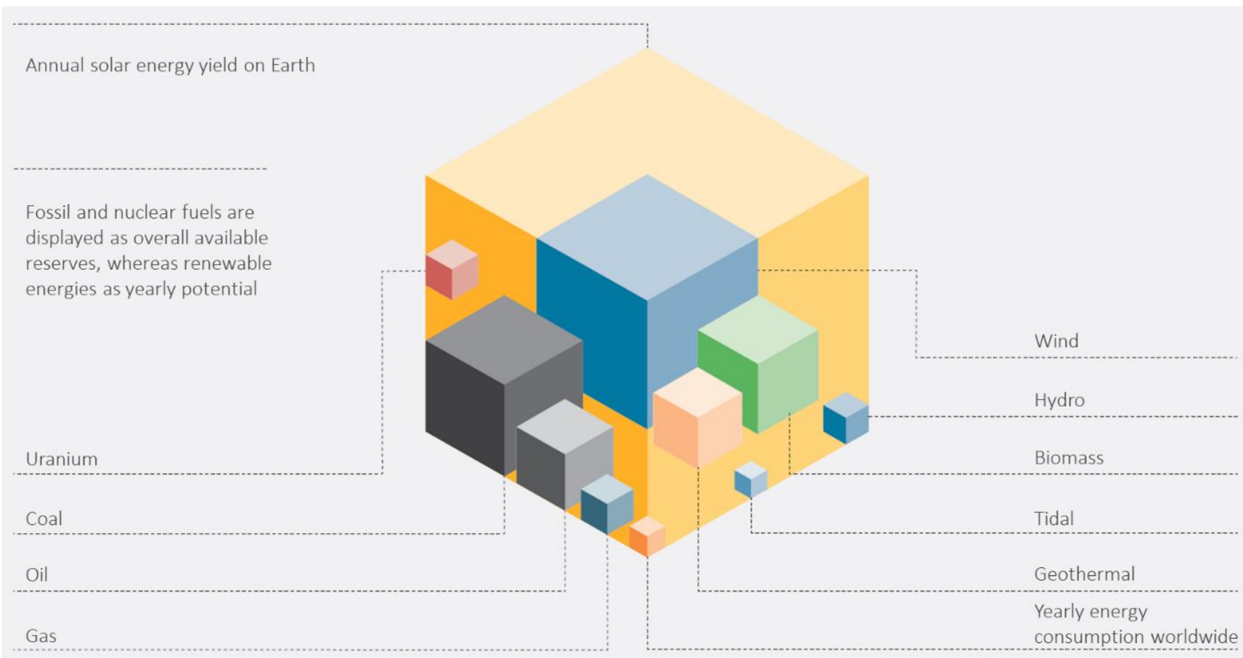

Figure 2 - Comparison of availability and potential capacities of different energy sources (Source: Swissolar)

Photovoltaic electricity generation has experienced a strong increase in the past 20 years reaching 500 GW of installed capacity and 800 TWh of generation in 2018 worldwide. PV systems are expected to play a key role in future energy systems due to the large physical potential for electricity generation. (IEA, 2018b)

However, the penetration of PV generation as well as other intermittent RES present several open issues with regards to daily as well as seasonal fluctuations. This could pose a strong threat on the stability of the electrical grid. The distribution network needs to be prepared for sudden high capacities available in the grid. (Schori, Moullet, & Höckel, 2019)

Storage is definitely a way to tackle the issue of intermittent energy sources. However, batteries in particular are well known for their high investment costs. Also the availability and the environmental footprint of the raw materials needed for batteries such as Lithium-Ion have been strongly discussed. However, according to Le Petit, resources of critical metals and rare earth minerals are unlikely to put constraints to the battery market growth, as long as the supply of the materials is diversified in order to avoid a strong dependency on imports from certain countries. (Le Petit, 2017)

3.1.1 Photovoltaic modules

Solar irradiation in Switzerland is also sufficiently high to cover a large part of the energy demand. (Figure 3)

The PV electricity potential on rooftops amounts to 50 TWh per year, which equals to 80% of the yearly electricity demand. PV modules on facades are excluded from this calculation. (Toggweiler, 2019)

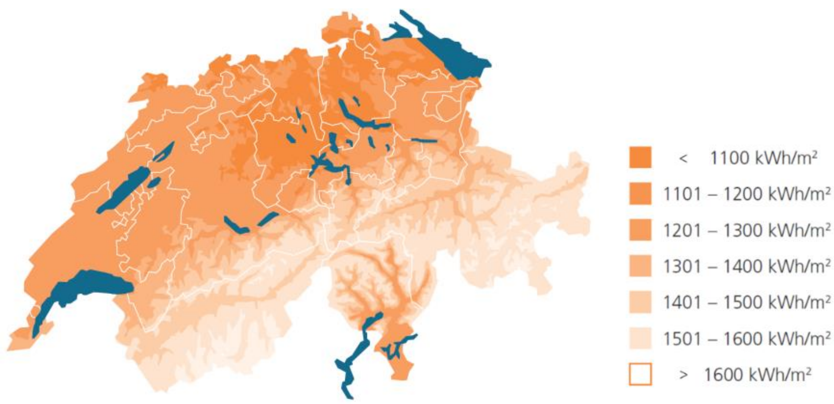

Figure 3 - Solar irradiation in Switzerland (Source: Swissolar*)*

PV modules prices have remarkably decreased over the past decades. Figure 4 shows the module price development in €/Wp from 1980 until 2018 compared to the cumulated installed capacity in GWp. According to the learning curve, each time the cumulative production doubled, the price went down by 24% for the last 38 years. (Wirth, 2019)

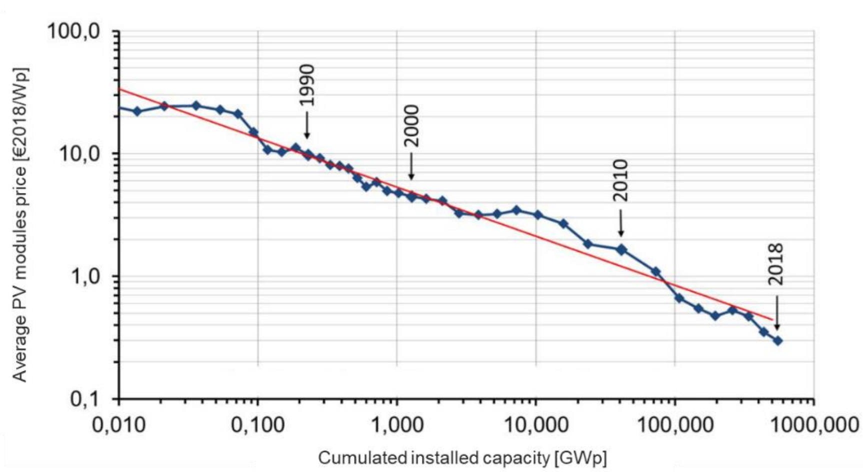

Figure 4 - Historical PV modules price development (Source: adapted from Wirth, 2019)

3.1.2 Storage

Energy storage technologies are defined as systems which can absorb, store and deliver energy when it is needed. They are therefore suitable for bridging gaps between supply and demand, as well as a balancing system for the grid. (HSLU, 2018)

A typical example can be found in hydropower plants, where water in a lake on a certain altitude has a specific potential energy, which can be converted into kinetic and then electrical energy when it flows down to valley through a turbine. On the other hand, when there is a surplus of electricity on the grid, a certain amount of energy can be used to pump up the water back to the lake and then stored for later use.

In Figure 5 it can be seen that there is a general positive trend in the use of storage systems along with services connected to storage.

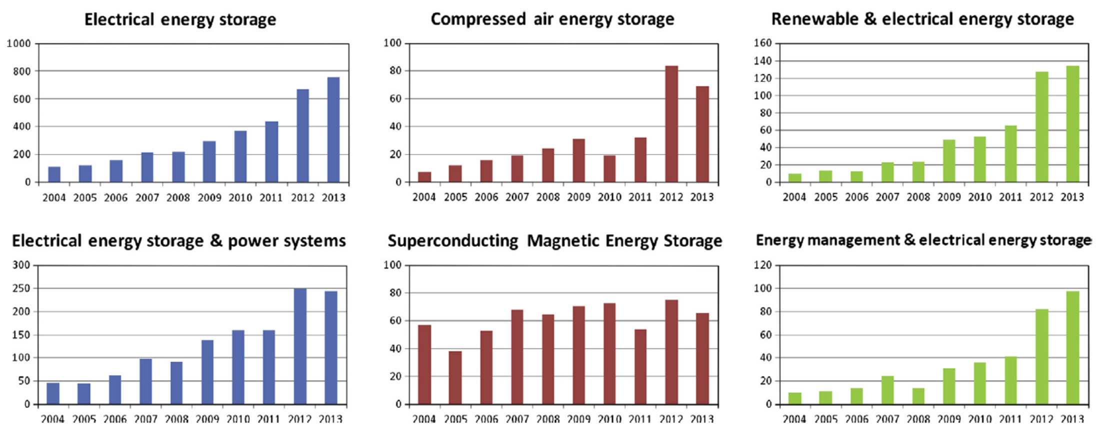

Figure 5 - A brief statistical study to the trend in EES related research (Source: Luo, Wang, Dooner, & Clarke, 2015 *)*

A general classification can be found in Figure 6.

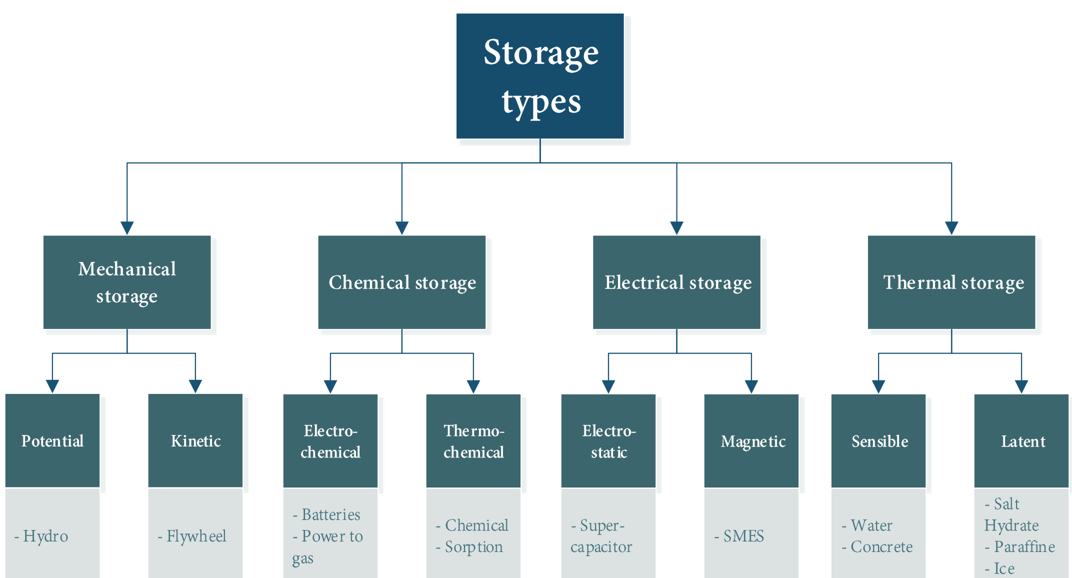

Figure 6 - Classification of storage types (Source: adapted from Gubler, Vinzenz, & Stamatiou, 2019)

Different types of storage can also be classified depending on the discharge time, power output and different applications. To assure power quality within short time, super capacitor, super-conductive coils and flywheels are the best alternatives. On the other hand, technologies such as power to gas as hydrogen and methane can be used for seasonal storage purposes. Batteries such as lead-acid or lithium-ion can be used for intraday and hourly applications and provide rather high power outputs. (Gubler et al., 2019)

This study focuses on Lithium-Ion batteries. These electric storage technologies are for sure the most well-known next to lead batteries. They are characterised by high energy density, high cell voltage, high power density but also rather large investment costs and possible security issues such as thermal runaway. Figure 7 shows the lithium-ion battery price development and outlook from 2010 until 2030. It is obvious that prices are decreasing, which could increase the profitability of an energy system with battery storage. However, prices for lithium-ion batteries including margins in stationary applications are in the range of 400-1’200 $/kWh.

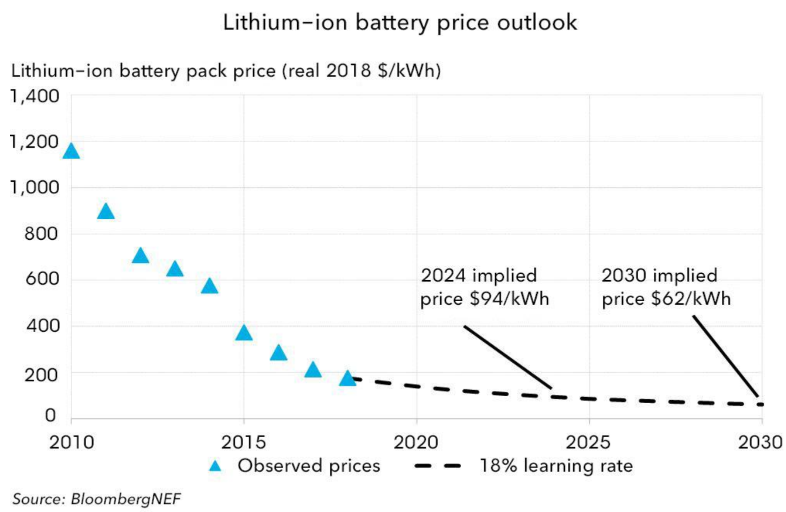

Figure 7 - Lithium-ion battery price outlook from 2010 until 2030 with according learning rate (Source: Goldie-Scot, 2019)

3.1.2.1 Battery storage in power grids

The increasing penetration of renewable energies in the electric grid as well as the increasing amount of electric devices such as heat pumps, electric vehicles and chillers are presenting some challenges for grid stability and grid quality. It is becoming more and more complex to forecast consumption loads. Even if the net energy demand can be covered from renewable source, it does not automatically mean that power peaks are also covered. This is a challenge most of all for the low-voltage grid, since power and voltage limits can be achieved rather quickly. (Schori et al., 2019)

In order to avoid oversizing of power grids with the consequent increase in grid investment costs and final grid tariffs for the end customer, storage can be a solution to avoid this problem. Potentially, high power tariffs should be introduced in order to responsibly reduce power peaks. (Schori et al., 2019)

3.2 Regulatory framework

This chapter aims at providing the relevant information regarding the regulatory framework, laws and incentive plans in Switzerland, first starting on a national level and then going deeper into cantons regulations.

3.2.1 National level

Energy consumption in Switzerland has decoupled from economic and population growth. Switzerland's total final consumption of energy did not increase from 2000 to 2016, even though the population increased by 15% as well as a GDP growth of over 30%. Switzerland is among the leaders in energy transition in IEA countries. It had the second-lowest energy intensity (TPES/GDP) and the lowest carbon intensity (CO2/GDP) of all IEA countries. Its TPES and CO2 emissions per capita are also significantly below the IEA average. (IEA, 2018a)

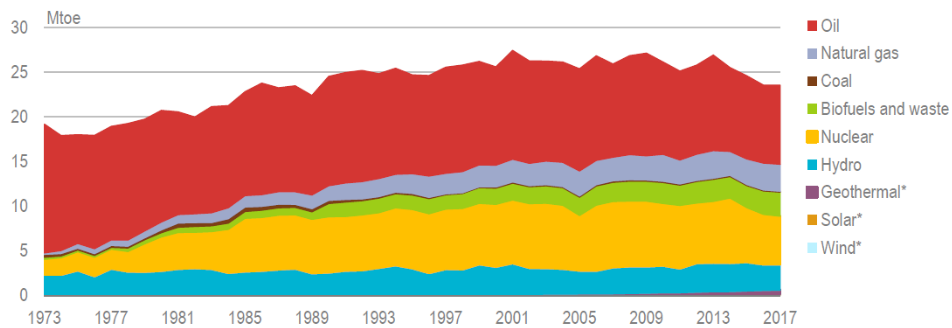

Figure 8 - TPES by source in Switzerland from 1973 to 2017 (Source: IEA, 2018)

The total primary energy supply in 2017 was mostly composed by oil (36.9%), natural gas (12.5%), biofuels and waste (11.2%), nuclear (22.2%), hydro (12.2%). (See Figure 8) (IEA, 2018)

Figure 9 shows the energy prices development in Switzerland from 1970 until 2017 from the Swiss Federal Office for Energy. The oil crisis started in 1973 is visible in the chart in the sharp increase of gasoline and heating oil prices. In general, heating oil, gasoline and gas experienced strong fluctuations. Electricity, in comparison, did not experience strong fluctuations but went through an overall price reduction.

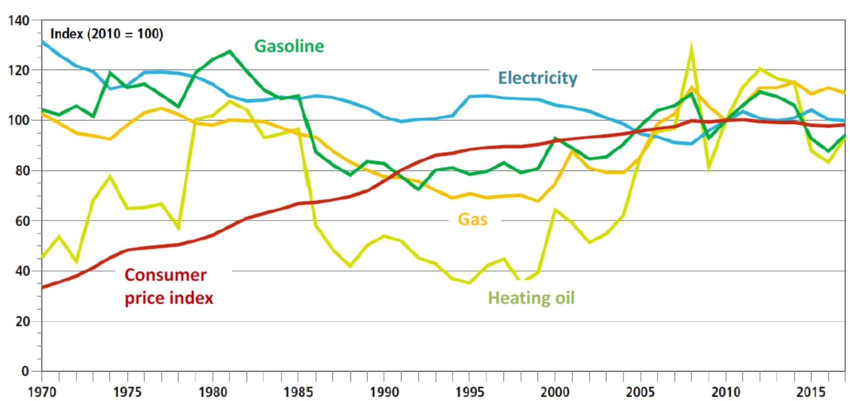

Figure 9 - Energy prices development in Switzerland from 1970 until 2017 (Source: BFE, 2017)

Switzerland has adopted and ratified the Energy Strategy 2050 (ES 2050), which is a set of measures to advance the country to a low-carbon economy. (IEA, 2018) The main strategic objectives of the ES 2050 are:

- Increase energy efficiency in buildings, mobility, industry and appliances;
- Increase the use of renewable energies by implementing its promotion and improving the regulatory framework;
- Replacement and new construction of large power stations for electricity production, with the gradual phase-out of nuclear power plants;
- Foreign energy policy. (BFE, 2018)

In terms of energy efficiency:

- Reduction of average per capita energy consumption of 16% by 2020 and 43% by 2035 in comparison to the level in 2000;
- Reduction of average per capita electricity consumption of 3% by 2020 and 13% by 2035 in comparison to the level in 2000. In comparison to the per capita energy consumption, the electricity consumption has lower reduction targets because of the increased electrification in the Swiss energy system. (BFE, 2018)

In terms of renewable energy:

- The target for average domestic production of renewable energy excluding hydropower is 4'400 GWh by 2020 and 11'400 GWh by 2035;
- Hydropower 37'400 GWh by 2035. (BFE, 2018)

Figure 10 shows the Swiss electricity production from renewable energies excluding hydropower from 2000 to 2017. The sharp increase in generation from PV plant can be immediately noticed.

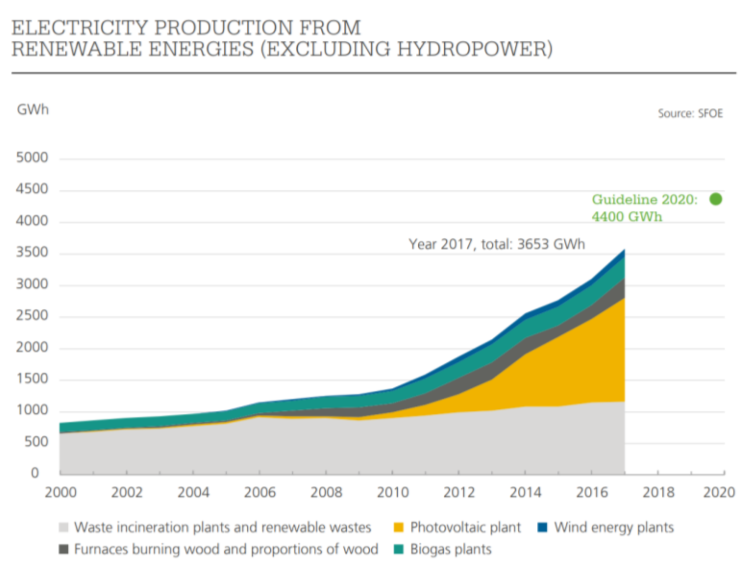

Figure 10 - Electricity production from renewable energies (Source: Monitoring report BFE, 2018)

3.2.2 Cantonal level

A set of energy directions known as MuKen[1] was jointly developed by the cantons of Switzerland. It includes several modules with instructions regarding e.g. insulation, electricity generation in existing and new buildings, renewable energy shares in buildings. Every canton can choose if the implementation of the MuKen is desired. Figure 11 shows the current rather low acceptance level of the different cantons towards MuKen.

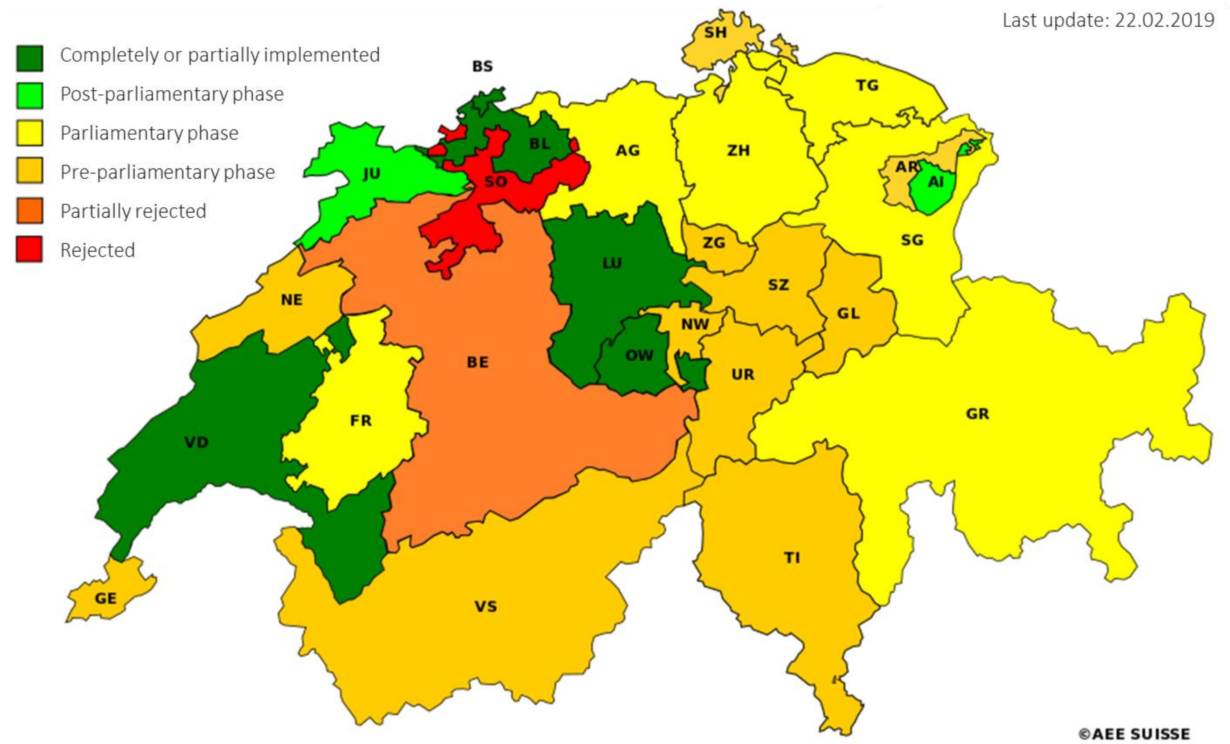

Figure 11 - Overview of cantons which decided to implement or reject the MuKen as well as cantons which are still on a decision-phase (Source: adapted from aeesuisse, n.d.)

Relevant for this study is that according to MuKEn 2014, new buildings ought to produce a share of their electricity demand locally. The capacity of the local electricity generation system is determined according to the respective energy consumption area of the building. The installed electricity generation system must at least generate 10 W/m^2 of energy consumption area of the building. If this condition is not met, a compensation of 1000 CHF per kW not installed must be paid to the canton. The building owner is not obliged to install an electricity generation system with a capacity larger than 30 kWp, since the maximum required capacity is 30 kWp irrelevant of the energy demand. In addition, buildings heating demand must be covered by at least 10% renewable energy. (EnDK, 2014)

[1] MuKen: Mustervorschriften der Kantone im Energiebereich

4 System

This chapter aims at providing information about the system being analysed. It includes delimitating the system and therefore analysing the current situation of the system. The technical system is then expanded. Afterwards, the regulatory framework including incentive plans and feed-in remuneration tariffs specific for the system is provided.

4.1 System delimitation

In 2011, the Siemens AG management board decided to start with the new project "Siemens Campus" in Zug. The construction phase started in May 2016. The first part of the new Siemens Campus was completed in July 2018. The investment amounted to 250 million Swiss Francs.

The international Head Quarters of Siemens Smart Infrastructure are based in the new campus in Zug. It consists of an office building hosting 1000 working spots, a production building and an existing Research & Development (R&D) building, which will be modernised between 2021 and 2022.

The concept for the new Siemens campus was to become a role model for future buildings in terms of sustainability. As a matter of fact, the campus pursued the Leadership in Energy and Environmental Design (LEED) certificate: the office building achieving "platinum" and the production building "gold". Both buildings have green rooftops. The campus is not relying on fossil fuels but rather on heat pumps and direct-cooling systems both using lake water. All HVAC systems are equipped with heat and cold recovery systems. The office building uses rainwater. A sustainable recycling concept for the whole campus was also introduced.

This study only analyses the production building due to the following reasons:

- Data availability for building load profiles;
- Complexity avoidance since parts of the office building are used by non-Siemens parties;
- The results of the study could be later used for similar cases involving production facilities.

Therefore, the system is delimitated around the production building itself.

4.1.1 Production building

The production building has the following characteristics:

- 3 floors plus basement;
- Floor area: 125 m x 50 m, therefore 6250 m^2;
- Building height: 16 m;
- Production only on ground and 1st floor;
- 2nd floor with 1000 m^2 available for renting (offices, vocational education, laboratory areas);
- Building integrated nitrogen tanks and waste containers;
- Automated transport and warehousing system for production;
- Air compression system with energy recovery for water heating.

Mainly Siemens Building Management System (BMS) products are being manufactured at the production building, e.g. fire detectors, heating controllers, valves and actuators.

The manufacturing process in the new production facility was initiated during summer 2018 gradually increasing production levels.

Figure 12 - Front picture of the new production building

Figure 13 shows the energy hub components of the production building. An energy hub is a way of displaying an energy system with inputs, outputs and internal components which can be energy converters or storage systems. (Bollinger, 2019)

The inputs of the system are lake water, solar radiation and grid electricity, whereas the outputs are heating, cooling and electricity demands. The energy converters are PV modules, heat pump and chiller and a battery is used as storage technology. As it can be seen, no fossil fuels are used in the system e.g. for heating. Lake water is directly used in the heat pump and in the chiller to provide heat and cold accordingly. Solar radiation is directly connected to PV, which consequently generates a portion of the electricity demand or can be fed back into the grid for different use cases. Most of the electricity needed in the system is supplied from the grid. Part of the electricity can be stored in the battery.

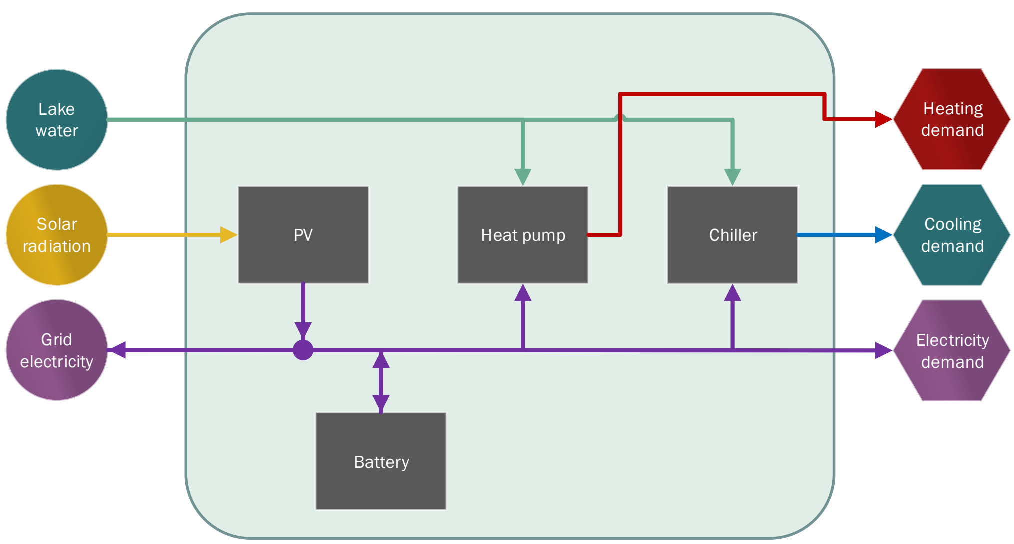

Figure 13 - Energy hub of the production building

4.1.1.1 Load profile

The load profile from 1st April 2018 until 9th April 2019 was provided from the energy utility company of Zug, WWZ (*Wasserwerke Zug*). The data provided from WWZ is from the metering device at the main transformer station supplying the production building. There are four additional transformers in the production building itself: the data from the according meters was however not available at this moment in time. Therefore, it was not possible to further analyse the load of the specific machines and devices inside of the production building.

Starting from the 19th April 2018, WWZ started supplying the building with electricity which was used mainly for construction work of the building itself. From August 2018 the production started ramping up gradually until it reached a regular pattern in November 2018. (See Figure 14) It can be seen that there is a sudden reduction in the electricity supply in late December 2018: this was due to Christmas holidays when there was no production.

In Figure 14 it can be seen that there is a constant baseload of 200 kW or more. After consulting the production manager of the facility, it was possible to identify the following drivers for the constant baseload:

- Lighting on 24/7;
- Automated Transport System (ATS) running during the night;
- Heat pumps for maintaining a certain temperature in the building.

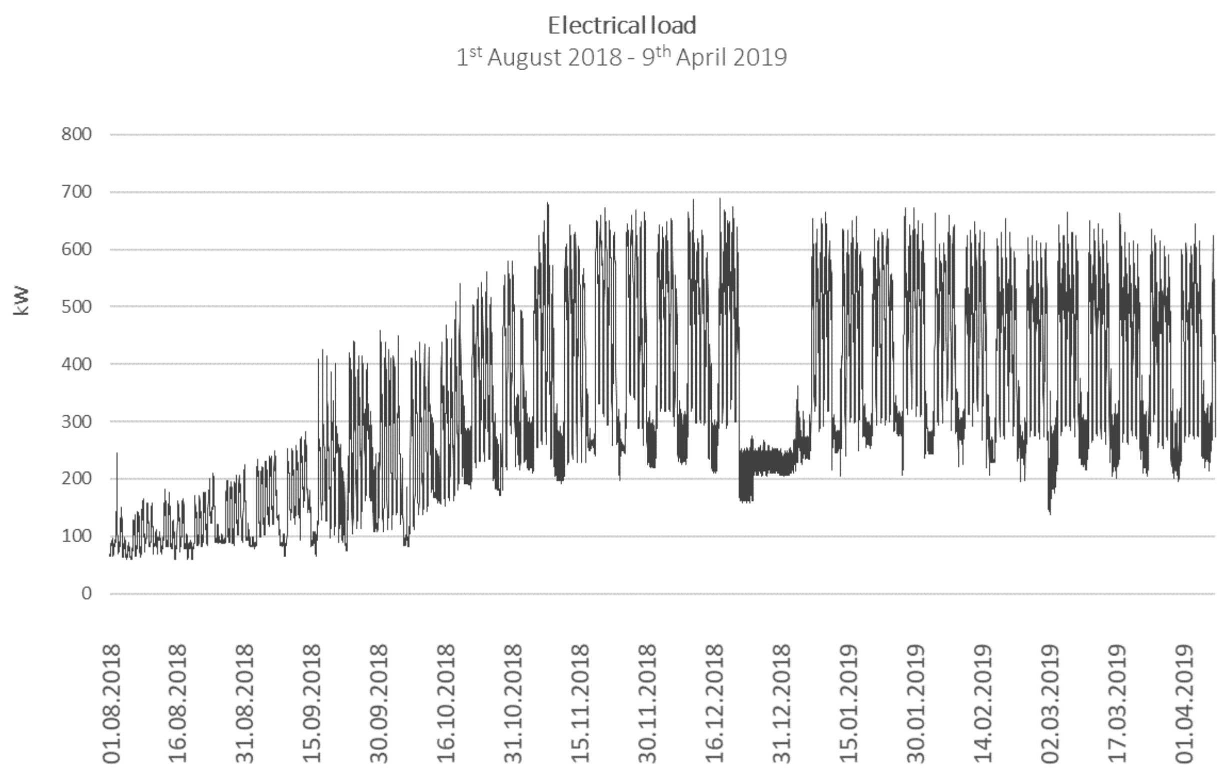

Figure 14 - Load profile of the production building from 01/08/2018 until 09/04/2019 (Source of data: WWZ)

Some of the critical components in the manufacturing process are the followings:

- Soldering furnaces and reflow ovens essential for the manufacture of electrical components;
- Air compressors used in the entire process;
- Automated Transport System (ATS).

Figure 15 shows a zoom-in in a typical week profile with 15-minutes measurements. The week from 12th November until 19th November 2018 was taken as a reference.

Until April 2019 two week shifts plus a partial Saturday shift were adopted. In the figure it can be seen that the building load starts increasing in the morning before the morning shift starts: this is due to the soldering ovens, which need to reach a certain temperature for operation and need to be ready when the production starts.

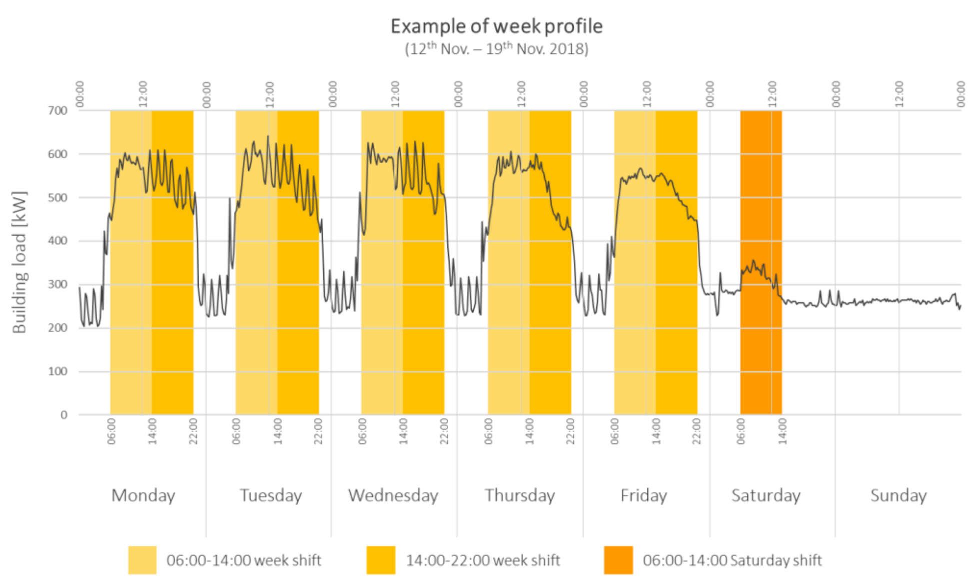

Figure 15 – Example of week profile with two week shifts and Saturday shift; the load curve belongs to the week from 12th November until 19th November 2018 and shows 15-minutes measurements; (Source of data: WWZ)

4.1.1.2 Extrapolation of yearly building load profile

The building load profile from WWZ can be taken as a reference for the analysis only from November until start of April. An extrapolation of the building load profile to a whole year is needed.

The first step was the comparison with the outside temperature profile for the given months. The data was collected from Agrometeo.ch. The outside air temperature and the building load profile do not show a strong correlation and therefore the extrapolation does not take outside air temperature into account.

Due to the recent construction, the production building is still in a transition phase. Some changes in the production and additional loads might affect the final building load.

According to the production manager of the facility, those changes will or might already have occurred:

- Approximately from the start of May 2019 the production schedule changed from two shifts plus Saturday (as shown in Figure 15) to three shifts without Saturday;
- A testing laboratory will be added to the current production building, which will strongly affect the consumption base load;
- Production levels are not constant throughout the year and they cannot be estimated accurately since they depend on external factors.

Based on these pieces of information, the load profile was extrapolated as follows:

- A typical week profile was selected: first, it was compared to other weeks e.g. in January and in April and afterwards adapted to better match them;
- The production schedule was changed from two to three shifts, taking the partial Saturday shift as a reference for the night shift;
- The new testing laboratory was neglected for the extrapolation due to lack of information about the size of the machines and their operation pattern throughout the week;
- Production fluctuations were not considered since those depend on several external factors such as financial shifts or past overproduction with following overabundant amount of products in stock;
- Holidays and long weekends were considered in the yearly profile.

Figure 16 shows the week profile used for the yearly extrapolation. The weekly consumption amounts to 65'786 kWh which is in the range of the real data from November 2018 to April 2019.

The yearly electrical consumption of the building based on real and extrapolated data is 3'375 MWh.

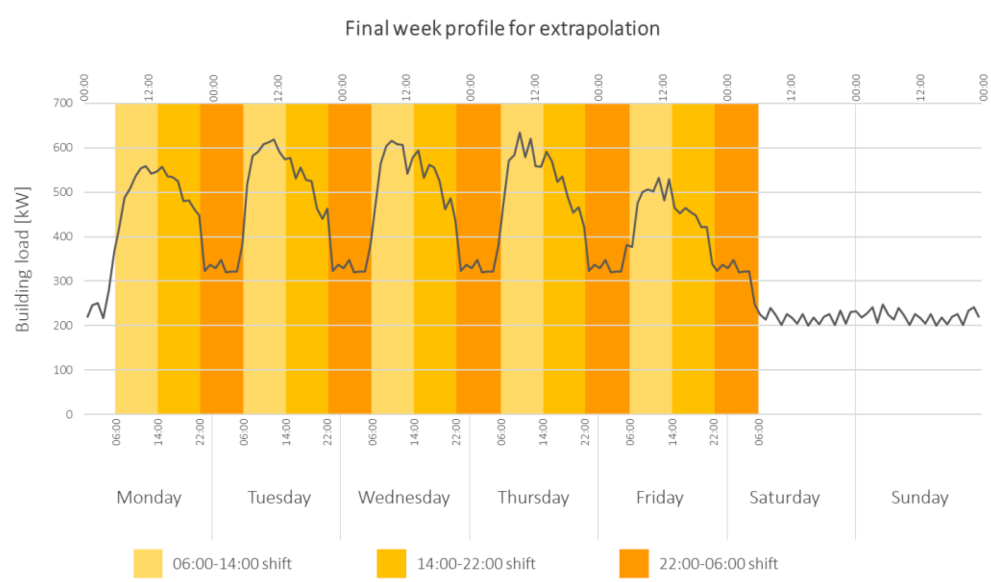

Figure 16 - Final hourly week profile used for yearly extrapolation of missing months

4.1.2 Installed PV and battery system

During the planning phase of the new campus several options were considered for the PV and battery system. The final decision was to install a 25 kWp PV system and 150 kWh/36 kW battery.

Two main reasons influenced the decision for the installation of such a rather small system:

- Upfront high investment costs;
- LEED[2] certification points, which favoured a green rooftop instead of a larger solar energy system.

4.2 System expansion

As mentioned in the previous chapter, the existing system is rather small and cannot be used for a comparison to the building load of the production facility. Therefore, an expansion of the PV system to the whole roof and an evaluation of a possible resizing of the battery is needed.

4.2.1 PV

The PV system was expanded to the whole roof using AutoCAD. Shading and roof components were taken into consideration.

The PV system analysed in this study is a 221 kWp system extended to the whole roof of the production building. The total electrical generation for a whole year based on the simulation from PV Syst amounts to 223 MWh. In comparison to the production building load, the PV system can generate up to 11%[3] of the building load. Figure 17 shows the a comparison of one week between building load, electricity generation from 221 kWp PV system and their difference as delta.

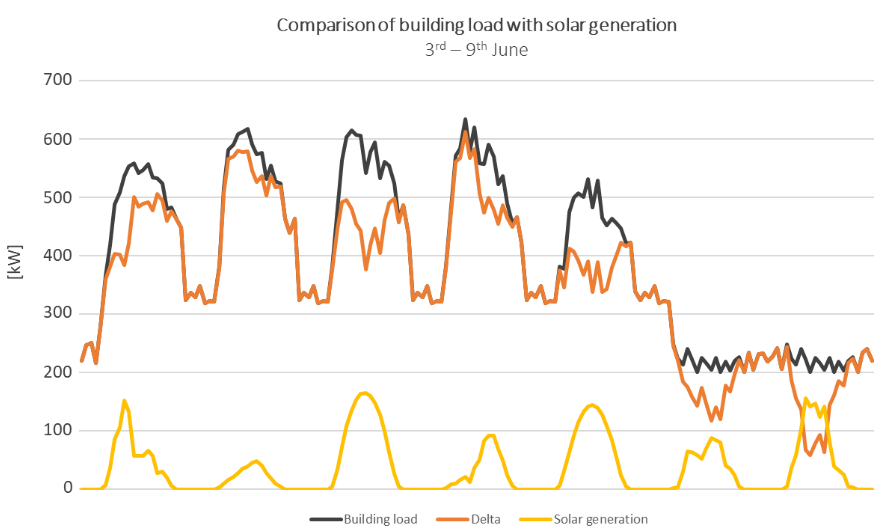

Figure 17 – Comparison of building load and solar generation with the 221 kWp PV system.

[2] LEED: Leadership in Energy and Environmental Design is one of the worldwide leading green building certification programmes.
[3] The PV system can cover 11% of the building load in the month of June.

4.2.2 Battery

The battery's sizing was approached mainly for the peak shaving scenarios. First, the peaks reduction goals were selected: on one hand considering direct consumption and on the other hand considering 100% feed-in to the main grid, since power peaks are different for the two cases. Afterwards, the difference between every hourly consumption value and peak was calculated, to determine when higher peaks occurred. In the end, the sum of that difference for each day was calculated in order to determine the needed daily battery capacity.

The power sizing was also approached by selecting first some peak reduction goals. Afterwards, the difference between the hourly consumption value and the peak reduction goal was calculated in order to determine the maximum hourly power needed to cover certain peaks.

The selection of the sizes for different battery scenarios is the following:

- 150 kWh / 36 kW, equal to the existing battery;
- 225 kWh / 80 KW;
- 375 kWh / 120 kW.

4.3 Specific regulatory framework for the system

4.3.1 Electricity prices for the production building

WWZ, the energy utility company supplying the production building with electricity, offers three different electricity products for large consumers depending on their consumption profile. The different products with the according electricity consumption profiles are shown in Figure 18.

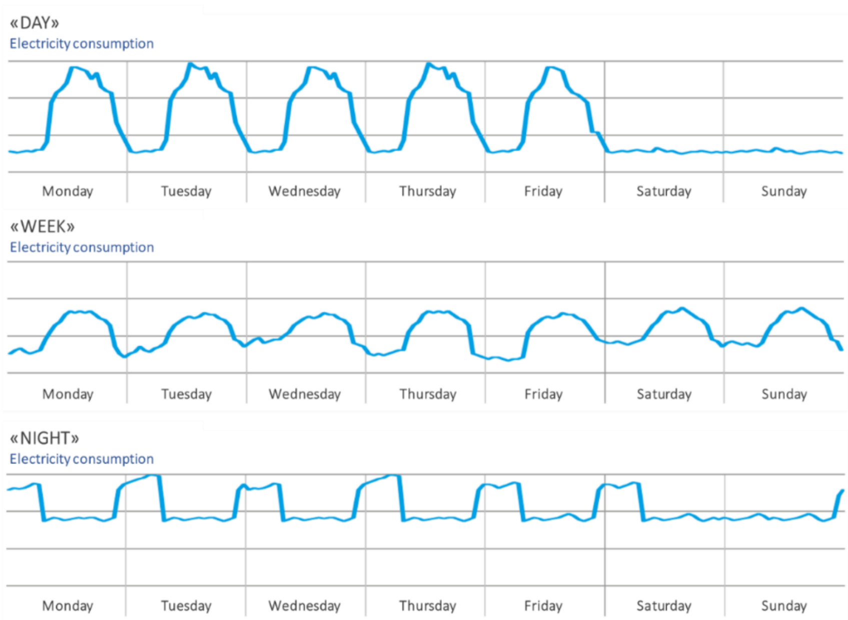

Figure 18 - Comparison of different electricity products for large consumers (Source: adapted from WWZ)

Table 1 shows the different electricity products in more detail. The product considered for this study is "Day", since the production building experiences higher consumption during weekdays. The product is beneficial also considering the power tariffs, which is optimised to reduce peak power costs.

Table 1 - Overview of different electricity products based on customer segment, advantages, requirements, price elements and tariff periods. (Source: WWZ)

	"Day"	"Week"	"Night"
Customer segment	Consumers with high electricity consumption during week days	Consumers with a 24/7 electricity consumption evenly distributed during the whole week	Consumers with a high electricity consumption during the night
Advantage	Convenient power tariff for consumption peaks during the week	Low tariff for the whole weekend	Convenient tariff during the night
Requirements	- Electricity consumption ≥ 100 MWh	- Electricity consumption ≥ 100 MWh - Remote meter reading	- Electricity consumption ≥ 100 MWh
Price elements	- Power tariff[4] [CHF/kW per month] - Working tariff[5] – High [Rp./kWh] - Working tariff – Low [Rp./kWh]	- Power tariff [CHF/kW per month] - Working tariff – High [Rp./kWh] Working tariff – Low [Rp./kWh]	- Power tariff [CHF/kW per month] - Working tariff – High [Rp./kWh] Working tariff – Low [Rp./kWh]
Tariff periods	- High tariff: 7:00-22:00 - Low tariff: 22:00-7:00 (Sunday continuously)	Monday until Friday - High tariff: 7:00-22:00 - Low tariff: 22:00-7:00 Weekend - Low tariff: Friday 22:00 until Monday 7:00	- High tariff: 7:00-22:00 Low tariff: 22:00-7:00 (Sunday continuously)

Pricing model

[4] Power tariff: price per kW per month for the monthly power peaks (15 minutes measurements)
[5] Working tariff: Price per kWh for the consumed electricity

The electricity product depends on the usage period, which is differentiated into “Low”, “Mid” and “High” as shown in

Table 2. The usage period for the production building analysed in this study is in the “High” range.

Table 2 - Usage period hours (Source: adapted from WWZ)

	Low	Mid	High
Usage period[6]	0-2800 h	2800 – 4200 h	4200 – 8760 h

As mentioned before, there are three main different electricity products for large consumers. The specific tariffs are listed accordingly in Table 3. The final electricity product and tariffs used for the analysis are “Day” and “High.500”. From a first glance, it can be seen that the power tariff is rather low.

Table 3 - Different electricity products for large consumers (Source: adapted from WWZ)

	“Day”	“Week”	“Night”
Low.500			
Power tariff per month [CHF/kW]	0.90	6.10	4.85
Working tariff - High [Rp./kWh]	6.05	5.90	8.35
Working tariff – Low [Rp./kWh]	4.20	3.45	3.45
Mid.500			
Power tariff per month [CHF/kW]	0.85	6.05	4.85
Working tariff - High [Rp./kWh]	6.00	5.80	8.20
Working tariff – Low [Rp./kWh]	4.05	3.30	3.15
High.500			
Power tariff per month [CHF/kW]	0.85	6.00	4.85
Working tariff - High [Rp./kWh]	5.90	6.35	8.10
Working tariff – Low [Rp./kWh]	3.90	3.10	3.00

[6] Usage period [h] = $\frac{Yearly\ supplied\ electricity\ [kWh]}{Maximum\ yearly\ power\ peak\ [kW]}$

4.3.2 Incentive plans and feed-in remuneration

The following figure provides an overview of the available incentive and remuneration plans on different levels as well as from energy utility companies. The boxes with a green outline show the programmes, which are relevant for this study.

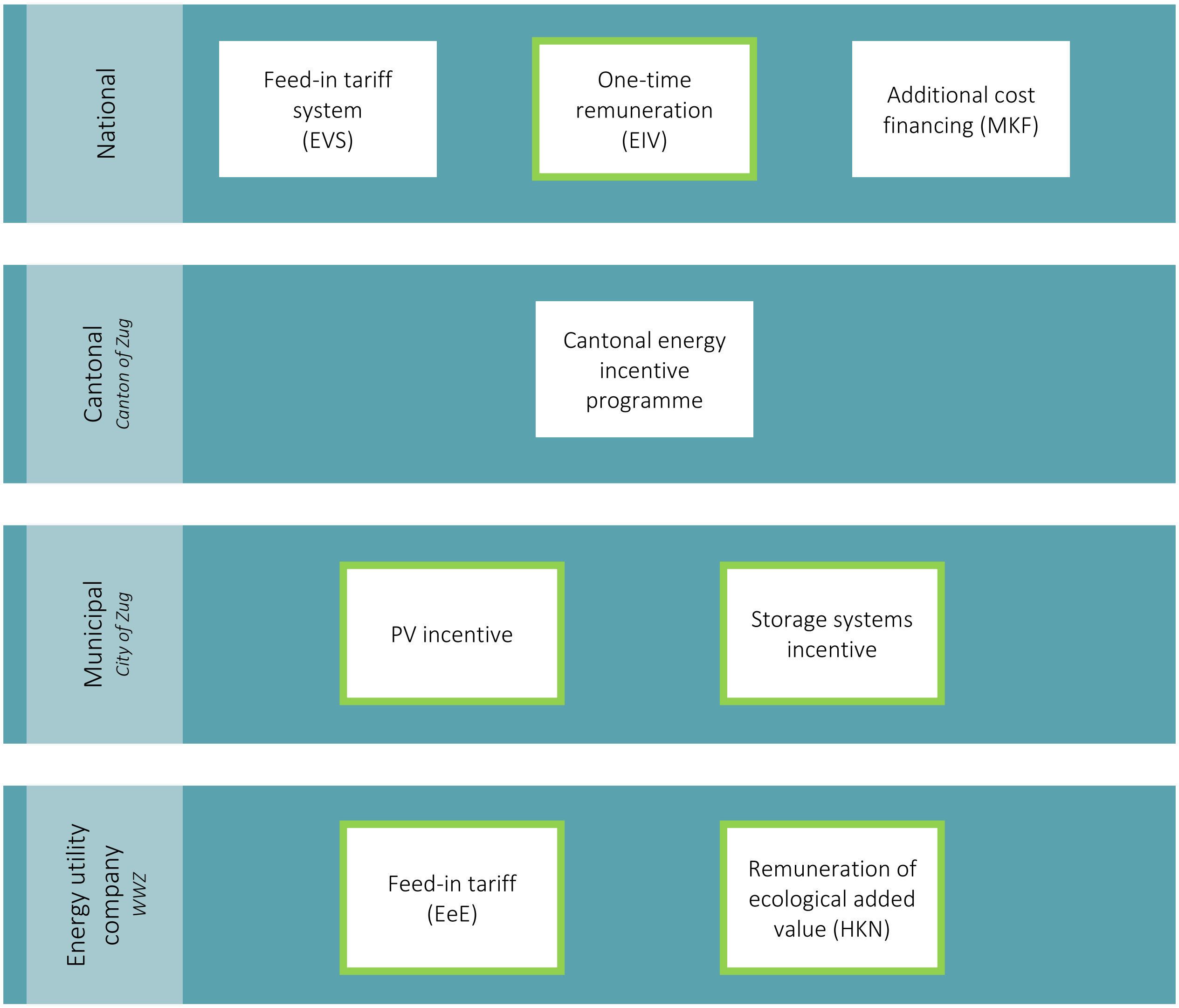

Figure 19 - Overview of incentive programmes on a national, cantonal and municipal level as well as feed-in remuneration from energy utility companies

4.3.2.1 National level

According to the new Energy act, one of the goals of the Energy Strategy 2050 is to promote renewable energy systems. Some of the methods to reach those is through incentive programmes.

Feed-in tariff system (EVS)

The first incentive programme for renewable energies is the feed-in tariff system, also known as *Einspeisevergütungssystem* (EVS). It applies for the following technologies:

- Hydropower from 1 MW to 10 MW;
- Photovoltaics from 100 kWp;
- Wind power;
- Biomass;
- Geothermal power.

The duration period of this incentive programme is 15 years, except biomass with 20 years. (Pronovo, 2019b)

EVS cannot be taken into consideration for this study since only PV systems which applied before the 20th of June 2012 can receive the feed-in tariff incentive. According to Pronovo, the expected feed-in tariff applicable for a 220 kWp would be 10 Rp./kWh.

One-time remuneration (EIV)

The one-time remuneration provides an incentive for approximately 30% of the investment costs of a PV plant. It is differentiated between:

- One-time remuneration for PV plants with less than 100 kWp (KLEIV) which are already in operation;
- One-time remuneration for PV plants with more than 100 kWp (GREIV) up to 50 MWp;

PV plants operators can decide between either applying for the feed-in tariff system or for the GREIV. The current waiting list for the GREIV is 2-3 years, whereas for KLEIV it is 1.5 years. PV plants with more than 100 kWp can willingly apply for the KLEIV in order to avoid a longer waiting time.

For the analysed 220 kWp PV system, the GREIV one-time remuneration would amount to CHF 68’900.-. If the plant operator was to apply for the KLEIV instead, the one-time remuneration would amount to CHF 32’600.-. (Pronovo, 2019a)

Additional cost financing (MKF)

The additional cost financing programme, also known as *Mehrkostenfinanzierung* (MKF), is the forerunner incentive programme for renewable energy systems in Switzerland. The system operators participating in this programme are guaranteed a remuneration of approximately 15-16 Rp./kWh.

However, MKF cannot be taken into consideration for this study since the incentive programme does not accept new power plants to the system. (Pronovo, 2019d)

4.3.2.2 Cantonal level

Cantonal energy incentive programme

The energy incentive programme of the Canton of Zug is also known as “Building programme”, since it mostly focuses on the energy efficiency increase of buildings by offering incentives for renovations according to GEAK and Minergie standards. This incentive programme is not relevant for this study.

4.3.2.3 Municipal level

The different municipalities in the Canton of Zug also offer incentive programmes. Interesting for this study is the energy incentive programme offered from the City of Zug.

PV incentive

The city of Zug supports hybrid PV collectors' operators with a nominal power of at least 1 kWp and PV systems which are not taking part to the EVS, added to the one-time remuneration (KLEIV or GREIV).

The incentive amounts to maximum 10% of planning, installation and construction costs up to a maximum of CHF 30'000.- per plant. (Stadtzug, 2019)

Storage systems

The city of Zug also supports the installation of storage systems in combination with PV plants in order to optimise the self-consumption. The minimum capacity is 6 kWh.

The incentive amounts to maximum 30% of planning, installation and construction costs up to a maximum of CHF 30'000.- per object. (Stadtzug, 2019)

4.3.2.4 Energy utility company

Energy utility companies are responsible for the remuneration of the supplied electricity to the grid. This is not part of the national feed-in tariff system (EVS).

There are two components adding up to the whole remuneration:

- Electricity remuneration;
- Ecological added value remuneration.

The main focus for this study will be on the energy utility company in Zug WWZ.

Feed-in tariff

The supplied electricity to the grid from any type of power plant, also known as *Einspeisung elektrischer Energie* (EeE), is remunerated directly from the energy utility company.

In the case of WWZ, a maximum nominal power of up to 10 MW is accepted.

There are two tariffs as displayed in Table 4:

- High tariff, 07:00-22:00 Monday to Saturday;
- Low tariff, 22:00-07:00 Monday to Saturday, 00:00-24:00 Sunday

Table 4 - Electricity feed-in tariff from WWZ (Source: WWZ)

	Excl. VAT	Incl. VAT
High tariff [Rp./kWh]	7.85	8.45
Low tariff [Rp./kWh]	4.60	4.95

Remuneration of ecological added value (HKN)

In order to reach a high transparency on the origin of electricity, the "Certificates of Origin" system, also known as *Herkunftsnachweise* (HKN), was introduced.

For every generated kWh, a certificate of origin is created. However, the HKN is decoupled from the physical electricity flow and the HKN is traded as an independent certificate.

For some utility companies, a remuneration of ecological added value is added to the energy feed-in tariff. When feeding in electricity from renewable energy power plants e.g. a photovoltaic plant is feed into the main grid, the utility company can use it in the HKN system by selling electricity to the end-consumer with a label on the electricity.

WWZ provides a remuneration of ecological added value to renewable energy systems operators which feed-in electricity to the main grid. This is added to the electricity feed-in tariff explained in the section before.

Table 5 - WWZ remuneration of ecological added value for different types of renewable energy power plants (Source: WWZ)

	Excl. VAT	Incl. VAT
Biomass [Rp./kWh]	5	5.39
Solar [Rp./kWh]	5	5.39
Hydro [Rp./kWh]	0.5	0.54
Wind [Rp./kWh]	5	5.39

A requirement to receive the ecological added value remuneration is the registration of the power plant in the Swissgrid HKN system as well as the signing of a HKN standing order for the purpose of transferring the certificates automatically to the WWZ account. The HKN standing order form can be found in the appendix.

The steps for the registration of the plant in the HKN system are shown below.

- Registration of the power plant
  The plant can be registered in the Pronovo website;
  There are different possible user accounts in the system:
  - plant operator;
  - electricity supplier;
  - trader;
  - auditor;
  - service provider;
  - energy utility company.
- Registration of power plant data
  In case of an installed power capacity < 30 kVa, a verification of the registered data through the

utility company is needed. For a power capacity > 30 kVa, an accredited auditor is responsible for the verification.

- **Collection of generation data and issuing of certificates of origin**
  The generation data can be collected through network operators or auditors. The certificates are issued monthly, quarterly or yearly.
- **Transfer of certificates**
  Certificates can be traded, e.g. from a plant operator to a trader, from a trader to another trader or from a trader to an electricity supplier. There are two main online steps for the transfer of certificates:
  - Market participant A must provide the certificate which he/she would like to sell to market participant B;
  - If market participant B agrees, he/she acquires the provided certificate which is not available for market participant A anymore.
  Certificates can be traded internationally only from a trader account.
- **Standing order creation for the transfer of certificates**
  Certificates can be transferred online through the plant operator or trader account with a standing order.
- **Voiding certificates**
  A voiding process is necessary in order to avoid double payments and it can be commissioned to a trader or electricity supplier account. (Pronovo, 2019c)

5 Use cases

This chapter provides an overview of the possible use cases to be later analysed.

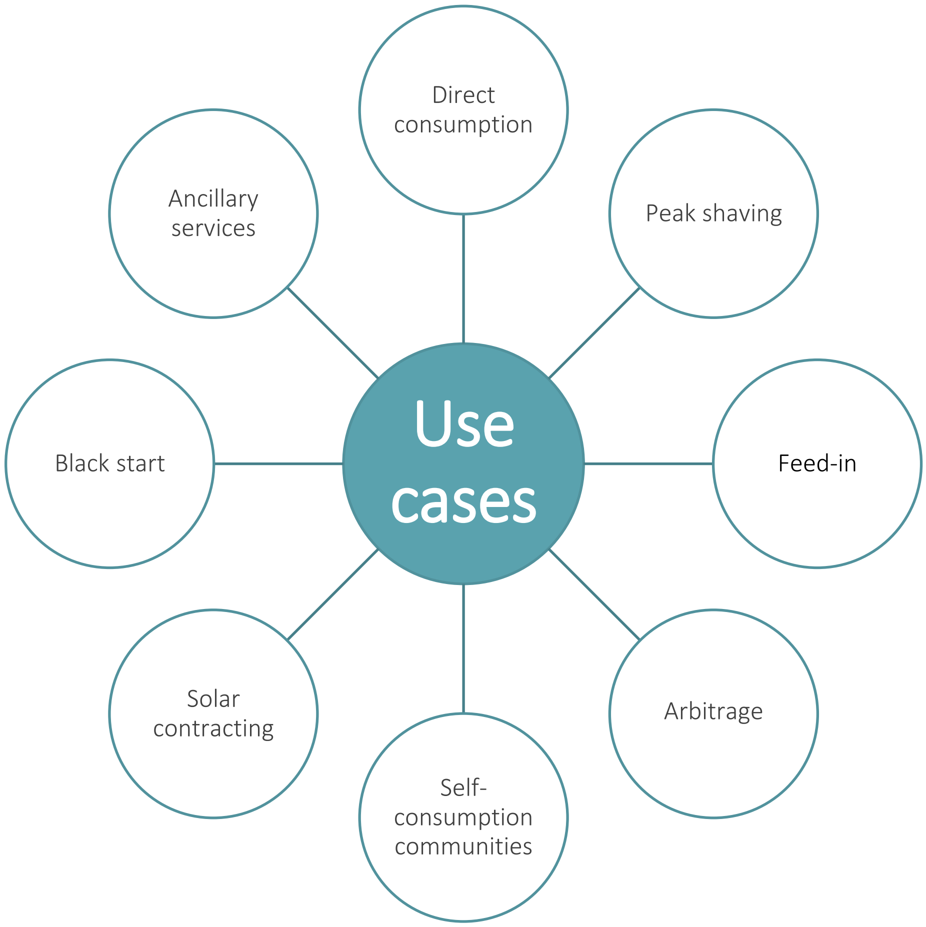

Figure 20 - Overview of use cases to be analysed

5.1 Direct consumption

As seen in the precedent chapter regarding the electricity generated from the PV system, the electrical load of the building is much higher than the PV generated electricity. Nevertheless, this chapter shows the savings if the generated electricity was to be directly used on site and therefore lowering the amount of supplied electricity from the utility company.

The PV modules produce electricity during the day which also corresponds to the time when the electricity price is at a high tariff. This obviously affects the total amount of the electricity bill. Additionally, according to the simulations, some peaks in the electrical consumption and peaks in PV generation occur simultaneously, which can partially decrease power peaks and therefore reducing the power costs. However, since the PV generation and electrical consumption profiles can strongly vary from the simulation profiles, the savings from the power costs can be rather considered as a coincidence.

5.2 Peak shaving

High power peaks can strongly affect grid stability. Therefore, utility companies are usually charging industrial and commercial consumer with a power tariff for occurring power peaks.

Power costs are usually calculated by taking the 15-minute power peak occurring during a month, which is then multiplied with the according power tariff for the monthly electricity bill. In case of a quarterly electricity bill, the average of the three power peaks occurring during three months is taken and afterwards multiplied with the power tariff.

Power tariffs can highly differ from one utility company to another. As a matter of fact, the power tariff applied to large consumers from WWZ is extremely low in comparison to some other Swiss utility companies. The very low power tariff is a consequence of the electricity product applied for the production building, which is already optimised to avoid high power costs. This is shown in Table 6.

Table 6 - Power tariffs for different Swiss utility companies

	Power tariff [CHF/kW][7]
EWZ [8]	10
CKW[9]	7.50
SES[10]	6.50

The low power tariff for the analysed case highly affects the savings if a battery was to be used for peak shaving.

Table 7 shows the peaks reduction by first consuming the PV generated electricity directly on site and applying peak shaving with a 150 kWh / 36 kW battery, equal to the existing one. It can be seen, that except for November when atypical high peaks and energy consumption occur, all months reduce power peaks smaller than 590 kW by utilising the existing battery.

An internal Siemens calculation tool for rate analysis was used to determine the power peak reductions by using the other larger batteries. For the 225 kWh / 80 kW battery, a power reduction target of 50 kW can be achieved. For the 375 kWh / 120 kW battery, 65 kW reduction is the target.

[7] All tariffs do not include VAT
[8] EWZ: Elektrizitätswerk der Stadt Zürich
[9] CKW: Centralschweizerische Kraftwerke
[10] SES: Società Elettrica Sopracenerina

Table 7 - Power peaks in kW for baseline, direct consumption and direct consumption with peak shaving by using a 150 kWh / 36 kW battery

Month	Baseline power peaks [kW]	DC power peaks [kW]	DC+PS 150/36 [kW]
January	616	609	573
February	620	620	584
March	614	614	578
April	634	606	570
May	634	589	553
June	634	613	577
July	634	625	589
August	634	584	548
September	634	618	582
October	634	621	585
November	661	648	612
December	637	614	578

5.3 Feed-in

Usually, feed-in tariffs including HKN are lower than electricity tariffs.

There are currently only two municipalities were the total feed-in tariff is higher than the price for the supplied electricity for large consumers and those are shown in the table below.

Table 8 - Municipalities with feed-in tariff higher than supplied electricity tariff. All values are in Rp./kWh. (Source: feed-in tariffs VESE, 2019, *supplied electricity prices* ElCom, 2019)

	Categories		Feed-in		
	C6[11]	C7[12]	Feed-in electricity	HKN	Total
Grabs	8.65	8.14	5	4	9
Matzingen	9.48	9.25	4	8	12

WWZ has currently one of the highest feed-in tariffs across Switzerland. However, the feed in tariff is slightly lower than the supplied electricity tariff for the production building category.

[11] C6: Electric consumption of 1'500'000 kWh/year.
[12] C7: Electric consumption of 7'500'000 kWh/year.

5.4 Arbitrage

Arbitrage in the electricity market is defined as the purchase of electricity when electricity prices on the market are low and reselling it when prices are high. This service is profitable only when the spread η between peak price and valley price is sustainably high. This can be different from one energy utility company to the other. (HSLU, 2018)

$$\eta = \frac{Valley\ price}{peak\ price}$$

For this study, the high and low tariffs for large consumers of WWZ will be used in the simulation.

5.5 Self-consumption communities

A Self-Consumption Community (SCC), also known as ZEV[13], is defined as a system composed of prosumers and consumers connected to each other with the goal of reaching a high self-consumption within the system. When referring to SCCs in this study, only systems with PV and or without electrical storage technologies are considered.

The term "self-consumption" was introduced first in the Energy law in 2014. Starting from 1st January 2018, SCCs are allowed and officially regulated by law. One of the main restrictions in the formation of a SCC is that the main grid from the grid operator cannot be used. For the community, there is only one connection point to the main grid which serves as a metering point for the utility company to supply the needed electricity and also for the community to feed-in the excess electricity back to the grid.

The so-called prosumers are the owners of the PV system. In certain cases from the prosumers side, only a low self-consumption can be achieved and therefore some of the PV generated electricity is fed into the grid. As discussed in the "Feed-in" chapter (5.3), the feed-in tariff is usually lower that the electricity price, which makes it more beneficial to consume the generated electricity directly on site.

Consumers in a SCC are building owners or tenants interested in reducing electricity costs and on the same time increasing the share of consumed electricity coming from renewable sources.

The connection between prosumers and consumers leads to a higher self-consumption rate when excess electricity is distributed among the SCC participants.

Figure 21 shows an example of a SCC within a building. The generated PV electricity is measured from the generation meter. Every tenant needs to be in possession of a consumption meter. An interconnection meter within SCC and main grid is needed. This connection point measures fed-in and supplied electricity.

[13] ZEV: Zusammenschluss zum Eigenverbrauch

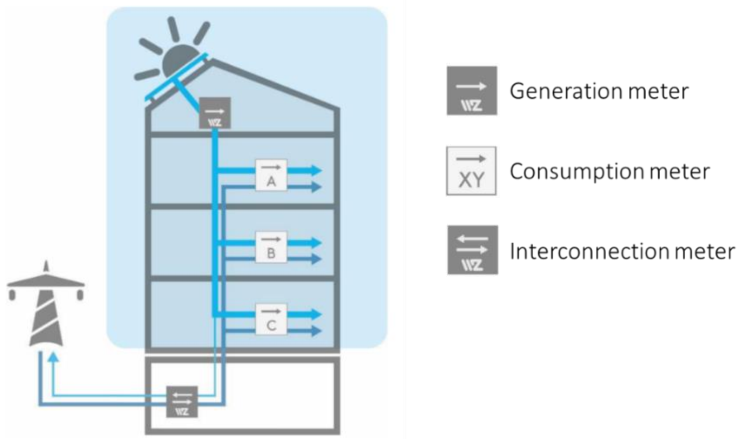

Figure 21 - SCC within a building with different tenants all participating in the SCC (Source: adapted from WWZ)

The new self-consumption guidelines published in April 2019 introduced major changes to the previous regulation regarding SCC, such as the possibility of forming a SCC across a street or a river as long as the land-owner is part of the community or agrees to it. An example is shown in Figure 22. (Energie Schweiz, 2019)

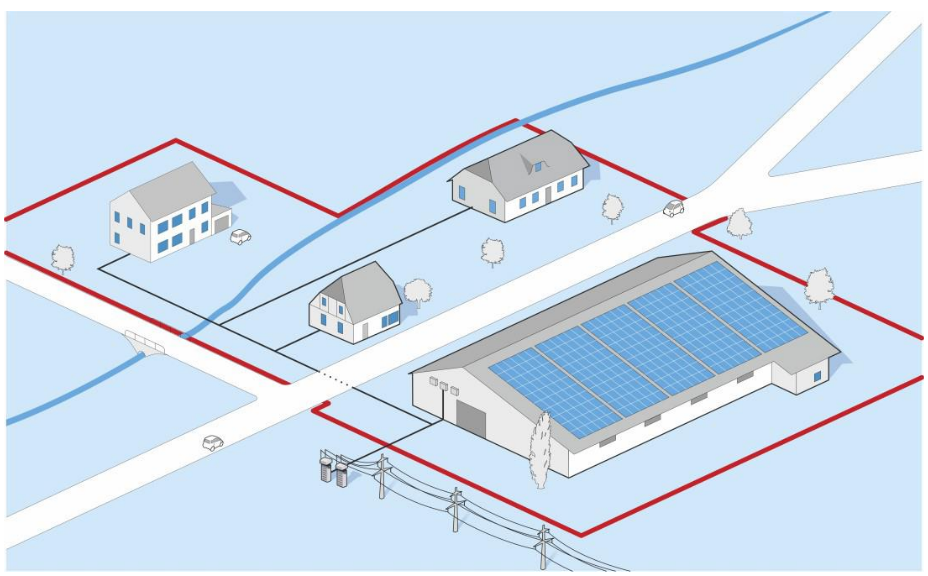

Figure 22 - Example of a SCC connected across a road: this is possible according to the new guidelines for self-consumption. (Source: Energie Schweiz)

According to ElCom[14], the Federal Commission for Electricity, the total electricity price for households ranges between 13 and 21.5 Rp./kWh depending on the category. Table 9 shows the different electricity tariffs applied to different types of consumers in the Canton of Zug.

[14] ElCom: Eidgenössische Elektrizitätskommission

Table 9 - Overview of total electricity prices for different types of households depending on yearly consumption, type and electric appliances (Source: ElCom)

Category	Yearly consumption [kWh/year]	Type	Electricity price [Rp./kWh]
H1	1’600	2-room apartment with electric stove	**21.52**
H2	2’500	4-room apartment with electric stove	**20.53**
H3	4’500	4-room apartment with electric stove and electric boiler	**16.70**
H4	4’500	5-room apartment with electric stove and tumble dryer	**18.93**
H5	7’500	5-room single-family house with electric stove, electric boiler and tumble dryer	16.18
H6	25’500	5-room single-family house with electric stove, electric boiler, tumble dryer and electric resistance heating	13.11
H7	13’000	5-room single-family house with electric stove, electric boiler, tumble dryer and 5 kW heat pump for heating	15.25
H8	7’500	Large, highly electrified apartment	**18.19**

Several apartment buildings are present in the neighbourhood of the new Siemens campus.

Potentially, a SCC could be formed by considering the following:

- Selling 100% of the generated PV electricity to the neighbours through a SCC contract. Self-consumption directly at the building cannot be considered since the whole generated PV electricity could be consumed directly in the production building without having excess electricity to be sold to the neighbours;
- The scenario of buying electricity from other SCC parties is not considered since it would be rather infeasible to achieve an internal tariff lower than the electricity price applied to the production building;
- There are no single-family houses in the direct neighbourhood of the building, therefore only apartment buildings and their according electricity price range are considered.

In order to calculate potential revenue streams for a SCC scenario, two tenants electricity prices – 16 Rp./kWh and 21 Rp./kWh - were selected and the SCC internal electricity tariff was calculated as it is displayed in Figure 23. The external electricity price for tenants and the PV system’s Levelised Cost of Electricity[15] (LCOE) – 9.6 Rp./kWh - plus administrative costs – 2 Rp./kWh - are taken as a reference for the calculation. The LCOE and administrative costs are deducted from the external electricity price for tenants.

[15] The Levelised Cost of Electricity (LCOE) represents the minimum electricity price that should be charged in order to break-even. This way, capital and maintenance costs can be covered.

The result is then divided by two and is equal to the revenue of the PV owner and to the reduction for the tenants.
The SCC administrative costs depend on the yearly electric consumption in the community – excluding the consumption for the production building in this case – and on the number of households participating in the SCC. The electric community consumption taken for the calculation is 350'000 kWh which is equivalent to approximately 100 households. By taking the fees of EVG-Zentrum[16], the final administrative costs are equal to 2 Rp./kWh.

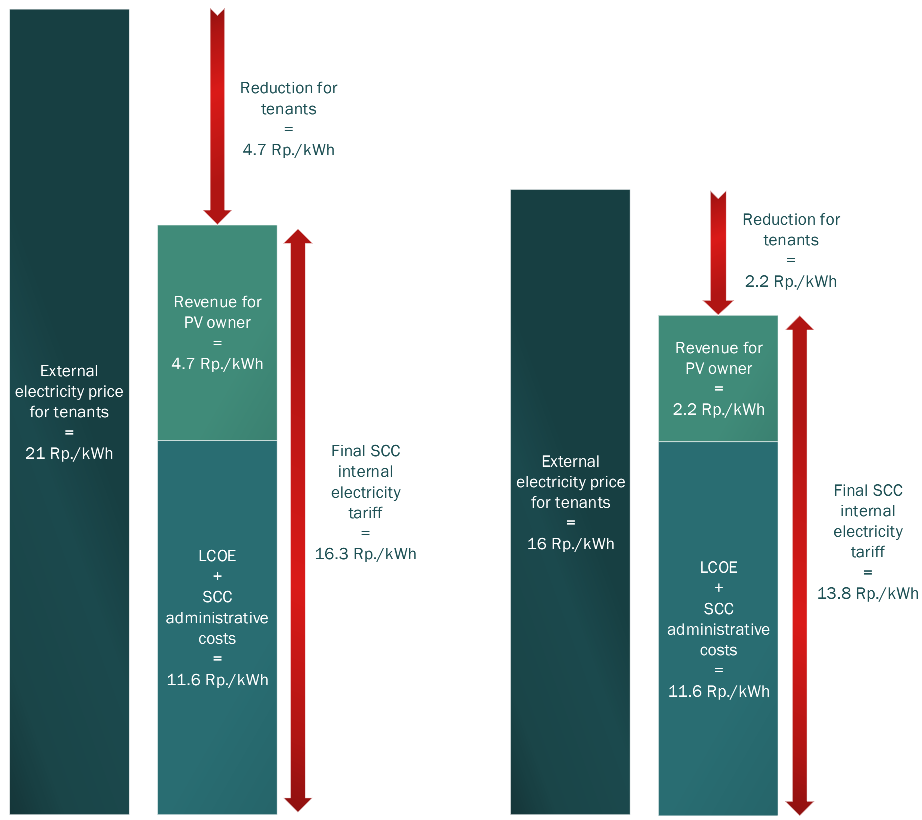

Figure 23 - SCC internal electricity tariff structure for two different external electricity prices for tenants

5.6 Solar contracting

Solar contracting can be an interesting option when upfront investment costs for a PV system can hinder its commissioning. The investment costs are covered directly from the service provider, who builds the PV system on the roof of the building owner. The price for the solar electricity is fixed over a certain amount of time, which can be the lifetime of the PV system.

Solar contracting providers can be energy utility companies or engineering firms. An example can be seen with the solar contracting service offered from CKW, the main energy utility company in central Switzerland. In order to set up a solar contracting arrangement, the built PV system's size must be at least 100 KWp, which requires a certain rooftop area. The goal of the service is to consume 100% of the PV

[16] EVG-Zentrum is an engineering firm offering services for SCCs. The service fees are the following: 900 CHF/year base fee + 5 CHF/month per meter.

generated electricity on site and feeding-in a minimum amount of the electricity back into the grid. (Castelanelli, 2019)

For some cases such as AEW, the energy utility company of Aarau, the building's rooftop is rented to the utility company. Therefore, the building owner receives a remuneration for the rooftop's utilisation. (AEW, n.d.)

5.6.1 Example of a solar contracting project - CRH Swiss Distribution

CRH Swiss Distribution is a company selling and distributing building materials and instruments. The company is part of the CRH group with headquarters in Dublin, Ireland.

The Swiss subsidiary owns several warehouses, whose rooftops can be potentially used for the installation of PV systems.

In 2014, the company decided to collaborate with Etawatt AG – an energy contracting company located in Schaffhausen – for a solar contracting project for PV installations on 14 rooftops of CRH Swiss Distribution. Etawatt owns the solar systems and is paying a yearly rental for the rooftops owned by CRH. Eventually, Etawatt sells the generated electricity to CRH and is responsible for the surplus electricity generated from the PV panels and for the maintenance work on the rooftops. CRH receives a monthly electricity bill for the consumed solar electricity directly from Etawatt. The stipulated contract lasts 25 years. (Energie Schweiz, n.d.)

Benefits for CRH:

- Peace of mind regarding project planning, implementation;
- Part of the electricity consumption is covered from solar electricity, which allows the target achievement for the sustainability strategy of CRH;
- Reduced electricity costs[17] and additional positive cash flow thanks to the rooftops rental;
- Initial investment is avoided.

Disadvantages for CRH:

- The stipulated contract of 25 years might hinder the development of other opportunities from different business models in the future.

5.7 Black start

Black start is defined as the process where electric power can be delivered after a blackout without relying on the external grid. This is critical for installations with low power reliability or installations with an unstable connection to the main grid. A conventional method to provide black-start is via diesel generators. (HSLU, 2018)

A feasible combination to improve the system's resiliency in the production building analysed would be a battery and diesel generator system. In case of a blackout lasting more than 5 hours, if only a battery was

[17] The price for the solar electricity is 1 cent/kWh cheaper than the grid electricity.

to be used, its size should be of at least 3 MWh / 650 kW in order to provide the needed power and electricity for the whole facility. A more economically feasible option would be the use of the battery to start the diesel generator so that full restoration of system load can occur.

In order for the battery to be used also for other purposes than black start, it should be assured that the battery always contains a certain amount of charge in order to provide the needed energy to the diesel generator in case of a blackout.

5.8 Ancillary services

The Swiss electricity grid experiences frequency fluctuations on a daily basis. This occurs due to imbalances in generation and production. Swissgrid, Switzerland's Transmission System Operator (TSO), is responsible for assuring the grid stability, which is achieved by implementing several frequency controls and grid services:

- Primary control, with a reaction time of 0.5 minutes usually with turbines;
- Secondary control, shortly after the primary control. Here, power plants are put into operation;
- Tertiary control, used in case of longer disturbances in the grid's frequency. (See Figure 24)

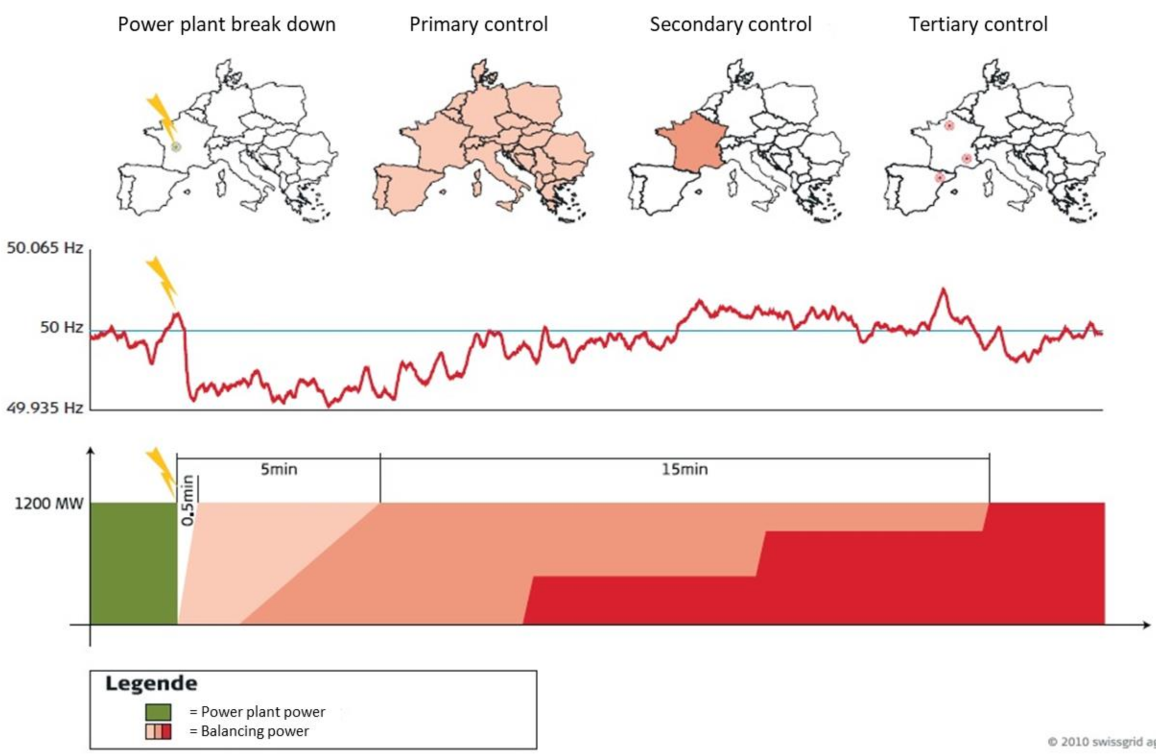

Figure 24 - Grid balancing process in case of a power plant break down (Source: adapted from Swissgrid, 2016)

Positive balancing energy is needed in case of an increase of demand, which can be approached by putting power plants into operation or by reducing power consumption in certain processes. Negative balancing energy is needed whenever there is a surplus of electricity in the grid, which can be addressed by reducing power plant generation or activating processes which can be put into operation in a flexible way, such as incinerators or waste water treatment plants. (Vogel, 2017)

Typical systems used in frequency regulation controls are hydropower plants, since they can deliver and absorb power fast. By implementing facilitations in the tendering procedure and therefore allowing more parties to join the balancing market, as well as participating in international pilot projects for reserves exchange, Swissgrid has increased by four times the amount of participators in the balancing market. In 2016, 51 different participators were available, therefore achieving a better grid security. (Swissgrid, 2016)

An example of a battery system participating in the Swiss balancing market is given by the energy utility company of Canton Zurich EKZ[18], which installed a 1 MW battery system in Dietikon (ZH) in order to provide primary balancing energy. Apart from delivering balancing energy, the system is able to run in island mode together with the PV system, provide peak shaving and reactive power control. The remuneration for the system in the balancing market was on average between 3'000 and 6'000 CHF per week and megawatt. In case of no availability from hydropower plants, the remuneration can reach higher values. (EKZ, n.d.)

5.8.1 Virtual power plants

The amount of participants in the balancing market can be increased by allowing smaller consumers or producers to participate. This can be achieved by creating so-called Virtual Power Plants (VVPs): several systems are combined so that together they reach the size and controllability of a conventional power plant.

In case of grid instabilities, Swissgrid can rely on the balancing power. A power tariff in CHF/MW is remunerated for readiness in case of a break down. Additionally, in case the power plant is put into operation, an energy tariff in CHF/MWh applies for the amount of delivered balancing energy.

A VPP business model is offered from EKZ. For the participation in such a system the following requirements must be fulfilled:

- E.g. diesel generators, emergency power systems, turbines, machines/pumps, cooling plants, heat pumps, combined heat and power plants, electrical heating systems, small-sized hydropower plants, compressors;
- System starting time of maximum 15 minutes;
- Readiness planning possible within 4 days in advance;
- Electric power of at least 200 kW;
- Available interface for external control. (EKZ, 2016)

The VPP scenario could be an interesting case for the analysed battery system and for the production building itself, since the building operates an emergency power system, several machines and pumps, cooling systems and heat pumps. Furthermore, the battery would not need to be oversized to be able to enter the balancing market.

[18] EKZ: Elektrizitätswerke des Kantons Zürich

6 Cost-Benefit Analysis and Results

This chapter aims at showing the results from the cost benefit analysis by applying some the different use cases explained in the chapter before. The selection of the use cases to be further analysed depended on the quantifiability of the parameters.

6.1 Use cases selected for the cost-benefit analysis

Figure 25 shows the use cases which were selected to perform the cost-benefit analysis.

The **direct consumption** use cases imply the use of the electricity generated from the PV system directly on site. It might occur that PV generation already reduces some power peaks, since consumption peaks in the production building usually occur during midday. Therefore, the peak shaving scenario combined with direct consumption might be more effective for reducing overall peaks. However, since the PV generation profile is highly variable due to its weather dependency, it can occur that power generation and consumption peaks do not correspond at all in real-life scenarios. Additionally, also an arbitrage case in combination with direct consumption is analysed: this is performed by charging during low energy tariff periods and discharging during high energy tariff periods, independently of the consumption profile. All peak shaving and arbitrage scenarios include a sensitivity analysis by utilising different battery sizes: a 150 kWh / 36 kW battery as the existing one, one with 225 kWh / 80 kW and the last one with 375 kWh / 36 kW.

The **feed-in** use cases imply no use of the PV generated electricity on site but rather feeding it into the main grid. The feed-in tariff for PV electricity from WWZ applies. (See Chapter "Energy utility company") Also a peak shaving scenario in combination with feed-in is considered. No arbitrage scenario is considered.

Furthermore, two **Self-Consumption Community** use cases are evaluated. The two use cases differ from each other in terms of the internal electricity tariff to be used towards the other parties of the community. The SCC feed-in tariffs used for the cost-benefit analysis are 11.8 Rp./kWh and 14.3 Rp./kWh, to which the administrative costs were already deducted. The 11.8 Rp./kWh corresponds to the "SCC with internal tariff of 13.8 Rp./kWh" scenario whereas the 14.3 Rp./kWh corresponds to "SCC with internal tariff of 16.3 Rp./kWh" in Figure 25.

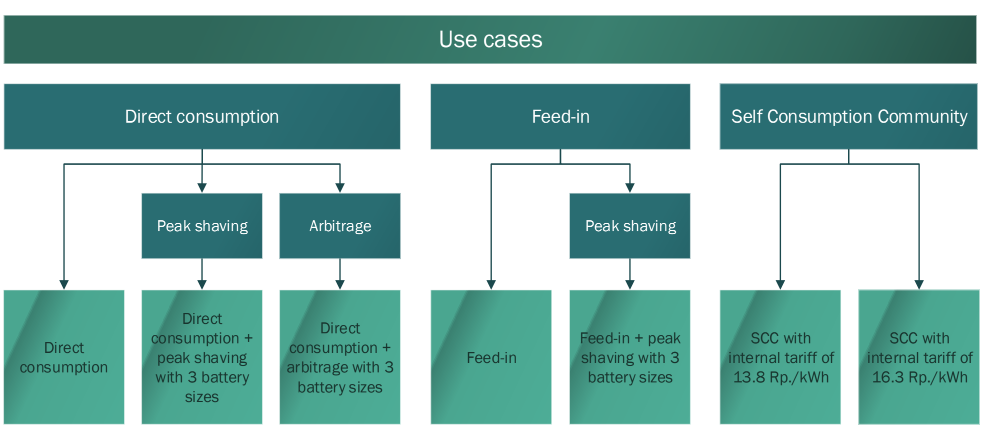

Figure 25 - Different use cases selected for the cost-benefit analysis

6.2 Cost-Benefit Analysis

All use cases mentioned in Figure 25 are compared to each other in the Cost-Benefit Analysis (CBA).

The analysis was carried out for a period of 25 years, which equals the lifetime of the PV system. Important to mention is the lifetime of the battery for the scenarios with peak shaving or arbitrage. The analysed batteries have a lifetime of at least 4’000 full cycles. Since peak shaving is applied to working days, a number of 245 full cycles per year and therefore a lifetime of 16 years was used for the CBA for the peak shaving use cases. For arbitrage, on the other hand, the battery experiences charging and discharging when tariffs are high and low, therefore day and night from Monday to Saturday excluding holidays (when the low tariff applies). Therefore, a number of 300 cycles per year was estimated with a lifetime of 13 years. Thus, the battery would need to be replaced after 16 years for peak shaving and after 13 years for arbitrage. At the time of replacement, a reduction in the investment costs for batteries was assumed: the present investment costs amount to 800 CHF/kWh whereas the future ones amount to 500 CHF/kWh. Capacity losses throughout the lifetime were not considered for the sake of simplicity in the calculation tool.

According to the PV Syst simulation, the degradation factor of the PV after 25 years amounts to 80% of the initial value. Therefore, a linear yearly degradation factor of 99.1% was used.

All tariffs equal the ones mentioned in the previous chapters. A discount factor of 2% was applied to the CBA. The Value Added Taxes (VAT) were not considered in the calculations.

6.3 Results

All use cases generate savings in the electricity bill, either from reducing the internal energy and power peaks costs or by generating revenues from selling the electricity to the main grid or to SCCs.

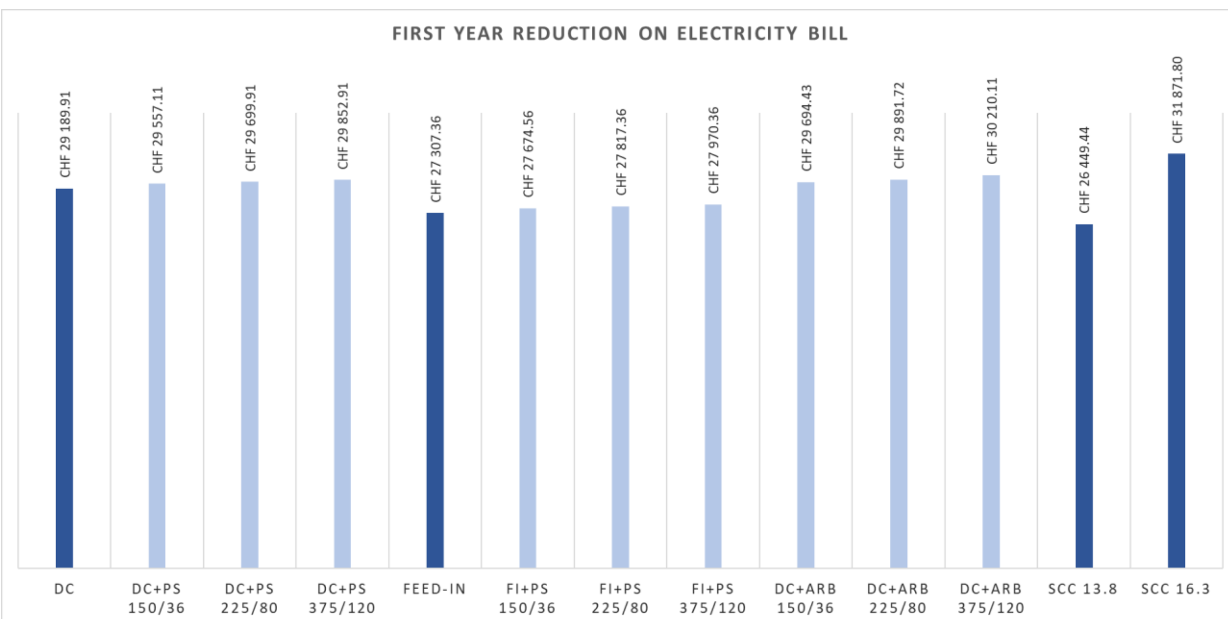

Figure 26 - Overview of reduction on electricity bill (first year) for the different use cases. The bars in dark blue show the cases with a positive NPV after 25 years.

Figure 26 shows the savings on the electricity bill for the different use cases. It can be seen that all scenarios are in the range of 26’500 and 31’900 Swiss Francs reduction per year, or in percentage 6-7% reduction. It can be seen that all use cases with batteries do not have a strong impact on the savings amount, which is definitely a consequence of the low power tariff applied from WWZ.

The graph in the figure also shows which use cases have a positive Net Present Value (NPV) after 25 years (dark blue bars). Due to the high investment costs for batteries, the need for a replacement during the analysed period as well as very low savings for peak shaving or arbitrage, all battery scenarios have a negative NPV after 25 years. On the other hand, scenarios without batteries have positive NPVs.

Table 10 shows the NPV for the different use cases and the payback time of those with a positive NPV. From a first glance, the SCC scenario with the higher internal electricity tariff seems to be the best option, followed by consuming the generated PV electricity directly on site. The payback periods are all in an acceptable range for a PV system investment.

Table 10 - NPV after 25 years for the different use cases

Use cases	NPV after 25 years	Payback time
Direct consumption	CHF 115 564.74	14 years
Direct consumption + peak shaving 150/36	CHF -76 849.80	
Direct consumption + peak saving 225/80	CHF -188 774.35	
Direct consumption + peak shaving 375/120	CHF -414 954.58	
Feed-in	CHF 82 469.04	16 years
Feed-in + peak shaving 150/36	CHF -109 945.50	
Feed-in + peak shaving 225/80	CHF -221 870.05	
Feed-in + peak shaving 375/120	CHF -448 050.28	
Direct consumption + arbitrage 150/36	CHF -74 435.74	
Direct consumption + arbitrage 225/80	CHF -185 402.35	
Direct consumption + arbitrage 375/120	CHF -408 675.09	
Self-Consumption Community 13.8	CHF 67 386.62	17 years
Self-Consumption Community 16.3	CHF 162 712.82	12 years

Since the WWZ power tariff is very low, a scenario with a higher tariff was also simulated to evaluate if battery scenarios can be a valid option for production buildings with similar energy tariffs supplied by other utility companies. The power tariff of EWZ in the city of Zurich amounts to 10 Rp./kW, as mentioned in the subchapter “Peak shaving”, and was used for the simulation.

By applying a power tariff of 10 Rp./kWh battery scenarios are economically more attractive than with the WWZ power tariff. Battery savings can increase up to CHF 7’800 with the largest battery of 375 kWh / 120 kW, or 7.8% including direct consumption compared to the baseline electricity bill. Additionally, the NPV after 25 years is positive for the direct consumption use case with peak shaving using the 150 kWh / 36 kW battery. However, high investment costs and needed replacement at the end of lifetime negatively affect the battery scenarios, making them still less attractive than direct consumption without batteries. (Figure 27).

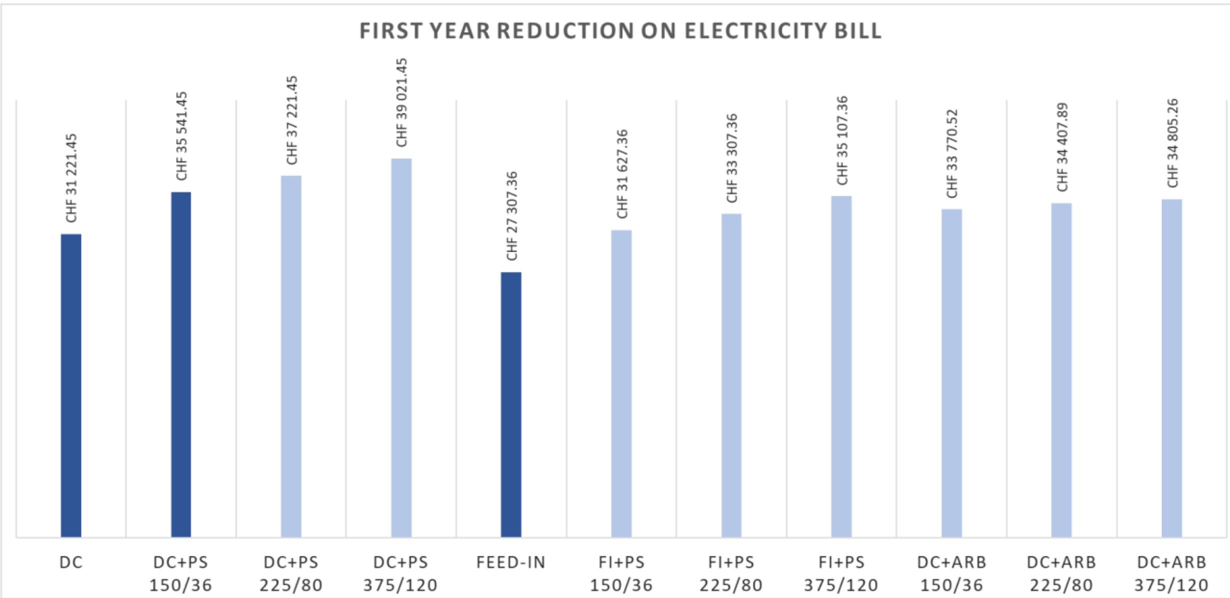

Figure 27 - Overview of reduction on electricity bill (first year) for the different use cases with a higher power tariff. The bars in dark blue show the cases a positive NPV after 25 years. The graph does not include SCC scenarios since a higher power tariff does not affect them.

Figure 28 shows an example of savings by applying direct consumption and peak shaving with the 375 kWh / 120 kW battery compared to the baseline electricity bill.

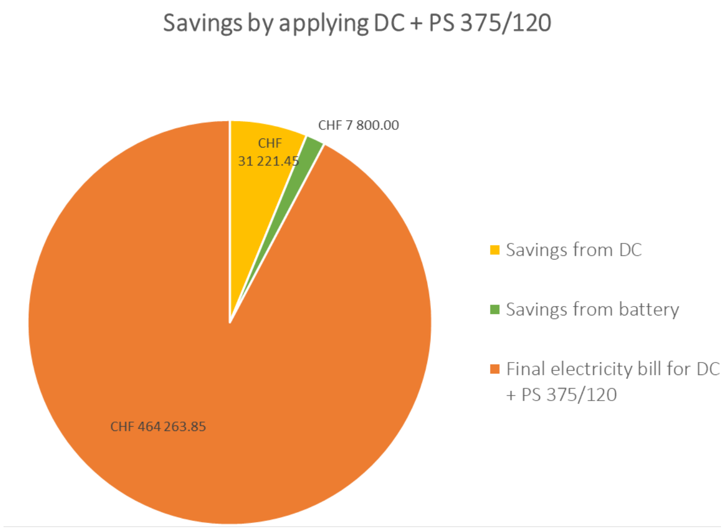

Figure 28 - Pie chart showing savings from direct consumption and peak shaving using the 375 kWh / 120 kW battery. The total area of the pie corresponds to the baseline electricity bill.

7 Discussion

According to the results, the SCC scenario with the highest internal tariff seems to be the most economically attractive one. Since the internal tariff is higher compared to the feed-in tariff to the main grid, revenues can be generated. Additionally, the internal tariff is also higher than the electricity price the production building is paying, which makes this scenario even more attractive than direct consumption. However, major hurdles might affect a SCC project's success: the involved bureaucracy for forming a SCC should not be overlooked. Furthermore, the system's delimitation of the community must be done in a way that lowest costs for infrastructure – e.g. distribution lines or cables – occur, which might be challenging in some situations. Last but not least, a preliminary analysis of the electricity tariffs of the neighbourhood should be thoroughly performed in order to identify if the possible SCC internal tariff is advantageous enough.

The direct consumption scenario would be eventually the simplest to realise in terms of planning and total effort for the implementation stage. It also retains acceptable payback time and NPV after 25 years.

For the existing system with 25 kWp PV and 150 kWh / 36 kW battery at the Siemens production facility, the extension of the PV to a 221 kWp system should be considered. The existing battery, on the other hand, should not be expanded since it would not be economical with the current tariff system. Economically speaking, it would be more reasonable to use the battery neither for peak shaving nor for arbitrage, since the battery would need to be replaced after a certain amount of cycles. This would lead to a negative NPV.

However, a possible battery use case could be the participation in the balancing market by joining a virtual power plant union. This should be monitored for possible opportunities.

7.1 Future developments

The current electrification and renewable penetration trends as well as the increase of electric vehicles on the roads will directly affect the power system. Higher needed capacities as well as intermittent renewable generation will present challenges for the distribution grid. One of the solutions to provide a higher grid stability and avoiding oversizing of power lines lies in storage technologies. Currently, high investment costs hinder the usage of battery systems, however price trends show a reduction which is expected to continue in the future and thus increase the economic feasibility of such systems.

Furthermore, higher power capacities on distribution lines will also negatively affect utility companies, which might consecutively increase power tariffs. This would definitely affect the feasibility of battery systems for peak shaving.

7.2 Recommendations for additional value creation for similar projects

Distributed Energy Systems should be definitely considered for projects within production facilities. However, the preliminary analysis for DES projects should be performed considering several scenarios. E.g., in the case of a PV installation, not only the direct consumption scenario should be evaluated but also possibilities for Self-Consumption Communities or solar contracting in case upfront high investment costs would hinder the viability of the project.

Industries are usually subject to a power tariff component in the calculation of the electricity bill. In case of a low power tariff such as in the analysed case, a peak shaving scenario should not be analysed at this moment in time, since batteries' high investment costs would lead to negative results. Power tariffs can however change in the future due to the mentioned trends in future developments and should be monitored to detect possible opportunities for a battery integration in the system. On the other hand, in case of a higher power tariff, batteries can generate monetary savings despite batteries' high investment costs.

Furthermore, the criticality of certain processes within the production building should be analysed in order to evaluate if the system should be able to provide black-start.

Additionally, the increasing importance of grid stability regarding the growing penetration of renewables in the energy system will open several opportunities for new players regarding ancillary services. Virtual power plants allow several parties to unite and access the balancing market. This should be monitored as it could potentially generate additional monetary benefits for the project.

The arbitrage scenario could also potentially create monetary benefits if the difference between high and low tariffs allows it. In case of projects such as the analysed case with a small tariff difference, arbitrage might not bring major monetary benefits.

Eventually, the combination of different use cases might generate even more savings and revenue streams compared by integrating only one use case. This is essential in the case of battery. Dynamic controllers which would allow the integration of different use cases might be interesting.

7.3 Constraints for the methodology applicability to other projects

The methodology applied in this study can apply to most of DES projects for production buildings, since it leads to a holistic understanding of the system and its environment by analysing the regulatory framework as well as evaluating the technologies involved.

The feasibility evaluation by using a cost-benefit analysis can also provide valid information regarding payback time, net present value after a certain amount of time. It gives an overview of the economic feasibility of the project.

A constraint might however be the tool used for the simulations for the different battery use cases, since its modelling can be time intensive to reach a certain accuracy. A recommendation would be to use an established simulation tool for this type of systems in order to obtain reliable results.

The quality of the gathered data for the analysis should be as reliable and complete as possible in order to avoid misleading results. As a matter of fact, the load profile of the production building was extrapolated following certain assumptions. If possible, real metering data should be taken.

7.4 Further research

A possible development for further research would be the analysis of the Siemens production building with the complete measured load profile data for one whole year, therefore without the need for profile extrapolation. If available, the data from the specific meters inside the building should be used for the analysis so that a closer comparison with the PV generation data can be achieved.

It would be worthwhile to investigate green buildings labels and certification for this type of systems, since it would be interesting to analyse potential occurring benefits. As a matter of fact, the analysed production building received a “gold” LEED certification: it would be worthy to analyse to what extent an expansion of the PV system would affect this certification.

A further possible step could be the integration of different future scenarios for electricity and power tariffs, since this could increase or diminish the economic feasibility of specific use cases.

8 Conclusion

The current development of renewable energy systems as a consequence of global warming is influencing today's energy system: from a regulatory perspective, more opportunities are created such as Self-Consumption Communities for PV electricity generation or increased possibilities for storage to provide ancillary services by participating in the balancing market as virtual power plants; from a technical perspective, challenges are created for the distribution grid due to the integration of volatile renewable generation technologies which can worsen grid stability or create additional expenses for the expansion and enlargement of power lines.

Distributed Energy Systems can provide several monetary benefits if the according technical system they apply to and their regulatory framework are suitable for the project.

For the analysed case, the system composed of a production building is suitable for the commissioning of a DES composed of a 221 kWp PV with battery system. Those would allow a share of PV generated renewable electricity used directly on site and steadier electrical consumption with lower peaks by using the battery. However, from an economic point of view, the PV and battery system only partially provides the desired savings. As a matter of fact, the scenario of peak shaving does not bring any return on the investment due to the low power tariff. This might however change in the future, since the energy utility company WWZ might be forced to increase power tariffs to avoid unexpected peaks in the distribution grid from both demand and supply sides. In this scenario, battery integration might become favourable as it is shown in the case of a higher power tariff from the energy utility company of the city of Zurich EWZ, where small-sized batteries are already worth the investment if used for peak shaving.

On the other hand, a PV system on its own already has good opportunities thanks to existing incentive programmes on a national and municipal level, new possibilities such as Self-Consumption Communities or solar contracting and acceptable feed in tariffs.

When analysing a system for possible DES projects, both technical and regulatory systems should be carefully analysed and understood in order to identify all possible use cases and evaluate them in an appropriate manner.

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Appendix

The following pages contain relevant information which is not essential to understand the mentioned results but can support in case specific aspects need to be analysed further. The Excel calculation tool is delivered separately.

The appendix structure looks as follows:

- Appendix A, Data sheets;
- Appendix B, PV extension;
- Appendix C, Feed-in tariffs;
- Appendix D, HKN Standing Order.

Appendix A - Data sheets

Varta Flex Storage E data sheet

▸ Technische Daten und Fakten

SYSTEMDATEN	FLEX STORAGE P	FLEX STORAGE E
Nutzbare Systemkapazität	26 - 260 kWh	75 - 750 kWh
Nominale Systemleistung	20 | 36 | 80 | 120 kW	20 | 36 | 80 | 120 kW
Maße (B x H x T) in mm	Abhängig von der Anzahl der Power-, Storage Units	
Gewicht	Abhängig von der Anzahl der Power-, Storage Units	
Sicherheit	Mehrstufige, hard- und softwareredundante Zellüberwachung	
Netzanschluss	400 V AC, 3-phasig, 50 Hz	
Netzformen	TN-Netze, TT-Netze	
Länderzulassung	Deutschland, Österreich, Schweiz	
Schutzklasse	IP 33	
Umgebungsbedingungen	+ 5°C bis + 30°C	
Systemgarantie	Applikationsabhängig	

STORAGE UNIT		
Bezeichnung	Storage Unit P 26	Storage Unit E 75
Nutzbare Speicherkapazität	26 kWh	75 kWh
Elektrochemie	Lithium-Eisenphosphat	Lithium-Nickel-Mangan-Kobaltoxid
C-Rate	1 C	0,5 C
Vollzyklen	> 8.000 Zyklen*	> 4.000 Zyklen*
Maße (B x H x T) in mm	600 x 2.000 x 600	550 x 2.000 x 670
Gewicht	520 kg	707 kg

POWER UNIT	
Leistung	20 | 36 | 80 | 120 kW
NA-Schutz nach VDE AR-4105	separat ausgeführt
Schrankmaße 20 | 36 (B x H x T) in mm	600 x 2.000 x 600
Schrankmaße 80 | 120 (B x H x T) in mm	1.000 x 2.000 x 600
Gewicht	250 | 270 | 370 | 430 kg

FUNKTIONEN	
Applikationen	Eigenverbrauchsoptimierung, Inselnetz**, Peak-Shaving**, externe Sollwertvorgabe**
Eigenverbrauchsoptimierung	3-phasig, phasensymmetrisch
Leistungserfassung	3-phasig über Stromsensor
Kaskadierbarkeit	Bis zu fünf VARTA flex storage Systeme
Auslesefunktionen / Service	Ethernet
Visualisierung	VARTA Webportal
Smart Home Schnittstellen	Modbus / TCP
Smart Home Kompatibilität	SolarLog

ZERTIFIZIERUNGEN UND RICHTLINIEN

CE-Konformität, Niederspannungsrichtlinie 2014/35/EU, EMV Richtlinie 2014/30/EU, EN 61000-6,2:2005, EN 61000-6-4 (2011-09), DIN EN 62109-1:2011, VDE-AR-N 4105:2011-08, TOR 2016 V.2.3 D4, UN 38.3, DIN VDE V 0124-100:2013-10

* Erwartete Restkapazität: 80 %.
** Optional

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Figure 29 - Appendix - Varta battery data sheet

Suntech STP310 – 24/Vem data sheet

STP315 - 24/Vem
STP310 - 24/Vem
STP305 - 24/Vem

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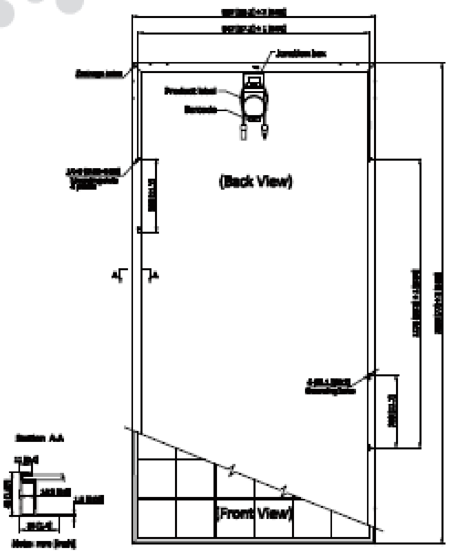


Electrical Characteristics

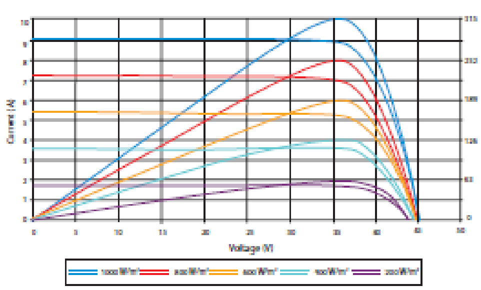
STC	STP315-24/ Vem	STP310-24/ Vem	STP305-24/ Vem
Maximum Power at STC (Pmax)	315 W	310 W	305 W
Optimum Operating Voltage (Vmp)	36.8 V	36.5 V	36.2 V
Optimum Operating Current (Imp)	8.56 A	8.50 A	8.43 A
Open Circuit Voltage (Voc)	45.1 V	44.9 V	44.7 V
Short Circuit Current (Isc)	9.02 A	8.96 A	8.89 A
Module Efficiency	16.2%	16.0%	15.7%
Operating Module Temperature	-40 °C to +85 °C		
Maximum System Voltage	1000 V DC (IEC)		
Maximum Series Fuse Rating	20 A		
Power Tolerance	0/+5 %		

STC: Irradiance 1000 W/m², module temperature 25 °C, AM=1.5;
Best in Class AAA solar simulator (IEC 60904-9) used, power measurement uncertainty is within +/- 3%

NOCT	STP315-24/ Vem	STP310-24/ Vem	STP305-24/ Vem
Maximum Power at NOCT (Pmax)	229 W	226 W	222 W
Optimum Operating Voltage (Vmp)	33.2 V	32.8 V	32.6 V
Optimum Operating Current (Imp)	6.91 A	6.88 A	6.80 A
Open Circuit Voltage (Voc)	41.5 V	40.9 V	40.8 V
Short Circuit Current (Isc)	7.30 A	7.26 A	7.19 A

NOCT: Irradiance 800 W/m², ambient temperature 20 °C, AM=1.5, wind speed 1 m/s;
Best in Class AAA solar simulator (IEC 60904-9) used, power measurement uncertainty is within +/- 3%

Current-Voltage & Power-Voltage Curve (315-24)



Excellent performance under weak light conditions: at an irradiation intensity of 200 W/m² (AM 1.5, 25 °C), 96.5% or higher of the STC efficiency (1000 W/m²) is achieved

Temperature Characteristics

Nominal Operating Cell Temperature (**NOCT**)	45±2°C
Temperature Coefficient of Pmax	-0.42 %/°C
Temperature Coefficient of Voc	-0.33 %/°C
Temperature Coefficient of Isc	0.067 %/°C

Mechanical Characteristics

Solar Cell	Polycrystalline silicon 156 × 156 mm (6 inches)
No. of Cells	72 (6 × 12)
Dimensions	1956 × 992 × 40mm (77.0 × 39.1 × 1.6 inches)
Weight	25.8 kgs (56.9 lbs.)
Front Glass	4.0 mm (0.16 inches) tempered glass
Frame	Anodized aluminium alloy
Junction Box	IP68 rated (3 bypass diodes)
Output Cables	TUV (2Pfg1169:2007)
	4.0 mm² (0.006 inches²), symmetrical lengths (-) 1100mm (43.3 inches) and (+) 1100 mm (43.3 inches)
Connectors	Original MC4 connectors

Dealer information

Packing Configuration

Container	20' GP	40' GP	40' HC
Pieces per pallet	25	25	25
Pallets per container	5	12	24
Pieces per container	125	300	600

Information on how to install and operate this product is available in the installation instruction. All values indicated in this data sheet are subject to change without prior announcement. The specifications may vary slightly. All specifications are in accordance with standard EN 50380. Color differences of the modules relative to the figures as well as discolorations of/in the modules which do not impair their proper functioning are possible and do not constitute a deviation from the specification.

E-mail: sales@suntech-power.com www.suntech-power.com IEC-STP-Vem-NO1.01-Rev 2015

Figure 30 - Appendix - PV modules data sheet

Appendix B - PV extension

AutoCAD

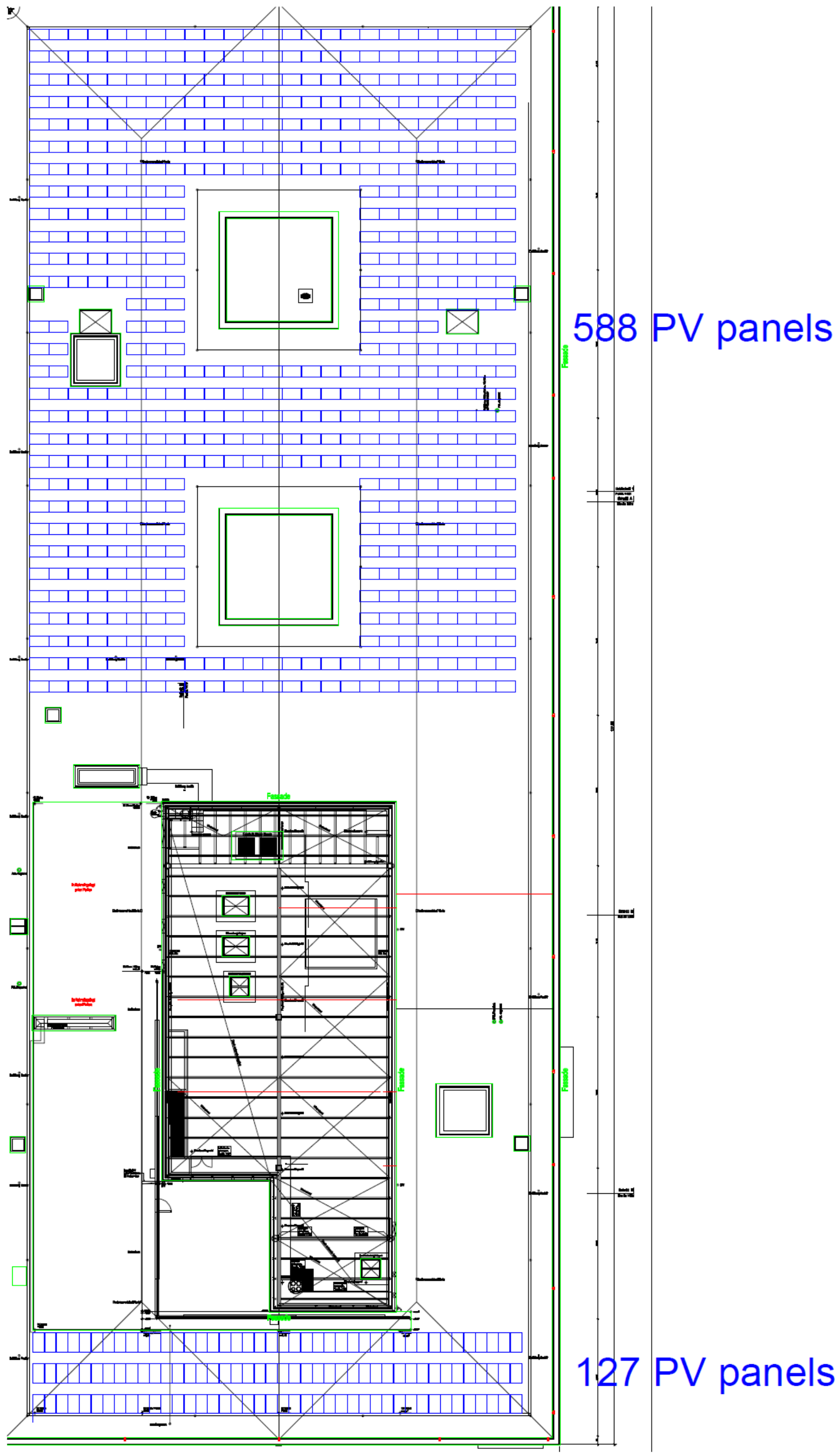


Figure 31 - Appendix - AutoCAD drawing for PV extension

PV Syst

PVSYST V6.75	Siemens Schweiz AG (Switzerland)	27/03/19	Page 1/3

Grid-Connected System: Simulation parameters

Project :	**BT@ZUG**			
Geographical Site	**Zurich**		Country	**Switzerland**
Situation	Latitude	47.38° N	Longitude	8.57° E
Time defined as	Legal Time	Time zone UT+1	Altitude	556 m
	Albedo	0.20		
Meteo data:	**Reckenholz**	MeteoNorm 7.1 station - Synthetic		

Simulation variant :	**New simulation variant**	
	Simulation date	27/03/19 09h54
	Simulation for the	**1st year of operation**

Simulation parameters	System type	**No 3D scene defined**		
Collector Plane Orientation	Tilt	15°	Azimuth	0°
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	No Shadings			
PV Array Characteristics				
PV module Si-poly	Model	**STP310-24/Vem**		
Original PVsyst database	Manufacturer	Suntech		
Number of PV modules	In series	17 modules	In parallel	42 strings
Total number of PV modules	Nb. modules	714	Unit Nom. Power	310 Wp
Array global power	Nominal (STC)	**221 kWp**	At operating cond.	198 kWp (50°C)
Array operating characteristics (50°C)	U mpp	554 V	I mpp	358 A
Total area	Module area	**1385 m²**	Cell area	1251 m²
Inverter	Model	**blueplanet 20.0 TL3**		
Original PVsyst database	Manufacturer	Kaco new energy		
Characteristics	Operating Voltage	200-950 V	Unit Nom. Power	20.0 kWac
Inverter pack	Nb. of inverters	17 units	Total Power	340 kWac
			Pnom ratio	0.65
PV Array loss factors				
Array Soiling Losses			Loss Fraction	3.0 %
Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	26 mOhm	Loss Fraction	1.5 % at STC
Serie Diode Loss	Voltage Drop	0.7 V	Loss Fraction	0.1 % at STC
LID - Light Induced Degradation			Loss Fraction	2.0 %
Module Quality Loss			Loss Fraction	-0.8 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %
Module average degradation	Year no	1	Loss factor	0.4 %/year
Mismatch due to degradation	Imp RMS dispersion	0.4 %/year	Vmp RMS dispersion	0.4 %/year
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05
System loss factors				
Wiring Ohmic Loss	Wires: 3x25.0 mm²	50 m	Loss Fraction	5.1 % at STC
User's needs :	Unlimited load (grid)			

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Figure 32 - Appendix - PV Syst simulation of extended PV system, page 1

PVSYST V6.75	Siemens Schweiz AG (Switzerland)	27/03/19	Page 2/3

Grid-Connected System: Main results

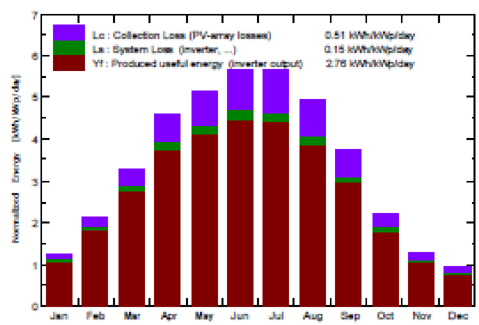
Project : BT@ZUG

Simulation variant : New simulation variant
Simulation for the 1st year of operation

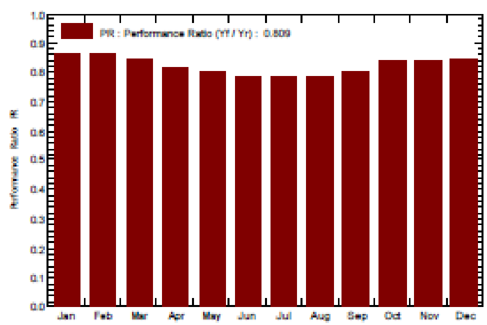
Main system parameters	System type	**No 3D scene defined**			
PV Field Orientation	tilt	15°	azimuth	0°	
PV modules	Model	STP310-24/Vem	Pnom	310 Wp	
PV Array	Nb. of modules	714	Pnom total	**221 kWp**	
Inverter	Model	blueplanet 20.0 TL3	Pnom	20.00 kW ac	
Inverter pack	Nb. of units	17.0	Pnom total	**340 kW ac**	
User's needs	Unlimited load (grid)				

Main simulation results				
System Production	**Produced Energy**	**222.8 MWh/year**	Specific prod.	1006 kWh/kWp/year
	Performance Ratio PR	80.90 %		

Normalized productions (per installed kWp): Nominal power 221 kWp



Performance Ratio PR



New simulation variant

Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR
January	28.9	16.90	0.78	39.2	36.1	7.86	7.47	0.861
February	48.9	30.00	2.05	59.8	55.5	11.98	11.41	0.862
March	88.7	50.10	5.62	102.1	95.1	20.03	19.06	0.844
April	125.5	57.70	9.66	137.5	128.6	26.23	24.90	0.818
May	155.0	78.70	14.55	159.9	149.7	29.75	28.24	0.798
June	169.1	84.90	17.92	170.7	159.8	31.32	29.75	0.787
July	171.6	79.80	18.95	175.1	164.2	31.97	30.35	0.783
August	143.8	67.50	18.50	152.5	142.8	28.00	26.59	0.788
September	99.0	45.70	14.06	111.7	104.5	20.89	19.83	0.802
October	57.6	37.40	10.26	68.3	63.4	13.23	12.60	0.833
November	29.9	18.90	4.67	38.3	35.3	7.51	7.13	0.841
December	21.4	13.80	1.65	28.9	26.5	5.72	5.43	0.847
Year	1139.4	581.40	9.94	1244.1	1161.7	234.48	222.76	0.809

Legends:				
	GlobHor	Horizontal global irradiation	GlobEff	Effective Global, corr. for IAM and shadings
	DiffHor	Horizontal diffuse irradiation	EArray	Effective energy at the output of the array
	T Amb	Ambient Temperature	E_Grid	Energy injected into grid
	GlobInc	Global incident in coll. plane	PR	Performance Ratio

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Figure 33 - Appendix - PV Syst simulation of extended PV system, page 2

PVSYST V6.75	Siemens Schweiz AG (Switzerland)	27/03/19	Page 3/3

Grid-Connected System: Loss diagram

Project : **BT@ZUG**

Simulation variant : **New simulation variant**

Simulation for the 1st year of operation

Main system parameters	System type	**No 3D scene defined**		
PV Field Orientation	tilt	15°	azimuth	0°
PV modules	Model	STP310-24/Vem	Pnom	310 Wp
PV Array	Nb. of modules	714	Pnom total	**221 kWp**
Inverter	Model	blueplanet 20.0 TL3	Pnom	20.00 kW ac
Inverter pack	Nb. of units	17.0	Pnom total	**340 kW** ac
User's needs	Unlimited load (grid)			

Loss diagram over the whole year

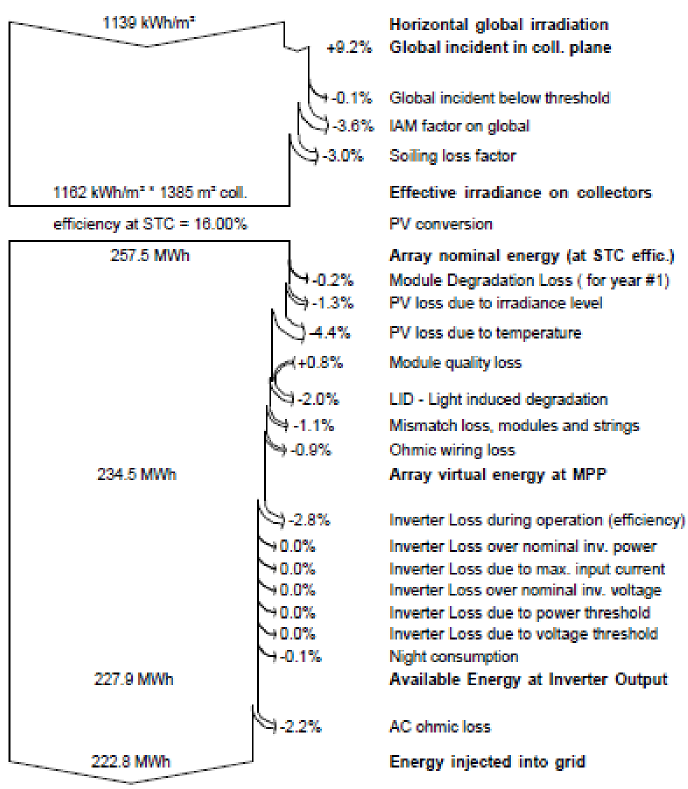

Figure 34 - Appendix - PV Syst simulation of extended PV system, page 3

Appendix C - Feed-in tariffs

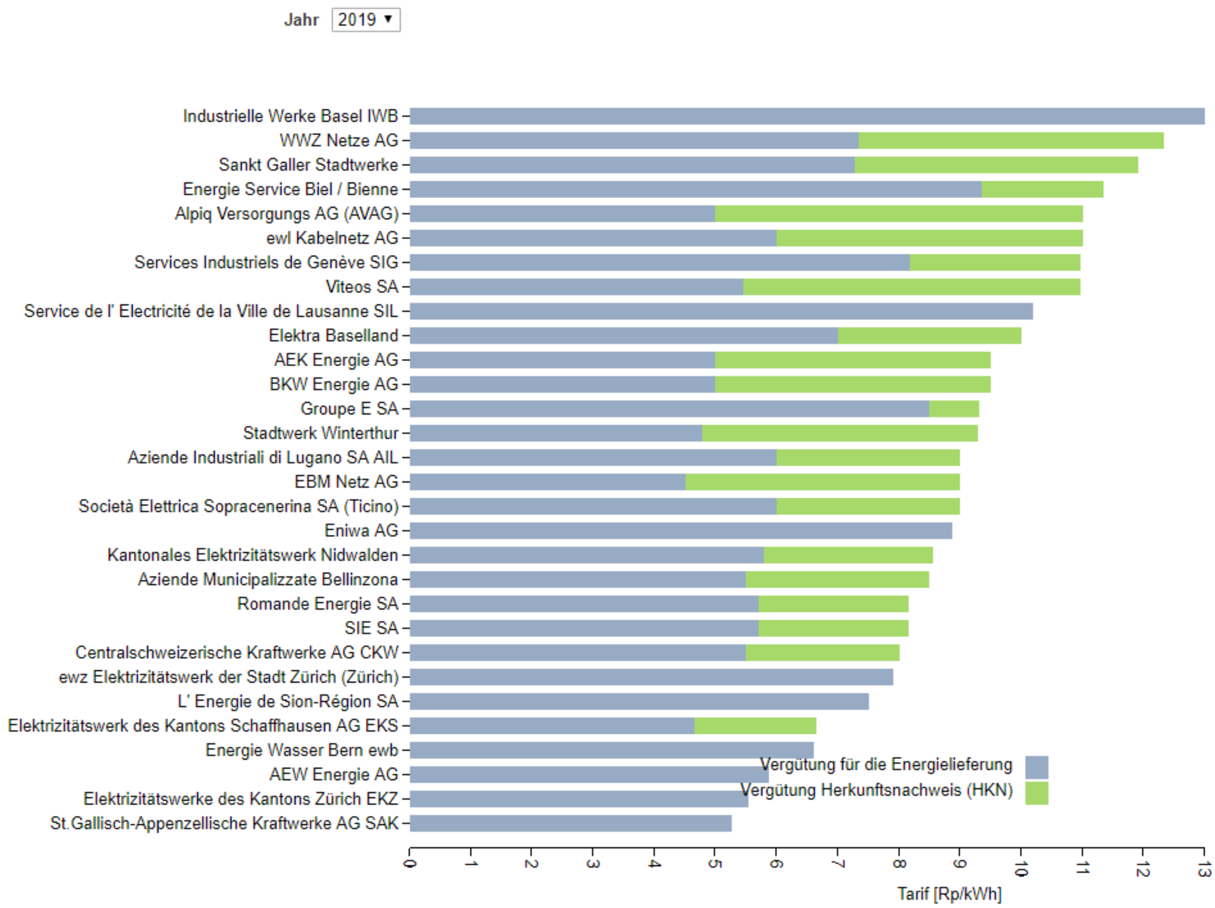

Figure 35 - Appendix - Different feed-in tariffs for 30 Swiss energy utility companies

Appendix D - HKN standing order form

pronovo	Dienstleistungserstellung - HKN HKN-Dauerauftrag		FO 08 41 22
Ausgabe/Datum: 01.07.2018	**Griff** 08	**Dateiname:** FO 08 41 22 Formular HKN-Dauerauftrag	**Seite:** 1 von 1

Formular für Einrichtung HKN-Dauerauftrag

Das Formular wird dafür verwendet, im System HKN CH einen **Dauerauftrag für den Übertrag von Herkunftsnachweisen von Konto A (Anlagenbetreiber) nach Konto B (Händler/ Lieferant) einzurichten.**

Achtung: Für Anlagenbetreiber mit einem Onlinezugriff auf das System HKN CH ist dieser Service kostenpflichtig. Anlagenbetreiber mit Onlinezugriff auf das System HKN CH können einen Dauerauftrag direkt im System HKN CH einrichten.

Konto A (HKN abgebender Anlagenbetreiber):

Name des Anlagenbetreibers	
Strasse , Nr.	
Postleitzahl, Ort	

Konto B (Händler/Stromlieferant): ☐ Händler ☐ Stromlieferant

Name des Händlers/Stromlieferanten	
Unternehmens-ID (gemäss System HKN CH)	
Strasse, Nr.	
Postleitzahl, Ort	

Hiermit bestätigen wir für die Produktionsanlage

Name (im System HKN CH) ____________________

Projekt-Nr. ____________________

die Verteilung der Herkunftsnachweise entsprechend der folgenden Anteile:

Anteil Anlagenbetreiber: ________ %

Anteil Händler/Stromlieferant: ________ %

Gültig von: ________

Gültig bis: ________

____
Ort, Datum:

____
Unterschrift
des Anlagenbetreibers

____
Unterschrift/Stempel
des Händlers/Stromlieferanten

Diese Verteilungsanzeige kann gegenüber Pronovo jederzeit widerrufen werden. Wenn eine oder beide der unterzeichnenden Parteien diese Verteilungsanzeige widerruft, so werden 100% der Herkunftsnachweise dem Anlagenbetreiber zugewiesen. Diese Zuweisung von 100% der HKN an den Anlagenbetreiber bleibt solange bestehen, bis Pronovo eine neue Verteilungsanzeige zwischen dem Anlagenbetreiber und dem anspruchsberechtigten Händler/Stromlieferant erhält, welche die Verteilung der HKN regelt. Die Verteilung wird ab dem Folgemonat nach Datum des Eintreffens der Verteilungsanzeige bei Pronovo geändert.

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Figure 36 - Appendix - HKN Standing Order form