Master Thesis

Technical and economical evaluation of electricity storage applications

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Declaration of Authorship

“I declare in lieu of oath that this thesis is entirely my own work except where otherwise indicated. The presence of quoted or paraphrased material has been clearly signaled and all sources have been referred. The thesis has not been submitted for a degree at any other institution and has not been published yet.”

A copy of the thesis has been sent to the university Mines Paristech and the company IFP Energies Nouvelles as they were part of the cooperation.

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Date Esther Maria Fellinger

Preface, Dedication, Acknowledgement

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Abstract

In the context of the increasing share of renewable energies in electricity production and tendencies towards decentralized generation of power, energy storage systems are considered a key technology since they are capable of balancing fluctuating (renewable) generation and demand.

However, the technical and economical evaluation of energy storage applications strongly depends on specific use cases and related business models are still not available. To approach this issue for the case of electricity storage systems, this work examines existing cases of electricity storage use and conducts a case study in an industrial zone in France in order to better understand storage valorization.

The analysis of existing cases of use allowed the deployment of electricity storage to be categorized in three groups. These groups are the non-grid-connected zones, grid-connected zones with intermittent electricity production and grid-connected zones without intermittent electricity production.

The second part of this work consists of a technical and economical evaluation for the application of an electrical storage system in an industrial zone in France. This case study can be assigned to the category of grid-connected zones without intermittent electricity production since it consists of industrial sites without any local renewable electricity generation. There are two value streams generated from the storage system: Electricity is purchased and stored during off-peak hours to reduce purchases on peak hours. Additionally, the demand rate which is calculated based on the peak demand per month is optimized.

The results of the case study demonstrate that in the configuration chosen and under current conditions the application of an electricity storage system is not profitable in this area.

Kurzfassung

Die wachsende Bedeutung erneuerbarer Energien in der Stromerzeugung und die Tendenzen hinsichtlich einer dezentralen Energieerzeugung ergeben interessante Anwendungsmöglichkeiten für Energiespeichersysteme. Diese können maßgeblich zur Flexibilität und Stabilität der Energieversorgung beitragen, da sie fluktuierende Erzeugung bedarfsgerecht auszugleichen vermögen.

Trotz technisch reifer Stromspeichertechnologien erweist sich die Entwicklung von Geschäftsmodellen im Bereich der Energiespeicherung als schwierig, da das Nutzungsverhalten und dadurch auch die Erträge sehr stark vom Kontext der jeweiligen Anwendungen abhängen. Um die Wertschöpfung von elektrischen Speichersystemen besser zu verstehen, wurden in dieser Arbeit existierende Anwendungen von Stromspeichersystemen untersucht, um in weiterer Folge jene Elemente definieren zu können, die essentiell dazu beitragen, dass die Systeme profitabel sind. Mithilfe dieser Elemente soll im Anschluss eine Gruppierung der Anwendungen möglich sein.

Das Ergebnis der Analyse ermöglicht eine Kategorisierung der Fallstudien in drei Gruppen. Die Unterteilung gliedert sich in Anwendungen in Zonen ohne Netzverbindung, in Zonen mit Netzzugang und zusätzlich lokaler, volatiler Stromerzeugung aus erneuerbaren Energiequellen sowie in Zonen mit Netzzugang ohne schwankende Erzeugung.

Im zweiten Teil dieser Arbeit wird eine technisch-wirtschaftliche Bewertung eines Stromspeichersystems in einem Industriegebiet in Frankreich durchgeführt. Diese Anwendung fällt in eine Zone mit Netzzugang ohne lokale, schwankende Stromerzeugung. Das Speichersystem generiert Gewinne, indem Strom zu Zeitpunkten niedrigerer Strompreise eingespeichert und in Phasen höherer Preise verbraucht wird. Parallel dazu wird der Fixbetrag optimiert, welcher monatlich an der Spitzenleistung berechnet wird.

Die Ergebnisse der Fallstudie zeigen, dass unter den gegenwärtigen Rahmenbedingungen und der ausgewählten Konfiguration die Anwendung dieses Stromspeichersystems nicht rentabel ist.

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1 Introduction

Electrical power generation is changing all over the world as countries have to move towards higher rates of penetration of renewable energy sources. As a result, the power network faces great challenges in the transmission and distribution of electricity in order to meet the demand of rising intermittent electricity production. Electrical energy storage (EES) is recognized as a technology to have huge potential in meeting these challenges.

The motivation to increase EES deployment varies depending on the application and the requirements for specific locations. Nevertheless, the following motivational aspects, to be considered as key drivers for EES deployment, can be distinguished:

- Strong penetration of intermittent electricity generation
- Decentralization tendencies leading to increased local power production and consumption
- Decreasing costs of EES systems due to further development and larger deployment
- Incentives and subsidies for EES systems

However, there are still barriers which have to be overcome to make electricity storage a widely used option in the power sector. These barriers include in particular governmental regulations, performance and safety issues, and utility acceptance.

Nevertheless, the electricity storage market is in an active market with high potential for economic growth in the following years. Worldwide, the total installed power of storage reached 150 GW of pumped storage hydropower and 2 GW of stationary battery storage in 2014 and the total installed power is expected to be a total of 300 GW in 2030. (IRENA, 2016)

Nowadays economically viable markets for EES can be found in areas which show at least one of the following characteristics:

- The regulatory framework subsidizes storage solutions.
- The area has no or poor grid connection and high penetration of renewable energies.

To give some examples, Germany has introduced incentives for residential storage systems in combination with photovoltaic systems in May 2013, which led to economic viability in this specific storage segment (EuPD, 2015) and an increase in deployment of storage systems in combination with photovoltaic systems. In January 2016 the number of installed storage systems nearly reached 35,000 in comparison with several hundred in May 2013. (Speichermonitoring, 2016)

Kodiak Island in Alaska serves as an example for a viable market for storage applications in areas with no grid connection and rates of high penetration of renewable energies. The island operates an isolated grid system with a peak load of 27 MW and a minimum load of 11 MW. Besides two 11.5 MW hydroelectric turbine generators there are also four independent diesel generation facilities totaling 33 MW, 9 MW of wind generation and a 3 MW battery-based energy storage system to provide robust and reliable frequency regulation. The battery system competed successfully against an increase of diesel generation facilities when it was decided to double wind generation from 4.5 MW to 9 MW. (Younicos, 2012)

Storage monetization and valorization strongly depends on the specific use, which is why it is difficult to define business models for energy storage applications. Regarding the immaturity of the storage market and the difficulties faced to valorize storage systems, the recommended approach is to examine holistic case studies in context, rather than place faith in generic cost estimations. The best way to understand the value of storage is to consider specific applications or services being offered by storage. (World energy Council, 2016)

To follow this approach, the present study evaluates existing cases of use of electrical energy storage in context and executes a technical-economical study for the application of an electricity storage system in an industrial zone in France in order to better understand the valorization streams for the storage system in this specific application.

2 Value streams for electricity storage applications

In order to understand the possibilities provided by electricity storage, this section gives an overview of a set of thirteen fundamental services that energy storage can deliver, inspired by the approach of the Rocky Mountain Institute's report: The Economics of Battery Energy Storage.

The ability of a technology or system to receive revenue from providing multiple compatible applications is referred to as "benefits stacking" and is critical in the value proposition for many energy storage technologies. (Rocky Mountain Institute, 2015)

2.1 Customer service

Customer services, like bill management, provide direct benefits to end users. Accordingly, the value created by these services can only be captured when storage is deployed directly at the end user. Table 1 defines these customer-facing services. (Rocky Mountain Institut, 2015)

Table 1: Customer services (Rocky Mountain Institute, 2015)

Service Name	Definition
Time-of-Use Bill Management	By minimizing electricity purchases during peak electricity consumption hours when time-of-use (TOU) rates are highest and shifting these purchase to periods of lower rates, behind-the-meter customers can use energy storage systems to reduce their bill.
Increased PV-Self-Consumption	Minimizing export of electricity generated by behind-the-meter photovoltaic (PV) systems to maximize the financial benefit of solar PV in areas with utility rate structures that are unfavorable to distributed PV (e.g., non-export tariffs).

Demand Charge Reduction	Demand charges are calculated on the peak demand of a certain time period (typically monthly or daily). Power purchases are shifted to times with lower demand to flatten peak-demand and therefore demand charges.
Backup Power	In the event of grid failure, energy storage paired with a local generator can provide backup power at multiple scales, ranging from second-to-second power quality maintenance for industrial operations to daily backup for residential customers.

2.2 Utility services

Utility services can generally be divided into two categories: distribution upgrades and transmission upgrades. Typically, distribution infrastructure upgrades are driven by peak demand events that occur on only a few, fairly predictable occasions each year. Transmission upgrades, on the other hand, are driven by large new interconnection requests or transmission congestion. (Rocky Mountain Institute, 2015) Table 2 gives an overview of the services.

Table 2: Utility services (Rocky Mountain Institute, 2015)

Service Name	Definition
Resources Adequacy	Instead of investing in new natural gas combustion turbines to meet generation requirements during peak electricity consumption hours, grid operators and utilities can pay for other assets, including energy storage, to incrementally defer or reduce the need for new generation capacity and minimize the risk of overinvestment in that area.
Distribution Deferral	Delaying, reducing the size of, or entirely avoiding utility investments in distribution system upgrades necessary to meet projected load growth on specific regions of the grid.
Transmisison Congestion Relief	Utilities are charged to use congested transmission corridors during certain times of the day. Assets including energy storage can be deployed downstream of congested transmission corridors to discharge during congested periods and minimize congestion in the transmission system.
Transmisison Deferral	Delaying, reducing the size of, or entirely avoiding utility investments in transmission system upgrades necessary to meet projected load growth on specific regions of the grid.

2.3 Ancillary and bulk energy services

Energy storage devices are capable of providing a suite of ancillary and energy bulk services. An overview of these services is provided and summarized in table 3.

Table 3: Ancillary and bulk energy services (Rocky Mountain Institute, 2015)

Service Name	Definition
Energy arbitrage	The purchase of wholesale electricity while the locational marginal price (LMP) of energy is low (off-peak hours) and sale of electricity back to the wholesale market when LMPs are high (peak- or mid-peak hours).
Frequency Regulation	Frequency regulation is the immediate and automatic response of power to a change in locally sensed system frequency, either from a system or from elements of the system. Regulation is required to ensure that system-wide generation is perfectly matched with system-level load on a moment-by-moment basis to avoid system-level frequency spikes or dips, which create grid instability.
Spin/Non-Spin Reserves	Spinning reserve is the generation capacity that is online and able to serve load immediately in response to an unexpected contingency event, such as an unplanned generation outage. Nonspinning reserve is generation capacity that can respond to contingency events within a short period, typically less than ten minutes, but is not instantaneously available.
Voltage Support	Voltage regulation ensures reliable and continuous electricity flow across the power grid. Voltage on the transmission- and distribution- system must be maintained within an acceptable range to ensure that both real and reactive power production are matched with demand.
Black Start	In the event of a grid outage, black start generation assets are needed to restore operation to larger power stations in order to bring the regional grid back online. In some cases, large power stations are themselves black start capable.

3 Electricity storage technologies

Energy storage technologies have developed tremendously in recent years. There are currently various electricity storage technologies available and the differences between the several electrical energy storage technologies is given in this chapter. Some of these systems are already technically mature or nearing maturity, while many others are still in the early stages of development. Figure 1 gives a structural overview of storage technologies for electricity, categorized in mechanical, thermal, chemical, electrochemical and electrical storage systems.

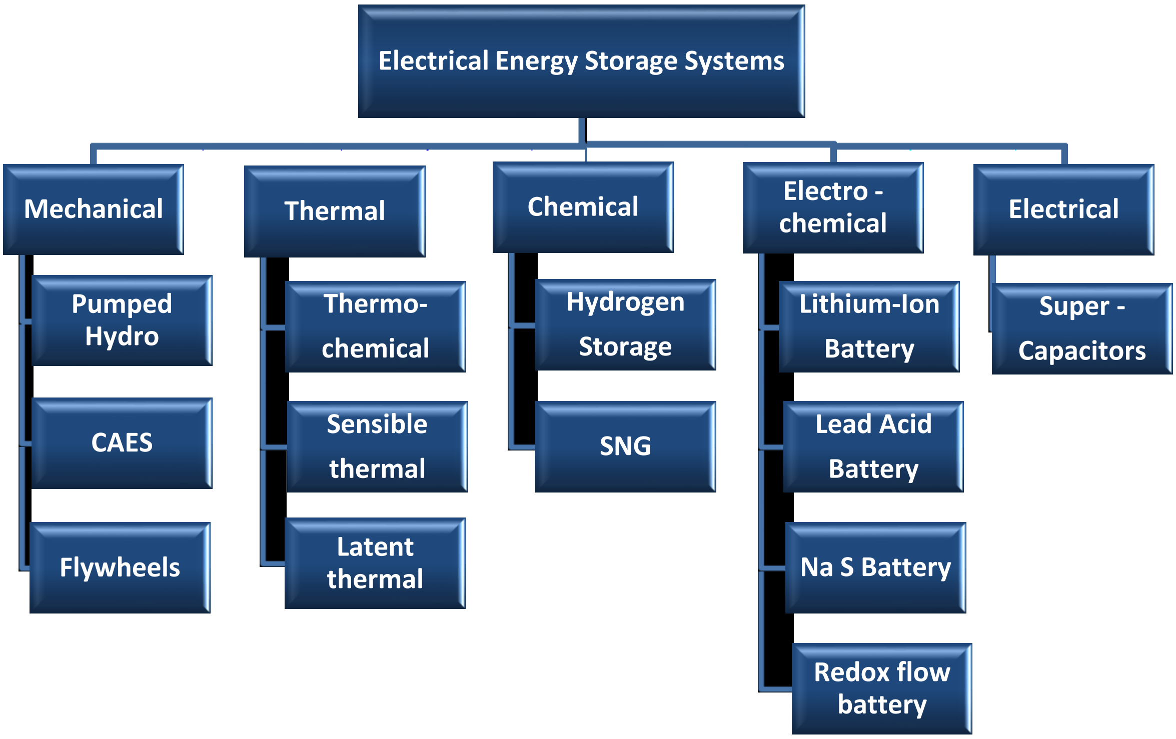

Figure 1: Electrical Energy storage technologies (World Energy Council, 2016)[1]

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[1] CAES is Compressed Air Energy Storage; LAES is Liquid Air Energy Storage; SNG is Synthetic Natural Gas; NaS battery is a Sodium–sulfur battery.

Figure 2 shows the grid-connected electricity storage capacity installed globally. Pumped hydro storage is a mature technology with known costs and a market share of 99 %. In general, project development times for PHS are long (> 6 years) and the legal framework often makes it difficult to obtain approvals.

The remaining market share of 1 % is covered by a mix of different technologies, notably CAES, sodium sulfur (NaS), lithium-ion and lead acid. Today there are only two commercialized CAES large-scale facilities in operation: Huntorf in Germany with an installed power of 320 MW and McIntosh in the US with a rated power of 110 MW. (Luo et al. 2014) Sodium sulfur batteries were popular as a large-scale energy storage technology in the USA and Japan. Japanese company Nippon Gaishi Kaisha is the world leader in NaS batteries, although demand for this technology is growing at a much slower rate than Li-ion technology. Several fire incidents and the development of alternative technologies reduced the number of NaS projects. Li-ion does not make up a large share of the existing market, but significant progress has been made to improve performance and reduce costs. (Christiansen and Murray, 2015)

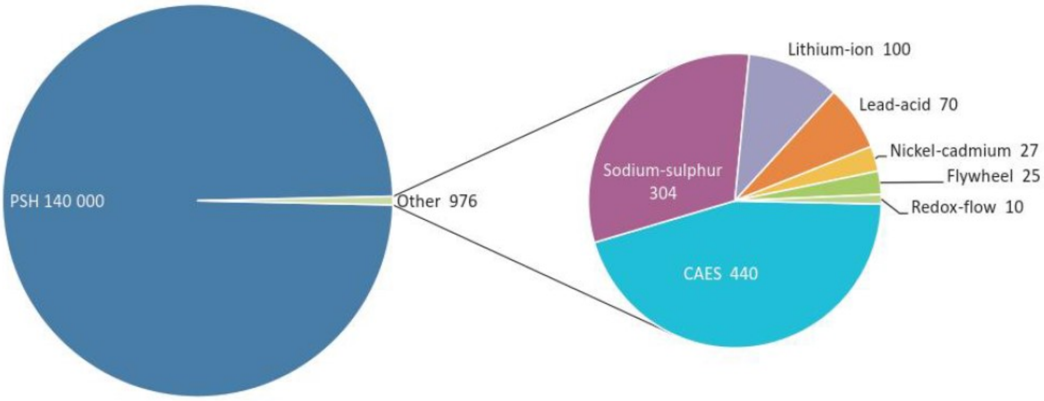


Figure 2: Global installed grid-connected electricity storage capacity (MW) (Christiansen and Murray, 2015)

3.1 Technology characteristics

Not every storage system is suitable for every application. In order to increase understanding of how to compare storage technologies, this section will explain several storage-specific parameters and characteristics.

3.1.1 Parameters

The following definitions of the parameters are adopted from the Technology Overview on Electricity Storage of (Fuchs et al., 2012).

Energy

Energy *E* is the core entity of a power system. The very purpose of power systems is the generation (conversion), transmission, distribution, consumption (conversion again) of (electrical) energy. Energy can occur in a diversity of forms, such as thermal, mechanical, electrical and chemical. With respect to storage systems, the term energy occurs as the capacity of a storage system as well as the amount of energy charged into a storage system or discharged from a storage system. The unit of energy can be *Ws* (Watt second), *Nm* (Newton meter) or *J* (Joule) and as the technically most commonly used unit kWh (Kilowatt hour).

Power

Power *P* as a physical value describes the rate of energy transfer per unit of time which can be supplied or consumed by a system. With respect to storage systems a high-power storage system is capable of releasing (or storing) its contained energy quickly. Low-power storage systems take longer to charge and discharge. The unit of power is Watt (*W*).

$$\boldsymbol{P(t)}\ [W] = \frac{\boldsymbol{dE(t)}\ [Ws]}{\boldsymbol{dt}\ \ [s]} \qquad (1)$$

Storage Capacity

The storage capacity *C* of an energy storage system is the amount of energy that can be stored by the system. The unit of the storage capacity is the same as for energy: *Ws*.

$$\boldsymbol{C}\ [Ws] = \boldsymbol{P}\ [W] * \boldsymbol{t}\ [s] \qquad (2)$$

Energy to Power ratio (E2P)

Energy to Power ratio (E2P) describes the ratio of installed capacity (energy) to installed power. Storage systems with a high E2P can deliver power for a longer time range than storage systems with a small E2P. Long-term storage systems therefore have a high E2P; short-term storage systems have a small E2P.

$$\boldsymbol{E2P}\ [s] = \frac{\boldsymbol{C}\ [Ws]}{\boldsymbol{P}\ [W]} \qquad (3)$$

Energy Density

Energy density *e* is the ratio of energy available from a storage system to its volume. The unit is e.g. Ws/m^3 or kWh/m^3. Systems with lower energy density, for example, need more space for installation. High energy density is important in mobile applications as the volume for the energy storage system is limited.

$$\boldsymbol{e}\ \left[\frac{Ws}{m^3}\right] = \frac{\boldsymbol{C}\ [Ws]}{\boldsymbol{V}\ [m^3]} \qquad (4)$$

Power Density

Power density *p* is the ratio of power available from a storage system to its volume. The unit is *W/m*^{3}. A high power density is beneficial for high power applications with short duration of power usage, like in hybrid electric vehicles e.g. for acceleration purposes, to achieve low weight and volume of the storage unit.

$$\boldsymbol{p}\ \left[\frac{W}{m^3}\right] = \frac{\boldsymbol{P}\ [W]}{\boldsymbol{V}\ [m^3]} \qquad (5)$$

Specific Energy

The specific energy *w* describes the ratio of energy delivered by the storage system in relation to its weight. The unit is *Ws/kg*. High specific energy is important for applications with weight limitations and high energy demand (e.g. electric vehicles).

$$\boldsymbol{w}\left[\frac{Ws}{kg}\right]=\frac{\boldsymbol{C}\,[Ws]}{\boldsymbol{m}\,[kg]} \qquad (6)$$

State of charge (SOC)

State of charge (SOC) is the amount of energy still remaining in the system as a percentage of usable storage capacity. The maximum SOC corresponds 100 % with a fully charged system.

Depth of Discharge (DOD)

The depth of discharge is the amount of discharge energy compared to the total storage capacity. The maximum DOD is 100%, which corresponds with a fully discharged system with no stored energy. Several storage technologies such as lead acid or Lithium-ion batteries react very sensitively to high depths of discharge which result in a diminished cycle life.

$$\boldsymbol{DOD}\,[\%]=\frac{\boldsymbol{SOC}\,[Ws]}{\boldsymbol{C}\,[Ws]} \qquad (7)$$

Efficiency

Efficiency *η* is the ratio of the output energy to the input energy. High efficiency of the systems means low losses and therefore also low costs for the compensation of these losses. High efficiency is important for systems with high cycle loads.

$$\boldsymbol{\eta}\,[\%]=\frac{\boldsymbol{E\ out}\,[Ws]}{\boldsymbol{E\ in}\,[Ws]} \qquad (8)$$

Self-Discharge

Self-discharge *SD* is the loss of energy content of a storage system due to internal processes.

Start-up time

The start-up time t_{start} is the time period from a power request until the first power delivery.

Ramp-up time

Ramp-up time t_{ramp} is the time from zero power to full power.

Ramp rate

The ramp rate r_{ramp} is the maximum power divided by the ramp-up time.

$$\boldsymbol{r_{ramp}} \left[\frac{W}{s}\right] = \frac{\boldsymbol{P}\ [W]}{\boldsymbol{t_{ramp}}\ [s]} \qquad (9)$$

Deployment time or response time

Deployment time or response time t_r is the time to reach the full power of a system starting from the point when it was requested. It is the sum of the start-up and ramp-up time. The parameters are illustrated in figure 3.

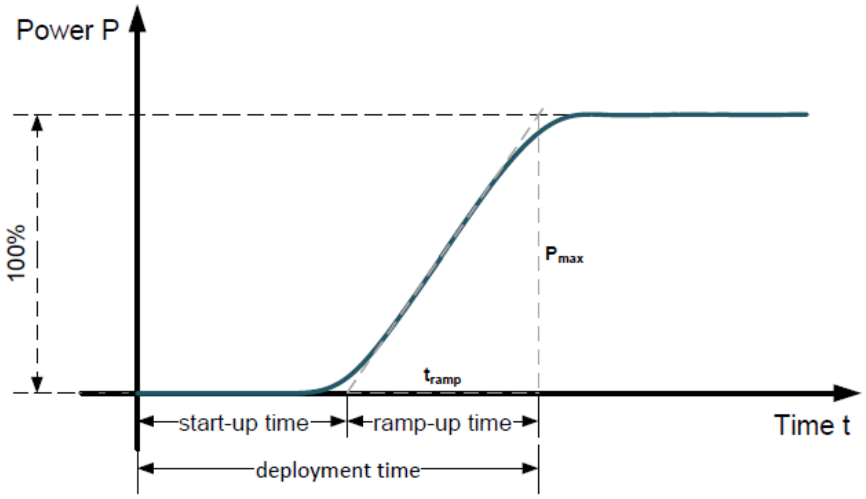


Figure 3: Storage system response (Fuchs et al., 2012)

Full Cycle

The full cycle *FC* is the complete discharging and charging process of a storage system. For example, in the case of pumped hydro, this means a complete emptying and refilling of the upper reservoir between the predefined minimum and the maximum water levels (available capacity).

Cycle life

Cycle Life *CL* is the number of full cycles which can be delivered by a storage system under specified conditions before it fails to meet specified criteria."

In addition to these definitions adopted from (Fuchs et al., 2012), the calendar lifetime is an important indicator for storage technologies.

Calendar life

The Calendar Life *CL* describes how long the battery is expected to last in terms of calendar years. It is independent of the charge and discharge cycles but is influenced by the state of charge (SOC) (Saft, 2014). Various battery technologies age very differently in terms of cycle life and calendar life.

3.1.2 Comparison and description of technologies

In figure 4 a comparison of different energy storage types is shown with regard to their discharge times, sizes (installed power) and efficiencies. Super capacitors and flywheels for example have typically low power sizes, but they operate very quickly over short times. Pumped hydro and compressed air technologies can be found in the exact opposite position of this diagram as they have large power sizes and discharge over a long period of time.

Batteries in general provide short- to medium-term storage over a wide range of output capacity. They are modular and scalable and can therefore provide any scale of power size. Furthermore, improving battery technologies are capable of for both fast and slow discharge rates. (Christiansen and Murray, 2015)

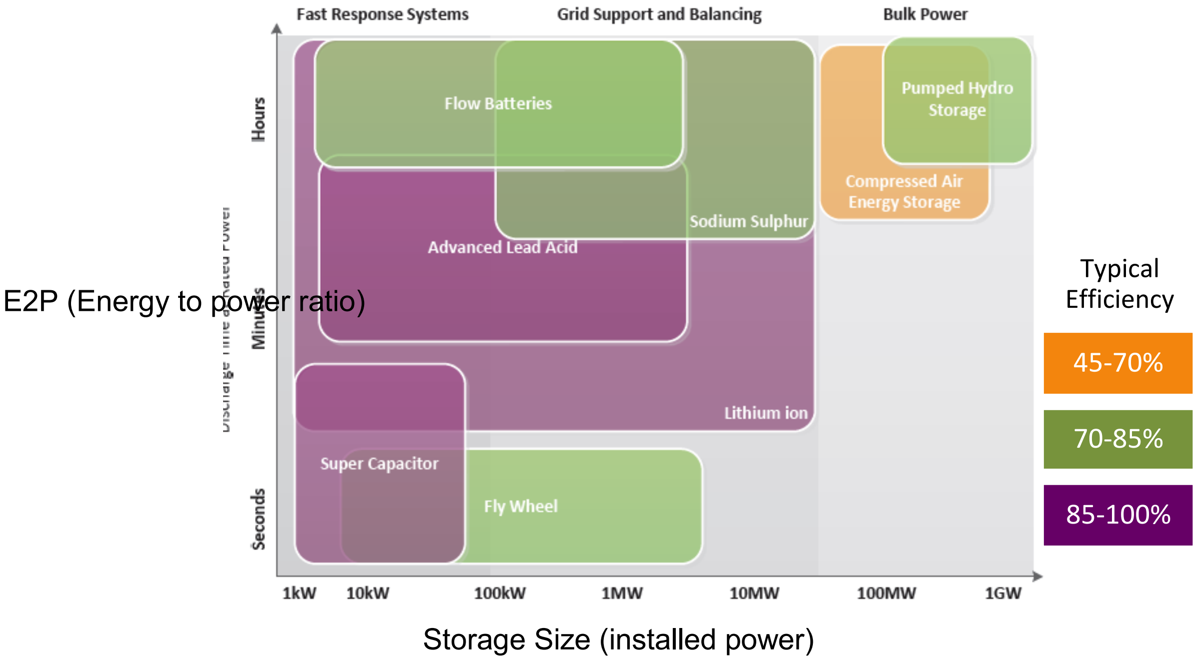


Figure 4: Electricity storage technologies comparison (Christiansen and Murray, 2015)

The following sections gives a brief overview of the main characteristics and features of the different storage technologies.

3.1.2.1 Mechanical electricity storage systems

Pumped Hydro Storage (PHS)

PHS is a technology with a long history, high technical maturity and large energy capacity. In 2012 the installed power worldwide was 127–129 GW and this represents more than 99% of worldwide bulk storage power and contributes to about 3% of global electricity generation. (IEC, 2011) (The Economist, 2012)

As shown in figure 5, a typical PHS plant uses two water reservoirs which are vertically separated. During periods of low electricity demand, the water is pumped into the higher level reservoir; during peak hours, the water can be released back into the lower level reservoir generating electricity. (Luo et al., 2015)

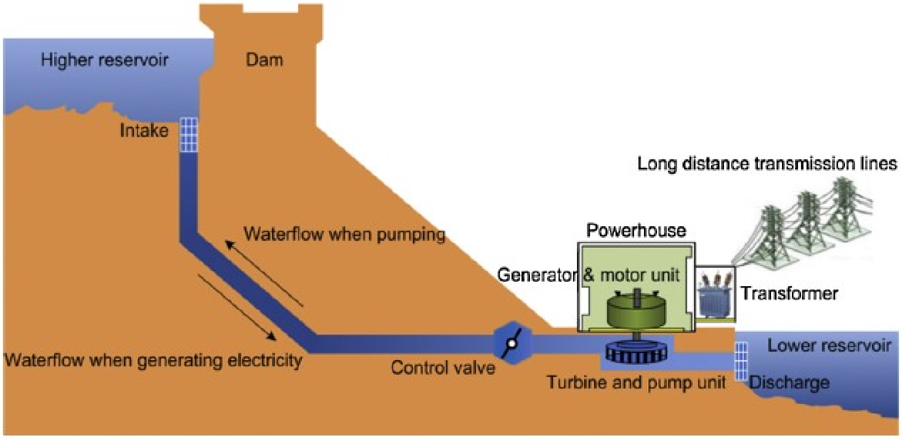


Figure 5: Pumped Hydro Storage Schema (Luo et al., 2015)

Table 4 gives an overview of the main features of pumped hydro storages, pointing out its strengths, weaknesses, opportunities and threats of this technology.

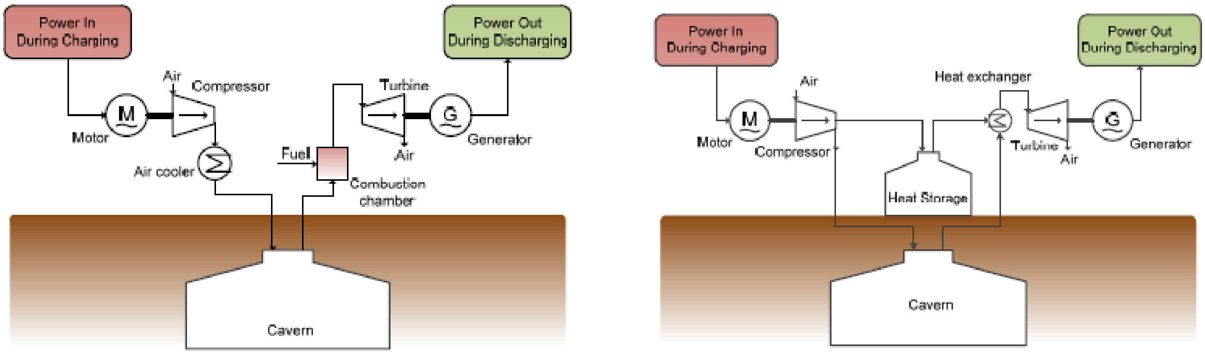
Table 4: Summary PHS (Fuchs et al., 2012)

Strengths	**Weaknesses**
- Established Technology - Long life time - Low self-Discharge - High efficiency	- Low energy density - Geographical restrictions - High investment costs - Long return of investments (> 30 years) - Only large units are economical
Opportunities	**Threats**
- Large additional potentials in Norway and Sweden, some smaller potentials elsewhere - Storage costs are very competitive compared with other storage technologies	- Long approval processes - High environmental standards to fullfill - Increasing competition from decentralized storage systems - Flexible use of hydropower represents even more competition - High Power requires connection to the transmission grid

Compressed air energy storage (CAES)

Compressed air energy storage (CAES) systems are another type of commercialized storage technology, as already mentioned in chapter 3. During periods of off-peak electricity, or over-supply, air is compressed to be stored in underground caverns or storage tanks. During the discharging process the stored compressed air is released, then it expands and cools down. Therefore, it needs to be heated by a heat source, which can be from the combustion of fossil fuel. It then drives a turbine/generator unit, which feeds power into the grid. (Luo et al., 2016)

To improve CAES efficiency and avoid the use of fossil fuels, research and development has been very active in recent years. The Advanced Adiabatic CAES (AA-CAES) system concept is a CAES combined with Thermal Energy Storage (TES), to extract heat from the stage of air compression and store it in an adiabatic reservoir. The heat is then reused for the air expansion and electricity generation process. The schema of a CAES plant (a) and an AA-CAES plant (b) is shown in Figure 7. (Luo et al., 2016)



a) b)

Figure 6: CAES and AA-CAES schema (Fuchs et al., 2012)

Table 5 gives a summary of the strengths, weaknesses, opportunities and threats of the CAES technology.

Table 5: Summary CAES technology (Fuchs et al., 2012)

Strengths	Weaknesses
- Small footprint on the surface due to underground storage - Long life of the air reservoir (caverns) and the power systems (compressors turbine) - Low self-discharge of compressed air	- Geological restrictions (caverns) - High investment costs - High self-discharge of the thermal storage - Low efficiency for diabatic CAES (< 55%) - Long return of investment (> 30 years) - Only large units are economical
Opportunities	**Threats**
- Good regional correlation between caverns and high wind areas in Germany	- Limited number of suitable sites for caverns - Competition in the use of the caverns (e.g. for gas and oil storage) - Increasing competition from decentralized storage systems - High Power requires connection to the transmission grid

Flywheels

Flywheels store electricity as rotational energy which is maintained in the flywheel by keeping the rotating body at a constant speed. Increasing the speed results in more energy which is stored in the flywheel. The flywheel is discharged by slowing the rotor, releasing quick bursts of energy (high power and short duration). (International Electrotechnical Comission) The following figure 7 shows the schema of a flywheel system and table 6 gives an overview of the main features of the flywheel technology.

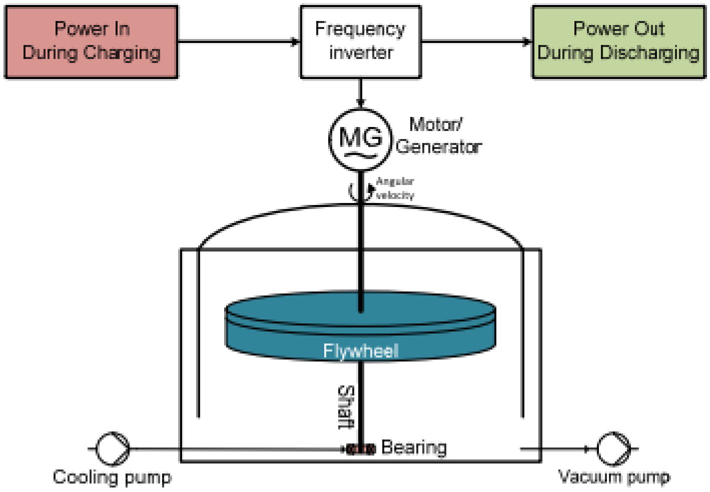


Figure 7: Flywheel schema (Fuchs et al. 2012)

Table 6: Summary Flywheel (Fuchs et al., 2012)

Strengths

- Well established in UPS (uniterruptible power supply) systems
- Already used in frequency control

Weaknesses

- Low energy density
- Vacuum chamber needed
- Safety reasons : cracks can occur due to dynamic load, bearing failure on the supports, external shocks
- Cooling system for superconducting bearings
- High self-discharge

Opportunities

- Fast charge capability
- Low maintenance requirements
- Long lifetime

-Better composite materials may allow higher rotational speed and therefore increased energy density

Threats

- In competition with cheaper techologies

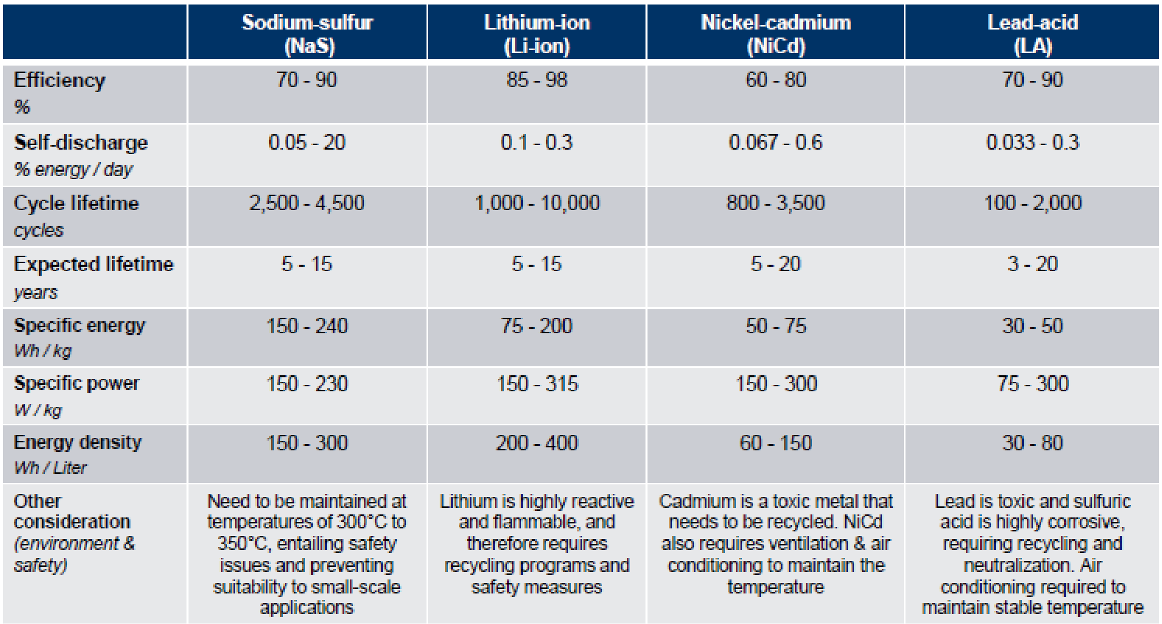
-Increase in efficiency is not reached yet

3.1.2.2 Electrochemical electricity storage systems

Electrochemical electricity storage systems consist of a number of electrochemical cells connected in series or parallel. The cells contain two electrodes (one anode and one cathode) with an electrolyte which can be at solid, liquid or ropy/viscous state. Electricity is produced via an electrochemical reaction. A cell can bi-directionally convert energy between electrical and chemical energy. While discharging, the electrochemical reactions occur on both anode and cathode simultaneously. On the external circuit, electrons are provided from the anodes and are collected at the cathodes. During the charging process, the reactions are reversed and the battery is recharged by applying an external voltage to the two electrodes. (Luo et al. 2015)

Various different electrochemical technologies are currently under development and have reached different stages of maturity. This section serves to give an overview of the main features of different battery technologies. Table 7 compares the technical performances of the most common battery types.

Table 7: Comparison of different battery technologies (Beswetherick, 2013) [2]



	Sodium-sulfur (NaS)	Lithium-ion (Li-ion)	Nickel-cadmium (NiCd)	Lead-acid (LA)
Efficiency *%*	70 - 90	85 - 98	60 - 80	70 - 90
Self-discharge *% energy / day*	0.05 - 20	0.1 - 0.3	0.067 - 0.6	0.033 - 0.3
Cycle lifetime *cycles*	2,500 - 4,500	1,000 - 10,000	800 - 3,500	100 - 2,000
Expected lifetime *years*	5 - 15	5 - 15	5 - 20	3 - 20
Specific energy *Wh / kg*	150 - 240	75 - 200	50 - 75	30 - 50
Specific power *W / kg*	150 - 230	150 - 315	150 - 300	75 - 300
Energy density *Wh / Liter*	150 - 300	200 - 400	60 - 150	30 - 80
Other consideration *(environment & safety)*	Need to be maintained at temperatures of 300°C to 350°C, entailing safety issues and preventing suitability to small-scale applications	Lithium is highly reactive and flammable, and therefore requires recycling programs and safety measures	Cadmium is a toxic metal that needs to be recycled. NiCd also requires ventilation & air conditioning to maintain the temperature	Lead is toxic and sulfuric acid is highly corrosive, requiring recycling and neutralization. Air conditioning required to maintain stable temperature

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[2] Table 7 is for comparative purposes only since battery storage technologies improve rapidly and these figures may not be totally reflective of all current applications.

Lithium-ion

Lithium-ion batteries have historically been used in the electronics and transportation industries. In recent years, rapid technological improvements have been made, along with significant cost reductions. This makes Li-ion batteries one of the most promising emerging battery technologies with abundant applications. Large scale electric vehicle (EV) manufacturing and recent developments (by the US company Tesla in particular) are thought to be driving drastic price reductions in Li-ion batteries, which should have an effect on all their applications. (Christiansen and Murray, 2015)

A lithium-ion battery consists of a positive electrode made of lithiated metal oxide and a negative electrode which is composed of layered graphitic carbon in the majority of Li-ion batteries produced today. The electrolyte is a non-aqueous organic liquid containing dissolved lithium salts, such as $LiClO_4$. (Luo et al. 2015)

While charging the battery, lithium-ions move from the positive to the negative electrode and are intercalated into the graphite layers. During the discharging process, the lithium-ions move to the positive electrode and are intercalated in the crystal structure. (Fuchs et al., 2012) Figure 8 shows the principle schema of the charging and discharging process.

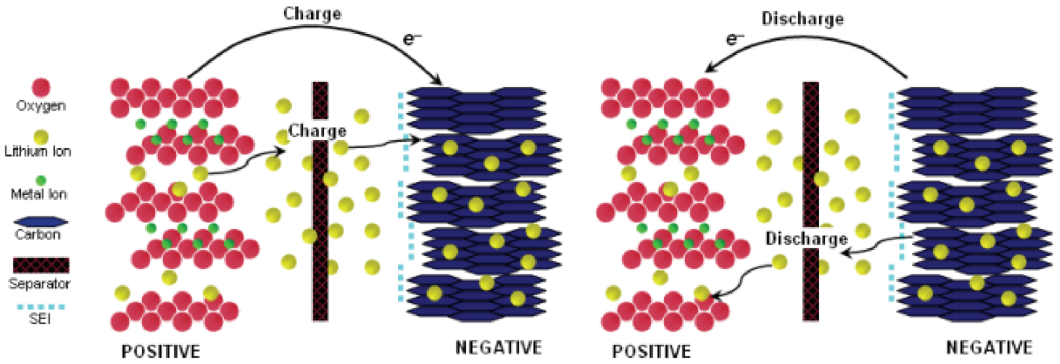

Figure 8: Principle schema of the Li-ion battery (McDowall, 2008)

The following equation (10) describes the chemical reaction on the positive electrode and equation (11) explains the reaction on the negative electrode; both are for the discharging process. The overall reaction is shown in equation (12). The reverse processes occur when the battery is charged. In the equations below, the negative electrode consits of carbon and the positiv electrode consits of Lithium cobalt oxide as this configuration is used in the majority of commercial Li-ion batteries. (Nitta et al., 2015)

$$Li_{1-x}CoO_2 + x\,Li^+ + xe^- \rightarrow LiCoO_2 \tag{10}$$

$$Li_xC_6 \rightarrow xLi^+ + xe^- + 6C \tag{11}$$

$$Li_{1-x}CoO_2 + L_xC_6 \rightarrow LiCoO_2 + C_6 \tag{12}$$

In general the Li-ion battery is considered a good candidate for applications where the response time, small dimensions and/or weight of equipment are important. (Luo et al., 2015) Table 8 gives a summary of the main features of the lithium-ion battery.

Table 8: Summary Li-Ion battery (Fuchs et al., 2012)

Strengths	Weaknesses
- High energy density - Long lifetime - High performance	- No inherent security (thermal runaway) - Sophisticated battery management system required (single cell monitoring) - Packaging and cooling costly depending on the cell shape - High costs - Only large units are economical
Opportunities	**Threats**
- High number of items in the automotive industry lead to faster cost reduction - No special requirements for storage location (no gasing) - Lithium ion battery models can be used in so-called "second life" applications	- Lithium resources limited to only a few countries - High energy and power densities represent a low added value in most staionary applications. - Safety issues

Lead Acid

Lead acid batteries were invented over 150 years ago and are the most commonly used type of rechargeable batteries. They are low cost and used in numerous applications including vehicles, off-grid power systems, uninterruptible power supplies and many more. (Christiansen and Murray, 2015) A lead acid battery consists of a cathode which consists of PbO_2, an anode which is made of Pb, and sulfuric acid which serves as an electrolyte. Figure 9 illustrates the schema of the lead acid battery technology.

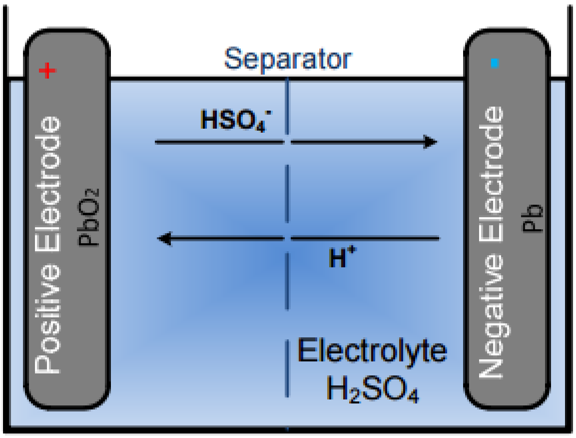

Figure 9: Lead acid battery technology schema (Fuchs et al., 2012)

Equation (13) shows the electrochemical reaction on the negative electrode and equation (14) describes the electrochemical reaction on the positive electrode, both for discharging the lead battery. Equation (15) shows the overall reaction. The reverse reactions occur, when the battery is charged.

$$Pb(s) + HSO_4{}^-(aq) \rightarrow PbSO_4(s) + H^+(aq) + 2e^- \qquad (13)$$

$$PbO_2(s) + 3H^+(aq) + \ HSO_4{}^-(aq) + 2e^{-1} \rightarrow PbSO_4(s) + 2H_2O(l) \qquad (14)$$

$$PbO_2(s) + Pb(s) + 2H_2SO_4(aq) \rightarrow 2PbSO_4(s) + 2H_2O(l) \qquad (15)$$

The so-called advanced lead acid battery technology was developed to increase efficiency, lifetime and partial state-of-charge operability. It is an emerging technology with increasing and larger-scale applications, but at a higher cost than traditional lead acid batteries (Christiansen and Murray, 2015). Table 9 shows the main features of lead acid technology.

Table 9: Summary lead acid battery (Fuchs et al., 2012)

Strengths	Weaknesses
- Already high number of applications - Acceptable energy and power density for stationary application - Inherent safety by controlled overcharged reaction - No complex cell management needed - Experience with large storage - Short amortization period	- Charging and discharging ability is not symmetrical - Ventilation required - Limited life cycle - Industrial batteries are still not built with fully automatic systems
Opportunities	**Threats**
- Significant cost savings possible through fully automated mass production - Large number of manufacturers around the world	- Prohibition of the use of the heavy metal lead - Limitations on lead deposits - Insufficient R&D capabilites available

Sodium Sulfur

In sodium sulfur batteries the two electrodes consist of molten sodium and molten sulfur. Beta alumina serves as solid electrolyte. Sodium sulfur batteries are classified as ‘high temperature’ batteries because the reactions normally require a temperature of 574–624 Kelvin to ensure the electrodes are in liquid states, which leads to a high reactivity. (Luo et al., 2015) Figure 10 demonstrates the charge and discharge process of a sodium sulfur battery.

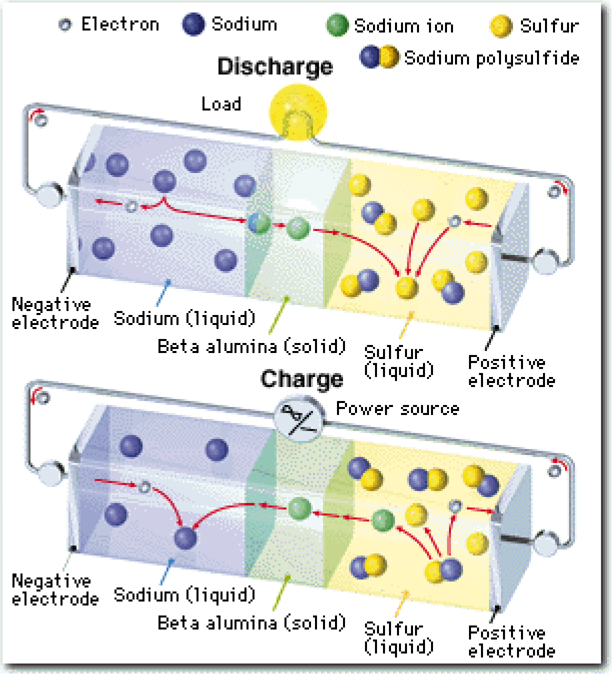

Figure 10: Sodium sulfur battery schema (Green car congress, 2006)

The discharge process can be described as shown in equation (16). While discharging, the sodium level in the cell drops. The reverse process occurs during the charging phase. The heat produced by charging and discharging cycles is sufficient to maintain operating temperatures and usually no external source is required. (Oshima et al., 2005)

$$2Na + 4S \rightarrow Na_2S_4 \qquad (16)$$

The sodium sulfur battery technology has a high power and energy density – more than four times higher than for lead acid batteries. (Christiansen and Murray, 2015) It uses inexpensive, non-toxic materials leading to high recyclability (99%). (Luo et al., 2015). The strengths, weaknesses, opportunities and the threats of this technology are summarized in table 10.

Table 10: Summary sodium sulfur batteries (Fuchs et al., 2012)

Strengths	Weaknesses
- High energy density - High cycle and calendar lifetime - Cheap raw materials (NaS) - Many staionary plants existing	- High thermal standby losses - Hazard potential due to high operating temperature
Opportunities	**Threats**
- Many patents expiring - No special site requirements - No or almost no restricitions of available raw materials	- Competition with lead acid and lithium-ion batteries - Safety issues (fire incidents) with NaS batteries

Redox flow batteries

Unlike conventional batteries, Redox flow batteries contain two electrolyte solutions in two separate tanks, circulating through two independent loops. The charging and discharging operation is based on reduction-oxidation reactions of the electrolyte solutions. While charging the battery, one of the electrolytes is oxidized at the anode and the other electrolyte is reduced at the cathode. This process is reversed in the discharging phase to convert the chemical energy stored in the electrolyte into electrical energy. The schema of a flow battery is shown in figure 11.

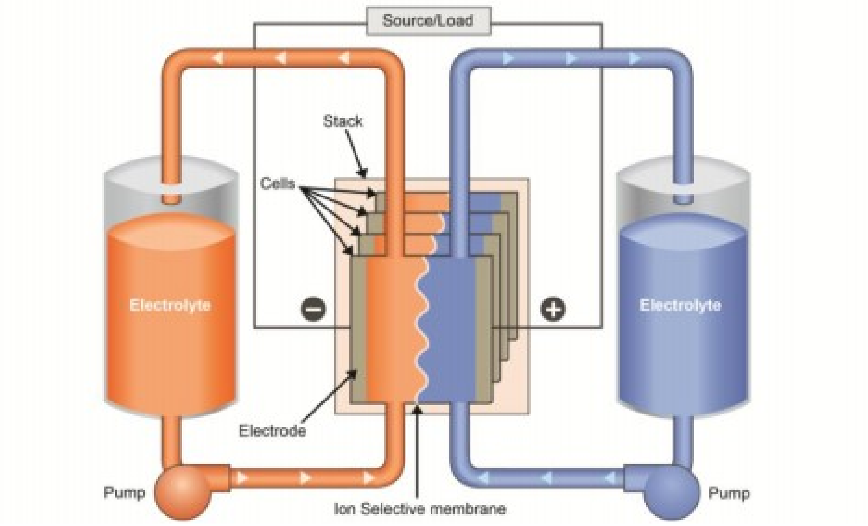

Figure 11: Schema flow battery (Beswetherick, 2013)

At the moment there are several types of flow batteries under development which can be categorized by the chemical composition of their electrolyte. The most important are the vanadium redox battery (VRB) and the zinc bromine battery (Zn/Br). For the following explanations, the VRB is taken as an example in order to demonstrate how a redox flow battery works. This battery type stores energy by using vanadium redox couples ($V2^+/V3^+$ and $V4^+/V5^+$) in two electrolyte tanks (Fig. 11). VRBs exploit the vanadium in these four oxidation states which makes the flow battery have only one active element. (Yang et al., 2011). H^+ are exchanged through an ion selective membrane during charge and discharge. The chemical reactions of a vanadium redox battery on the negative electrode can be described with equation (17) and the chemical reactions on the positive electrode are shown in equation (18).

$$V^{4+} \rightarrow V^{5+} + e^- \qquad (17)$$

$$V^{3+} + e^- \rightarrow V^{2+} \qquad (18)$$

An essential advantage of this technology is that the power of a flow battery energy storage system is independent from the storage capacity since the power is determined by the size of the electrodes and the number of cells in the stack, whereas the capacity only depends on the amount of electrolyte. (Luo et al., 2015) Table 11 gives an overview of the features of flow batteries.

Table 11: Summary redox flow battery (Fuchs et al., 2012)

Strengths	**Weaknesses**
- Scalable independent of energy and power - High life cycle - Variety of chemical compositions possible	- Leakage caused by acidic fluids - Life of the cell stack is limited - Costs for vanadium-based redox solution is too high - Pumps and valves are prone to errors and costly maintenance
Opportunities	**Threats**
- Cost reduction can be achieved due to larger cell stacks - No restrictions for storage location -Many patents expiring, so that new producers can increase the competitive pressure	- Legal approval problems for large systems with large amounts of acid -Vanadium is a limited ressource - A lot of R&D effort necessary to obtain favorable redox pairs

3.1.2.3 Chemical electricity storage systems

Hydrogen storage

Hydrogen storage technology uses hydrogen as an energy carrier to store electrical energy. The use of a water electrolysis unit is a common way to produce hydrogen, which is subsequently stored in high-pressure containers and/or transmitted by pipelines for later use. The discharge process consists of re-converting the chemical hydrogen into the desired end-use form.

One of the biggest hydrogen storage plants of the world was inaugurated in 2015 in Mainz, Germany. It is situated next to a wind park with 10 MW installed power. The plant is equipped with a 6 MW electrolyzer (3 stacks à 2 MW peak) and a hydrogen storage capacity of 33 MWh. In times of excess electricity production from the wind park, hydrogen is produced via the water electrolysis unit and can be stored and reused when needed.[3] (Siemens, 2015) The following table 12 serves to give an overview of the features of Hydrogen storage.

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[3] For further information: http://www.energiepark-mainz.de/, Accessed: 17 August 2016

Table 12: Summary hydrogen storage (Fuchs et al., 2012)

Strengths	**Weaknesses**
- Large amounts of energy can be stored - Water for electrolysis available in unlimited quantities - "Low footprint" because of underground storage	- High costs for electrolyzers - Low efficiency (less relevant for long-term storage) -Hydrogen is very diffusive
Opportunities	**Threats**
- A realsitic option for long term storage of electricity - Progress in the field of high-pressure electrolyzers is excpected - Synergies with the development of new power plants processes which use hydrogen-rich gas - Hydrogen can also be used in other energy sectors	-Operating costs strongly depent on the price of purchased power due to low efficiency - Competition in the use of suitable caverns - Safety issues

Synthetic gas storage, also known as power-to-gas, is another technique that produces chemical hydrogen through an electrolysis process followed by a methanation process, where the hydrogen is used to synthesize methane as shown in equation (19). The gas can then be transported in the natural gas networks (when adjusted to gas norms) or be stored in CH_4 storages like tanks, caverns etc.

$$CO_2 + 4\,H_2 \rightarrow \; CH_4 \; + \; 2H_2O \qquad (19)$$

3.1.2.4 Electrical electricity storage systems

Supercapacitors

This technology stores energy in large electrostatic fields between two conductive plates, which are separated by a small distance. The electricity can be released very quickly and, due to the absence of any chemical reaction (unlike batteries), they have a high number of cycles in a lifetime (up to 100,000). Furthermore, supercapacitors are used in voltage- and frequency-regulation as well as energy recovery on locomotive breaking systems (Christiansen and Murray, 2015). Research and development in this technology has been very active in recent years with a focus on the development of materials for chemical capacitive energy storage.

As shown in figure 12, supercapacitors contain two conductor electrodes, an electrolyte and a porous membrane separator. Energy is stored in the form of static charge on the surfaces between the electrolyte and the two conductor electrodes. (Luo et al., 2015)

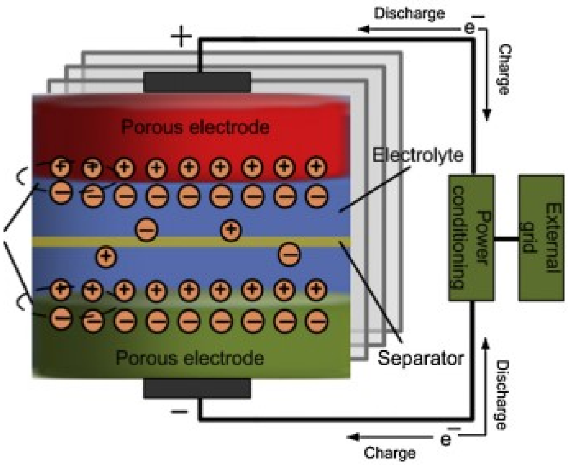


Figure 12: Schema of a supercapacitor (Luo et al., 2015)

Table 13 summarizes the basic features of supercapacitors.

Table 13: Summary Supercapacitors (Fuchs et al., 2012)

Strengths	Weaknesses
- High efficiency - High power capacity - Long lifetime cycle	- Low energy density - High costs
Opportunities	**Threats**
- Applications with high power demand and cycle load	-In competition with high power lithium-ion battery for high power applications

Superconducting magnetic energy storage (SMES)

Superconducting magnetic energy storage systems store energy in a magnetic field. The flow of direct current (DC) electricity into a super-cooled coil results in a magnetic field. In low temperature superconducting materials, electric currents encounter almost no resistance, so they can cycle through the coil of superconducting wire for a long time while losing very little energy. In the discharging process, SMES react almost instantaneously and possess a very high cycle life. However, to keep the system at low temperatures a lot of energy is required. Due to this complexity, SME storages are currently at an early demonstration phase. (Beswetherick, 2013). Figure 13 shows the setup of SMES system.

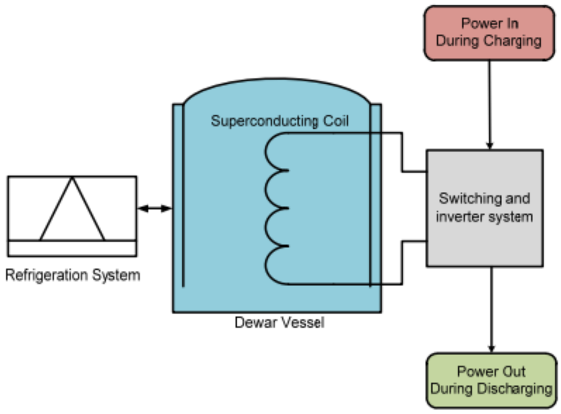


Figure 13: Setup of a SMES system (Fuchs et al., 2012)

The most important features of the SMES are summarized in table 14.

Table 14: Summary Superconducting magnetic storage (Fuchs et al., 2012)

Strengths	**Weaknesses**
- High power capability - High cycle life	- High cooling demand - Expensive raw materials for superconductors - Complicated inverter design
Opportunities	**Threats**
- New superconductive materials	-Security requirements due to very low temperatures and high magnetic fields

3.2 Institut Français du Pétrole Énergies nouvelles (IFPEN) Technologies

Regarding storage sizes, small-scale storages such as for residential and for micro grids are technologically well addressed by battery technologies such as lithium-ion. Large scale storage is covered by pumped hydro storage, but intermediary energy storage technology in the range of 0, 1 – 20 MW and 4 - 8 hours of rated discharge time is lacking. IFPEN has investigated this opportunity and chosen to start innovation projects for redox flow battery and advanced adiabatic compressed air energy storage (AA CAES) development.

The main advantages of redox flow batteries were already presented in the technology overview in the previous chapter. Regarding development and research activities, IFPEN is focusing on reducing costs with the help of less expensive electrolytes and/or membranes. There are currently several chemical compositions under development which have strong potential to significantly reduce costs for raw materials compared to common vanadium-based solutions. Promising compositions are iron-based or organic molecule redox couples such as quinones. Another R&D focus is on improving round-trip efficiency, which is one of the technology’s main weaknesses.

The AA CAES is expected to be a cheap technology on paper, but this could not yet be confirmed since the world’s first AA CAES demonstration plant called ADELE, in Germany, is still under construction. (Luo et al., 2014) Regarding this technology, IFPEN is focusing its development efforts on an innovative thermal management in order to improve the efficiency of the system.

4 Market overview

As already mentioned in the introduction, the energy storage market is an emerging market. The growing focus on producing clean energy all over the world results in more and more unpredictable daily and seasonal variations in power production which is a great challenge for the power grid.

Driven by policy and technological-progress, renewable energy has been installed at unprecedented rates in recent years. This is particularly true of variable renewable energy like wind and solar PV. In the period from 2006 to 2012, solar PV and wind energy experienced an annual capacity growth rate worldwide of 190% and 40% respectively. They both present the fastest growth of all types of renewable energy. (IRENA, 2015b)

The growth in fluctuating renewable energy is expected to continue. The International Renewable Energy Agency's (IRENA) global renewable energy road map analyzed the possibility of doubling the global share of renewable energy by 2030. Its authors foresee win -and solar power growing to 1,635 and 1,250 GW. (IRENA, 2014) This would mean installed wind power would be five times and installed PV power would be nine times higher than in 2013 (REN21, 2014).

Energy storage systems are considered a key technology to meet the challenges of intermittent power sources, since energy can be stored and then converted into electricity when needed. As can be seen in the previous chapter, there is a wide variety of technologies available, but no clear pattern or preferred application has yet emerged. Local policies and regulatory frameworks have a strong influence on the application of a storage system and they vary widely across countries and complicate the development of business models for storage applications (IRENA, 2015a).

Figure 14 shows the total operational battery projects by country, where the yellow bar represents the number of projects and the purple bar the capacity commissioned. The United States is the leading country in this comparison of the number of projects. However, the capacity commissioned in Japan is higher than in any other country. This indicates that the average project size in Japan is significantly larger than the average project size in other countries.

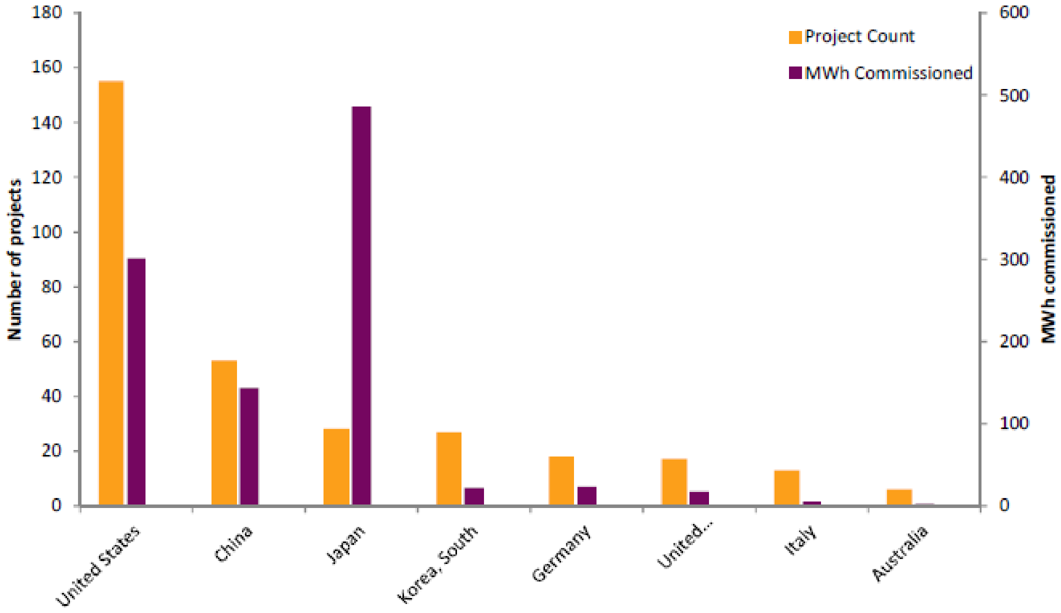


Figure 14: Total operational battery projects by country (Christiansen and Murray, 2015)

As already explained in the introduction, markets which are economically viable today are those where the regulatory framework subsidizes storage solutions and off grid areas with high penetration of renewable energies. Storage monetization and valorization strongly depends on the specific use cases and this is the reason why related business models are still not available.

Regarding the immaturity of the storage market and the difficulties faced to valorize storage systems, the recommended approach is to examine holistic case studies, rather than place faith in generic cost estimations. The best way to understand the value of storage is to consider specific applications, or else specific services, being offered by storage. It is also important that these case studies are not examined in a geographic vacuum, as it is the local energy market that critically determines the revenue available for each service. (World Energy Council, 2016) IFPEN decided to follow the approach via case studies.

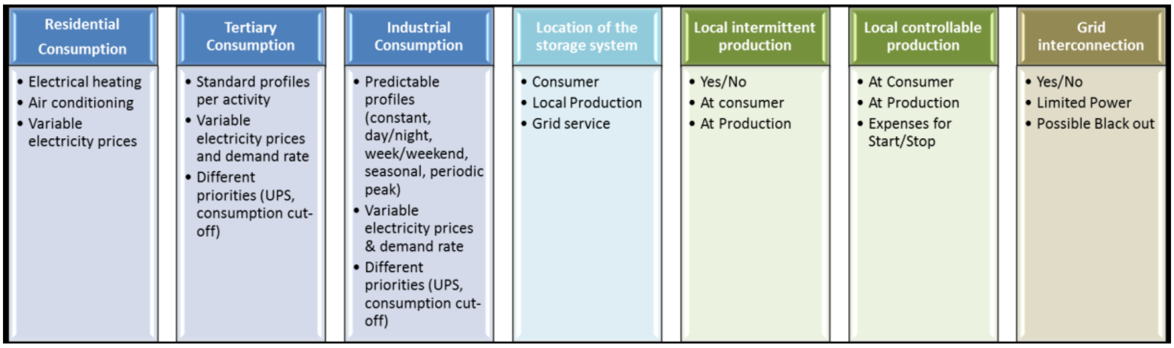
5 Analysis of existing cases of use

Electricity storage system valorization depends heavily on the context of its application. In the following first approach, a method was developed in order to categorize existing storage case studies all over the world into case groups. This method consists of specific modules which separate each use case into components which help to characterize and categorize it in a group.

Existing electricity storage case studies were screened and analyzed for similarities and for parameters that allow to distinguish them. The parameters which were identified to organize the cases are listed below.

- Grid interconnection
- Electricity generation
- Electricity consumption
- Location of the storage system

Figure 15 explains the characteristics of each of these parameters. The parameters have to be checked on the existing case studies in order to create an evaluation table which permits them to be categorized into groups.



Residential Consumption	Tertiary Consumption	Industrial Consumption	Location of the storage system	Local intermittent production	Local controllable production	Grid interconnection
• Electrical heating • Air conditioning • Variable electricity prices	• Standard profiles per activity • Variable electricity prices and demand rate • Different priorities (UPS, consumption cut-off)	• Predictable profiles (constant, day/night, week/weekend, seasonal, periodic peak) • Variable electricity prices & demand rate • Different priorities (UPS, consumption cut-off)	• Consumer • Local Production • Grid service	• Yes/No • At consumer • At Production	• At Consumer • At Production • Expenses for Start/Stop	• Yes/No • Limited Power • Possible Black out

Figure 15: Method for organizing the case studies in groups

This method was then tested on 47 storage projects, 23 from the Department of Energy's Global Energy Storage Database[4] and 24 from a literature review and the internet.

For this test, the cases from the Department of Energy Global Database were filtered for the following parameters:

- Storage projects which are verified by the DOE
- Confirmation date of the project was no older than 2012
- Electro-chemical storage technology type
- Duration of rated power: > 4h
- Rated power: > 100kW

These 47 cases were screened for the parameters illustrated in figure 15 in order to verify if each of the cases can be described by this approach. The evaluation table of this process can be found in the annexes on page IV. The result was that 46 out of 47 cases could be categorized by the method and for one case of use it was not possible because the information available was not sufficient.

Based on the evaluation table, the following three case groups could be identified.

- Non grid-connected zones
- Grid-connected zones with intermittent electricity production
- Grid-connected zones without intermittent electricity production

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[4] http://www.energystorageexchange.org/. Accessed 17 August 2016

6 Case study industrial park

This case study is located in an industrial park in the north of France and it can be classified in the case group “grid-connected zone without intermittent electricity production”. The zone consists of 180 companies with activities in different sectors.

It was decided to conduct the technical-economical study for the application of an electrical storage system on a reduced scale of 4 companies with 5 industrial sites. The study will be executed with the help of the Distributed Energy Resources Customer Adoption Model (DER-CAM) which is an economic and environmental optimization program for buildings and micro grids developed by Berkeley Lab since 2000.

“*DER-CAM is a mixed integer program formulated in GAMS* [5] *(General Algebraic Modeling System). The objective function to be minimized is the annual cost of providing energy services to a site, through either utility electricity and gas purchases or DER operation (or a combination of both) in total dollars for a test year. The test year is typically a recent historic year. The objective function value is an annuity based on the estimated annual costs of electricity purchases, gas purchases, operating and maintenance costs and the amortized costs of DER equipment.*” (Bailey et al., 2003 p. 26)

Key inputs to the model are (Stadler et al.):

- Customers end use hourly load defined over three day types: week days, weekend-days and peak/outlier days per month (only one load curve can be considered)
- Customer’s electricity tariff, natural gas prices, and other relevant price data
- Capital costs, operation and maintenance (O&M) costs, and fuel costs of the various available technologies, together with the interest rate on customer investment and maximum allowed payback
- Basic technical performance indicators of generation and storage technologies

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[5] The General Algebraic Modeling System (GAMS) is a modeling system for mathematical programming and optimization. Further information: https://www.gams.com/, Accessed 17 August 2016

The key outputs to be determined by the optimization model are:

- Optimal capacity of on-site distributed energy resources
- Optimized strategic dispatch of all distributed energy resources
- Detailed economic results, including costs of energy supply and all distributed energy resources - related costs.

6.2 Structure of the case study industrial park

Due to the limitation that only one load curve can be considered in DER-CAM, it was decided to realize six different cases, one consumption pool configuration as illustrated in figure 16 and five individual configurations, as illustrated in figure 17. CPR, CPB, RP, CPC and SKF are the names of the production sites.

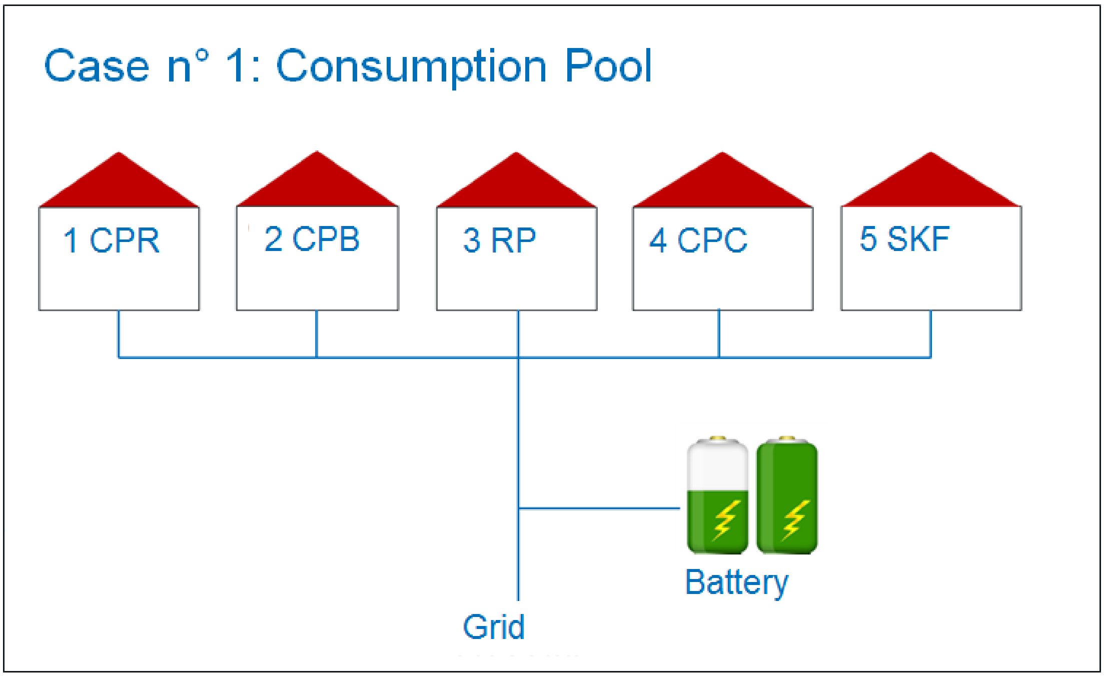

Figure 16: Configuration consumption Pool

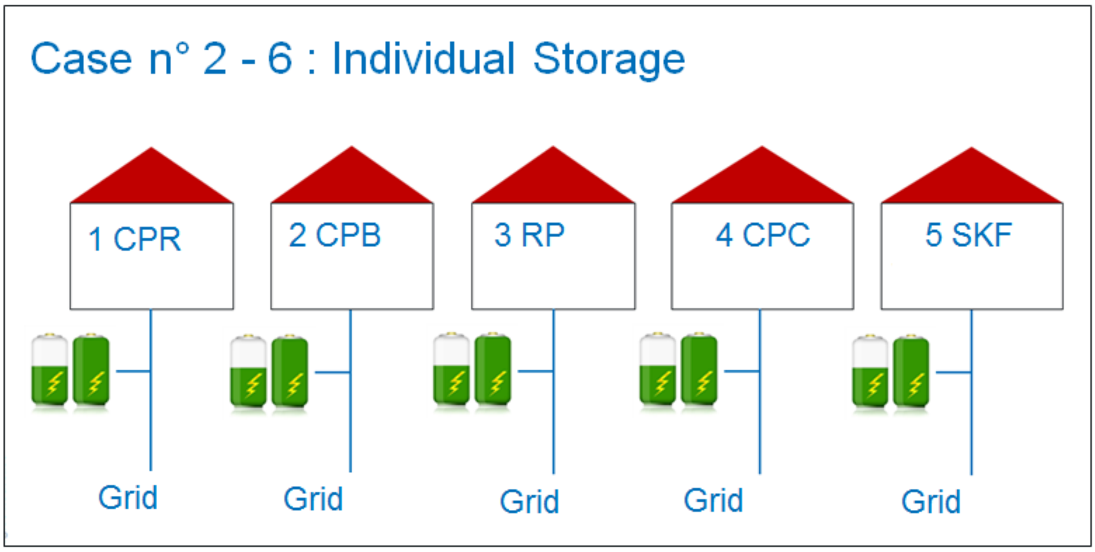

Figure 17: Configuration individual storage

The five industrial sites have very different loads and sizes. The list below gives an overview over the production routine.

CPR:

- Maximal load: 1,7 MW
- Consumption per year: 4.000 MWh
- Typical production on weekdays from 06:00-22:00; no production on weekends

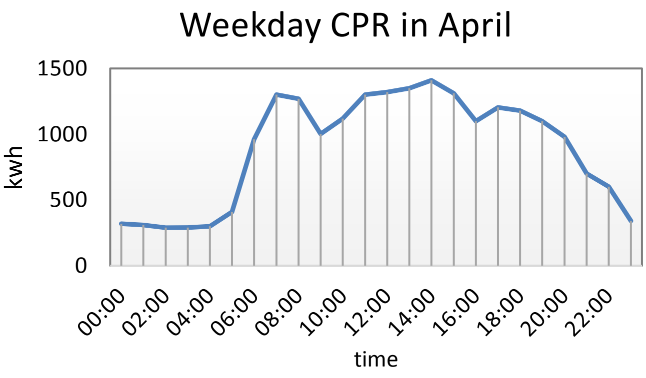

Figure 18: Example load curve weekday CPR in April

CPB:

- Maximal load: 0.4 MW
- Consumption per year: 830 MWh
- Typical production on weekdays from: 06:00-20:00; no production on weekends

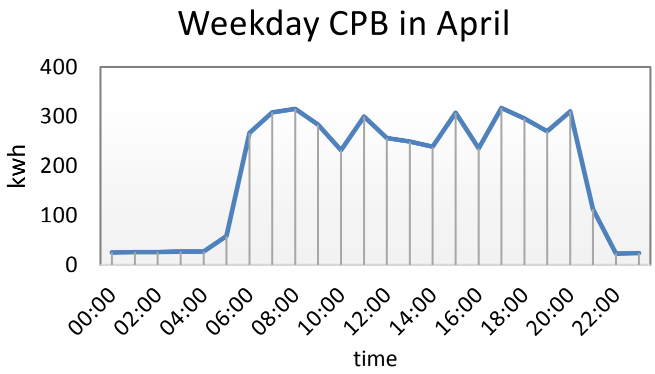

Figure 19: Example load curve weekday CPB in April

RP:

- Maximal load: 0.8 MW
- Consumption per year: 4.600 MWh
- Production on weekdays is constant; production on weekends is constant

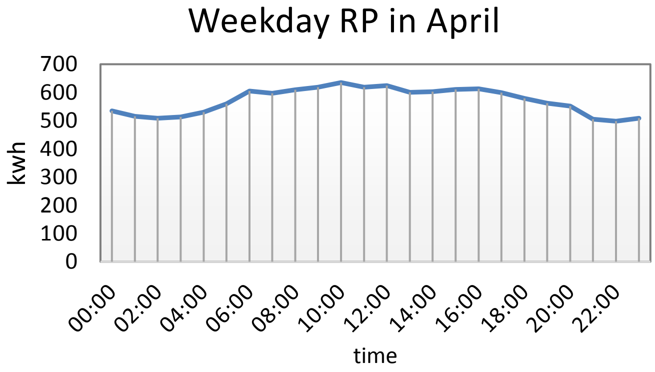

Figure 20: Example load curve weekday RP in April

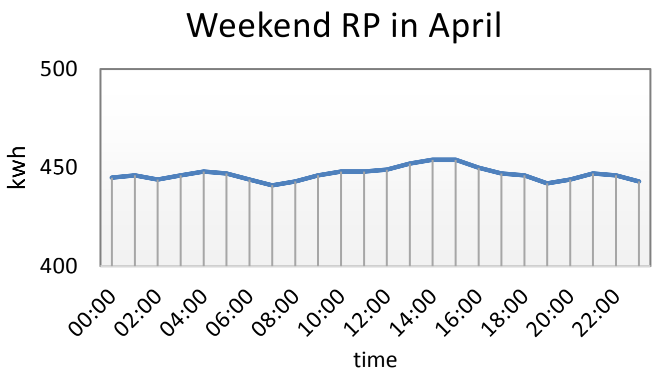

Figure 21: Example load curve weekend RP in April

CPC:

- Maximal load: 0.77 MW
- Consumption per year: 2,600 MWh
- Production on weekdays is constant; production on Saturdays but not on Sundays

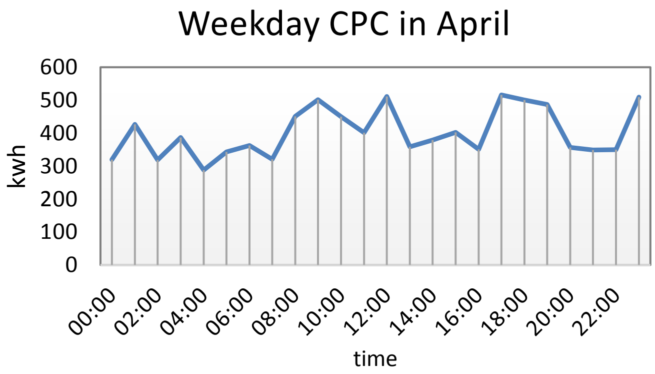

Figure 22: Example load curve weekday CPC in April

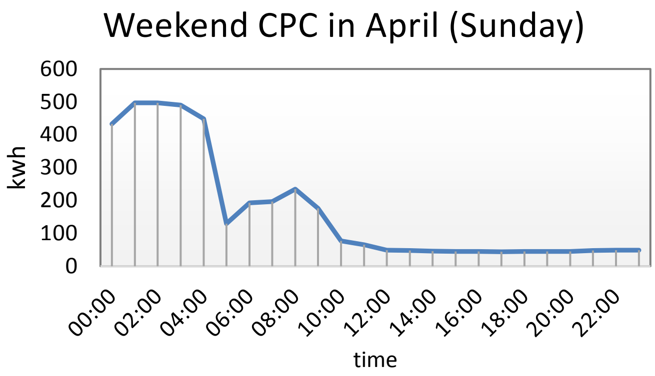

Figure 23: Example load curve weekend CPC in April

SKF:

- Maximal load: 1.9 MW
- Consumption per year: 11,100 MWh
- Production on weekdays is constant; production on weekends is constant

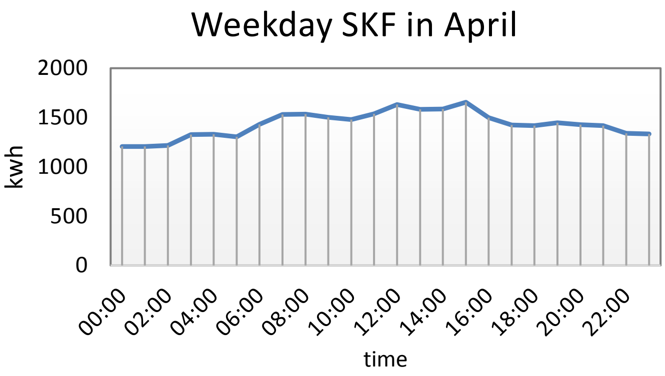

Figure 24: Example load curve weekday SKF in April

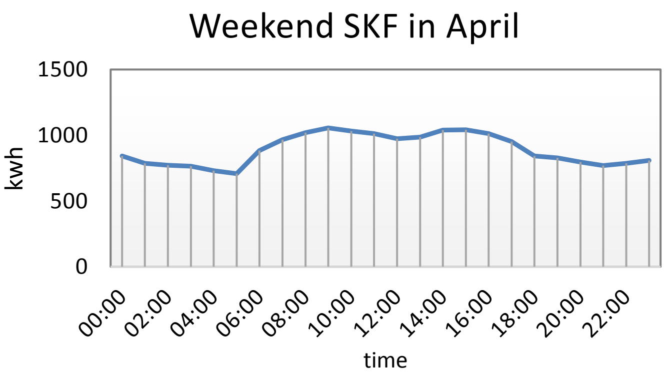

Figure 25: Example load curve weekend SKF in April

6.3 Calculation steps

The case studies are executed in four main steps. The following approach has been chosen, because the source codes of DER-CAM are not available and therefore the simulation results are analyzed separately to get a deeper understanding of the valorization of the storage system.

Firstly, all configurations are simulated with the optimization program DER-CAM, taking into account the load, electricity tariff and technical parameters for the storage system. In this first approach, the costs for the storage system are not considered. This allows its optimal utilization in the given context.

Secondly, an optimization of the battery size is carried out since the results regarding battery size from the first simulation are certainly oversized, because no costs were taken into account for the storage system.

Thirdly, the simulation is executed again with the optimized storage capacities, again without any costs for the storage system.

Finally, the results from this second simulation will be used to perform economic calculations to determine the profitability of the case studies and to perform sensitivity analyses on battery costs and electricity prices.

It was decided to conduct the study this way in order to understand how the optimal (therefore costless) battery is operated in the given context and to optimize the size of the battery later on step by step.

6.3.1 First simulations with the optimization program DER-CAM

For the first simulations with the optimization program DER-CAM, the following assumptions were made:

- To simulate yearly consumption, three typical days per month were taken into account. One weekday, one day for the weekend, and one peak day. Since the consumption generally does not show a peak day on weekdays, the peak days have the same configuration as the "normal" weekdays. The hourly dataset for all the simulations can be found in the annexes on pages XI-XIII.
- Off-peak hours are from 01:00-07:00 and from 13:00-15:00 on weekdays.
- The whole weekend consists of off-peak hours.
- Variable electricity prices are considered as illustrated in table 15 below.

Table 15: Electricity Prices for the DER-CAM simulation

	Mid-peak hours [€/MWh]	**Off-peak hours** [€/MWh]
Summer (April – October)	**45**	**34**
Winter (November – March)	**55**	**40**

- The fixed demand rate is 0.77 €/kW and is calculated on the peak demand per month. This is a gross simplification of the actual demand rate in France.[6] Furthermore, in the case studies the demand rate is paid only once, when the battery is charged with power from the grid.
- No costs for the storage system.
- The round trip efficiency of the battery is 85%.
- The maximal charge and discharge rate of the battery is 1.
- The minimum state of charge of the battery is 1%.

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[6] The document (in French) for the detailed calculation of the French demand rate can be found here: http://www.erdf.fr/sites/default/files/ERDF_Turpe_bareme_2015.pdf. Accessed 20 July 2016

The output for the first simulations is illustrated in the following table 16. The simulation determines the optimal size of the storage system and shows the revenues made compared to the initial case without a battery for the given context. The financial optimization is based on time of use bill management and demand charge reduction which have been explained in chapter 2.1.

Table 16: Outputs first simulations

Case	Power battery [MW]	Capacity battery [MWh]	Revenues per year [€]
Consumption Pool	3.44	41.51	16,000
CPR	1.64	17.21	12,000
CPB	0.38	3.79	2,200
RP	0.64	8.16	2,600
CPC	0.55	6.16	2,600
SKF	1.80	21.62	7,700

It was observed that the revenues made with the help of the storage system are not correlated to the size of the storage system. In other words, the bigger consumers do not automatically have the greatest revenues even if they have much bigger ideal storage systems. Figure 26 highlights this fact by showing the revenues made from each case study compared to the different power sizes.

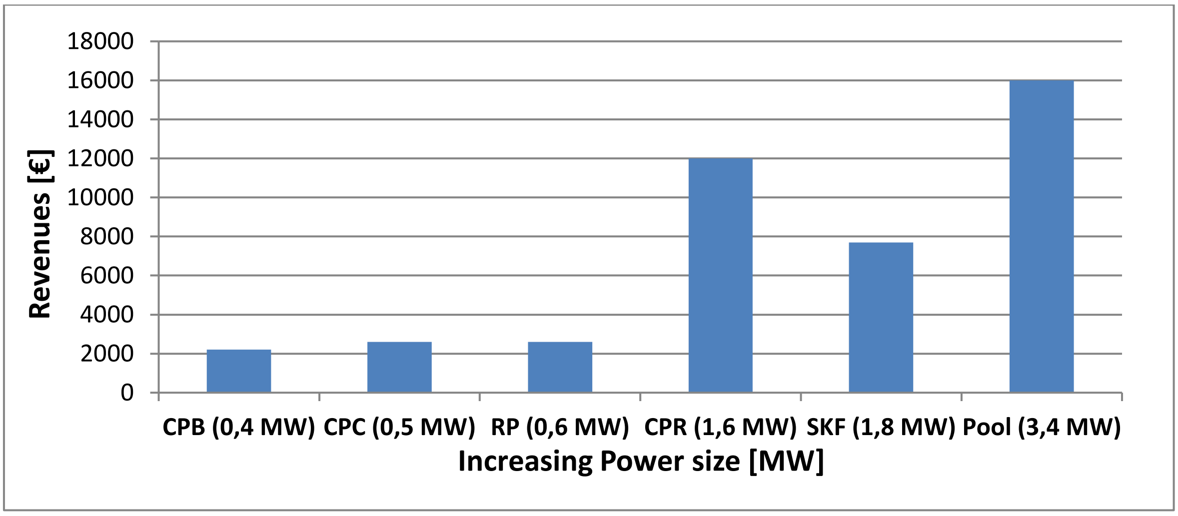

Figure 26: Revenues per power size

These first results lead to the conclusion that the valorization of the storage system depends heavily on the consumption profile and not on the size of the storage system. As already mentioned above, the sizes of the batteries proposed by DER-CAM were optimized within the context that the storage system does not cost anything.

When applying typical capital costs for a standard battery in the range from 100-200 €/kW and 150-400 €/kWh (Leuthold, 2016) are added to the result, it can be seen that the storage system is not profitable. This is why the results of this first simulation are evaluated regarding the size of the battery in the following section.

6.3.2 Optimization of the size of the batteries after the first simulation

The objective of the evaluation regarding the storage system's size is to determine if there is potential to reduce the power and capacity size of the battery. Since capital costs depend on the size of the battery, a reduction on capacity and/or power of the battery reduces capital costs in the economic calculations, following the simulation processes. The capital costs are separated in a part which depends on the power size of the battery and a part which depends on the capacity of the battery.

The size-optimization will be executed in two steps. In the first step the power size of the storage system is evaluated and in the second step the capacity of the storage system is evaluated.

6.3.2.1 Optimization of the power size

In a first step, the detailed results from the simulation regarding the battery management are analyzed. It has to be analyzed how often the battery has to deliver power in the whole year in order to detect possible over-sized battery systems.

The power sections are analyzed in 50 kW and hourly steps over the whole year. In the next step, this information is used to determine the level of revenues gained by each power section during the year, with the help of equation (20) where P represents the power section in *kW, t* for time this power is provided in *hours*, n for the times this section is used in a year, p_m for the electricity price of the mid-peak hour in *€/kWh*, p_0

for the electricity price of the off-peak hour in *€/kWh* and *η* for the battery efficiency in %.

$$Level\ of\ revenues\ [€] = P * t * n * (p_m - p_o) * \eta \qquad (10)$$

To illustrate this method, an example is given where the maximum power of the system is only used once a year. The specific revenues from the maximum power are very low. The power size of the battery can therefore be reduced without losing a significant part of the overall revenues. Figure 27 shows the schema of a power size evaluation diagram, where the maximal power of the battery is rarely used.

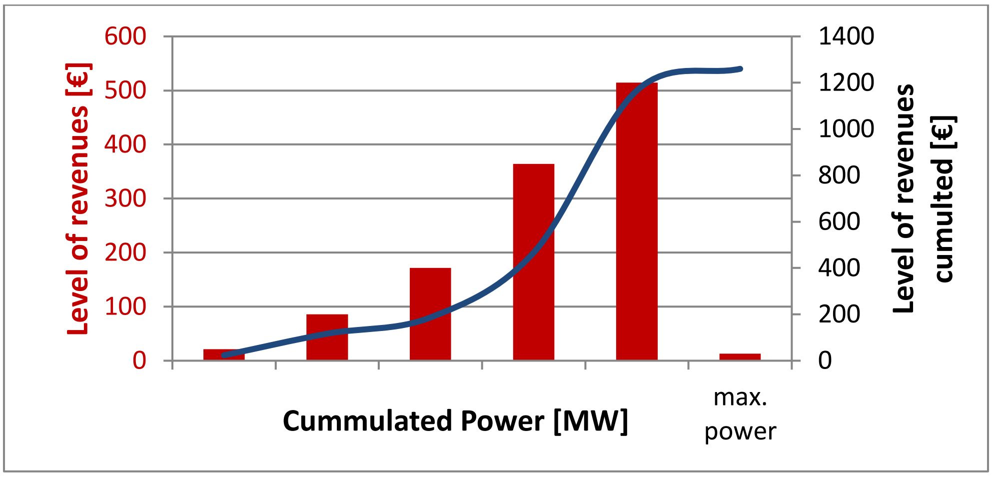

Figure 27: Example of a power size evaluation diagram; level of revenues (red bars) and cumulated revenues (blue) line over power

The power size evaluation diagram for each case study has the same structure as the example given in figure 27 and they can be found in the annexes on page V-VII. The following table 17 summarizes the results from the power size evaluation diagrams.

Table 17: Results power size reduction

Case	Power battery [kW]	Potential of reduction [kW]
Consumption Pool	3,440	50
CPR	1,640	50
CPB	380	50
RP	640	0
CPC	550	50
SKF	1800	50-150

The results for the evaluation of the power size of the batter show no potential to reduce the power size and therefore capital costs drastically.

6.3.2.2 Optimization of the capacity

In this approach, the different state of charges of the batteries are analyzed over a year. More precisely, it is determined how often every state of charge is attained while charging and discharging the battery. This procedure is carried out in steps of 5 % in the range of 1 %-100 % state of charge, where 1% was fixed as minimum state of charge in the DER-CAM simulation.

While charging the battery all states of charges, which are attained have specific costs which are calculated with the help of equation (21), where Δ SOC is the part of the state of charge taken into account in %, E_{max} is the capacity of the battery in kWh, p_m is the electricity price of the peak-hour in *€/kWh* and η_d is the discharge efficiency of the battery.

$$Level\ of\ costs\ [€] = \Delta SOC * E_{max} * n * p_m * \eta_d \qquad (21)$$

On the other side, while discharging the battery, revenues are made when attaining a lower state of charges. These revenues are calculated with the help of equation (22), where η_c is the charge efficiency in *%* and p_o is the electricity price of the off-peak hour in *€/kWh* .

$$Level\ of\ revenues\ [€] = \frac{\Delta SOC * E_{max} * n * p_o}{\eta_c} \tag{22}$$

The difference between costs and revenues is the level of revenues made by the specific state of charge attained. If, for example, specific sections of the state of charge of the battery are rarely used, the specific revenues of this section are low and the capacity of the battery can therefore be reduced without losing a significant part of the overall revenues.

Figure 28 shows the schema of a capacity size evaluation diagram, where the state of charge between 40-80% is attained repeatedly and therefore their specific revenues are responsible for most of the overall revenues. The capacity of this battery example could be reduced by 60% without losing significant parts of the overall revenues.

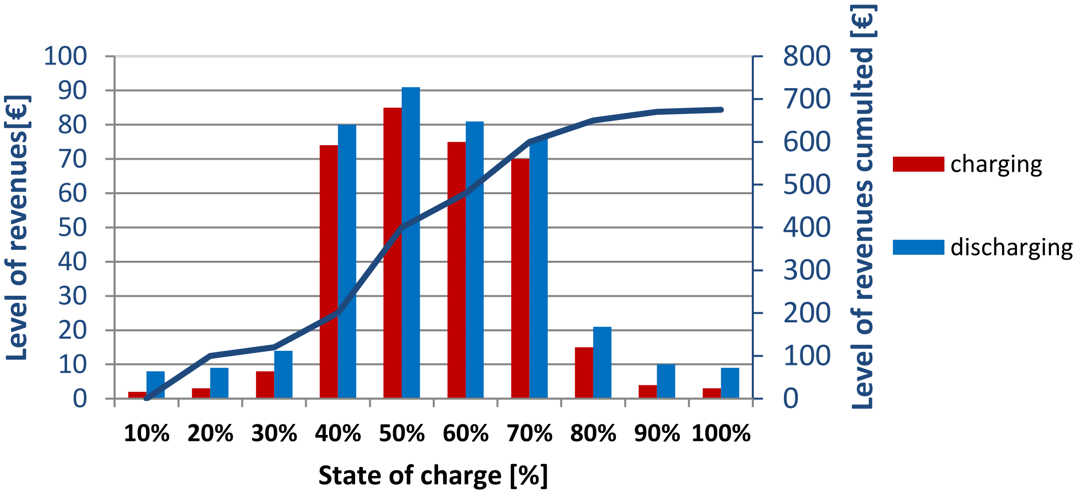

Figure 28: Example of a capacity size evaluation diagram

The capacity size evaluation diagram for each case study has the same structure as the example given in Figure 28 and they can be found in the annexes on page VIII-X. Table 18 summarizes the results from the capacity size evaluation diagrams.

Table 18: Results capacity size reduction

Case	Capacity [kWh]	Potential of reduction [%]
Consumption Pool	41.51	10-20
CPR	17.21	45-50
CPB	3.79	45-50
RP	8.16	15-20
CPC	6.16	15-20
SKF	21.62	30-35

All cases show little potential to reduce the capacity of the battery, but the cases CPR and CPB are significantly more interesting, since their capacity can be reduced by up to 50% without losing a significant part of the overall revenues. Figure 29 and figure 30 show the corresponding diagrams for the case CPB and CPR.

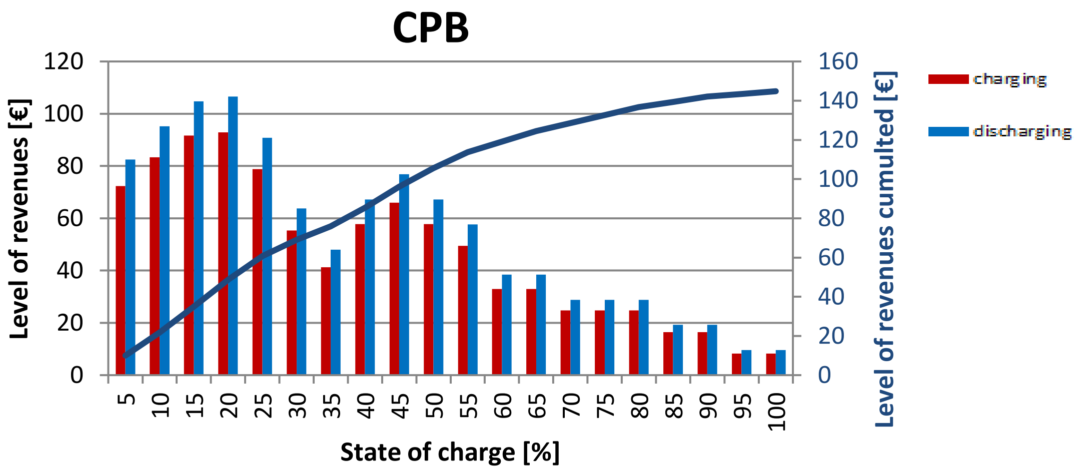

Figure 29: Capacity size evaluation diagram CPB

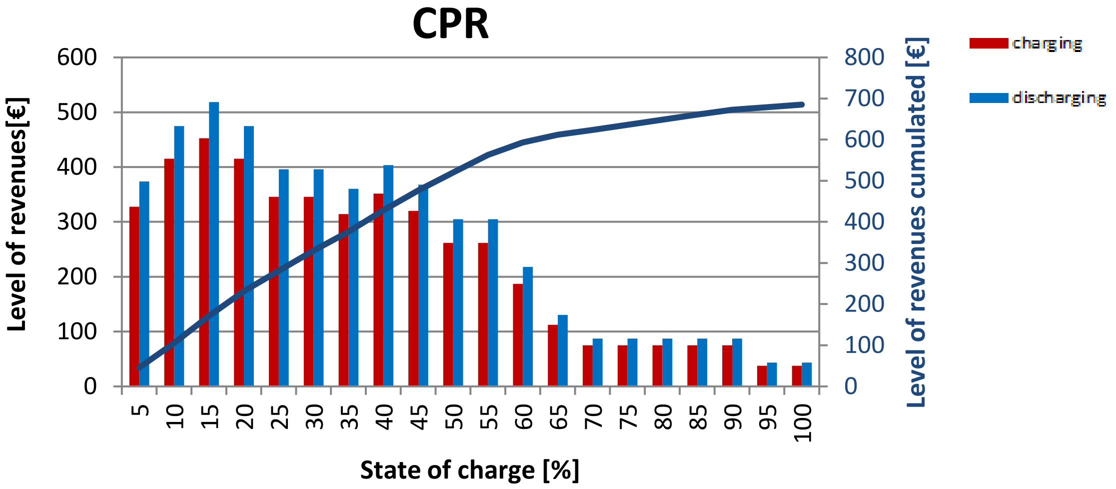

Figure 30: Capacity size evaluation diagram CPR

The further procedure will only be carried out for these two most promising cases CPR and CPP with capacities reduced by 50%.

6.3.3 Second simulation with DER-CAM

The chosen cases CPR and CPB are simulated again with capacities reduced by 50%. It is not possible to fix the maximum power size of the storage system in DER-CAM, only the maximum capacity size. Since the results from the evaluation of the power size show that the reducible part is only 50 kW in both cases, it can be neglected.

The second simulations are executed with the same parameters as the first simulations, but the capacity size is fixed at 50% of the initial size. The results of the simulation are shown in table 19 and table 20.

Table 19: Results second simulation CPB

Case	Power battery [MW]	Capacity battery [MWh]	Revenues per year [€]
CPB **First simulation**	0.375	3.8	2,200
CPB **Second simulation**	0.375	1.9	2,000

Table 20: Results second simulation CPR

Case	Power battery [MW]	Capacity battery [MWh]	Revenues per year [€]
CPR **First simulation**	1.6	17.2	12,000
CPR **Second simulation**	1.6	8.6	11,000

The reduction of the initial capacity by 50 % results in a reduction of 9.1 % of the overall revenues in the case of CPR and 8.3 % of the overall revenues in the case of CPB.

6.3.4 Economic analysis

For the economic evaluation, two financial parameters, the net present value and the internal rate of return are considered. The two indicators are often used together to evaluate investment projects. The net present value (NPV) allows one to evaluate a projects potential profitability by discounting future cash flow expectations and compare the sum of the cash flows to the initial Investment costs.

If the net present value is positive after a certain time, the project starts to add value. The calculation for the *NPV* is demonstrated in equation (23), where *T* stands for the time period, *t* for the year and *i* for the interest rate.

$$NPV\ [€] = Inital\ Investment[€] - \sum_{t=1}^{T} \frac{Cash\ flow_t}{(1+i)^t}\ [€] \qquad (23)$$

The internal rate of return (*IRR*) indicates the interest rate where the *NPV* equals zero after a specific time period as demonstrated in equation (24). The general problem of finding the roots of equation (24) can be solved by numerical methods that can be used to estimate *I* by, for example, using the secant method, which is shown in equation (25). In this equation i_n is considered the i^{th} approximation of the IRR. The IRR values for this work were calculated with the help of the IRR formula in Microsoft Excel which provides an accuracy of 0.00001%. (Microsoft)

$$NPV = Initial\ Investment - \sum_{t=1}^{T} \frac{Cash\ flow_t}{(1+i)^t} = 0 \qquad (24)$$

$$i_{n+1} = i_n - NPV_n * \left(\frac{i_n - i_{n-1}}{NPV_n - NPV_{n-1}} \right) \qquad (25)$$

For the economic evaluation of the two projects CPR and CPB, the NPV and IRR are calculated after five and ten years.

The investment costs of a battery considered for the economic analyses are shown in table 21. They take into account the costs for the whole system including cell, converter and battery management system.

Table 21: Investment cost parameters for a standard battery (Leuthold, 2016)

Investment cost parameters for a standard battery	
Power costs [€/kW]	**100 - 200**
Capacity costs [€/kWh]	**150 - 400**

The total capital expenditures (CAPEX) for the battery are calculated as shown in equation (26).

$$\boldsymbol{CAPEX} = Power\ cost\ \left[\frac{€}{kW}\right] * Power\ [\mathrm{kW}] + Capacity\ cost\ \left[\frac{€}{kWh}\right] * Capacity\ \ [kWh] \quad (26)$$

The calculations are conducted on the best case scenario, which takes into account the lowest costs for the battery (100 €/kW and 150 €/kWh) and the widest spread between mid-peak and off-peak electricity prices currently available in this region of France. The electricity prices for this scenario are shown in table 22. All other parameters as off-peak hours, demand rate and battery parameters are the same as for the first simulation described on page 50. The discount rate for the calculation was set to 8%.

Table 22: Electricity prices for the best case scenario

Best case	Mid-peak hours [€/MWh]	Off-peak hours [€/MWh]
Summer (April – October)	60	36
Winter (November – March)	47	30

6.4 Results

The results from the economic evaluation of the two cases CPR and CPB in the best case scenario are shown in table 23. As indicated, even in a best case scenario, the application of the battery system in these two most promising cases is not profitable under current conditions and with the parameters chosen. The net present value and internal rate of return is highly negative after five and after ten years.

Table 23: Results economic evaluation

Best case	Revenues per year [€]	CAPEX battery [€]	NPV (5 years) [€]	IRR (5 years) [%]	NPV (10 years) [€]	IRR (10 years) [%]
CPB	9,200	322,000	- 285,000	- 42	-260,000	- 18
CPR	27,800	1,454,000	- 1,343,000	- 48	- 1,267,000	- 22

As mentioned above, the economic indicators are very negative and the project is not profitable. In a further step, it has to be determined if the economic indicators are sensitive to certain parameters chosen for the calculation, such as battery costs and electricity prices, in case there are subsidies available or the price spread between peak and off-peak hours increases.

In addition to that, it has to be analyzed if the battery system is using all capacities or if there are spare capacities available to generate additional value streams for the application. In this current evaluation, only the time-of-use bill management and demand charge reduction are considered.

6.5 Sensitivity analysis and prospects

A sensitivity analysis on electricity prices and battery costs is conducted in order to analyze the profitability evolution under more favorable conditions. The electricity prices considered in the sensitivity analysis are shown in table 24. The demand rate from the further simulation was not changed.

Table 24: Electricity prices tariff 1 and tariff 2

Tariff 1	Mid-peak hours [€/MWh]	Off-peak hours [€/MWh]
Summer (April – October)	65	31
Winter (November – March)	52	25

Tariff 2	Mid-peak hours [€/MWh]	Off-peak hours [€/MWh]
Summer (April – October)	72	24
Winter (November – March)	55	21,5

The sensitivity analysis on battery costs and electricity prices is shown in figure 31.

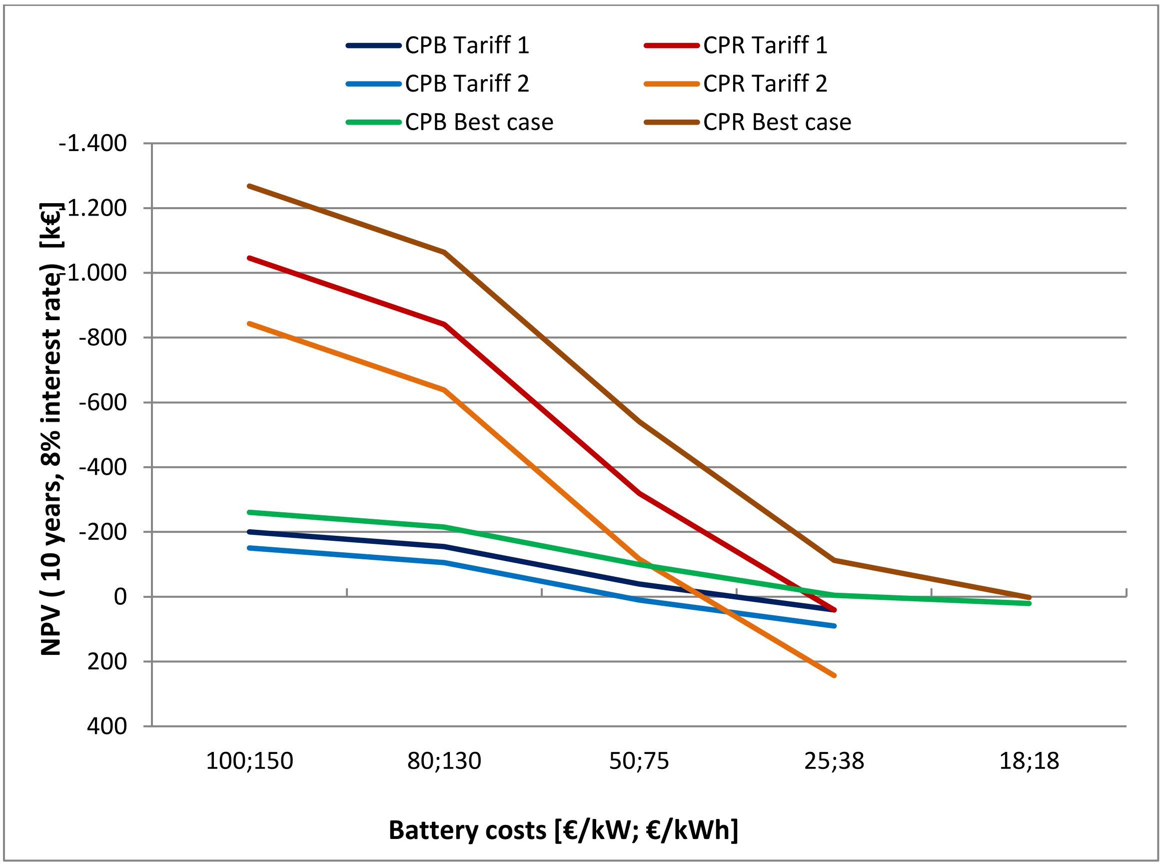

Figure 31: Sensitivity analysis on battery costs and electricity prices

Figure 31 highlights that even with a further reduction of battery costs and more favorable electricity prices, the net present values after 10 years remain low.

But since the battery simulated in this approach only responds to two services (time-of-use bill management and demand charge reduction) additional services could be examined to add value to the system. The batteries in the cases CPB and CPR are for example never used on weekends and both show a seasonal difference in the utilization of the battery in summer and winter.

For the purposes of illustration, figure 32 and figure 33 show the maximal capacity used per month with regards to the maximal capacity available.

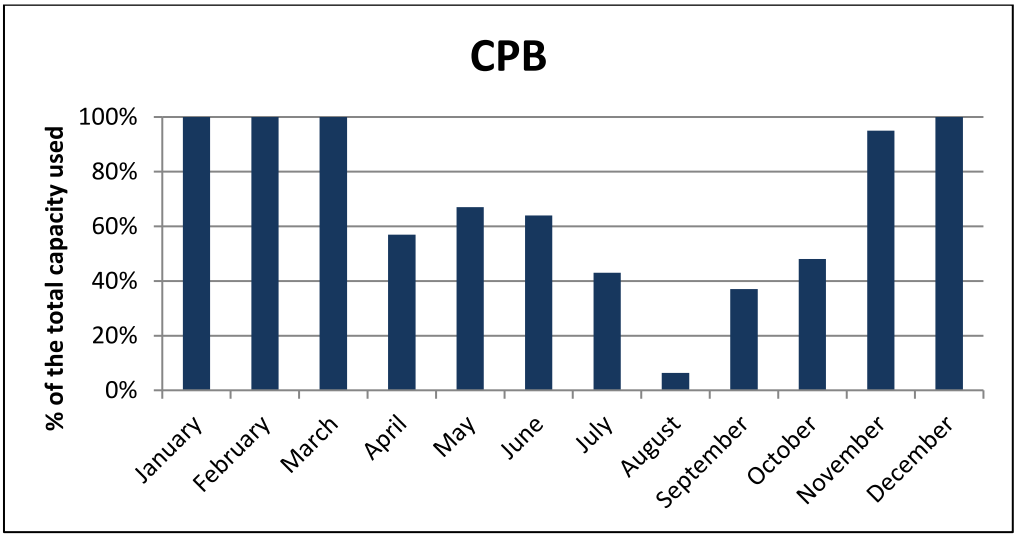

Figure 32: Share of the total capacity used per month case CPB

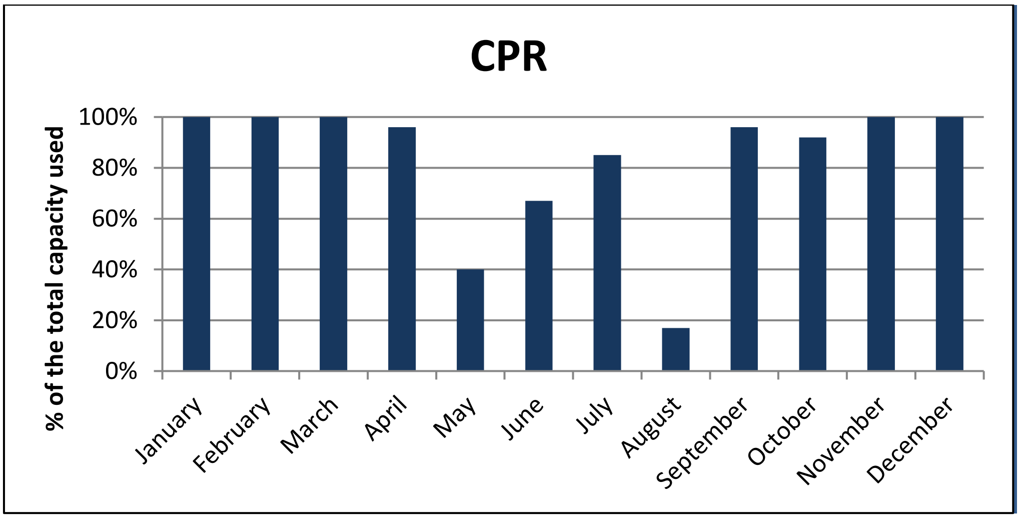

Figure 33: Share of the total capacity used per month case CPR

In times of low utilization, the unused capacity could be used by other consumers who consume mostly in summer and/or on weekends. In a next step it could be examined if there are sites with load profiles complementary of those of the companies considered in the industrial zone.

As already mentioned above, another approach for the valorization of the storage system could be found in an additional service for the storage system. Some possible services to which the battery could respond are:

- Demand-side management
  Some electricity providers in France provide load management contracts where the consumer agrees to cut off a certain part of his consumption during periods of high demand. The availability to reduce the demand is remunerated by the provider. A battery system could secure the power supply during these periods.

- UPS (uninterruptible power supply)
  Some facilities, such as hospitals or special industrial sites, need an uninterruptible power supply in times of unstable energy supply or black-outs. The storage system could respond to this service.

- Capacity market
  The unused capacities of the battery could be remunerated on the French capacity market.

As can be seen in the propositions made, the storage system could respond to additional services to improve its profitability. In a further step, it has to be evaluated if there is a need for the services mentioned above in the industrial zone. Additionally, the regulations and requirements for the participation on the French capacity market have to be reviewed.

7 Summary

Electricity production has changed in recent years, showing a general trend of increasing shares of renewable generation in the energy mix of many countries. The integration of intermittent energy sources like solar energy or wind power remains a major challenge for transport and electricity distribution networks.

This development has led to opportunities for electricity storage, considered a key technology for future energy markets. It facilitates the integration of intermittent renewable energy by enabling the storage of electricity production surplus and reinjecting them during peak demand. Furthermore, storage systems can enhance network security and improve the flexibility of energy systems in general.

Faced with an energy sector of strong mutation both in terms of energy production and regulation, it is critical to rigorously analyze the value of storage solutions in the context of their application, since each case study presents their specificities and reliable business models are not available.

To approach this issue for electricity storage systems, the present work analyzes existing case studies, followed by the completion of a technical and economical evaluation for the application of an electricity storage system in a French industrial zone. In a first step, various case studies were analyzed in order to determine key elements which allow existing case studies to be classified into groups. The essential components to consider are:

- Grid connection
- Electricity generation
- Electricity consumption profiles
- Location of the storage system

A methodology taking into account the above criteria has been developed and tested on 47 existing cases of use. It allowed 46 of them to be classified in the three groups listed below:

- Non-grid-connected zones
- Grid-connected zones with intermittent electricity production
- Grid-connected zones without intermittent electricity production

The second part of this work is a techno-economical evaluation of an electricity storage system in an industrial zone in France. The area includes 180 companies but the decision was made to carry out an initial study on a sample of 5 consumer sites. The case study chosen belongs to the group "grid-connected zone without intermittent electricity production", which means that there is grid access but no local intermittent energy production.

The storage system of the case study generates two value streams: Electricity is stored during off-peak hours and later reinjected during peak hours in order to reduce the costs for the consumer. In addition to that, the potential to reduce the demand charge which is calculated based on the maximum power demand each month is also optimized.

The simulations were conducted for every consumer individually and for the case of a shared consumption between all five sites. Initially, the storage usage simulations are performed in the absence of costs for the battery to optimize the "perfect" use. At this point, the comparison of results for the various sites shows that the value of a storage facility is to be found in its consumer profile rather than the size of the storage system.

In the next step, the potential to reduce the size of the battery is analyzed in order to minimize storage investment costs. The final step is a profitability evaluation with the help of economic indicators.

The case study concludes that a storage system is not profitable for the case considered in the present techno-economical context. Even in case of a sharp decline in battery costs (for example through subsidies) or rising electricity prices, economic indicators remain unpromising.

Moreover, it appears that the storage is not used during the summer and weekends. A first possible step to improve profitability is therefore to add sites where consumption habits are complementary to the sites considered in the study.

Another approach to increase profitability is the valorization of an additional service, such as:

- Demand-side management
- USP (uninterruptible power supply)
- Capacity market

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Annexes

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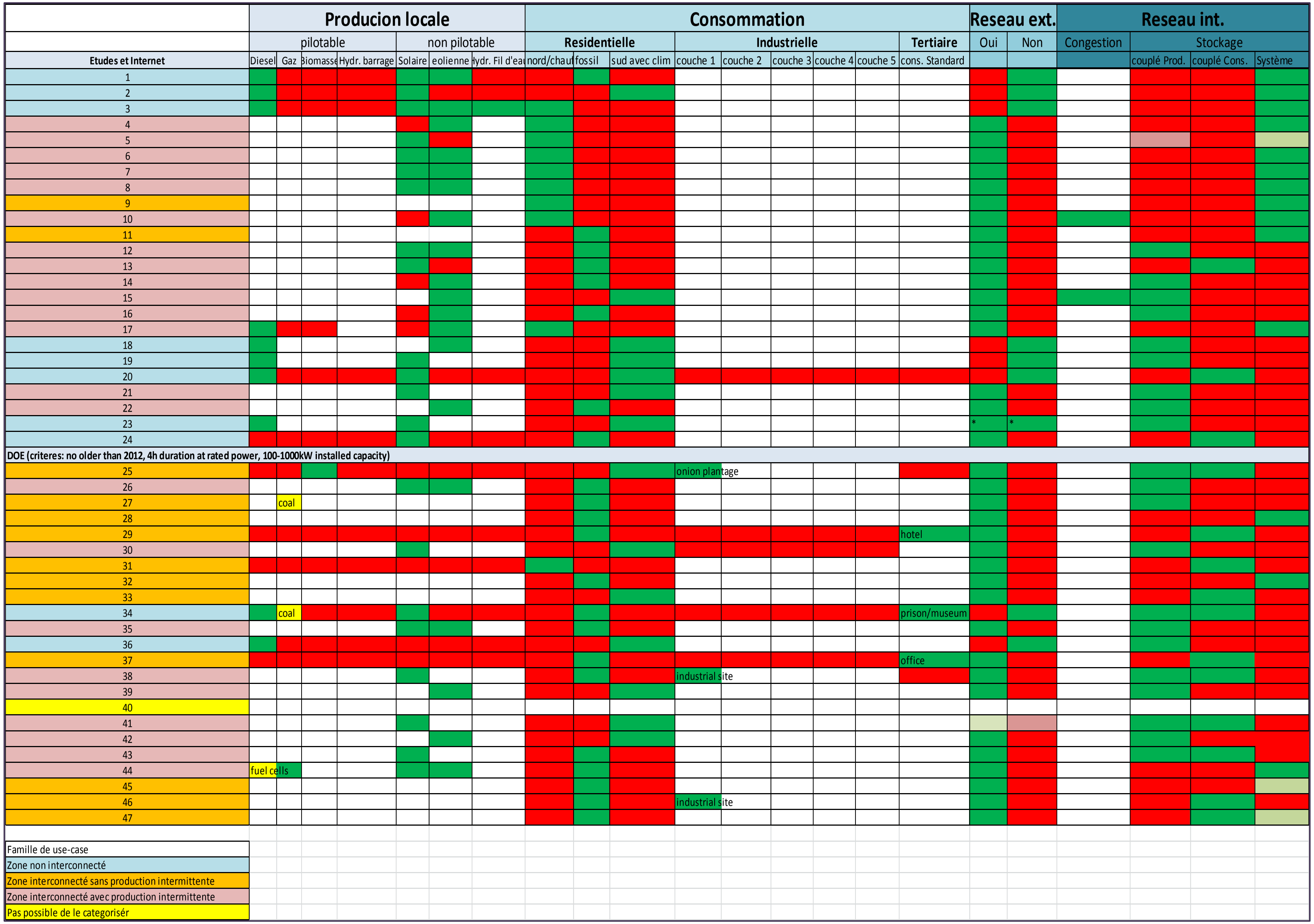
1. Organizing cases of use in case groups



	Producion locale							Consommation										Reseau ext.		Reseau int.			
	pilotable				non pilotable			Residentielle			Industrielle					Tertiaire	Oui	Non	Congestion	Stockage		
Etudes et Internet	Diesel	Gaz	Biomasse	Hydr. barrage	Solaire	eolienne	Hydr. Fil d'eau	nord/chau	fossil	sud avec clim	couche 1	couche 2	couche 3	couche 4	couche 5	cons. Standard				couplé Prod.	couplé Cons.	Système
🟦 1	🟩	🟥	🟥	🟥	🟩	🟩	🟥	🟥	🟩	🟥							🟥	🟩		🟥	🟥	🟩
🟦 2	🟩	🟥	🟥	🟥	🟩	🟥	🟥	🟥	🟥	🟩							🟥	🟩		🟥	🟥	🟩
🟦 3	🟩	🟥	🟥	🟥	🟩	🟩	🟩	🟩	🟥	🟥							🟥	🟩		🟥	🟥	🟩
▨ 4					🟥	🟩		🟩	🟥	🟥							🟩	🟥		🟥	🟥	🟩
▨ 5					🟩	🟥		🟩	🟥	🟥							🟩	🟥		▨	🟥	▧
▨ 6					🟩	🟩		🟩	🟥	🟥							🟩	🟥		🟥	🟥	🟩
▨ 7					🟩	🟩		🟩	🟥	🟥							🟩	🟥		🟥	🟥	🟩
▨ 8					🟩	🟩		🟩	🟥	🟥							🟩	🟥		🟥	🟥	🟩
🟧 9								🟩	🟥	🟥							🟩	🟥		🟥	🟥	🟩
▨ 10					🟥	🟩		🟩	🟥	🟥							🟩	🟥	🟩	🟥	🟥	🟩
🟧 11								🟥	🟩	🟥							🟩	🟥		🟥	🟥	🟩
▨ 12					🟩	🟩		🟥	🟩	🟥							🟩	🟥		🟩	🟥	🟥
▨ 13					🟩	🟥		🟥	🟩	🟥							🟩	🟥		🟥	🟩	🟥
▨ 14					🟥	🟩		🟥	🟩	🟥							🟩	🟥		🟩	🟥	🟥
▨ 15						🟩		🟥	🟥	🟩							🟩	🟥	🟩	🟩	🟥	🟥
▨ 16					🟥	🟩		🟥	🟩	🟥							🟩	🟥		🟩	🟥	🟥
▨ 17	🟩	🟥	🟥		🟥	🟩		🟩	🟥	🟥							🟩	🟥		🟥	🟥	🟩
🟦 18	🟩					🟩		🟥	🟥	🟩							🟥	🟩		🟩	🟥	🟥
🟦 19	🟩				🟩			🟥	🟥	🟩							🟥	🟩		🟩	🟥	🟥
🟦 20	🟩	🟥	🟥	🟥	🟩	🟥	🟥	🟥	🟥	🟩	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟩		🟥	🟩	🟥
▨ 21					🟩			🟥	🟥	🟩							🟩	🟥		🟩	🟥	🟥
▨ 22						🟩		🟥	🟩	🟥							🟩	🟥		🟩	🟥	🟥
🟦 23	🟩				🟩			🟥	🟥	🟩							🟩 *	🟩 *		🟩	🟥	🟥
🟦 24	🟥	🟥	🟥	🟥	🟩	🟥	🟥	🟥	🟩	🟥							🟩	🟥		🟥	🟩	🟥
DOE (criteres: no older than 2012, 4h duration at rated power, 100-1000kW installed capacity)																						
🟧 25	🟥	🟥	🟩	🟥	🟥	🟥	🟥	🟥	🟥	🟩	🟩 onion plantage					🟥	🟩	🟥		🟩	🟩	🟥
▨ 26					🟩	🟩		🟥	🟩	🟥							🟩	🟥		🟩	🟥	🟥
🟧 27		🟨 coal						🟥	🟩	🟥							🟩	🟥		🟩	🟥	🟥
🟧 28								🟥	🟩	🟥							🟩	🟥		🟥	🟥	🟩
🟧 29	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟩	🟥	🟥	🟥	🟥	🟥	🟥	🟩 hotel	🟩	🟥		🟥	🟩	🟥
▨ 30					🟩			🟥	🟥	🟩	🟥	🟥	🟥	🟥	🟥		🟩	🟥		🟩	🟥	🟥
🟧 31	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟩	🟥	🟥							🟩	🟥		🟥	🟩	🟥
🟧 32								🟥	🟩	🟥							🟩	🟥		🟥	🟥	🟩
🟧 33								🟥	🟥	🟩							🟩	🟥		🟥	🟩	🟥
🟦 34	🟩	🟨 coal	🟥	🟥	🟩	🟥	🟥	🟥	🟩	🟥	🟥	🟥	🟥	🟥	🟥	🟩 prison/museum	🟥	🟩		🟩	🟩	🟥
▨ 35					🟩	🟩		🟥	🟩	🟥							🟩	🟥		🟩	🟥	🟥
🟦 36	🟩	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟩							🟥	🟩		🟩	🟥	🟥
🟧 37	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟩	🟥	🟥	🟥	🟥	🟥	🟥	🟩 office	🟩	🟥		🟥	🟩	🟥
▨ 38					🟩			🟥	🟩	🟥	🟩 industrial site					🟥	🟩	🟥		🟩	🟩	🟥
▨ 39						🟩		🟥	🟥	🟩							🟩	🟥		🟩	🟥	🟥
🟨 40																						
▨ 41					🟩			🟥	🟥	🟩							▧	▨		🟩	🟩	🟥
▨ 42						🟩		🟥	🟥	🟩							🟩	🟥		🟩	🟥	🟥
▨ 43					🟩			🟥	🟩	🟥							🟩	🟥		🟩	🟩	🟥
▨ 44	🟨 fuel cells	🟩			🟩	🟩		🟥	🟩	🟥							🟩	🟥		🟥	🟥	🟩
🟧 45								🟥	🟩	🟥							🟩	🟥		🟥	🟥	▧
🟧 46								🟥	🟩	🟥	🟩 industrial site						🟩	🟥		🟥	🟩	🟥
🟧 47								🟥	🟩	🟥							🟩	🟥		🟥	🟩	▧

Famille de use-case
🟦 Zone non interconnecté
🟧 Zone interconnecté sans production intermittente
▨ Zone interconnecté avec production intermittente
🟨 Pas possible de le categorisér

Figure a: Table for organizing the cases of use in use-case groups

2. Optimization Power size

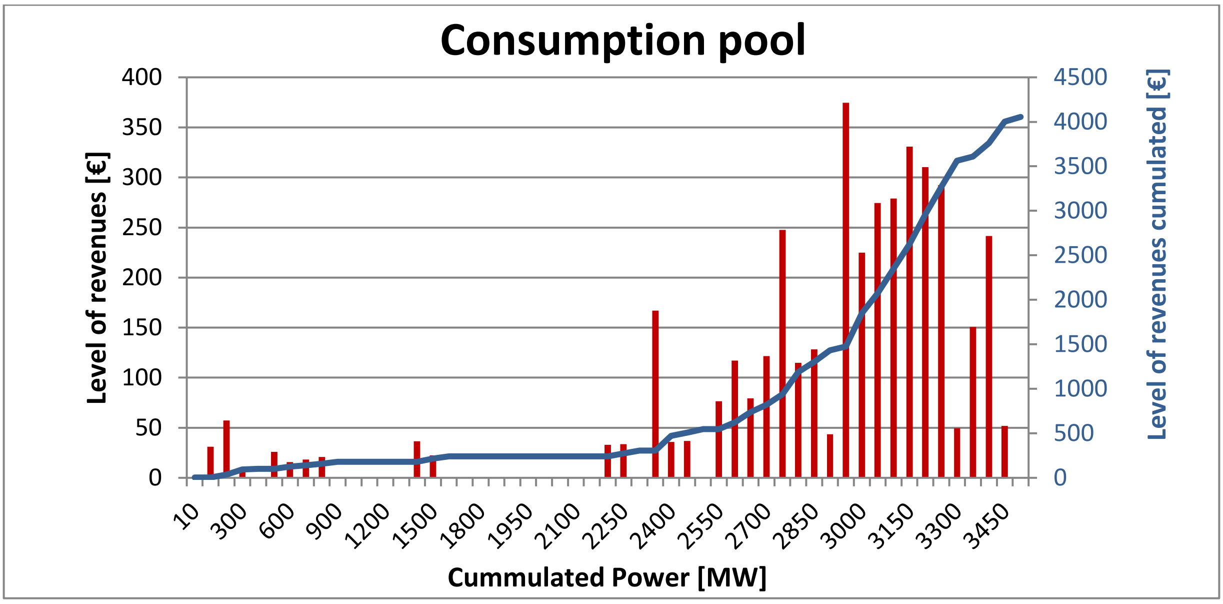


Figure b: Optimization power size for the case consumption pool

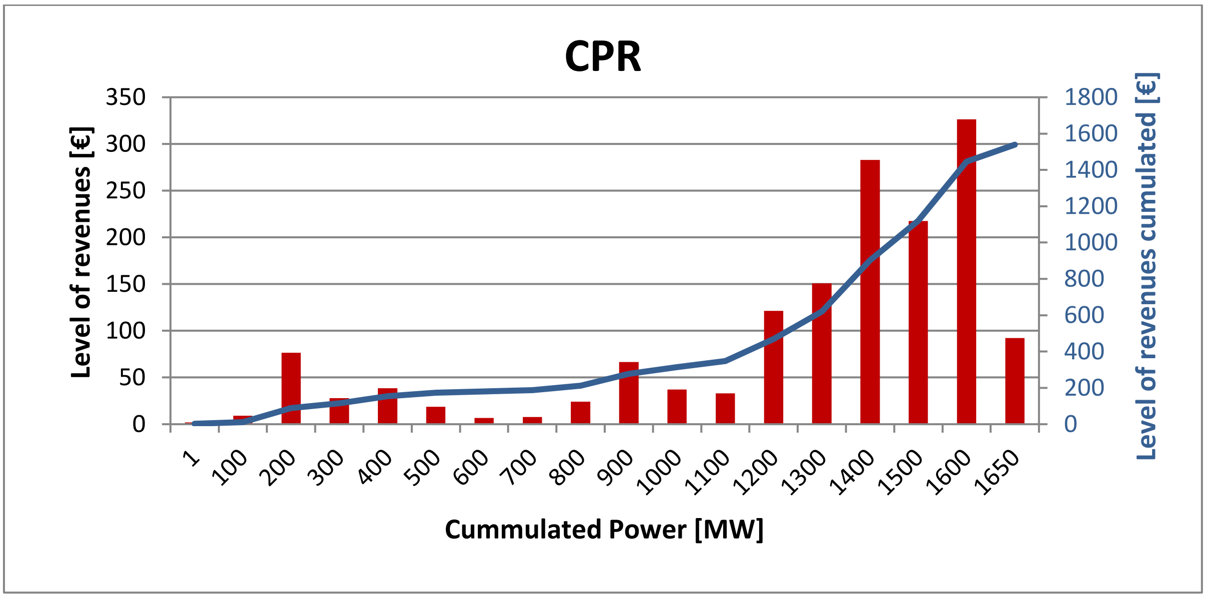


Figure c: Optimization power size for the case CPR

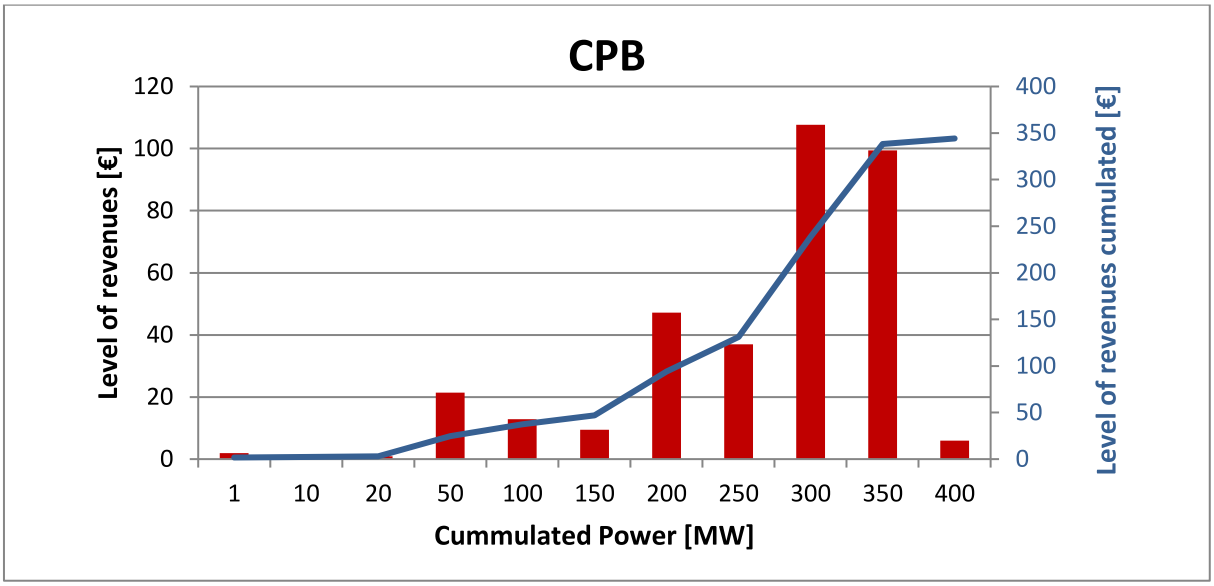


Figure d: Optimization power size for the case CPB

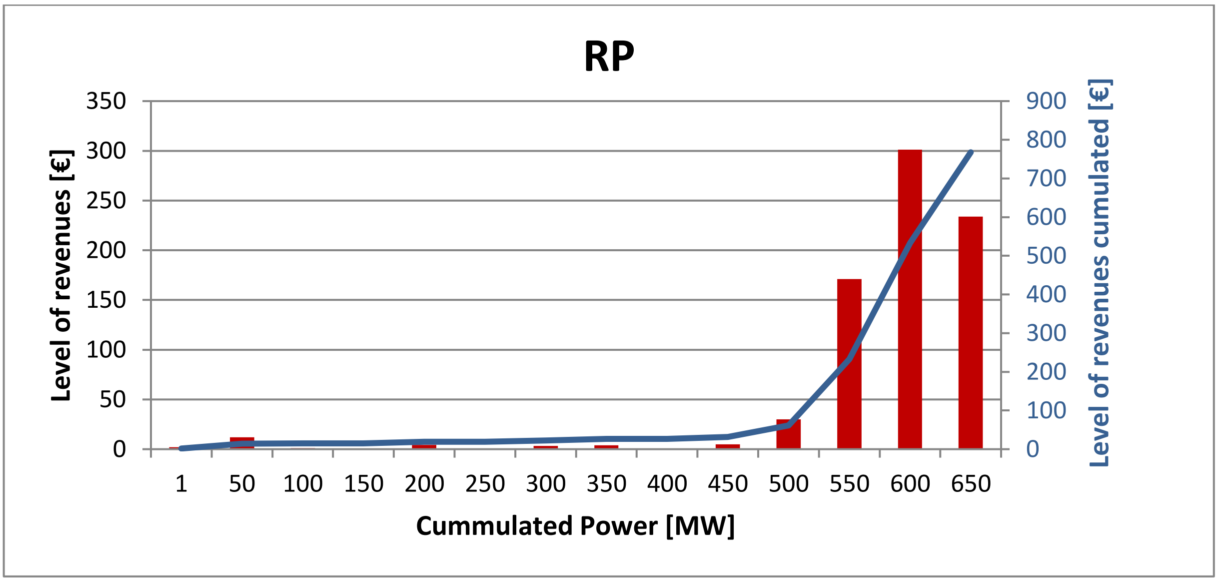


Figure e: Optimization power size for the case RP

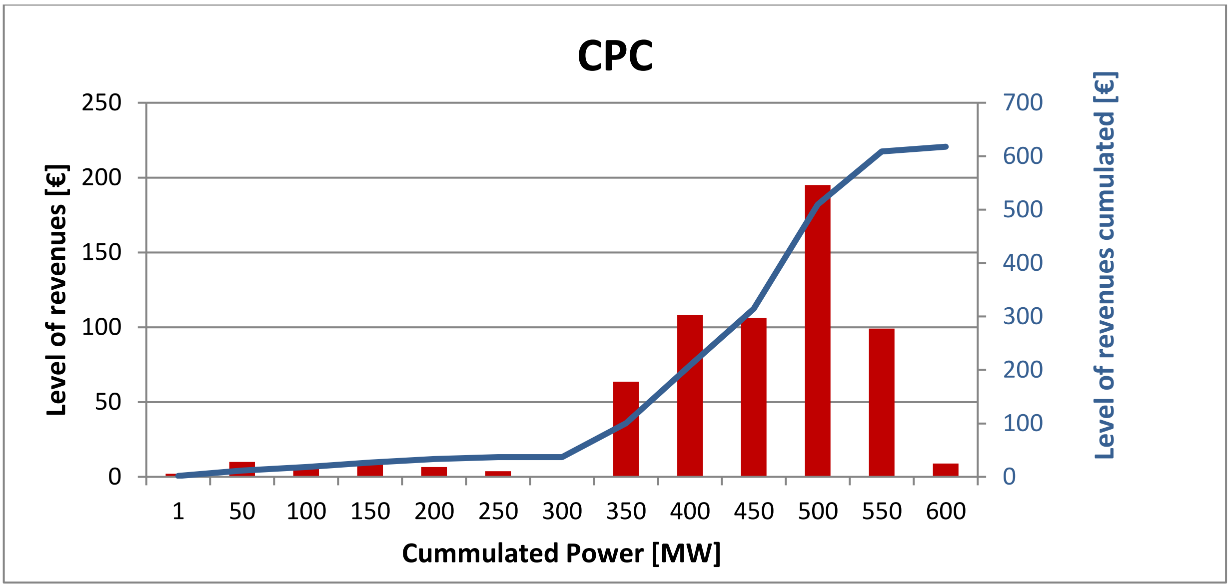


Figure f: Optimization power size for the case CPC

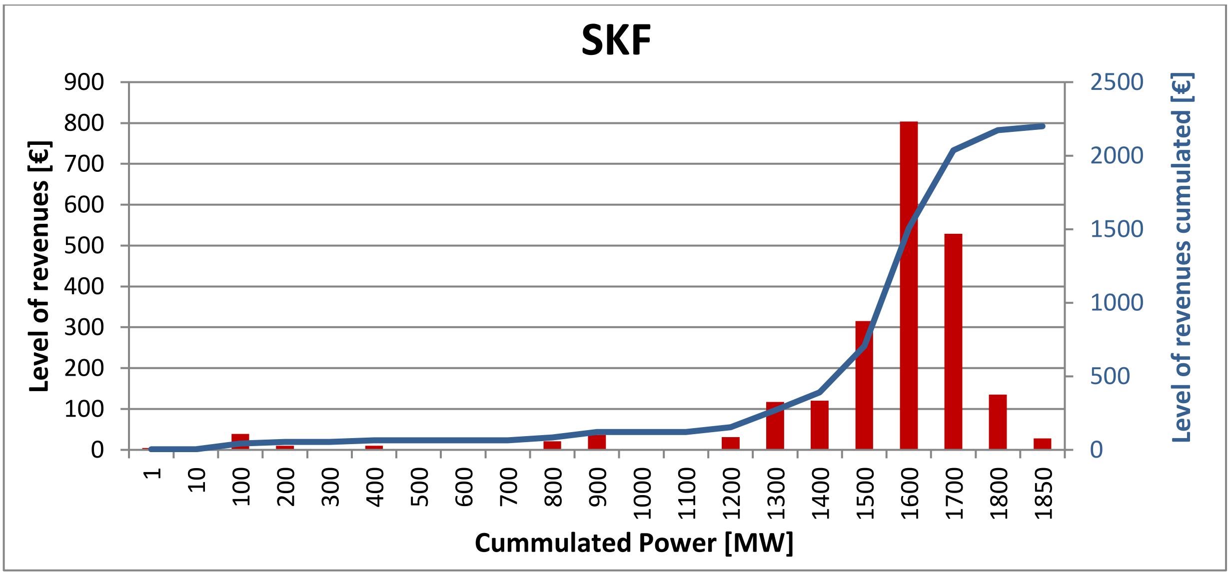


Figure g: Optimization power size for the case SKF

3. Optimization capacity size

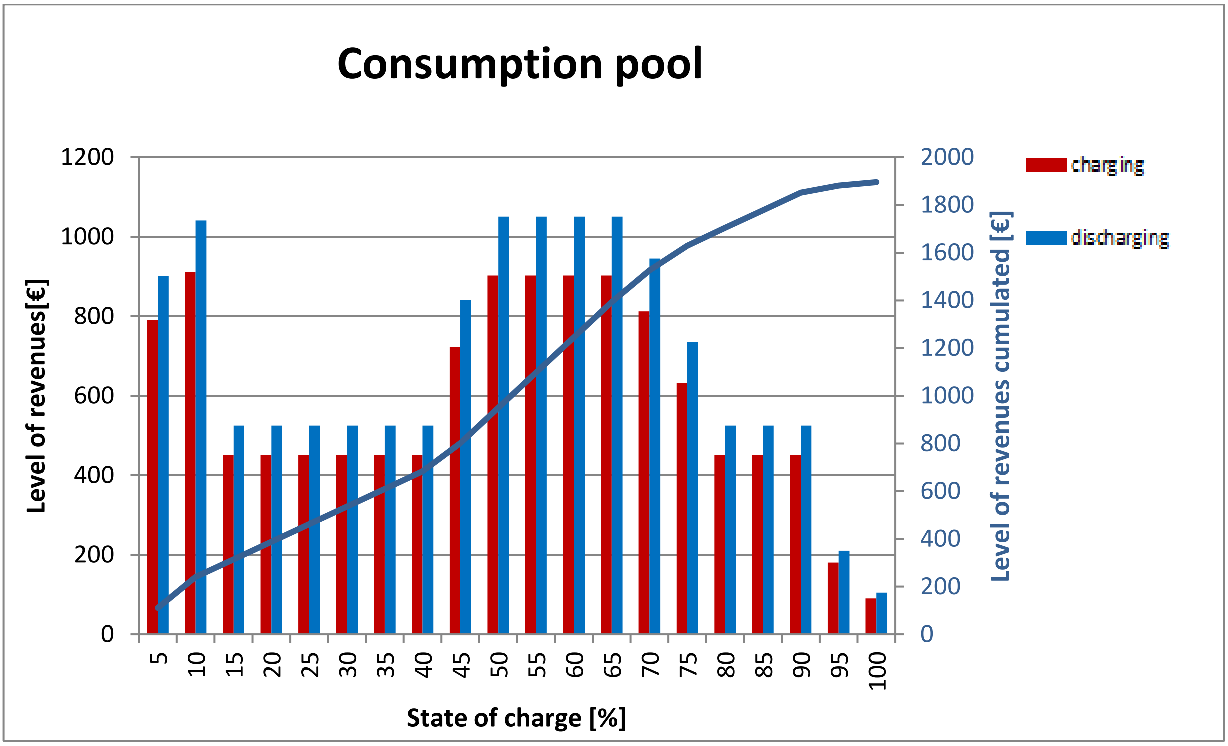


Figure h: Optimization capacity size for the case consumption pool

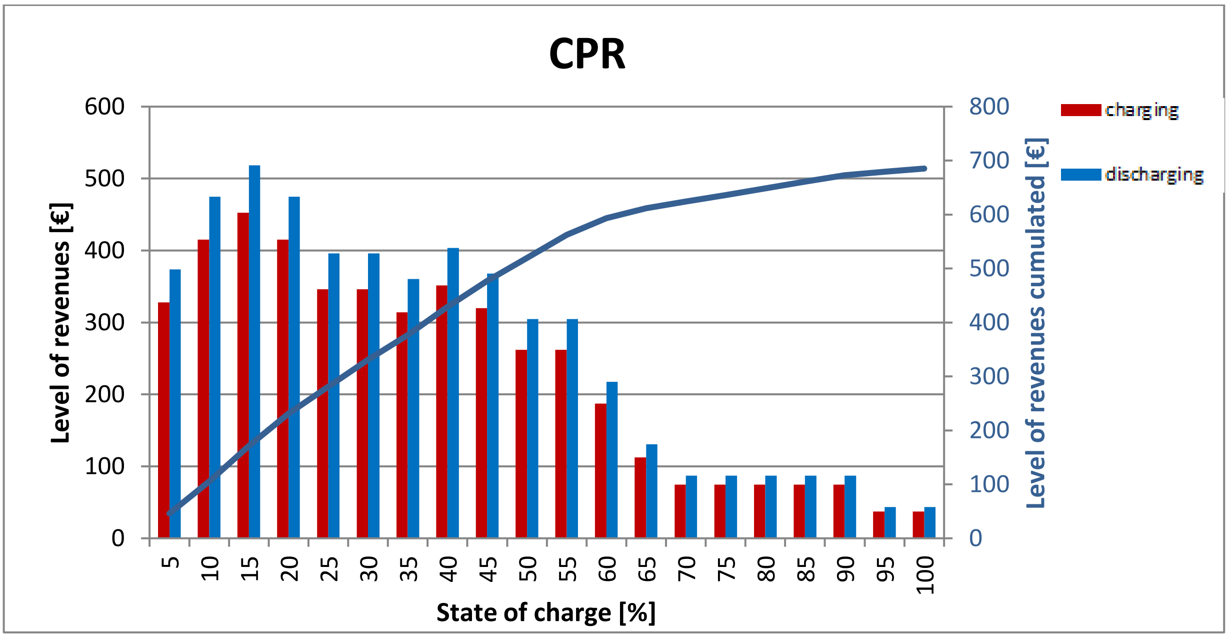


Figure i: Optimization capacity size for the case CPR

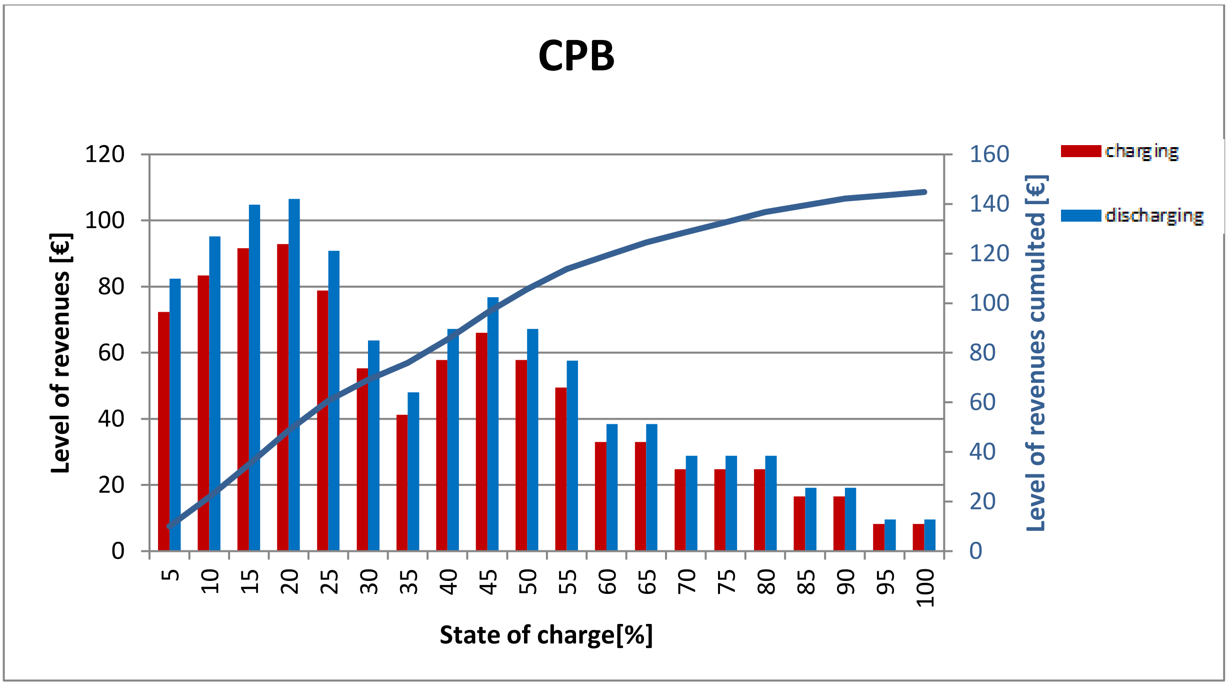


Figure j: Optimization capacity size for the case CPB

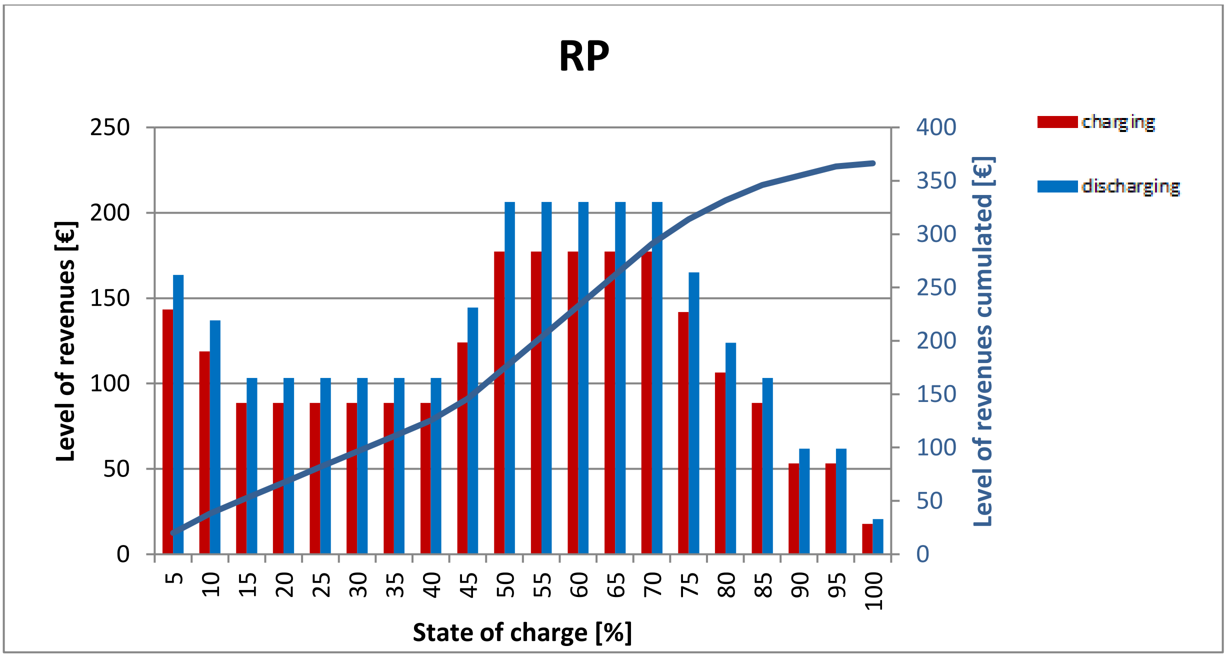


Figure k: Optimization capacity size for the case RP

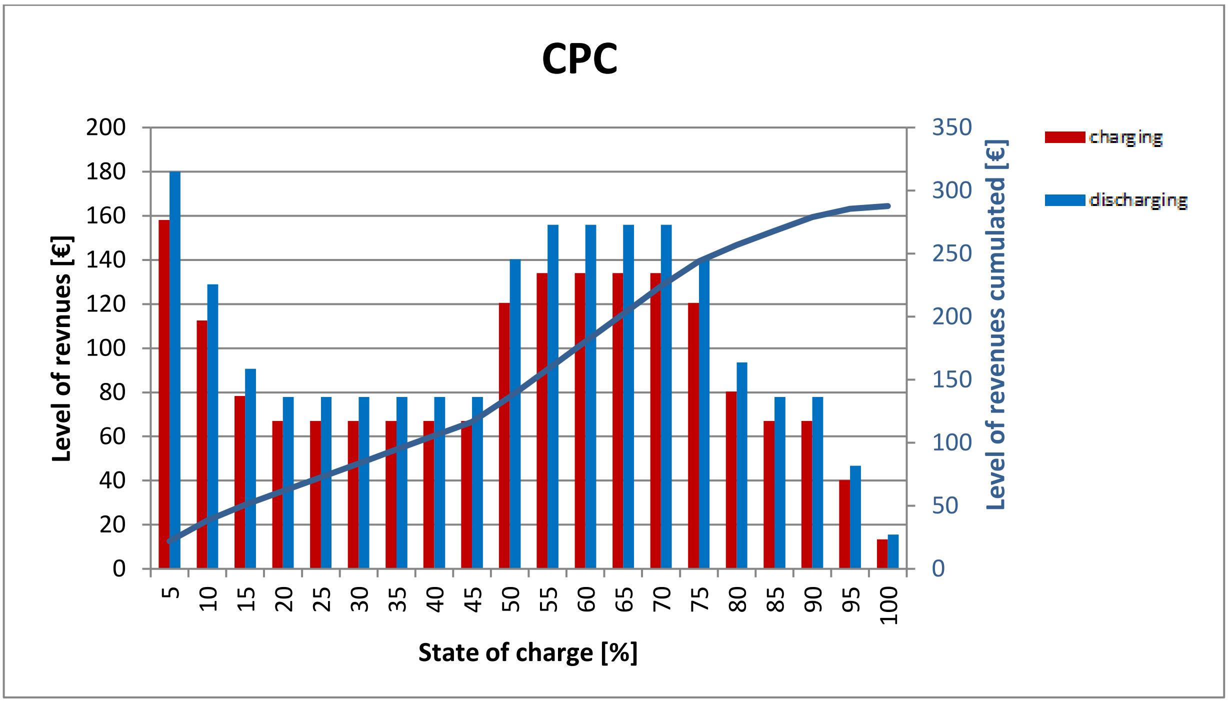


Figure l: Optimization capacity size for the case CPC

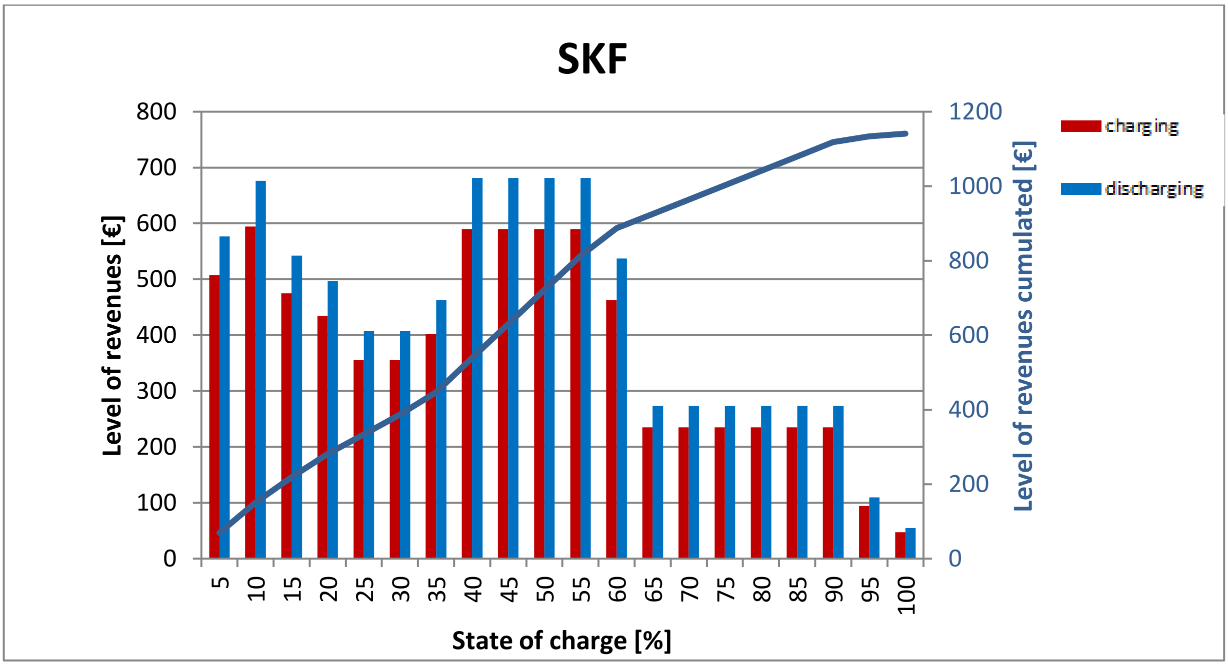


Figure m: Optimization capacity size for the case SKF

4. Hourly load data

Consumption pool

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
January	2154	2166	2327	2488	2443	2524	2969	3342	3212	3072	3171	3318	3358	3229	3237	3440	3133	3084	3115	3149	3128	2812	2736	2574
February	2335	2203	2258	2282	2325	2403	2867	3086	3217	3211	3382	3316	3377	3279	3241	3273	3237	3036	2968	2902	2975	2729	2570	2394
March	2240	2344	2310	2326	2376	2208	2706	2937	2916	3020	2971	3192	3086	3209	3103	3002	2826	2599	2750	2859	2930	2680	2520	2464
April	2102	2191	2087	2271	2193	2280	2685	2907	3160	3172	3058	3117	3256	3055	3057	3172	2780	2874	2812	2784	2571	2383	2225	2237
May	2211	2178	2257	2321	2369	2405	2911	3151	3087	3166	3257	3356	3328	3195	3176	3191	2926	2763	2684	2789	2862	2410	2124	2230
June	2496	2456	2419	2644	2614	2582	2970	3369	3365	3205	3324	3438	3355	3335	3244	3221	3070	2989	3050	3027	2854	2863	2627	2545
July	2297	2281	2412	2562	2603	2527	2838	3166	3156	3029	3254	3512	3487	3322	3232	3296	2999	3049	3051	3058	2934	2760	2703	2573
August	1619	1611	1600	1666	1735	1723	2075	2334	2280	2189	2349	2393	2358	2352	2290	2253	2259	2124	1896	2024	1971	1973	1921	1743
September	2229	2155	2249	2348	2398	2252	2490	2766	2919	3113	3171	3168	3271	3153	2963	3054	2746	2791	2645	2653	2683	2567	2390	2533
October	2312	2433	2478	2487	2402	2448	2658	2944	3021	3005	3174	3296	3243	3215	2969	2991	2712	2599	2746	2765	2882	2586	2503	2547
November	1445	1430	1435	1435	1426	1541	2434	2717	2954	3102	3211	3083	2913	3071	3049	3079	2831	2686	2640	2643	2570	2517	2427	2218
December	2324	2359	2232	2343	2367	2257	2653	2970	3010	3043	3138	3198	3103	3096	2999	3245	3002	2751	2680	2741	2720	2398	2330	2376

Table I: Load data Consumption pool weekday and peak day

Consumption pool weekend

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
January	1815	1798	1704	1678	1616	1560	1736	1765	1808	1802	1809	1780	1707	1694	1661	1665	1660	1629	1470	1470	1454	1444	1441	1429
February	1815	1798	1704	1678	1616	1560	1736	1765	1808	1802	1809	1780	1707	1694	1661	1665	1660	1629	1470	1470	1454	1444	1441	1429
March	1815	1798	1704	1678	1616	1560	1736	1765	1808	1802	1809	1780	1707	1694	1661	1665	1660	1629	1470	1470	1454	1444	1441	1429
April	1815	1798	1704	1678	1616	1560	1736	1765	1808	1802	1809	1780	1707	1694	1661	1665	1660	1629	1470	1470	1454	1444	1441	1429
May	1815	1798	1704	1678	1616	1560	1736	1765	1808	1802	1809	1780	1707	1694	1661	1665	1660	1629	1470	1470	1454	1444	1441	1429
June	1815	1798	1704	1678	1616	1560	1736	1765	1808	1802	1809	1780	1707	1694	1661	1665	1660	1629	1470	1470	1454	1444	1441	1429
July	1815	1798	1704	1678	1616	1560	1736	1765	1808	1802	1809	1780	1707	1694	1661	1665	1660	1629	1470	1470	1454	1444	1441	1429
August	1815	1798	1704	1678	1616	1560	1736	1765	1808	1802	1809	1780	1707	1694	1661	1665	1660	1629	1470	1470	1454	1444	1441	1429
September	1815	1798	1704	1678	1616	1560	1736	1765	1808	1802	1809	1780	1707	1694	1661	1665	1660	1629	1470	1470	1454	1444	1441	1429
October	1815	1798	1704	1678	1616	1560	1736	1765	1808	1802	1809	1780	1707	1694	1661	1665	1660	1629	1470	1470	1454	1444	1441	1429
November	1815	1798	1704	1678	1616	1560	1736	1765	1808	1802	1809	1780	1707	1694	1661	1665	1660	1629	1470	1470	1454	1444	1441	1429
December	1815	1798	1704	1678	1616	1560	1736	1765	1808	1802	1809	1780	1707	1694	1661	1665	1660	1629	1470	1470	1454	1444	1441	1429

Table II: Load data Consumption pool weekend

CPR weekday and peak day

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
January	120	111	115	125	111	121	124	109	109	122	112	109	120	108	119	105	112	118	109	120	116	115	116	115
February	120	111	115	125	111	121	124	109	109	122	112	109	120	108	119	105	112	118	109	120	116	115	116	115
March	120	111	115	125	111	121	124	109	109	122	112	109	120	108	119	105	112	118	109	120	116	115	116	115
April	120	111	115	125	111	121	124	109	109	122	112	109	120	108	119	105	112	118	109	120	116	115	116	115
May	120	111	115	125	111	121	124	109	109	122	112	109	120	108	119	105	112	118	109	120	116	115	116	115
June	120	111	115	125	111	121	124	109	109	122	112	109	120	108	119	105	112	118	109	120	116	115	116	115
July	120	111	115	125	111	121	124	109	109	122	112	109	120	108	119	105	112	118	109	120	116	115	116	115
August	120	111	115	125	111	121	124	109	109	122	112	109	120	108	119	105	112	118	109	120	116	115	116	115
September	120	111	115	125	111	121	124	109	109	122	112	109	120	108	119	105	112	118	109	120	116	115	116	115
October	120	111	115	125	111	121	124	109	109	122	112	109	120	108	119	105	112	118	109	120	116	115	116	115
November	120	111	115	125	111	121	124	109	109	122	112	109	120	108	119	105	112	118	109	120	116	115	116	115
December	120	111	115	125	111	121	124	109	109	122	112	109	120	108	119	105	112	118	109	120	116	115	116	115

Table III: Load data CPR weekday and peak day

CPR weekend

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
January	120	111	115	125	111	121	124	109	109	122	112	109	120	108	119	105	112	118	109	120	116	115	116	115
February	120	111	115	125	111	121	124	109	109	122	112	109	120	108	119	105	112	118	109	120	116	115	116	115
March	120	111	115	125	111	121	124	109	109	122	112	109	120	108	119	105	112	118	109	120	116	115	116	115
April	120	111	115	125	111	121	124	109	109	122	112	109	120	108	119	105	112	118	109	120	116	115	116	115
May	120	111	115	125	111	121	124	109	109	122	112	109	120	108	119	105	112	118	109	120	116	115	116	115
June	120	111	115	125	111	121	124	109	109	122	112	109	120	108	119	105	112	118	109	120	116	115	116	115
July	120	111	115	125	111	121	124	109	109	122	112	109	120	108	119	105	112	118	109	120	116	115	116	115
August	120	111	115	125	111	121	124	109	109	122	112	109	120	108	119	105	112	118	109	120	116	115	116	115
September	120	111	115	125	111	121	124	109	109	122	112	109	120	108	119	105	112	118	109	120	116	115	116	115
October	120	111	115	125	111	121	124	109	109	122	112	109	120	108	119	105	112	118	109	120	116	115	116	115
November	120	111	115	125	111	121	124	109	109	122	112	109	120	108	119	105	112	118	109	120	116	115	116	115
December	120	111	115	125	111	121	124	109	109	122	112	109	120	108	119	105	112	118	109	120	116	115	116	115

Table IV: Load data CPR weekend

CPB weekday and peak day

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
January	43.8	43.2	43.5	43.0	43.5	60.2	218.2	301.7	328.2	309.5	306.8	330.0	273.2	278.3	301.3	311.7	245.5	273.7	302.7	295.3	276.3	161.8	44.7	43.2
February	42.3	42.0	41.5	42.0	43.0	69.7	277.8	345.0	375.0	343.8	347.2	344.0	275.7	273.5	270.7	337.5	332.0	337.3	345.2	281.8	316.2	162.3	42.8	42.2
March	25.2	25.5	26.5	26.0	27.0	59.2	256.5	255.0	259.0	266.3	288.8	291.5	259.5	274.7	255.2	259.0	275.7	255.8	263.0	247.7	274.7	162.3	34.2	33.5
April	25.2	25.5	26.0	26.7	27.0	57.8	266.7	308.0	315.2	283.7	231.7	300.2	256.5	249.5	239.2	307.7	236.0	311.3	293.5	274.8	220.8	97.3	21.8	22.2
May	23.5	24.0	24.8	25.2	25.5	53.0	229.0	266.5	328.2	333.5	366.7	356.3	305.5	288.7	287.2	327.3	283.5	317.2	295.7	270.0	310.3	112.5	22.8	23.7
June	17.0	17.0	17.3	17.8	18.5	47.2	238.5	237.5	239.8	251.5	273.7	290.2	278.3	302.8	264.2	300.0	278.3	268.8	246.7	187.0	167.3	115.5	16.3	16.0
July	13.7	13.8	14.0	14.0	13.8	31.5	192.7	209.8	227.2	135.3	130.7	135.5	107.7	168.5	151.3	182.2	123.3	177.0	179.7	151.8	155.5	76.2	13.8	14.2
August	16.2	16.5	17.2	17.8	17.3	17.5	29.2	58.7	62.3	62.3	60.8	55.8	44.3	49.7	43.2	20.8	17.8	15.8	15.8	15.3	16.2	16.7	17.3	17.2
September	12.8	12.7	13.0	12.8	13.0	25.3	163.2	184.8	200.3	222.7	206.3	233.0	171.5	144.8	127.3	146.7	157.0	148.5	123.8	95.2	139.8	81.3	13.0	12.8
October	16.3	16.3	17.2	18.7	17.5	49.3	144.3	218.2	248.7	277.8	263.0	233.0	230.0	206.8	132.2	112.5	103.2	92.2	131.3	155.0	158.5	95.0	25.5	24.7
November	32.0	32.3	31.5	31.8	31.5	55.3	172.3	174.0	197.0	186.0	192.7	193.2	128.5	137.7	172.3	186.3	176.5	175.5	176.8	95.8	32.8	34.5	33.5	34.3
December	44.7	44.7	45.7	44.7	44.8	65.2	203.3	275.8	277.8	267.2	228.3	271.0	244.2	200.0	216.8	198.0	189.8	179.5	101.3	75.3	37.5	35.8	36.3	34.7

Table V: Load data CPB weekday and peak day

CPB weekend

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
January	34.83	34.67	34.67	34.83	35.33	36.00	35.67	34.67	34.50	34.83	34.67	34.00	34.00	34.00	33.00	33.50	33.83	35.17	34.83	35.67	36.83	38.17	37.83	38.00
February	34.83	34.67	34.67	34.83	35.33	36.00	35.67	34.67	34.50	34.83	34.67	34.00	34.00	34.00	33.00	33.50	33.83	35.17	34.83	35.67	36.83	38.17	37.83	38.00
March	34.83	34.67	34.67	34.83	35.33	36.00	35.67	34.67	34.50	34.83	34.67	34.00	34.00	34.00	33.00	33.50	33.83	35.17	34.83	35.67	36.83	38.17	37.83	38.00
April	34.83	34.67	34.67	34.83	35.33	36.00	35.67	34.67	34.50	34.83	34.67	34.00	34.00	34.00	33.00	33.50	33.83	35.17	34.83	35.67	36.83	38.17	37.83	38.00
May	34.83	34.67	34.67	34.83	35.33	36.00	35.67	34.67	34.50	34.83	34.67	34.00	34.00	34.00	33.00	33.50	33.83	35.17	34.83	35.67	36.83	38.17	37.83	38.00
June	34.83	34.67	34.67	34.83	35.33	36.00	35.67	34.67	34.50	34.83	34.67	34.00	34.00	34.00	33.00	33.50	33.83	35.17	34.83	35.67	36.83	38.17	37.83	38.00
July	34.83	34.67	34.67	34.83	35.33	36.00	35.67	34.67	34.50	34.83	34.67	34.00	34.00	34.00	33.00	33.50	33.83	35.17	34.83	35.67	36.83	38.17	37.83	38.00
August	34.83	34.67	34.67	34.83	35.33	36.00	35.67	34.67	34.50	34.83	34.67	34.00	34.00	34.00	33.00	33.50	33.83	35.17	34.83	35.67	36.83	38.17	37.83	38.00
September	34.83	34.67	34.67	34.83	35.33	36.00	35.67	34.67	34.50	34.83	34.67	34.00	34.00	34.00	33.00	33.50	33.83	35.17	34.83	35.67	36.83	38.17	37.83	38.00
October	34.83	34.67	34.67	34.83	35.33	36.00	35.67	34.67	34.50	34.83	34.67	34.00	34.00	34.00	33.00	33.50	33.83	35.17	34.83	35.67	36.83	38.17	37.83	38.00
November	34.83	34.67	34.67	34.83	35.33	36.00	35.67	34.67	34.50	34.83	34.67	34.00	34.00	34.00	33.00	33.50	33.83	35.17	34.83	35.67	36.83	38.17	37.83	38.00
December	34.83	34.67	34.67	34.83	35.33	36.00	35.67	34.67	34.50	34.83	34.67	34.00	34.00	34.00	33.00	33.50	33.83	35.17	34.83	35.67	36.83	38.17	37.83	38.00

Table VI: Load data CPB weekend

RP weekday and peak day

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
January	585	577	572	576	575	589	604	632	630	632	630	613	635	638	620	628	631	610	613	604	600	567	567	579
February	498	485	485	518	544	584	579	576	568	571	590	583	569	571	561	541	538	550	529	505	510	504	509	504
March	546	539	551	534	529	560	597	598	629	618	616	643	633	635	619	616	598	578	567	598	570	571	565	572
April	535	515	508	513	530	559	605	597	609	619	635	619	624	600	603	611	613	599	579	562	552	505	498	509
May	514	507	500	510	525	554	587	599	586	578	588	610	607	601	619	612	623	601	582	589	582	535	530	525
June	550	541	519	518	500	525	576	609	611	608	623	617	626	636	634	629	635	603	595	559	563	554	564	568
July	521	515	504	505	517	550	583	596	632	636	666	690	699	682	652	669	664	672	652	657	632	602	566	542
August	464	468	463	471	464	478	520	522	532	513	524	535	529	497	490	513	518	483	482	479	459	459	463	464
September	511	516	508	524	514	528	578	585	579	593	603	660	688	667	670	689	673	639	628	640	622	589	584	545
October	490	494	474	488	506	539	574	580	565	542	557	565	569	557	558	557	560	557	563	571	558	501	504	520
November	474	470	472	476	467	490	536	553	561	573	583	581	578	563	568	557	543	528	526	529	526	491	500	512
December	521	509	487	487	503	538	580	590	605	610	607	609	619	608	608	616	603	584	591	591	600	530	517	516

Table VII: Load data RP weekday and peak day

RP weekend

January	498	498	501	498	500	499	498	499	505	499	500	501	499	503	498	498	498	499	506	505	503	498	497	496
February	473	473	473	475	464	453	452	449	453	449	447	446	451	453	454	451	451	448	450	460	459	458	469	468
March	507	507	504	509	506	509	509	500	502	496	498	496	496	496	497	494	494	481	477	482	501	507	508	508
April	445	446	444	446	448	447	444	441	443	446	448	448	449	452	454	454	450	447	446	442	444	447	446	443
May	470	471	467	468	469	455	448	444	442	447	452	464	473	480	491	501	503	503	500	493	483	468	481	476
June	492	492	491	490	489	488	486	482	485	489	487	489	493	501	503	501	503	489	491	483	479	473	470	473
July	492	482	465	464	475	463	443	447	460	471	482	488	493	437	427	429	428	425	425	425	423	431	444	443
August	416	418	419	420	421	420	422	420	411	412	411	413	416	417	418	419	416	417	410	409	409	415	417	422
September	481	477	475	475	478	478	471	468	465	461	459	456	459	462	464	468	467	464	458	452	462	460	460	459
October	497	494	495	496	495	492	490	488	491	498	498	503	507	526	531	532	523	492	467	464	465	460	462	464
November	455	453	454	456	455	439	437	438	433	437	432	433	435	437	437	435	435	437	440	436	438	437	436	448
December	481	478	476	476	476	480	476	475	473	469	467	469	467	470	472	470	472	470	471	469	471	475	475	476

Table VIII: Load data RP weekend

CPC weekday and peak day

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
January	413	448	387	351	452	377	429	461	421	463	529	551	513	545	487	451	492	472	463	391	381	386	337	356
February	451	316	342	266	288	317	274	247	319	374	497	505	512	430	432	447	502	402	364	413	482	479	519	400
March	390	440	454	393	425	266	328	339	331	390	374	481	375	447	440	370	414	357	451	525	506	472	481	367
April	320	427	319	387	288	343	363	321	451	502	450	401	511	359	379	402	351	516	501	487	357	349	350	359
May	430	402	456	386	389	404	480	419	355	488	464	551	542	529	506	466	409	372	339	431	484	420	351	471
June	537	482	470	536	542	438	396	546	559	468	500	513	442	446	421	393	447	549	601	603	456	562	416	474
July	401	385	525	543	550	461	472	458	449	421	545	657	633	534	513	572	509	520	528	503	468	481	512	470
August	36	36	36	36	36	36	69	82	87	116	166	168	173	170	145	141	127	64	39	31	31	33	33	32
September	412	312	409	360	406	255	219	308	316	497	516	358	499	481	295	313	350	451	354	330	345	392	354	527
October	447	559	594	569	442	502	480	544	505	449	517	604	511	472	352	469	379	366	511	452	559	462	507	574
November	346	349	364	380	332	150	272	404	506	511	504	496	477	452	484	513	424	416	468	473	495	406	364	359
December	371	471	447	416	474	377	377	416	458	464	401	360	479	482	350	457	435	397	432	491	496	335	341	474

Table IX: Load data CPC weekday and peak day

CPC weekend

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
January	383	335	292	214	167	149	185	188	177	169	148	105	39	37	35	37	34	36	37	39	38	39	40	40
February	444	387	409	472	333	207	156	154	164	164	174	175	78	69	64	64	60	46	35	37	37	36	37	36
March	294	237	247	218	262	223	39	35	42	39	38	52	57	56	58	55	59	58	37	32	32	32	31	32
April	433	497	479	490	448	130	193	197	235	176	77	65	49	48	46	45	45	44	45	45	45	48	49	49
May	398	449	430	471	420	181	37	34	52	64	61	72	65	65	69	66	70	79	60	30	28	29	31	31
June	554	471	409	420	332	164	30	31	45	45	66	57	52	39	26	26	26	27	26	26	26	25	28	29
July	408	415	401	452	387	349	252	283	259	198	230	108	46	48	47	44	44	44	43	43	43	46	45	46
August	37	36	37	36	37	36	35	33	50	54	53	53	53	52	43	36	36	36	35	36	36	38	39	38
September	421	484	551	455	249	212	171	159	153	169	167	167	72	64	31	30	29	29	29	31	33	33	33	32
October	576	502	427	429	282	170	172	187	196	194	188	167	62	60	36	37	36	36	35	38	39	41	40	39
November	278	284	352	218	174	118	220	227	239	221	208	176	38	38	38	39	38	41	41	42	42	43	42	42
December	340	385	408	369	338	209	194	342	334	338	200	173	68	64	64	64	65	67	68	68	48	42	42	41

Table X: Load data CPC weekend

SKF weekday and peak day

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
January	1202	1191	1265	1392	1457	1424	1581	1778	1583	1511	1593	1650	1709	1658	1650	1786	1599	1544	1510	1583	1548	1545	1535	1393
February	1239	1273	1313	1410	1417	1409	1560	1680	1650	1583	1637	1655	1734	1730	1692	1666	1563	1497	1454	1458	1368	1316	1248	1244
March	1246	1290	1242	1346	1376	1324	1424	1530	1487	1526	1509	1605	1623	1634	1638	1682	1513	1414	1468	1517	1561	1473	1441	1503
April	1206	1206	1217	1328	1331	1304	1429	1530	1535	1501	1479	1537	1633	1582	1586	1655	1500	1421	1419	1446	1426	1417	1340	1332
May	1228	1230	1258	1384	1414	1373	1529	1688	1577	1502	1572	1637	1758	1680	1668	1692	1566	1445	1449	1483	1470	1326	1202	1194
June	1380	1404	1399	1560	1537	1549	1670	1812	1717	1630	1675	1761	1796	1687	1724	1777	1679	1550	1593	1665	1655	1619	1618	1475
July	1348	1352	1356	1484	1509	1471	1552	1717	1600	1585	1665	1773	1794	1702	1677	1735	1648	1650	1671	1729	1663	1583	1595	1530
August	1089	1076	1070	1125	1201	1174	1403	1616	1529	1431	1532	1568	1548	1571	1548	1516	1573	1545	1341	1482	1449	1451	1391	1214
September	1278	1300	1304	1439	1452	1431	1513	1644	1612	1546	1584	1659	1685	1602	1609	1717	1505	1529	1521	1573	1561	1491	1423	1432
October	1346	1350	1379	1398	1424	1344	1445	1559	1472	1473	1566	1646	1681	1726	1708	1728	1636	1563	1523	1570	1591	1513	1452	1413
November	874	860	863	859	859	917	1459	1652	1659	1701	1802	1700	1695	1728	1653	1612	1579	1605	1496	1511	1574	1557	1525	1321
December	1273	1294	1279	1373	1436	1361	1472	1620	1628	1560	1623	1581	1595	1555	1584	1673	1549	1468	1446	1540	1563	1461	1423	1432

Table XI: Load data SKF weekday and peak day

SKF weekend

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
January	1043	1005	896	854	848	874	1060	1090	1127	1127	1141	1100	1042	1030	1018	1012	1007	980	915	908	887	878	875	862
February	1090	883	852	835	851	1075	1130	1148	1192	1204	1122	1060	1017	1020	1012	1013	998	919	913	898	903	902	899	880
March	913	863	855	835	833	846	1068	1114	1097	1109	1084	1041	1007	965	963	972	987	974	802	789	770	776	775	760
April	834	787	773	764	730	708	884	966	1021	1056	1033	1012	974	987	1039	1043	1012	953	842	829	796	770	786	809
May	977	951	920	881	871	912	1090	1127	1132	1145	1170	1154	1121	1104	1098	1057	1053	1026	953	911	896	895	890	882
June	872	826	828	829	817	848	1002	1029	1070	1071	1063	1060	1047	1041	1068	1068	1079	1049	906	898	880	868	871	856
July	1048	1003	981	983	984	1005	1142	1217	1237	1228	1243	1219	1159	1138	1149	1143	1147	1115	1044	1031	1022	1012	1012	971
August	782	788	786	784	782	782	782	776	765	767	788	816	827	824	829	832	847	842	837	837	824	803	787	786
September	1024	979	959	950	929	939	1133	1156	1144	1149	1136	1119	1086	1104	1077	1085	1091	1043	952	925	853	863	864	865
October	954	902	880	879	861	873	1015	1048	1051	1049	1043	1007	986	997	1006	1006	1018	998	947	939	900	888	885	868
November	1070	1048	964	948	937	963	1101	1151	1153	1150	1148	1121	1078	1064	1048	1015	1005	997	948	947	949	946	936	937
December	1037	991	962	933	928	944	1065	1094	1102	1099	1085	1049	976	969	967	945	930	913	866	863	843	840	847	849

Table XII: Load data SKF weekend