# Deployable Storage-to-Cash Solution - WP 5 report

## ACES project

## Adaptive Control of Energy Storage

Final Version

MINcom Smart Solutions GmbH

2021-02-12

## INTERNAL REFERENCE:

| | |
|---|---|
| **Deliverable name** | Work package WP 5 report |
| **Author(s):** | Gerhard Kleineidam (MINcom Smart Solutions), Hjalmar Phil (RISE), Anton Göller (MINcom Smart Solutions), Magnus Brolin (RISE) |
| **Reviewer(s):** | Adam Holmer (WSP)<br>Ellinor Forsström (RISE) |
| **Released by:** | Gerhard Kleineidam (MINcom Smart Solutions) |
| **Lead Partner:** | Metrum Sweden AB |
| **Document (File):** | ACES_WP5_Report_v1.0-final.docx |
| **Issue (Save) date:** | 2021-02-12 |
| **Confidentiality (TLP):** | **COLOR - WHITE** |

## DOCUMENT SENSITIVITY

| | | |
|---|---|---|
| ☒ | **Not Sensitive** | Contains only factual or background information; contains no new or additional analysis, recommendations or policy-relevant statements |
| ☐ | **Moderately Sensitive** | Contains some analysis or interpretation of results; contains no recommendations or policy-relevant statements |
| ☐ | **Sensitive** | Contains analysis or interpretation of results with policy-relevance and/or recommendations or policy-relevant statements |
| ☐ | **Highly Sensitive Confidential** | Contains significant analysis or interpretation of results with major policy-relevance or implications, contains extensive recommendations or policy-relevant statements, and/or contain policy-prescriptive statements. This sensitivity requires SB decision. |

## VERSION MANAGEMENT

| Ver-sion | Status | Date | Changes |
|---|---|---|---|
| V 0.1 √ | released | 19.05.2020 | Table of contents to be discussed with RISE |
| V 0.2 √ | released | 27.05.2020 | TOC released – start to develop first draft |
| V 0.3 √ | released | 23.08.2020 | First draft waiting for comments from project management |
| V 0.4 √ | released | 22.09.2020 | Update from 25/8 "ACES Final Report check in #1" meeting |
| V 0.5 √ | released | 24.11.2020 | Update from 22/9 "ACES Final Report check in #2" meeting |
| V 0.6 √ | released | 02.12.2020 | Document to be reviewed by PM and RISE |
| V 0.7 √ | released | 12.12.2020 | Document to be reviewed MINcom Smart Solutions |
| V 0.8 √ | released | 17.12.2020 | Version sent out for release |
| V 0.9 √ | released | 09.02.2021 | Update from PM - ACES_WP5_Report_v0.8_PM.docx |
| **V 1.0 √** | **released** | **12.02.2021** | **This document - Final ACES WP 5 Report** |

## TRAFFIC LIGHT PROTOCOL (TLP)[1]

The Traffic Light Protocol (TLP) was created by the UK Centre for the Protection of National Infrastructure (CPNI) in order to encourage greater sharing of information. In order to encourage the sharing of sensitive (but unclassified) information, however, the originator needs to signal how widely they want their information to be circulated beyond the immediate recipient, if at all. The TLP is based on the concept of the originator labelling information with one of four colours to indicate what further dissemination, if any, can be undertaken by the recipient. The recipient must consult the originator if wider dissemination is required.

Sharing of information is classified with four states (colours). The four colours and their meanings are:

| | |
|---|---|
| **RED** | **Personal distribution for named recipients only**<br><br>Information is shared in the context of a meeting, for example. RED information is limited to those present at the meeting. In most circumstances, RED information will be passed verbally or in person. |
| **YELLOW** | **Limited distribution**<br><br>The recipient may share YELLOW information with others within their organization, but only on a 'need-to-know' basis. The originator may be expected to specify the intended limits of that sharing. |
| **GREEN** | **Community wide distribution**<br><br>Information in this category can be circulated widely within a particular community. However, the information may not be published or posted on the Internet, nor released outside of the community. |
| **WHITE** | **Unlimited distribution**<br><br>Subject to standard copyright rules, WHITE information may be distributed freely, without restriction. |

[1] RULES OF PROCEDURE FOR THE EUROPEAN FORUM FOR MEMBER STATES (EFMS) ON PUBLIC POLICIES FOR SECURITY AND RESILIENCE IN THE CONTEXT OF CRITICAL INFORMATION INFRASTRUCTURE PROTECTION, Version 3.0 FINAL – May 2011 "Traffic Light system"

# ABSTRACT – EXECUTIVE SUMMARY


*Introduction*

Energy storage is the key enabler for the transition to a 100% renewable power system. The Adaptive Control of Energy Storage (ACES) project has invested in energy storage and associated equipment for measurement, monitoring and control in order to provide effective energy storage solutions using artificial intelligence. In this context work package WP 5 has investigated the market for a "Storage to Cash Solution" and has developed a software component, which monitors and invoices the services provided by the ACES solution. The billing solution developed here can be applied to a high variety of business cases not just limited to those described in this report.

*Background*

Payment transactions and billing solutions are becoming increasingly important in the energy business and future energy market places. There is an increasing demand for "energy-to-cash" solutions, e.g. for load balancing, for e-car charging, for power quality, for SMEs providing local RES production, and other energy related services. Additionally, new regional market places for local energy trading will emerge, which would require billing services to handle flexibility and flexible tariffs on demand and on production side.

*Methodology*

Work package WP 5 focusses on software development and market penetration for emerging energy related services including billing. It divides its software development process into distinct phases starting with (i) requirement specification, (ii) ICT architecture and design, (iii) software development, (iv) installation and integration, and finally (v) demonstration and evaluation of the project results. In parallel to this software development activities a thorough market analysis has been done which builds the basis for a suitable and convincing dissemination and exploitation strategy of the ACES solution.

*Results*

All components of the ACES solution have been developed and tested by independently acting teams. System design, integration and testing have been executed under the guidance of the partner EMBRIQ. The Billing System has been developed by partner MINcom Smart Solutions. On various occasions WP5 partners have contacted ACES stakeholders and potential customers and presented the ACES project focusing on billing. They have received high interest and convincing readiness to invest into the billing solution developed.

*Conclusions*

Work package WP5 invites interested parties to receive a demonstration on features and performance of the Billing System developed. Potential customers, investors, operators and end-users will be supported by our experts to get our billing solution integrated and applied to any specific IT environment, regardless which kind of ERP system – like SAP, Schleupen, … – they might have in use.

**Legal Disclaimer**

**The content and views expressed in this material are those of the authors and do not necessarily reflect the views or opinion of the ERA-Net SES initiative. Any reference given does not necessarily imply the endorsement by ERA-Net SES.**

**Copyright**



Managing Partner:

Partners:

Observers:

*This project has received funding in the framework of the joint programming initiative ERA-Net Smart Energy Systems' focus initiative Smart Grids Plus, with support from the European Union's Horizon 2020 research and innovation programme under grant agreement No 646039.*

TABLE OF CONTENTS

# 1. Acronyms

| Word/abbreviation / acronym | Explanation |
|---|---|
| ACES Project | Adaptive Control of Energy Storage project |
| ACES Service Provider | is meant to be the operator of energy storage services comprising energy / battery management, order processing and billing. The ACES Service Provider causes OPEX which is necessary to calculate the economic value of an ACES business application. The ACES Service Provider expects remuneration of OPEX plus profit. |
| ACES Service Receiver | is meant to be a user of energy storage services provided by the ACES Service Provider. The ACES Service Receiver pays the bill and thus covers CAPEX, OPEX and profit in the business model of the specific ACES application. |
| ACS | Adaptive Control System |
| aFRR | Automatic Frequency Restoration Reserve |
| AMS | Automatic Measurement System |
| B2B | Business-to-Business |
| Battery Owner | Is meant to be the party which invested into ACES technology, where the main share of investment will be related to the battery. The Battery Owner causes CAPEX which is necessary to calculate the economic value of an ACES business application. The Battery Owner expects ROI including coverage of CAPEX (interests, depreciation) plus profit or any other value. |
| Billing System | Shall be the complete software package including all necessary services provided by MINcom Smart Solutions to achieve the required ACES goals. This comprise services like: TS (Tariff Service), BS (Billing Service), print services, file transfer services for bills and credit notes provided to the ACES demo sites. |
| BMS | Battery Management System, A battery management system (BMS) is any electronic system that manages a rechargeable battery (cell or battery pack), such as by protecting the battery from operating outside its safe operating area, monitoring its state, calculating secondary data, reporting that data, controlling its environment, authenticating it and / or balancing it. (Barsukov and Qian 2013) |

| | |
|---|---|
| BO | Battery Owner |
| BRP | Balance Responsible Party |
| | |
| BS | Billing Service |
| CAPEX | Capital Expenditure |
| CHP | Combined Heat and Power |
| DER | Distributed energy resource |
| DSO | Distribution System Operator |
| DSOA | DSO Aggregator |
| EEG | Erneuerbare-energien-gesetz (German renewable energy sources act) |
| EEX | European Energy Exchange |
| EMS | Energy Management System. Generally, this is a system of computer-aided tools used by operators of electric utility grids to monitor, control, and optimize the performance of the generation and/or transmission system. It also is used by systems which control the dispatch and thereby energy flows (charging, discharging of batteries) between the battery storage system and the electrical grid it is connected to. |
| ERP | Enterprise Resource Planning |
| EUR | Euro |
| EV | Electric Vehicle |
| FCR-D | Frequency Containment Reserve – Disturbance |
| FCR-N | Frequency Containment Reserve – Normal |
| FMS | Facility Management System |
| H2E | Hydrogen to Electricity |
| ICT | Information and Communication Technology |
| kVAr | Kilovolt-ampere reactive power |
| kW | Kilowatt |
| kWh | Kilowatt hour |

| | |
|---|---|
| kWp | Kilowatt Peak - The optimal power delivery from a solar cell, int0 the best possible environment. In Sweden a solar panel typically delivers 800-850 kWh/year for every 1 kWp. |
| mFRR | Manual Frequency Restoration Reserve |
| MINcom | Short for MINcom Smart Solutions GmbH |
| MTTI | Mean Time To be Informed – receive information about an event |
| MTTR | Mean Time To Repair |
| MVP | Minimum Viable Product |
| MW | Megawatt |
| MWh | Megawatt hour |
| OPEX | Operational Expenditure |
| OS | Operating System |
| PCR | Primary Control Reserve |
| PQ | Power Quality |
| PtH | Power to Heat |
| PV | PhotoVoltaic |
| RES | Renewable Energy Sources |
| REST | Representational State Transfer: a software architectural style that defines a set of constraints to be used for creating Web services. [Wikipedia – Representational state transfer. 2019] |
| ROI | Return on Investment |
| SCR | Secondary Control Reserve |
| SEK | Swedish krona |
| SME | Small Medium-sized Enterprise |
| SWOT | Strength – Weaknesses – Opportunities – Risks |
| TCR | Tertiary control reserve |
| TRL | Technology Readiness Level |

| | |
|---|---|
| TS | Tariff Service is a part of the Billing System |
| TSO | Transmission System Operator |
| UPS | Uninterruptable Power Supply |
| USD | United States Dollar |
| VAT | Value Added Tax |
| VPP | Virtual Power Plant |

# 2. Introduction – Deployable Storage-to-Cash Solution

Energy storage is the key enabler for the transition to a 100% renewable power system. The Adaptive Control of Energy Storage (ACES) project has invested in energy storage and associated equipment for measurement, monitoring and control in order to contribute to an affordable 100% renewable power system with effective battery storage solutions using artificial intelligence. The Adaptive Control of Energy storage (ACES) project has been performed by a consortium of ten [10] partner organisations: lead partner Metrum Sweden AB (Sweden), Glava Energy Center (Sweden), RISE Research Institutes of Sweden AB (Sweden), Insplorion AB (Sweden), Embriq A/S (Norway), MINcom Smart Solutions GmbH (Germany), Fraunhofer Institute for Factory Operation and Automation IFF (Germany), Krebs engineers GmbH (Germany), VänerEnergi AB (Sweden), ABB AB (Sweden).

The ACES project has received funding from the Swedish Energy Agency, The Research Council of Norway and the German Federal Ministry of Economic Affairs and Energy in the framework of the joint programming initiative ERA-Net Smart Grids Plus, with support from the European Union's Horizon 2020 research and innovation programme.

The "Deployable Storage-to-Cash Solution" is created as part of the Adaptive Control of Energy storage (ACES) project. In this context work package WP 5 has investigated the market for a "Storage to Cash Solution" and has developed a software component, which monitors and invoices the services provided by the ACES solution.

Remuneration of energy services makes this work packages key to the adoption and roll out of the ACES solution. The billing solution developed here can be integrated to a high variety of business cases not just limited to those described in this report.

Billing solutions with effective interfaces to advanced energy management systems will become more and more important in the future. There is an increasing need for remuneration of energy services, e.g. for load balancing in the distribution grids (see Figure 1), for charging to push e-mobility, for owners and operators of the highly raising number of small RES installations, for upcoming new markets regarding regional energy supply and the demand for flexible tariffs. MINcom Smart Solutions who are in charge of driving the work package WP 5 have contacted several potential customers who expressed high interest in the ACES solution and the Billing System in particular.

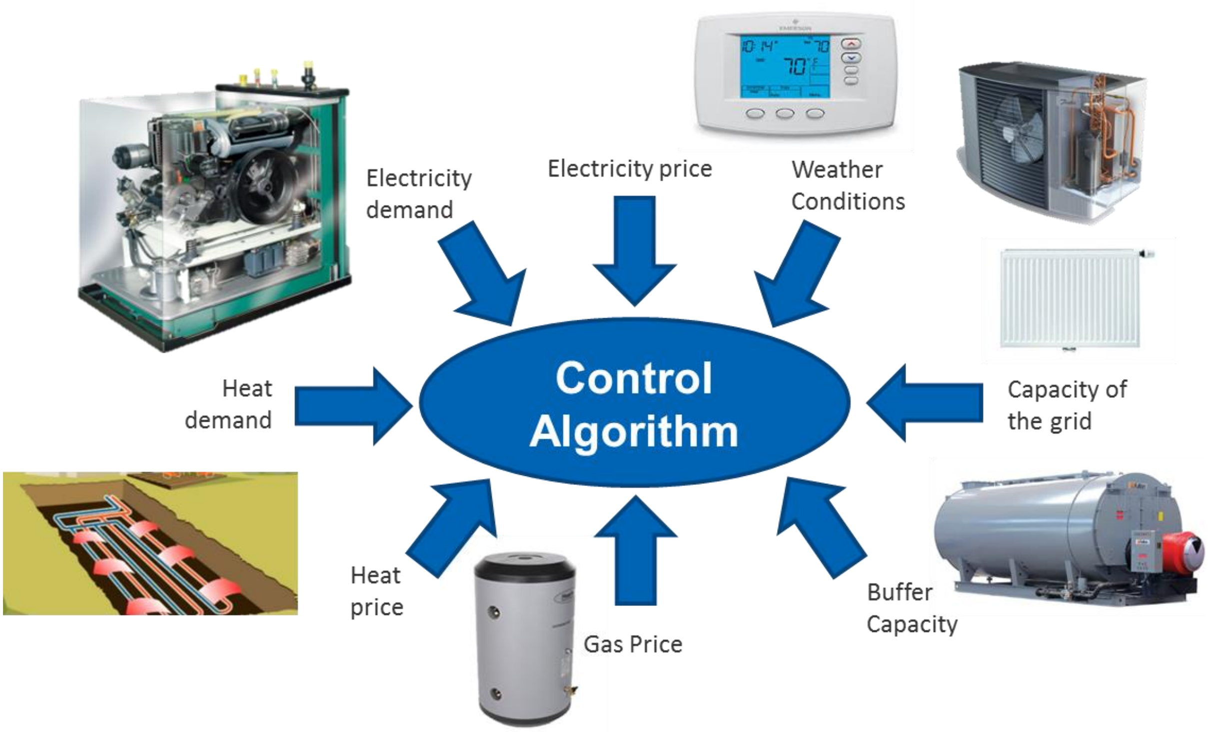


*Figure 1: Conflicting targets require intelligent energy control and storage capacity to manage fluctuating power demand and feed – Picture Source*[2]

The overall objective of the ACES project is to develop, implement, and test advanced measurement technology and adaptive control algorithms for energy storage systems in order to allow for improved economics of operation. By reaching the project objectives, the ACES project aim is to contribute to an affordable 100% renewable power system with smart battery storage solutions using artificial intelligence.

More information on the ACES project can be found on: http://www.acesproject.eu/

## PURPOSE OF WORK PACKAGE 5

The ACES project has been organized in six [6] different work packages with multiple dependencies and collaborations in-between. The purpose of this report is to present the findings and conclusions related to project goals of work package 5. In addition, a general description and evaluation of the project execution is given, in order to share not only findings related to the project objectives, but also learnings about project methodology and tools in order to further contribute to the research community regarding successful project design.

Work package 5 focusses on creating a possibility for the battery storage system operators to offer different services on several markets simultaneously. This document describes:

1. Markets and new opportunities for energy storage (battery) services

[2] Prof. Dr. George Huitema (TNO), EuroCASE 2015, TU/d, 2 November 2015.

2. A Billing System which has been developed to get such new services remunerated.
3. A complete Storage-to-Cash solution to be tested as a prototype at least at two demonstration sites.

Figure 2 describes the generic ICT architecture of the ACES solution including the interfaces between the different system components. The Billing System provides various services to the ACS component which has been developed by the project partner EMBRIQ as part of work package WP3. The main output of the Billing S system are invoices or credit notes that can be sent to the users of the storage services.

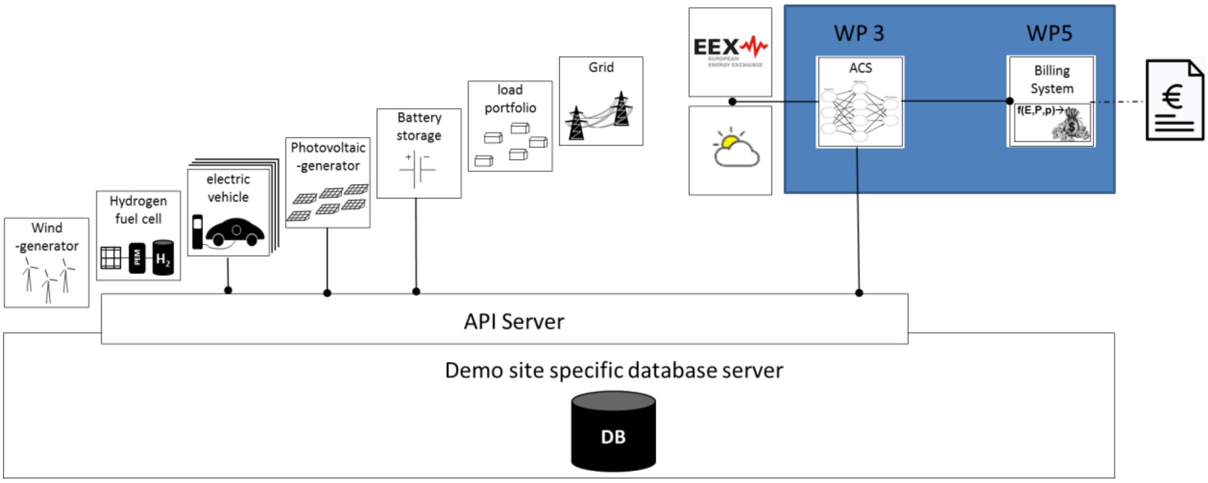


*Figure 2: Generic ICT architecture of the "Storage to Cash Solution" with WP3 ACS software and WP 5 Billing System.*

## GOALS AND RESEARCH QUESTIONS

The overall goal of work package 5 has been the development and testing of a billing solution for energy storage (battery) services provided for markets that for the most part do not exist today.

## DELIMITATIONS

Limitations for the economic evaluation is the amount of data and the chosen dispatch algorithm for the BMS.

# 3. Background information – Smart Dynamic Billing

There have been several project prior to ACES which have dealt with remuneration of flexibility or battery services regarding dynamic pricing in local markets. The project which came very close to what ACES has in focus has been one of the so called Smart-Community projects co-financed by the Japanese governmental institution of NEDO[3]. In 2019 the German city of Speyer with its Stadtwerke Speyer (SWS) of Germany have implemented and tested a similar installation of various energy storages (electrical storage and PtH). This project aimed to use as much as possible of the PV generated power from the roofs of two selected apartment buildings to satisfy household energy consumption while reducing total household energy costs including heating costs. The presentation of results and sustainable business models have given guidance to the evaluation of the ACES project – see Figure 3 [1].

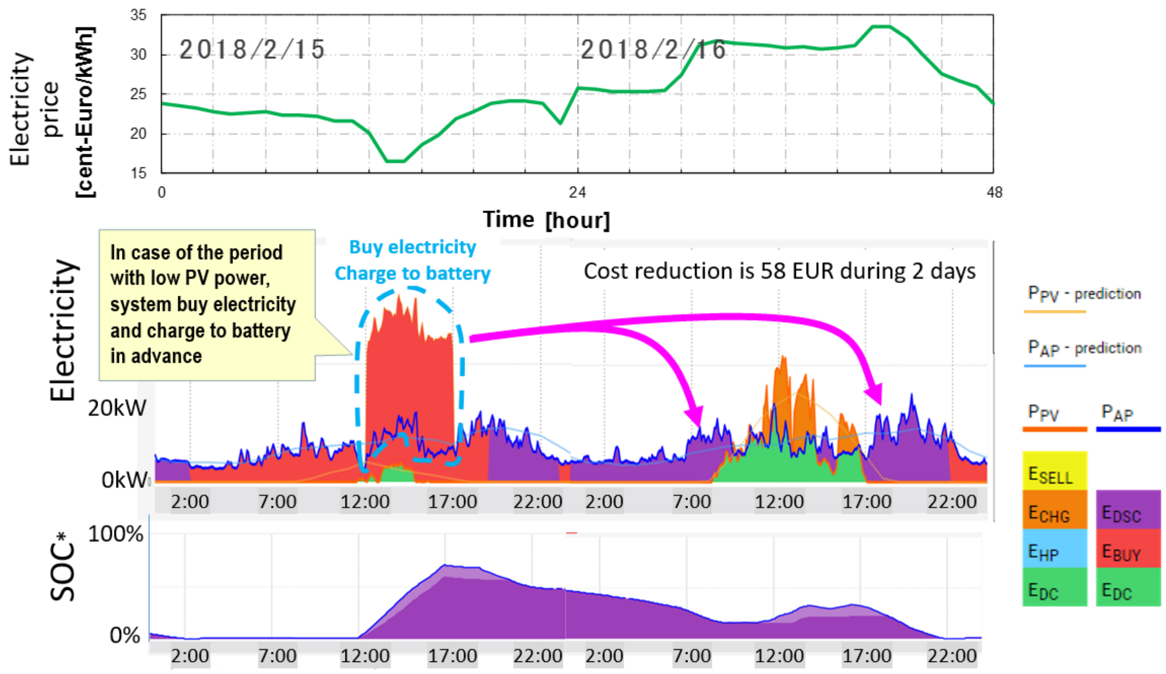


*Figure 3: Intelligent battery management where flexible tariffs would drive cost-efficiency in use of storages* [1]

## CURRENT STATE OF THE ENERGY STORAGE MARKET

This chapter provides an overview of the current state of the battery energy storage market, focusing on Sweden and Germany. Only stationary battery storage systems are considered.

The first two subsections provide an overview of the global battery energy storage market and some notable illustrative examples from around the world. The subsequent sections discuss Swedish and German regulations and taxes that, in some cases, affect the business case for battery energy storage solutions.

[3] NEDO – New Energy and Industrial Technology Development Organization https://www.nedo.go.jp/english/

**International overview**

Global investments in electrochemical stationary battery storage has grown to around 3-5 billion USD per year in recent years [2]. This amount includes both smaller behind-the-meter battery storage and larger grid-scale applications, with global investments divided roughly equally between these two categories. The stationary battery storage market is still relatively small compared to many other sectors within the electrical power industry. For example, global investments in solar PV is estimated to have been almost 140 billion USD in 2019.

Globally, the United States, Korea and Japan has been accounted for large shares of the market while investments in China has increased substantially during 2018-2019 [2]. Australia also stand out as having attracted a relatively large amount of investment in recent years. A large proportion of currently operational grid-scale battery energy storage systems are used for providing services to TSOs, especially frequency control. Further, grid-scale batteries installed in combination with large solar PV or wind-power projects are becoming increasingly common [3].

The behind-the-meter storage market is often supported by incentives for pairing a battery with distributed solar PV. This has created a relatively large market for behind-the-meter batteries, for example in Germany, Korea, the United States and Australia [2] [3].

**International examples**

This section briefly describes some notable cases where battery energy storage is used commercially today, from large grid-scale applications to smaller behind-the-meter batteries. The cases in this section highlight a few illustrative examples and is not meant to provide an exhaustive list.

*Grid-scale applications*

*Hornsdale Power Reserve*

The Hornsdale Power Reserve is a 100 MW/129 MWh lithium-ion battery energy storage system in South Australia, built in 2017 by Tesla for the French power producer Neoen. During 2020, an expansion project is adding an additional 50 MW and 64.5 MWh. The system shares the same network connection as the 300 MW Hornsdale Wind Farm, also owned by Neoen.

70 MW of the battery discharge capacity and about 10 MWh of the energy storage capacity is reserved for providing contingency frequency reserve, and for a control scheme protecting a particular transmission line. The remaining 30 MW discharge capacity, and most of the energy capacity, is available for other market uses, including energy arbitrage and provision of regulation frequency control. [4]

*Gemini Solar Project*

Another example of a very large battery energy storage system is the planned Gemini Solar Project in Nevada, USA. This project involves combining a 380 MW and 1400 MWh battery energy storage system with a 690 MW solar PV project [5]. The project is expected to be completed in 2023.

*Pomona Energy Storage*

The Pomona Energy Storage facility is a 20 MW and 80 MWh battery energy storage facility in Pomona, California. It is owned and operated by AltaGas, who offers the full capacity of the battery to the California ISO integrated energy and ancillary services market, thereby enabling the battery to provide energy arbitrage and/or ancillary services such as frequency regulation.

The Pomona Energy Storage facility was built as a response to the emergency shutdown of the Aliso Canyon natural gas storage facility in 2016 – an event that caused a significant risk for insufficient flexible generation in Southern California. As a response to this emergency, the California Energy Commission requested the local utility Southern California Edison (SCE) to solicit an energy storage solution that could be brought online within a very short time-fame. Therefore, in addition to the revenues received for the day-to-day operations of the facility, AltaGas receives Resource Adequacy payments from SCE for allowing SCE to count the facility towards meeting their Recourse Adequacy obligations. [6]

*Pen y Cymoedd Battery*

The 22 MW Pen y Cymoedd battery in Wales is owned and operated by Vattenfall, who uses the battery for providing Enhanced Frequency Response (EFR) to the TSO National Grid. EFR is a new service developed by National Grid specifically for resources that can respond to frequency deviations faster than what is required for the traditional frequency response services. The Vattenfall Pen y Cymoedd facility is one of eight storage facilities, with a joint capacity of about 200 MW, that were selected in a competitive tendering process for supplying the new service. These facilities are providing the EFR service for a four-year contracting period and are receiving a compensation based on the bid they submitted during the tendering process.

*Leighton Buzzard*

As part of the Smarter Energy Storage project, a 6 MW and 10 MWh battery was placed at a substation in Leighton Buzzard north of London in the UK. The primary purpose of the battery was to defer upgrades in traditional distribution network infrastructure, which otherwise would have been needed due to peak loads occasionally exceeding the capacity rating of the existing infrastructure. A detailed description of the case, including a social cost-benefit analysis, is provided by [7]. In addition to the distribution network deferral, the battery was also used for providing a range of other services, such as frequency response and energy arbitrage. Despite this, the battery investment likely did not have a positive net social benefit, given the high battery costs at the time of investment [7].

*Behind-the-meter applications*

*Stem*

The US-based company Stem offers battery energy storage solutions and related software, primarily targeting somewhat larger commercial and public sector behind-the-meter applications. Many of their use cases involve using behind-the-meter energy storage for managing demand charges (peak shaving) at commercial sites [8].

*SonnenBatterie*

The German company Sonnen manufactures and sells energy storage systems under the brand name SonnenBatterie. The SonnenBatterie is primarily targeted to households and small businesses for behind-the-meter applications and integrate with new or existing solar PV installations. This enables the customer to increase the amount of self-consumption. [9]

*Tesla Powerwall*

The Powerwall from Tesla is intended to be used for home energy storage for maximizing solar self-consumption and/or providing backup power. The Powerwall has a usable capacity of 13.5 kWh and can supply up to 7 kW of power.

## REGULATORY CONSIDERATIONS

Some potential battery energy storage business models may be affected by regulations that prevent some market actors from engaging in certain activities. Specifically, so called *unbundling* rules may, in certain cases, prevent DSOs or TSOs from directly owning and operating battery energy storage.

To ensure a level playing-field with non-discriminatory access to grid infrastructure for all market players, DSOs and TSOs are subject to various forms of unbundling requirements. These regulations attempt to prevent conflicts of interest by promoting the independence of TSOs and DSOs from entities that are active in other parts of the electricity value chain, such as generation and retail of electricity.

The main EU legislation concerning unbundling of TSOs and DSOs was introduced with the Third Energy Package in 2009, specifically the electricity directive [10]. The 2019 recast of the electricity directive [11] (part of the Clean Energy of all Europeans Package, CEP) introduced some changes relevant to unbundling, but the main unbundling provisions remain unchanged compared to the 2009 directive [12]. Since these legislations have been adopted as directives, they are transposed into national law meaning that the specific unbundling regulations differ across different EU member states.

The unbundling requirements set out in the directives are stricter for TSOs than for DSOs. TSOs are required to go through a certification process with their national regulatory authorities. Full ownership unbundling, where the TSO is not part of a vertically integrated undertaking[4], is the preferred regulatory approach and is the approach chosen by most member states. However, other unbundling models are also allowed which allows existing vertically integrated undertakings to maintain ownership of transmission assets, provided that the TSO role is independent of any generation and retail interests.

For DSOs, the directive does not require unbundling in terms of ownership. However, independence in terms of legal form, organization and decision making from activities not related to distribution is required. Member states may choose to not require such unbundling for DSOs with less than 100 000 connected customers. Irrespective of size, separate financial accounts for the distribution activities should be maintained. The regulations are intended to prevent any cross-subsidies to or from the DSO and other parts of a vertically integrated undertaking.

As mentioned above, the DSO unbundling requirements remain largely unchanged in the electricity directive of the CEP compared to the 2009 electricity directive. However, the CEP introduced some additional articles that relate to the roles and responsibilities of DSOs. Specifically, it requires that DSOs should not own or operate energy storage facilities (except under some specific circumstances where exemptions may be granted).

**Unbundling in Sweden**

Swedish unbundling goes beyond the EU requirement. All network owners (including DSOs of all sizes) are prevented from engaging in production and trade of electricity, with only two exemptions: to restore service in case of a black-out, and to compensate for losses in their own networks. However, this unbundling requirement only concerns legal separation, i.e. it requires that the network operation and ownership is carried out in a separate legal entity. However, it does not prevent a DSO from being part of a group of companies with common ownership, where other entities within the same group may engage in production and trade of electricity. If the DSO has more than 100 000 customers, then the EU-mandated rules apply for functional separation in terms of management and

[4] A vertically integrated undertaking is defined as "an electricity undertaking or a group of electricity undertakings where the same person or the same persons are entitled, directly or indirectly, to exercise control, and where the undertaking or group of undertakings perform at least one of the functions of transmission or distribution, and at least one of the functions of generation or supply of electricity" [10].

organization between the network company and other legal entities within the same group.

As of 2020, the CEP has not yet been transposed into national law and Swedish law does not yet explicitly state how the unbundling rules should be interpreted when it comes to the possibilities for DSOs to own and operate battery energy storage. The Swedish Energy Markets Inspectorate have communicated that their interpretation of the current law is that a DSO is allowed to build and own a battery energy storage, but that they are restricted in how they can operate it [13]. Essentially, a DSO is not allowed to use the battery for anything that can be considered arbitrage trading. However, a DSO could rent services from a battery energy storage from a third party.

Some modifications to Swedish law is necessary to comply with the new restriction regarding energy storage ownership imposed by the CEP. The Swedish Energy Markets Inspectorate has proposed new legislation which more clearly specifies that DSOs cannot own energy storage facilities, unless an exemption has been granted by the Swedish Energy Markets Inspectorate [14].

### Unbundling in Germany

By and large, the German unbundling rules follow the EU minimum requirements, meaning that strict legal unbundling is not required for DSOs with less than 100 000 customers. 90 percent of DSOs in Germany are sufficiently small to fall under this threshold [15]. However, also for the smaller DSOs, a range of unbundling rules may be applicable, for example concerning separate accounting for the distribution activities, and how the DSO should handle potentially confidential and valuable data [16]. This is to ensure that the DSO provides non-discriminatory access to their network for third parties.

As for the TSOs, Germany's four TSOs have chosen somewhat different approaches for how to comply with the unbundling requirements. Two TSOs (TenneT and 50Hertz) have complete ownership unbundling and are not part of any vertically integrated undertakings. The other two TSOs (Amprion and TransnetBW) have owners that are active also in other parts of the electricity value chain [17].

## TAXES AND FEES

Many business cases for battery energy storage are affected by taxation. The effect of taxation on battery energy storage business cases can go both ways: some business cases may be undermined by taxes, while others may become more attractive because of a tax.

### Swedish taxes and fees

*Energy tax on electricity*

Sweden imposes a national tax on electricity consumption. For 2020, the tax rate is 35.3 öre per kWh (about 0.035 EUR per kWh). Certain consumption, primarily electricity for industrial processes, is exempt from the tax, and consumers in some northern municipalities pay a reduced rate.

The DSO is responsible for collecting the tax when delivering electricity to its customers. Therefore, the DSO adds the tax as an additional volumetric fee when billing its customers. However, the tax is not exclusively applicable to grid-supplied electricity. Self-produced electricity is also taxable, with some exceptions for small-scale generation.

Until recently, the energy tax on electricity has had a significant impact on some battery energy storage business cases. Delivery of electricity from the grid to a battery for charging is, for tax purposes, considered consumption even if the electricity is later fed back to the same grid. This has effectively made business cases based on wholesale market arbitrage much less profitable, since the battery owner would have to pay tax on all stored electricity. Business cases based on provision of grid services to DSOs or TSOs have also been negatively affected by this.

A modification in the tax law approved in November 2018 removes this effective double taxation [18]. Electricity used for charging a battery is still considered consumption and is therefore still taxable, but the tax will be reimbursed for electricity that is fed back to the same grid that it came from. The battery owner will therefore only need to pay tax for the energy losses, if the electricity is fed back to the grid.

*Renewable energy certificates*

The energy certificate system is intended to provide additional incentives for investment in renewable electricity production. New facilities that generate renewable electricity receive one certificate for each MWh produced during the first 15 years of the life of the asset. The owner can sell these certificates in an open market, which provides an additional revenue stream that complements the revenue from selling the electricity itself.

Demand for certificates is created by obliging consumers to buy a certain number of certificates for each MWh consumed. The quota requirement for 2020 is 26.5 percent, which means that consumers are required to purchase 0.265 certificates for each MWh consumed. It is the responsibility of the electricity supplier to buy certificates on behalf of its customers, which means that the supplier adds the cost of the certificates to the amount they charge their customers.

If a battery owner buys the electricity for charging the battery from an electricity supplier, then the certificate system affects battery energy storage business cases in much the same way as the energy tax on electricity did before the modification in 2018, albeit at a lower rate. This is because the electricity supplier is required to purchase certificates for the electricity, even if the electricity is later fed back out to the same grid that it came from. However, it may be possible for a battery owner to circumvent this issue by trading directly on the wholesale market instead of via an electricity supplier. In this case, the owner itself is responsible for procuring certificates, and may not be required to buy certificates for the electricity that was fed back out [19].

*Network fees*

DSOs are funded by fees charged to end-users. Because of the natural monopoly aspects of electricity distribution, the fees that DSOs charge are regulated. In Sweden, this is regulated by the Swedish Energy Markets Inspectorate who determines a revenue cap for each DSO. As long as the revenue cap is satisfied, the DSOs have some flexibility in how they choose to design their pricing structure. For smaller low-voltage customers (such as households) most DSOs charge two types of fees: a fixed price and a variable price. The fixed price is unrelated to the electricity usage, and the variable price is a per-kWh price. Other types of pricing schemes also exist, such as fees based on peak electricity use, but these are more common for larger industrial end-users.

Some Swedish DSOs have chosen to rely primarily on fixed charges and therefore have zero or very low variable prices. Others collect the bulk of their revenues through variable charges. This means that consumers that have different DSOs face different marginal (per-kWh) prices for their electricity. This has implications for certain battery energy storage business cases. In similarity with the energy tax on electricity and the renewable energy certificate costs, the variable network fee creates a difference between the price that a prosumer pays for electricity bought from the grid and the price received for electricity sold to the grid. This price difference encourages the use of battery energy storage for self-consumption of distributed generation.

Further, the DSO network fees may also affect business cases where a third party owns and operates a battery energy storage and provide grid services to a DSO. Because of non-discrimination requirements, the DSO may have to charge network fees for electricity delivered to the battery and/or for electricity fed back to the grid, even if the battery is providing a service to the DSO.

*Tax reduction for distributed generation*

Households with renewable small-scale distributed generation may be eligible for a tax deduction for every kWh that is *not* self-consumed. The tax deduction is therefore based on the amount of surplus electricity that is delivered to the grid at times when the amount generated exceeds the amount consumed. The deduction allows the owner of the distributed generation to deduct 60 öre (about 0.06 EUR) for each surplus kWh that has been delivered to the grid. At most 18 000 SEK per year can be deducted, and the owner of the distributed generation must have sufficient income, such that there is a tax from which to deduct.

This tax deduction affects the profitability of investing in battery energy storage in order to maximize self-consumption from, for example, solar PV. The business case for maximizing self-consumption is based on the premise that the prosumer pays a higher price for electricity bought from the grid than it receives for electricity supplied to the grid. Because of the tax deduction, this price difference is greatly reduced (it may even be reversed) which reduces the profitability of investing in battery energy storage for this purpose.

**German taxes and fees**

Figure 4 below shows the total per-kWh electricity price that a typical German household pays, broken down by its various components [20].

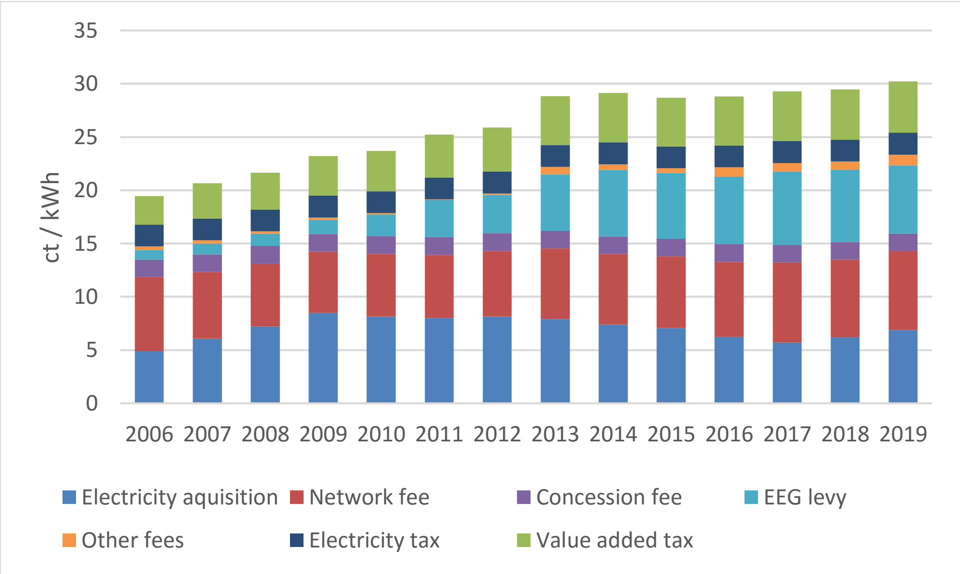


*Figure 4: Composition of electricity price for a typical German household, 2006-2019. Data source: [20]*

*Electricity consumption tax*

The German electricity consumption tax is a tax on electricity that originates when electricity is withdrawn from the grid in Germany. The tax rate as of 2018 is 0.0205 EUR per kWh, and the tax is collected by the supplier who includes the tax in the price of electricity. Some businesses in the manufacturing, agricultural and forestry industries can get a partial tax refund, and certain energy-intensive processes are fully exempt from the tax.

Self-produced electricity may be taxable at the same rate as grid-supplied electricity, but self-produced electricity from renewable sources is exempt.

Electricity consumed for the purpose of generating electricity is exempt from electricity tax. The German tax law explicitly states that this exemption applies to pumped storage, but it does not mention other types of storage technologies. However, according to [21], battery energy storage could in some cases be considered part of the grid infrastructure, in which case it may be exempt from electricity consumption tax.

*EEG-levy*

Under the German feed-in tariff system, renewable energy producers are guaranteed a fixed feed-in tariff for 20 years for electricity supplied to the grid. For small-scale producers, the tariff is received from the DSO, who in turn gets reimbursed from the TSO, who sells the power in the wholesale market. Alternatively, larger producers can sell the power directly in the wholesale market and receive a compensation for the difference.

The size of the feed-in tariffs, which are differentiated by generation type, are determined by the federal government. The tariffs have been decreasing, reflecting the lower costs for new installations.

The system is financed by a levy paid by consumers. For 2018, the levy was about 0.07 EUR per kWh. It is predicted to peak around 2023, and then decline. Energy storage systems are exempt from paying the EEG-levy to the extent that the electricity is resupplied to the grid, such that the levy is paid by a different end-user.

*Network fees*

There are more than 800 DSOs in Germany. The DSOs are funded by fees charged to the end-users of the distribution grids, and the fees are regulated via revenue caps set by the regulator. Different DSOs may therefore charge different fees. In addition to the network fee, DSOs charge a concession fee which is a fee for the use of public space that the utility passes on to the consumer.

Storage facilities, including battery energy storage, are exempt from paying network fees for the energy used for charging the storage, as long as the discharged electricity is returned to the same network. This exemption applies for storage facilities commissioned after August 2011 and applies for the first 20 years of the life of the asset. Older storage facilities may be entitled to reduced rates. [22]

## BATTERY ENERGY STORAGE COSTS

The investment costs for battery energy storage systems is an important component in assessing the financial viability of different use cases. [23] provides an up-to-date analysis of observed costs associated with commercially available energy storage technologies. It focuses on stationary energy storage applications and provides cost estimates broken down by technology type and system size.

Although [23] primarily presents results in terms of leveled costs of energy supplied from the storage systems for various applications, it also provides ranges for the initial capital costs that were used to calculate these values. Combining the cost estimates for storage module, power conversion, balance of system and related EPC costs for lithium batteries, these cost estimates correspond to a range of around €250 - €400 per kWh for very large grid-scale applications, up to around €600 - €700 per kWh for small residential behind-the-meter applications.

The costs for lithium-ion battery packs has fallen substantially in recent years and is expected to continue to fall over the next decade. For example, Bloomberg New Energy Finance assumes an 18 percent yearly learning rate, meaning that the per-kWh price of battery packs would fall by about 67 percent to 2030 [24].

## BILLING AND BILLING SYSTEMS IN THE ENERGY MARKET

*Requirements and Market Practice*

Energy billing is split along two customer groups: (i) Residential customers and small enterprises: For this group, standardized mass billing and a limited amount of service options are in place. The specifics of energy billing and (ii) Medium and large enterprises: Large enterprises can not only negotiate discounts, but also specific services. Most often, this is not compatible with the options supported by mass biling systems. Customer or customer group specific processing steps are applied to handle the highly customized contracts of large customers. In extreme cases, those customers are processed by dedicated data processing and billing systems and the resulting invoices are fed into accounting (ERP) systems similar to manual bills (e.g. via SAP SD).

*The Effect of Regulation*

Regulation in the energy market was driven by planning for many decades, i.e. regulation was and is refined to solicit commitments from actors in the electricity network and to penalize non-conformance to these commitments. In recent years, the growing share of renewable energy sources allowing only short-term planning (hours or days instead of years) is driving regulation from a planning approach for network resources to a dynamic control approach. Presently, we are right in the middle of this disruptive transition. "Planning-approach" regulation is still being refined, while "dynamic-control-approach" regulation is only emerging.

*Consequences for Billing Systems in the Energy Market*

Classic energy products are subject to classic "planning-approach" regulation, with complex billing and customer information requirements including specific taxes and fees unknown in other markets.

Example: Compare a residential electricity bill with a telecom bill. Behind the price the telecom customer pays, there are lots of complex B2B relationships (inter carrier billing, termination fees, peering agreements, …) as in the energy market. But none of those have to be disclosed to the customer who is just presented with amounts and standard VAT tax rates.

Due to "planning-approach" regulatory demands, classic regulated energy services have to be billed by specialized products for the (often national) energy industry, with deep integration of the metering process and the regulated taxes and fees with their transparency requirements towards customers.

Example: In Germany, the legacy billing products used for mass-billing of classic regulated energy services are SAP IS-U, Schleupen and Wilken. A new contender is Power-Cloud, a cloud native SaaS billing system. Power-Cloud is a good example for the chasm between regulated and unregulated business. Their micro-services approach in principal is able to handle both types of business. However since regulated business has so many specific billing requirements they decided to support only regulated business at first.

On the other hand, new energy services in the "dynamic control approach" model have completely different demands on a billing system. Some of these demands – e.g. multiple bonus and allowance accounts for loyalty and pseudo flat rates – can be served by generic billing systems known from telecommunications. Other demands are new and not deployed in large-scale billing systems yet – e.g. fully dynamic pricing based on energy availability or on the negotiation among different market actors, e.g. producers, network and sales, or cells in a cellular power network.

In addition to that, new energy services will be provided by the collaboration of many partners and prosumers, creating new demands on massive multiparty billing. The multi-service marketing of costly battery resources covered in this project is just one example for this.

So some of these demands can be fulfilled by large products such as Amdocs One, Comarch, Netcracker Digital BSS or SAP BRIM. The most innovative demands, i.e. fully dynamic pricing and massive, dynamically negotiated multiparty billing are not available in established, large scale billing offerings. Most probably, these demands will be served by emerging cloud-native microservice billing systems. Those are already on the market (e.g. BillingCloud, KillBill, T-Systems' Cloud Billing), but applying them to specific services still requires significant programming and finetuning of configuration for static or dynamic sizing. An additional problem is the prevailing belief that large and complex billing applications can be served from a single multitenant SaaS offering and do not require customer-specific instances of the same microservice platform. (An example for this is the way SAP Subscription Billing is marketed.) Before a market is mature and mainly offers known services, the deployment of innovative services in a productive multitenant environment creates risk for the existing productive services and slowdown for the new innovative services.

A good example for the effects of regulation and the multitenant approach is Power-Cloud. Power-Cloud initially tried to cover all kinds of services with its microservice multitenant offering but found out it could not do regulated and innovative services at the same time. It then concentrated on standardized classic energy services, and even entering this legacy market with a modern platform was a hard task.

*Billing Approach for the Transition to New Energy Systems*

Due to the incompatible demands for the billing of classic energy services and new energy services the advice is not to use legacy energy billing systems for the billing of new energy services. Vice versa, it makes no business sense to replicate the regulatory demands from the "planning-approach" era in a new billing system. Keep the legacy system running  for legacy services, and choose a long-term approach for the increasing volume in  new energy services.

Approach for new energy services:

1. Since cloud-native auto scaling micro service billing is not mature in all required aspects, we recommend an established and generic core system. Due to the massive multiparty billing requirement, this core system should have a close association with the with the group's ERP system.

For large company groups, a typical candidate is SAP with its S/4HANA ERP system and BRIM. For smaller companies with in-house development resources, an OSS product like odoo – the system we used in ACES – may be a good choice.

2. Keep billing out of your energy management system, and keep industry-specific logic out of your billing system wherever possible. Do precalculations of dynamic prices in your energy management system – which acts like a mediation system in this case. This is an approach we used in the worksplit between the ACS energy management system and our billing system in the ACES project.

3. As long as the market is moving fast even within countries and national regulation is not settled for emerging energy markets, do not even try to use single-instance multitenant SaaS offers. Instead, drive your vendors to offer customer specific cloud instances of their billing platform.

4. Since differentiation is possible and necessary in a period of disruptive changes, select a core billing system capable of delivering customer-facing and loyalty features, e.g. allowances, bonus accounts and dynamic rule changes driven by marketing campaigns.

5. In countries with strong banking oversight, consider to involve a payment service provider for clearing when you plan for multiparty services. Otherwise, you may hold revenue on account of other parties which may require a payment provider or banking license.

6. Since a disruptive transition requires a try-and-error approach to find and parametrize workable solutions fast, design your architecture to minimize the cost of new service introduction into biling. In many legacy billing systems, new service introduction cost can be 500,000 Euro or more. This will crush your new service ideas before you can try them out on the market. To be successful in an emerging market, your new service introduction cost into billing should be below 100,000 Euro. This should be a measured KPI for your new billing system.

7. In this transition and in the rapid changes associated with it, you need an end-to-end view on billing architecture and billing quality, i.e. reliable billing operations. Since billing is rarely taught in universities, get your best billing experts from internal and external sources together to drive this change. This ensures you can generate revenue frpm the best ideas of your energy and energy market experts.

## NEW MARKETS AND OPPORTUNITIES FOR BATTERY SERVICES

Distributed flexibilities and automated dynamic pricing are a cornerstone for the transition towards a more flexible energy system facilitating a higher penetration of distributed renewable energies on regional level. A holistic approach for smart energy solutions that are easy to integrate in existing eco systems which are open for new services and new players is an enabler for this transformation process.

Flexibility trading and regional energy sales are just two examples which will open new business opportunities and a new type of actors on the European energy market. Many research project like GOFLEX[5] (see Figure 5) help to develop these new markets. The main objective of GOFLEX is to make a set of technology solutions for distributed flexibilities and automated dynamic pricing market ready which enables regional actors like Generators, Prosumers, Flexible Consumers and Demand Side Operators, Energy Suppliers, Microgrid Operators and Energy Communities to aggregate and trade flexibilities.

[5] https://goflex-project.eu

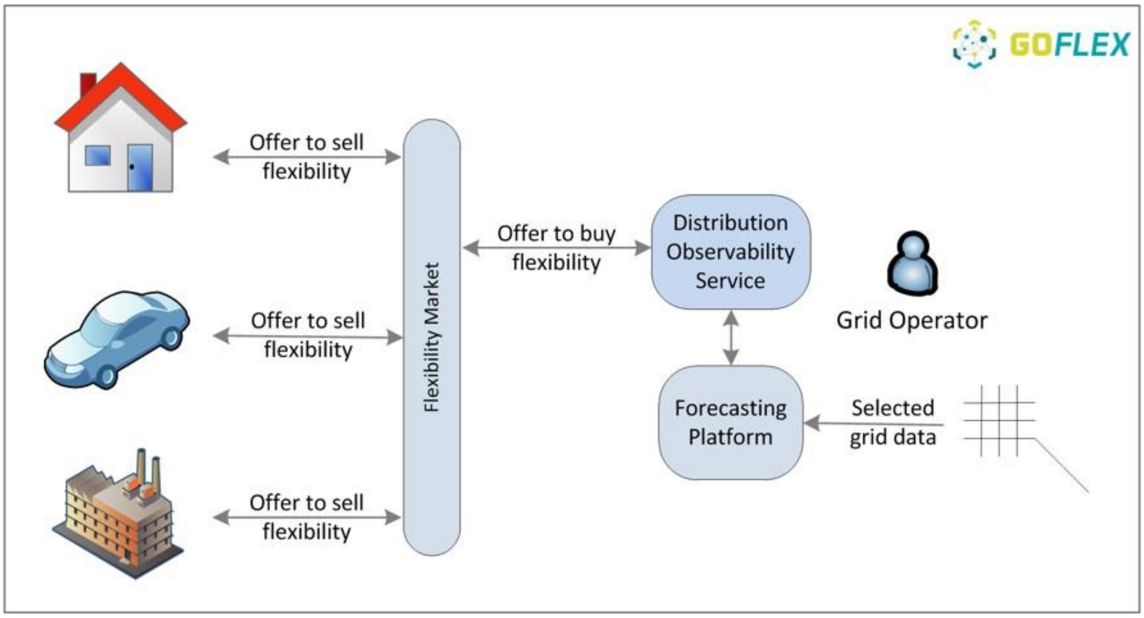


*Figure 5: Example – The future new flexibility market requires billing solutions like that developed in ACES work package 5. Picture source: www.goflex-project.eu*

Distribution networks have traditionally been dimensioned such that the physical network infrastructure is capable of handling any power flows that reasonably can be expected to occur. DSOs have typically not had the ability to control power flows in real time, which has necessitated this passive approach to DSO network operations and planning. However, with modern ICT solutions, the possibilities for a more active management of power flows have improved.

Further, increased penetrations of distributed generation (such as rooftop solar PV) and new loads (such as electric vehicles) lead to new power flow patterns in distribution networks. Consequentially, some distribution networks are reaching, or are expecting to reach, their capacity limitations. With the traditional approach, this would necessitate investments in network equipment to increase the physical capacity. However, if the DSO has access to flexible resources (such as battery energy storage) in the right locations, then procurement of flexibility services from these flexible resources could be a cost-effective alternative.

In many cases, the DSO would not itself own and operate the flexibility resources. Instead, some form of market mechanism is needed for enabling the DSO to buy flexibility services. There are many potential ways for how this could be done, and a range of research projects and commercial initiatives have been launched in Europe in recent years to develop such market solutions. In addition to the GOFLEX project mentioned above, other examples include the PicloFlex marketplace in the UK [25], the NODES market concept [26] and the CoordiNet project [27].

These flexibility markets differ in terms of market design, where some primarily focus on short-term trading for individual activations of flexibility services, while others rely on longer-term contractual agreements. They also differ in scope, where some have a DSO focus, while others attempt to enable flexibility services also to other actors such as TSOs or BRPs.

**SMART DYNAMIC BILLING – HOW TO DO BUSINESS WITH INTELLIGENT BATTERIES**

Batteries can be used for many applications e.g. shaving and shaping load profiles in electrical grids, improvement of power quality, provision of reactive power, energy trading, increase of self-sufficiency, asset protection and more as described in Section 5 of this report. Figure 6 describes an example of how to save cost by reducing the power demand and thus the power demand rate by shaving the peaks from the load profile.

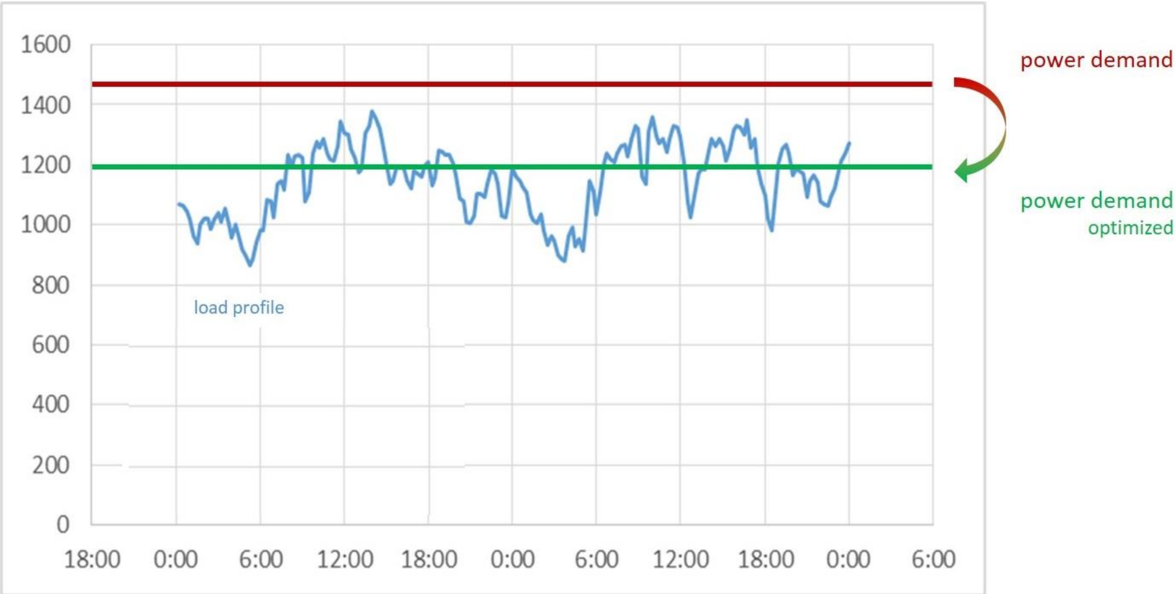


*Figure 6: example cost savings - battery used to reduce power demand by peak shaving*

Dissemination and exploitation of the ACES project results target but are not limited to the following businesses: grid operation, facility management, EV fleet operation, utility management, energy generation, industry. ACES provides benefits to the operation and generates economic value to said businesses – see Figure 7.

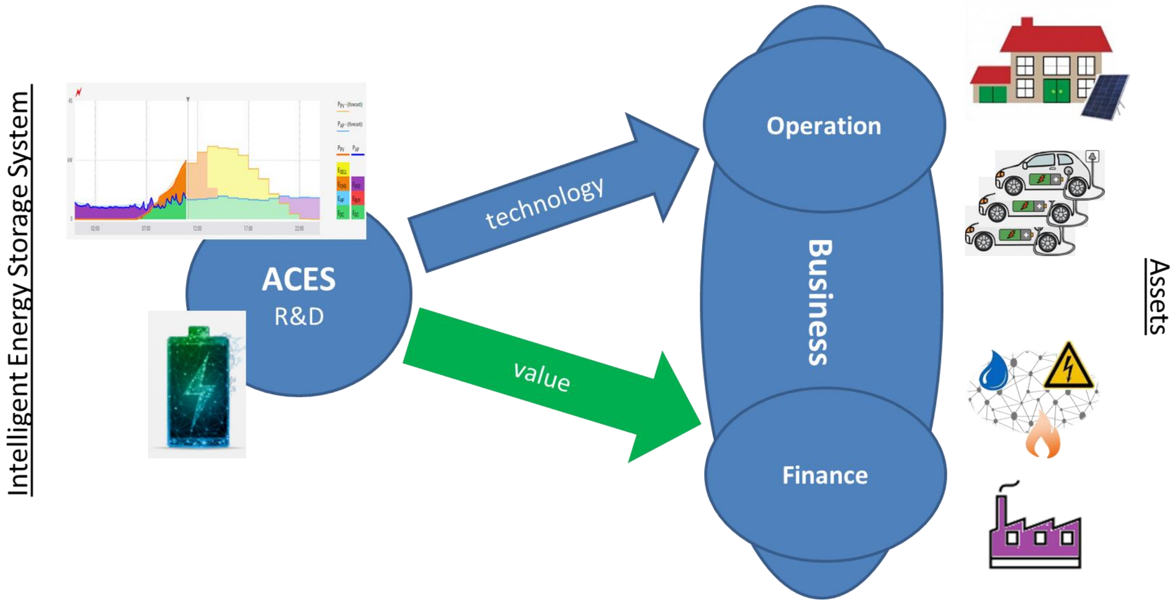


*Figure 7: The ACES solution provides both (i) benefits to the operation or management of assets and (ii) economical value to the organization of various kinds of businesses.*

# 4. Methodology and How to Approach a Deployable Solution

## MARKET STUDIES AND BUSINESS MODELS

Battery energy storage systems can be used to provide value in many different ways and for many different types of actors within the electric power system. With lower production costs, not least for lithium-based storage technologies, as well as an increased demand for storage services, the market for battery energy storage has expanded rapidly in recent years. This means that the battery energy storage market is evolving quickly, with a variety of actors involved and new types of services and business models being developed and tested. WP5 has aimed at helping the ACES project in navigating this complex market, by providing analyses on the type services that a battery storage system can provide and how the financial value of these services can be estimated.

As a first step of this analysis, WP5 carried out a review of the current battery energy storage market. Since the attractiveness of many battery energy storage services is heavily influenced by regulations and taxation, the review gave special attention to these topics, with a focus on relevant regulations and taxes in Sweden and Germany. The outcome of this review is in provided as background information in this report, in Section 3.

The next step for the WP5 market analysis was to conduct a review of possible services that battery energy storage systems can provide. In this review, services were categorized based on how and for whom they create financial value. One important objective with this classification was to provide a common terminology within the ACES project, to enable discussions about which type of services the project should prioritize. In this regard, the different services were viewed as building blocks that could be combined to create stacked services.

Once a collection of services had been identified and described, WP5 proceeded to estimate the financial value that the various services could potentially deliver. Since these values typically are highly case-specific, it is not possible to provide generally applicable financial estimates. Instead, the estimates were based on assumptions which were chosen to represent current conditions in Sweden.

Finally, an analysis of possible combinations of services was conducted, with the objective of identifying and analyzing possible stacks of services that could be of interest for the ACES project. These suggested service stacks served as a starting point for the project-wide discussions about which services to develop further, and to test in the ACES demonstration sites.

These analyses and the resulting outcomes are described below, in Section 5.

## THE SOFTWARE DEVELOPMENT PROCESS – BILLING SYSTEM

The ACES WP5 project implementation approach has been designed as a user-driven project with user and technology provider aiming at high acceptance rates among the group of stakeholders including investors, operators and end-users. From the beginning WP5 has had the ultimate goal achieving the highest possible TRL level of the Billing System to be developed. This orientation has been intended to be strengthened by an iterative development schema enhanced with agile characteristics. Due to communication issues and delays it has not been possible to carry out the development in several cycles according to agile project management methodology as it has been intended at start of the WP5 project. Effects of the Corona virus may have been the main reason for this.

The overall implementation approach consists of five (5) interrelated phases separated by milestones which serve as quality gates to minimize costs and efforts related to changes and corrective actions from later project stages – see Figure 8.

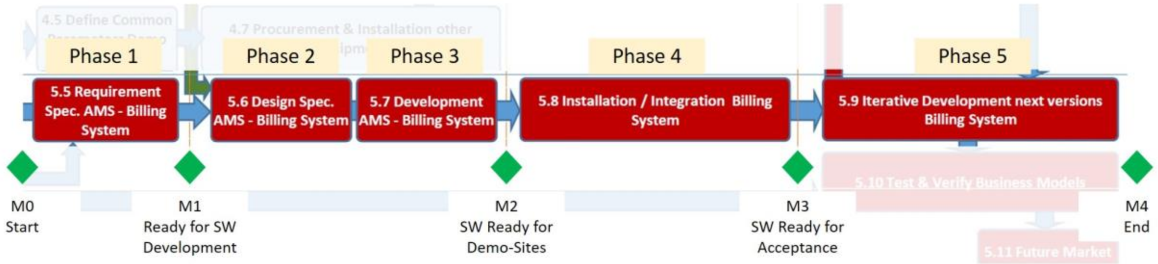


*Figure 8: The Billing System software development process (detail of the overall ACES project plan)*

**Phase one (1) Task T5.5: Requirement Specification.**

Definition of Requirements sets the groundwork of the project and includes all activities required to define the multifaceted domain of all ACES development activities. The underlying fundamental objectives to be addressed are: (i) Defining system requirements specifications (ii) Identifying user and market requirements and needs, in respect to the targeted project vision which should be addressed or connected to the ACES framework; (iii) Analyzing and identifying technological requirements for the integration of energy storages, other related assets for sector coupling, and ICT at the selected demo sites; (iv) Outlining the system architecture based on required functionalities and interconnections. The output of the Definition Requirements & System Design phase has been a comprehensive set of requirements which has driven the whole implementation of all ACES components at milestone M1 – see [28].

**Phase two (2) Task T5.6: Design Specification.**

After the successful completion of all tasks in the Requirements Specification phase, where the definition of the generic ACES architectural framework has been designed according to work package WP3, this phase involves the conceptual design of the Billing System. It encapsulates the development of the core architectural elements conforming to their high-level functional, technical & interoperability specifications. The output of this phase is the effective translation of the application requirements defined by users into a software structure, which is understood by software programmers. It consists of four major sections as follows; database, software architecture, system behavior, and computer hardware configuration, defining system boundaries and interfaces. Also the test environment, test procedures and pass / fail acceptance criteria have been specified here. The document developed has been classified as company confidential. A light version of this document has been offered to be used by the ACES partners.

**Phase three (3) Task T5.7: SW Development and Implementation**

The implementation of the billing solution was based on the design specification. The input mediation for the Billing System has been implemented based on JSON[6] for JavaScript object generation and documentation. The Billing System itself is based on the

[6] What is JSON? https://www.w3schools.com/whatis/whatis_json.asp

standard OSS product odoo[7]. WP 5 announced the Billing System to be Ready for Installation at demo-sites at milestone M2.

### Phase four (4) Task T5.8: Installation and Integration

This phase involves the implementation and application of the ACES Billing System to the demo sites. At first the Billing System has been tested in a virtual test environment together with ACES WP3 partner Embriq. A real runtime live demo has been announced when writing this report. End of this phase should have been the Ready for Accepting the prototype and start of data collection within the *Phase five (5) Task T5.9: Demonstration & Evaluation* and evaluation at milestone M3[8]. Billing System Test specification and test results have been summarized in a supplementary ACES deliverable, which could be provided on request.

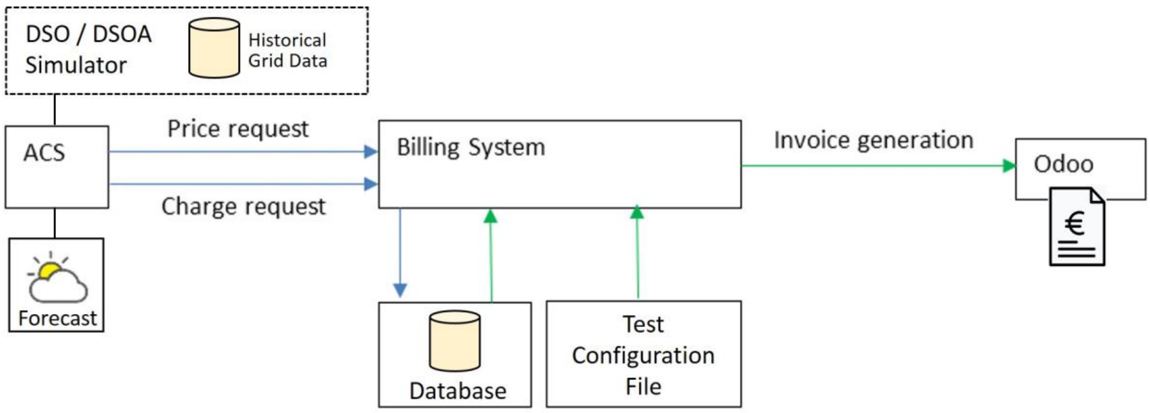


*Figure 9: Virtual test system to check the communication and data exchange between the ACS software (Embriq) and the Billing System*

### Phase five (5) Task T5.9: Demonstration & Evaluation

This phase of the project concerns the iterative development of the Billing System as well as the evaluation (lessons learned) and the preparation of activities regarding the sustainability and replicability of said software component. Overall activities will include: (a) Pilot activities at demo-sites and validation of technology; (b) Implementation and demonstration in real-life environments; (c) delivery of live data for evaluation and verification of the business models.

[7] https://www.odoo.com

[8] The Ready for Acceptance at demo sites has been set to Oct. 2020.

# 5. Results of Work Package 5

## POTENTIAL BATTERY ENERGY STORAGE SERVICES

Battery energy storage systems can be used to provide many different potential services, for a range of different types of customers and applications. This section briefly describes some of these potential services. The services are here described one-by-one, but many of them could be stacked to improve the profitability of the investments. The summary of potential energy storage services in this section is inspired by descriptions in [29], [30], [31] and [32]. The list is not complete, there are other possible services, but it represents a selection of frequently discussed services.

The services are here categorized into four categories, depending on which type of actor that would be interested in the service. These four categories are balance responsible parties, end-users, DSOs and TSOs. Note that this categorization does not necessarily correspond to the ownership of the battery energy storage. For example, a battery could be owned by an end-user but provide a service to the DSO.

**For balance responsible parties**

*Wholesale market arbitrage*

A battery can be used for arbitrage trading in wholesale electricity markets. Conceptually, this is relatively simple: it involves charging the battery when the wholesale electricity price is low and discharging when it is high. In most European electricity markets, the main wholesale electricity markets include a day-ahead auction in combination with some form of intraday trading.

Wholesale market arbitrage is a market-oriented service and is not related to any other electricity production or consumption activities. The actual market trading could be carried out by the battery owner itself (if it is a BRP), or it could be outsourced to a different entity.

Given that wholesale electricity prices typically follow the load profile, there are typically one or two potential arbitrage cycles per day, with the wholesale price difference depending on season, weather conditions, geographical location etc.

The financial viability of arbitrage trading is dependent on the taxes and fees that are associated with charging and discharging the battery. For example, if the battery owner needs to pay significant taxes and fees for the electricity used for charging the battery but does not recover these expenses when discharging the battery, then the number of profitable cycles will be greatly reduced.

*Imbalance risk management*

A BRP with a portfolio of consumers and/or producers is subject to imbalance charges when the final metered amount of the portfolio differs from the amount that the BRP has bought or sold in the market. If a BRP could use a battery energy storage for balancing its imbalances in real-time, it may be able to reduce its imbalance liabilities.

For this to be practically possible, the BRP needs to be able to know the imbalance position of its portfolio in real-time. One example where this may be the case is for a BRP that is responsible for some hard-to-predict intermittent generation. In this case, it may be beneficial if the battery energy storage could be charged directly by the intermittent generation, since this may enable charging the battery without the need to pay taxes and network fees.

The profitability per cycle depends on the imbalance prices, which are likely to be unknown in real-time. The number of potential cycles per day depends on the intermittency of the consumption or production that the battery is balancing, and the length of the imbalance settlement period.

**For end-users**

*Load shaping*

Time-of-use pricing means that the electricity prices faced by the end-user are different at different times of the day, and days of the week. Sometimes, these pricing schemes are not directly connected to the wholesale market prices of the specific day, but instead follows a pre-specified pattern that corresponds to average market prices at different times. Network fees could also be time-varying, with higher prices at times when network congestion is anticipated. A similar but slightly different pricing model, often called critical peak pricing, has a flat price for most hours of the year but a steep increase during some critical hours.

A battery energy storage installed behind-the-meter at an end-user site can be used to minimize the electricity bill by shifting load form high-price to low-price hours. This battery service is likely not affected by taxes and other flat fees, but it is highly sensitive to changes in the electricity supplier or network owner pricing structure.

*DER self-consumption*

A prosumer with distributed generation (such as solar PV) can use a behind-the-meter battery energy storage to maximize the self-consumption of the distributed generation. For example, many prosumers with rooftop solar PV generate most of their electricity during the mid-day hours, while the electricity consumption often peaks in the early evening. A battery could therefore be charged in the middle of the day and discharged in the evening, thereby increasing the amount of self-consumption.

The profitability of this battery service stems from a price difference between the per-kWh price that the prosumer pays for grid-supplied electricity, and the per-kWh price that the prosumer receives for surplus electricity fed to the grid. This price difference can occur for many different reasons, including taxes, network fees and renewable generation support schemes. Therefore, the value of maximizing self-consumption can differ widely between different locations.

*Peak shaving*

Certain consumers, especially larger commercial or industrial consumers, may face network fees that are a function of their peak electricity consumption level. The exact specification of this type of peak pricing (sometimes also called demand charges) can differ across different DSOs. For example, the fee might be based on the peak electricity consumption for each month, quarter, or year. The peak consumption may also be calculated in different ways: it may be based on the single highest value recorded during the period, or on an average of, for example, the three highest values. Although peak pricing schemes often refers to the peak power demanded (kW), in practice it is often based on the average power consumption at an hourly or 15-minute level. Yet another kind of peak pricing is to charge a high per-kWh fee whenever the load exceeds some prespecified limit.

Irrespective of the type of peak pricing, a consumer who faces this type of pricing could use a battery for reducing their peak loads. This type of peak shaving is likely to be most profitable if the load profile is relatively variable, such that the peak can be substantially reduced by relatively few battery cycles.

*Enabling load surges*

A battery energy storage system could be used to enable temporary load surges that might otherwise not be feasible given existing grid connections or capacity limits. An example could be an end-user who wishes to be able use electric vehicle fast-charging but does not have the appropriate grid connection to accommodate these loads.

In this case, the battery could be viewed as an alternative to investing in a higher capacity connection to the grid. The financial benefits from this depend on the one-time fee that would be associated with increasing the connection capacity, as well as any increased grid charges that may be applicable for a higher connection capacity.

*Uninterruptible power supply or back-up power*

Some consumers, such as data centers, have very high reliability requirements for their electricity supply. Such consumers may wish to install an emergency power system that can provide near-instantaneous response when the main power source fails. A battery energy storage can provide this service. This can complement a backup generator that may require a somewhat longer start-up time but can provide power for a sustained period of time in case of a longer supply interruption.

The value of providing an uninterruptible power supply service depends on how costly it would be for the end-user to temporarily lose power, and on the probability of such an event. Further, the capturable value for a battery energy storage to provide this service depends on the cost of alternative competing technologies.

A simplified version of the UPS service is to use a battery energy storage as a source for back-up power but allowing for a short interruption in power supply at the time of the grid interruption. This allows for a less costly installation.

Alternatively, the UPS service could also be viewed from the perspective of the DSO, with the primary purpose of reducing the costs for the DSO related to power outages. A discussion about this type of UPS is provided in [33].

*Power quality management*

Some end-users, primarily certain industrial consumers, may prefer an electricity supply of higher quality than what they can get from the grid. This includes quality issues such as, for example, voltage dips, transients, harmonics and unbalanced voltages across the three phases. Certain end-user processes may be negatively affected by such quality issues, even when most consumers do not notice them.

A battery energy storage system may be able to alleviate some of these quality issues and protect downstream loads. As for the UPS-service, the capturable value of power quality management depends both on the fundamental value provided to the end-user and of the cost of alternative competing solutions.

*Reactive power management*

Reactive power is sometimes considered a power quality component. However, from an end-user’s perspective, limiting the injections or withdrawals of reactive power can create direct financial value in a way that differs from the types of power quality management described above. This is applicable if the DSO charges for reactive power injections or withdrawals, which typically would only be the case for very large end-users. The power converters of a battery energy storage system can be used to manage reactive power without significantly affecting the battery’s state of charge.

**For DSOs**

*Investment deferral or substitute*

When the peak loads in a distribution grid (or a part thereof) increases, such that the rated capacity of some components in the grid may not be sufficient, the DSO typically needs to invest in higher-capacity network equipment. However, if the peak loads are few and far apart, it may be cost effective to invest in a battery energy storage instead of traditional "poles and wires" infrastructure. This could be done either as a substitute to traditional investments, or as a temporary solution to defer the traditional investments. The potential cost-savings for such services are highly case-specific, since they depend on the cost of the traditional investments that otherwise would be necessary. In certain situations, the actual need to cycle the battery may be very infrequent, contributing to a high per-cycle value.

The use of battery energy storage for distribution grid purposes is legally complex, due to unbundling rules that prevent DSOs from engaging in electricity trading in many cases. Therefore, the day-to-day operation of the battery may have to be carried out by an independent entity. Further, as with wholesale arbitrage trading, per-kWh taxes and fees may negatively affect the cost effectiveness of battery energy storage for this application.

*Voltage stability*

DSOs are responsible for ensuring that the voltage in their networks remain within rated limits. A battery energy storage system could help a DSO managing the system voltage, for example by regulating reactive power.

This battery service shares many of the features of the afore mentioned investment deferral case: unbundling rules may prevent the DSO from operating the battery directly, the capturable value depends on the site-specific cost of solving the issue with traditional grid reinforcement options, and per-kWh taxes and fees may negatively affect the cost effectiveness of a battery-based solution.

*DSO peak shaving*

This service is similar to the peak shaving case for end-users described above but concerns the peak load of an entire DSO relative its overlying regional or national grid. The network fees the DSO pays to the overlaying network may include some peak-load charges, either in the sense that the DSO pays a fee based on the yearly or monthly peak load, or in the sense that the DSO needs to pay a significant penalty if the load ever exceeds a certain contracted level.

This means that the DSO in certain situations has an interest in reducing the overall peak load of its system. This could be performed by a battery energy storage system owned by the DSO itself, or by a third party. Again, the issues concerning unbundling legislation and taxes may make a third-party model more attractive.

**For TSOs**

*Frequency regulation*

TSOs are responsible for ensuring a continuous match between production and consumption of electricity within its control area. Because both aggregate production and aggregate consumption behaves stochastically over time, the TSO needs to ensure that some resources (producers, consumers or storage) regulate their production or consumption in response to system imbalances. TSOs typically do not own the resources for doing this themselves, but instead procure these services as standardized products from other market actors.

The precise definition of the products varies across TSOs. Some products are activated by frequency deviations directly, such as FCR (Frequency Containment Reserve) in the Nordics or PCR (Primary Control Reserve) in Germany, and some are activated by a frequently updated signal from the TSO, such as aFRR (automatic Frequency Restoration Reserve) in the Nordics and SCR (Secondary Control Reserve) in Germany.

Certain products involve more or less continuous regulation, such that a battery energy storage that provides the service would frequently switch between charging and discharging. An example of this is FCR-N (Frequency Containment Reserve – Normal) in the Nordics. The PCR product in Germany is similar but has a dead-band such that a battery that provides this service would spend more time neither charging nor discharging.

Other products are intended for counteracting the more significant frequency drops that may occur as a result of, for example, the sudden loss of a large generator. One example of such a service is FCR-D (Frequency Containment Reserve - Disturbance) in the Nordics. A battery energy storage providing this service would spend most of its time charged, ready to immediately discharge in the event of a major frequency drop.

The ability of a battery energy storage system to provide these services depends on the requirements that TSOs define for the various products, such as requirements for duration, and minimum bid size requirements. The provision from small-scale battery storage systems may also be hampered by strict requirements for pre-qualification and metering.

*Manual reserves and congestion management*

In addition to the frequency regulation services discussed above, TSOs need access to resources that can adjust their production or consumption upon a TSO operator request. The TSO operator may use these resources to restore the frequency regulation capacity after a major event, or for more proactive purposes. It may also be necessary for internal congestion management.

These products typically allow for a somewhat longer activation time but may also require the resource to sustain output for a longer period of time. Examples of these types of services include mFRR (manual Frequency Restoration Reserve) in the Nordics, and TCR (Tertiary Control Reserve) in Germany.

Because of the manual activation, this type of product may lead to higher staffing costs, if someone needs to be available for receiving the request from the TSO. The pre-qualification and metering requirements may however be less stringent.

## FINANCIAL ESTIMATES FOR INDIVIDUAL SERVICES

The financial value that can be created by the various battery services listed above depend on many factors. It is therefore not possible to provide a generally applicable estimate of how much value a service can provide. This is not only because of differences in prices, regulations and taxation across different markets, but also because of the differences in, for example, load shape and predictability between different end-users. The same battery storage service can therefore generate very different financial values for two different end-users, even if they are in the same market. Further, some services, such as the provision of back-up power, have a value that is of a more subjective nature (for example, the end-user's subjective value from peace of mind or sense of self-sufficiency). Such values are of course very difficult to quantify in any objective way.

Nevertheless, for some of the services listed above, it is possible to make some assumptions about the main parameters that influence the financial value of the service, and thereby provide some rough estimates for how much financial value a service can be expected to generate. In this section we provide such financial illustrations for a selection of the services listed above.

**Costs and price assumptions**

The assumptions made for the financial estimates in this section represent values that currently are reasonable to observe in Sweden. However, in several cases the values are so case-specific that a wide range of values may be viewed as reasonable.

**Price paid for electricity delivered from the grid to end-users:** For most behind-the-meter services, a constant electricity price is assumed (i.e. the price does not vary within the day). The assumed price is €0.12 per kWh, excluding VAT. This includes costs for wholesale electricity (€0.04/kWh), electricity consumption tax (€0.03/kWh), variable DSO network fee (€0.04/kWh) and other retail fees (€0.01/kWh). For the load shaping service where the price is based on a time-of-use tariff, the price difference between peak and off-peak hours is assumed to be €0.02/kWh.

**Price received for electricity fed to the grid from a prosumer:** The amount received for electricity supplied to the grid is assumed to be €0.05/kWh, based on a wholesale electricity price of €0.04/kWh and €0.01/kWh for renewable certificates and certificates of origin. This means that it is assumed that the owner of the battery is not eligible for the income tax reduction for distributed generation.

**Price paid for electricity delivered from the grid to large-scale standalone battery:** For larger battery system installations, we assume a much lower variable network fee (€0.005/kWh) since the network fees for higher-voltage customers tend to rely more on peak power tariffs. Further, the retail fees are also assumed to be lower (€0.005/kWh), meaning that the total average price is assumed to be €0.08 per kWh. The average price difference between peak and off-peak hours is assumed to be €0.03/kWh.

**Price received for electricity fed to the grid from a large-scale standalone battery:** The amount received for electricity supplied to the grid is assumed to be €0.07/kWh, based on a wholesale electricity price of €0.04/kWh and an electricity tax reimbursement of €0.03/kWh. Again, the average price difference between peak and off-peak hours is assumed to be €0.03/kWh.

**Peak power charge:** For the peak shaving service, the end-user faces network charges that are based on the monthly peak power consumption. A monthly network charge of €7 per peak kWh/h is assumed, which is in line with the peak power charges that are charged by Swedish DSOs that have this type of pricing for low-voltage customers (e.g. [34] and [35]).

**DSO peak power charge:** For the DSO peak power service, it is assumed that the DSO pays an overdraft fee if the yearly load peak for the network area exceeds a contracted amount. This is typically the case for Swedish DSOs. We assume that the overdraft fee is €40 per kW and year, which is in line with the amount charged by [36].

**Cost of increased connection capacity:** In the enabling load surges service, the costs associated with an increased connection capacity for an end-user is considered. It is here assumed that the increase in connection capacity requires that the DSO installs a new cable, at a cost of €20 000. This is based on the approximate cost for 1 km of a 0.4 kV ground cable, installed in a rural setting (see [37]). It is further assumed that upgrading to a higher capacity connection point is associated with an increased monthly fixed network fee of €30. This is in line with the cost increase for upgrading one level (such as from 25A to 35A, from 35A to 50A, or from 50A to 63A) in [38] and [39].

**Compensation received for frequency regulation:** In one service, we consider the provision of frequency regulation. We here use FCR-N (Frequency Containment Reserve – Normal) in Sweden as an example. The compensation in this market is currently based on a pay-as-bid structure, meaning that no uniform market price exists. Instead, we estimate the potential revenue by assuming an average compensation level of €30 per MW and hour. This is in line with the weighted average compensation for recent years [40].

**Reactive power:** For the reactive power management case, it is assumed that the DSO charges for injections or withdrawals in excess of an allowed amount. The charge is based on the hourly peak reactive power injection or withdrawal for each month, and we assume a charge of €2 per kVAr and month for the amount that exceeds the allowed amount.

**Battery energy storage system costs, behind-the-meter:** For the behind-the-meter services we assume a battery system with a capacity of 20 kW and 40 kWh. This approximately represents 3 Tesla Powerwall and is therefore a bit larger than what is likely to be applicable for a single-family home, but more reasonable for, for example, an apartment building. Based on the information in the previous chapter, we assume an investment cost of €24 000 (€600 per kWh) which includes the cost for the whole battery system, including power converter and installation costs, but excluding VAT.

**Battery energy storage system costs, large-scale standalone:** For the large-scale standalone services we assume a battery system with a capacity of 1 MW and 2 MWh. Based on the information in the previous chapter, we assume an investment cost of €800 000 (€400 per kWh) which includes the cost for the whole battery system, including power converter and installation costs, but excluding VAT.

**Battery life and residual value:** We assume that the economic life of the battery system is 5000 full battery cycles, or 20 years, whichever comes first. After this, the system is assumed to have a residual value in the second-life market of 25% of its original investment cost. Some of this amount also represents the reduced investment cost for battery renewal due to an existing installation. The assumptions regarding battery life and residual value do not affect the financial estimates in terms of pay-back time, but they do affect the investment cost when viewed as an annuity.

**Battery efficiency:** For the purpose of estimating the cost of losses incurred by cycling the battery, an efficiency of 92.5% is assumed, in line with the estimates from [41]. This efficiency estimate corresponds to a case where the battery is charged directly from solar PV (DC), and then converted to AC after discharging from the battery.

**Cost of capital:** When future cashflows are discounted we use a 6% real interest rate.

### Service-specific assumptions

We here briefly discuss the specific calculations and assumptions made for each considered service. These estimates are summarized and compared to investment costs in the next section.

#### *Wholesale market arbitrage*

For this service, we assume a large-scale standalone battery system (1 MW, 2 MWh) used for discharging when the wholesale prices are high and charging when they are low. Assuming 200 full cycles per year (depends on how frequently large wholesale price variations occur), and the assumptions listed above, net revenues would amount to around €5000-€6000 per year.

#### *Load shaping*

For this behind-the-meter service we assume that the battery follows a fixed daily price-cycle, and therefore performs one full cycle per day. Further, we assume that the end-user remains a net consumer also during hours when the battery is discharging. With the 20 kW / 40 kWh battery system, this leads to cost savings of about €150 per year.

#### *DER self-consumption*

The cycling frequency of this behind-the-meter service depends on how often the end-user has over-production and feeds power to the grid. We here assume that this occurs on 200 days per year. However, not all cycles are assumed to take full advantage of the battery system storage capacity, and we therefore assume 160 full cycle equivalents per year. Given the assumptions above, this leads to cost savings of almost €400 per year using the 20 kW / 40 kWh battery system.

*Peak shaving*

The theoretical maximum peak shaving amount when using a 20 kW / 40 kWh battery system is 20 kW peak reduction. However, given forecasting errors and battery capacity limitations, some peaks will likely be missed, and some will only be partially reduced. We here assume that the peak is successfully reduced for 80% of months, and that it is reduced by 80% of the battery capacity during those months. Therefore, the average peak reduction is assumed to be 12.8 kW. The cycling frequency for the peak shaving service depends on the type of end-user. We here assume the same cycling frequency as for DER self-consumption, i.e. 160 full equivalent cycles per year. Given these assumptions, a cost reduction of about €1000 per year is achieved.

*Enabling load surges*

This behind-the-meter service is of course very sensitive to the assumption about how much the connection capacity upgrade would cost. The operational assumptions for the battery are less financially important. We assume one daily battery cycle with an 80% average depth of cycling, and that the 20 kW / 40 kWh battery system is sufficient. Together with the assumptions listed above, the annualized cost savings are than almost €1500.

*Investment deferral*

As for enabling load surges, the value from the investment deferral service is highly case-specific. In order to provide an estimate for the potential financial value of investment deferral, we follow the case described in [7]. In that case, a relatively large (6 MW / 10 MWh) battery storage system was used to defer a network reinforcement by about 10 years. The cost of the deferred network reinforcement was in that case estimated to be about €7.25 million. With a 6% discount rate, the annual value of the investment deferral was therefore €435 000. In our example, we consider a distributed solution where a similar service is provided by many small batteries instead of one large. Since the battery in our example has a capacity of 20 kW, about 300 batteries of this size would be needed to provide a total capacity of 6 MW. Therefore, the per-battery cost savings from the investment deferral service is estimated to be around €1450 per year. Assuming that the battery system owner receives 50% of this amount (after sharing revenues with DSO and aggregator), and after accounting for some costs for cycling the battery, the battery owner would receive around €700 per year for the investment deferral service.

*DSO peak shaving*

The DSO peak shaving service means that the battery energy storage can be discharged based on a need from the DSO to reduce the overall load in the DSO network area. We consider a behind-the-meter installation where the battery owner can capture half of the value created for the DSO. If we assume that the DSO has a 50% probability of exceeding the subscribed amount in a given year, and that the battery can achieve a peak reduction for the DSO corresponding to 90% of the battery power capacity, then the expected yearly revenues for a 20 kW / 40 kWh battery system would be almost €200 per year. This is here assumed to only require 10 cycles per year.

*Frequency regulation*

For a behind-the-meter case, an aggregator would be needed as an intermediary to sell this service to the TSO, and to provide all necessary additional services regarding communication, metering and pre-qualification. For the purposes of this example, we assume that the battery owner and the aggregator share the revenues equally. If we assume that the FCR service is provided 300 days per year, 18 hours per day (leaving some hours for resetting the charge-level and for times when bids were not accepted in the auctions), then the annual FCR revenues for the battery owner would be almost €1200. This is here estimated to require about 1000 full equivalent cycles per year.

*Reactive power management*

We here use the same assumptions as for the peak shaving service, i.e. that the battery system successfully reduces the peaks during 80% of months, and that they are effectively reduced by an amount that corresponds to 80% of the battery system power capacity. Therefore, the reactive power withdrawal (or injection) is reduced by 12.8 kVAr, leading to yearly cost savings of about €300. If we assume that a $400 additional investment is needed when buying the battery system in order to get a power converter that is capable of managing reactive power and an assumed 10 year life of the power converter, then annualized net contribution towards the battery system investment from the reactive power management service is about €250 per year.

**Summary of financial estimates**

The estimated financial values are summarized in Table 1 below. The wholesale market arbitrage service is the only one for which a large-scale standalone installation (1 MW / 2 MWh) is assumed, all other services here assumes a behind-the-meter installation with a 20 kW / 40 kWh battery system.

The column with the annualized battery investment costs (leftmost numerical column) shows the investment cost for the battery system (rounded to nearest €100) when converted from a one-time investment cost to an annual value assuming a 6% real interest rate and a lifetime based on the expected cycling as described above. Note that most of the behind-the-meter services have an annualized investment cost around €2000 per year, with relatively infrequent battery cycling and a long expected life. The frequency regulation service stands out as an exemption with more frequent cycling and a higher yearly investment cost.

The annualized investment cost is calculated in order to provide a reference point for how much revenues or savings a service would need to deliver per year to become an attractive investment option (given our list of assumptions). The second numerical column of Table 1 shows the estimated yearly revenues or savings, whichever is applicable (rounded to nearest €100). As seen, no service reaches the target annual investment cost value, and some services are at less than 10% of the target value.

The third numerical column shows the revenues or savings from each service, divided by the amount of energy cycled through the battery. This is an important complement since some services do not generate much revenues per year but have a high per-cycle value, which make them potentially interesting when combining multiple services.

Finally, the third column provides the simple pay-back time for each service. This value does not take the expected life of the battery into account, but instead simply divides the one-time investment cost by the estimated annual revenues or savings. This can for example be used to gauge how much cheaper battery systems need to get in order to provide a more attractive pay-back time. If we e.g. use 7 years pay-back time as a target value for an attractive investment, then the costs of battery systems need to fall by more than 2/3 to make peak shaving an attractive service on its own, for example.

Figure 10 illustrates the information from the two right-most columns of Table 1 graphically.

| Service | Installation type | Annualized battery investment cost (€) | Annual revenues/savings (€) | Per cycled kWh revenues/savings (€) | Pay-back time (years) |
|---|---|---|---|---|---|
| **Wholesale market arbitrage** | Large-scale standalone | 64300 | 5500 | 0.01 | 147 |
| **Load shaping** | Behind-the-meter | 2300 | 100 | 0.01 | 160 |
| **DER self-consumption** | Behind-the-meter | 1900 | 400 | 0.06 | 61 |
| **Peak shaving** | Behind-the-meter | 1900 | 1000 | 0.16 | 24 |
| **Enabling load surges** | Behind-the-meter | 2100 | 1500 | 0.12 | 16 |
| **Investment deferral** | Behind-the-meter | 1900 | 700 | 1.80 | 33 |
| **DSO peak shaving** | Behind-the-meter | 1900 | 200 | 0.44 | 136 |
| **Frequency regulation** | Behind-the-meter | 4900 | 1200 | 0.03 | 19 |
| **Reactive power management** | Behind-the-meter | 2800 | 300 | | 95 |

*Table 1 Estimated financial value for some battery storage services*

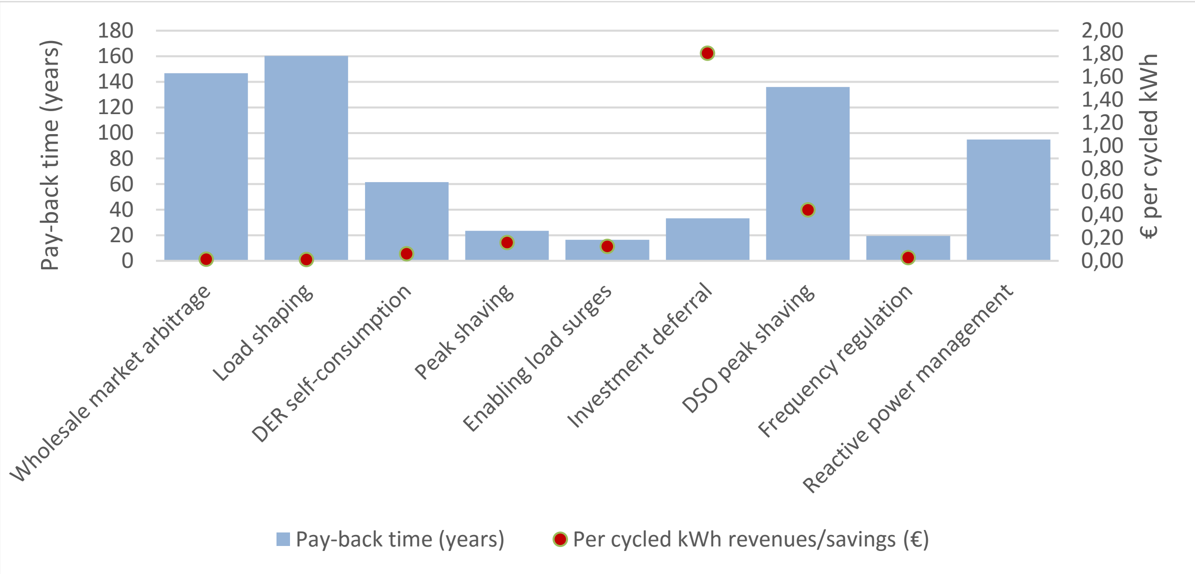


*Figure 10 Estimated pay-back time and financial value per cycled kWh*

## STACKED SERVICES AND BUSINESS USE CASES

In this section, four different stacked business use cases are presented, each of which consisting of a combination of three or four different services the battery energy storage can provide. The objective of this section is to provide some examples that illustrate some possibilities to combine various battery services in order to improve the financial viability of a battery energy storage investment. For each stacked use case, an illustrative financial example is provided, comparing investment costs and service benefits.

Battery services can be combined in a very large number of ways. Which combination of services that is most interesting for a particular end-user depends on a large set of user-specific factors, such as load characteristics, local network and energy pricing, reliability considerations, etc. The four stacked use cases discussed in this section should therefore not be viewed as representing an optimal combination of services in any general sense. Instead, they are meant to represent combinations of services that may be interesting given the right circumstances. In the ACES project, they were used as a starting point for analyzing and developing stacked use cases.

For most battery energy storage services, the potential value in terms revenues or cost savings that the service can deliver is highly case-specific, especially for behind-the-meter applications. It is therefore often impossible to quantify the financial value of a battery service with a single value that is generally applicable. In order to provide some financial examples for the stacked used cases, it is necessary to make a large number of assumptions. The illustrative financial examples in this section are meant to provide rough estimates of the costs and benefits that might be observed, given the assumptions made. The calculations provided in this section are based on the same assumptions as the in the previous section. One simplification made for the estimated value of stacked services is that we assume a 10-year expected life of the investment across all examples.

**Business Use Case 1 – The hotel in the mountains**

**Service stack:** Enabling load surges + DER self-consumption + UPS or back-up power

*Description of use case*

This use case targets property owners who has (or wants to have) some distributed energy production, such as solar PV. Further, the use case assumes that the property owner would like to install some equipment that will lead to high peaks in the power consumption (for example, EV chargers), but that the current connection to the grid does not have sufficient capacity to accommodate these peaks.

As an illustrative example, we here consider the case of a small hotel in a rural location. The hotel owner would like to be able to offer EV charging to its guests. However, the resulting power demand peaks could at times be too much for the existing grid connection to accommodate.

An increase in fuse size would require local network reinforcements, which means that the DSO would charge a cost-based fee for providing this upgrade.  Further, a higher fuse size would be associated with a higher monthly network fee. The hotel owner would like to avoid these costs. Therefore, the owner invests in a battery energy storage solution that can provide support when load exceeds the capacity.

There is some form of distributed generation, such as solar PV, installed behind the meter. Due to taxes and network fees, the hotel owner has an incentive to maximize self-consumption of locally generated power.[9] If the electricity consumption for the property is low, then the installation of EV chargers in combination with a battery energy storage system can increase the potential for DER self-consumption.

As an additional optional service, the battery could be used to provide back-up power in case of a grid service interruption. A true UPS solution would require installation of additional components for enabling instantaneous response. Alternatively, a simpler back-up power service could be offered, where a momentary service interruption is acceptable. The UPS or back-up component of this service stack may be more interesting for applications in relatively weak grids with a higher probability of service interruption and higher costs for grid reinforcements.

In this use case, the battery energy storage system does not supply any services to external actors, which means that there is no need for an aggregator.

**Baseline use case:** The single-service baseline for this stacked business use-case is the case where the battery is used only for enabling load surges.

---

[9] This may or may not be the case in Sweden. This depends on whether the hotel owner is able to benefit from tax deductions for electricity supplied to the grid, as well as on the pricing scheme of the local DSO.

*Illustrative financial example*

We assume that upgrading to a higher capacity connection point would require the installation of a new cable, at a one-time cost of €20 000. The battery energy storage solution would alleviate the need for increased connection point capacity. In addition to avoiding the €20 000 one-time investment cost, this would also mean that an increase in the monthly network fee associated with a higher capacity connection can be avoided. It is here assumed that this saves €30 per month.

Assuming a discount rate of 6%, the annualized cost reduction for the end-user for avoiding this upgrade is therefore €1560 (0.06*20000 + 12*30). Although the components needed for the connection point reinforcement have a limited economic life, the DSO will be financially responsible for maintaining the capacity of the connection point in the future. Therefore, from the end-user's perspective, the investment can be viewed as a one-time investment with infinite life.

It is assumed that a 20 kW / 40 kWh battery is sufficient to meet the needs of this use case, and this battery system is assumed to cost €24 000 (€600 per kWh). The technical life of the investment is 10 years, after which a residual value of 25% of the initial investment remains. With a 6% discount rate, this corresponds to an annualized cost of about €2800.

The battery is used to meet an expected daily load peak in the evening. Therefore, one cycle per day is expected, with an average depth of discharge of 80%. Assuming a battery efficiency of 92.5% and a cost of grid-supplied electricity of €0.12 per kWh, this means that the yearly energy cost of losses in the battery is about €100.

Therefore, the single-service baseline use case does not reach break-even in this example. In terms of pay-back time, the pay-back time for the single-service baseline use case is about 16 years (24000/(1560-100)), which exceeds the expected technical life of the battery.

If the battery is charged with self-produced solar generation that otherwise would have been fed out to the grid, then the business case is improved. If we assume that the property owner receives €0.05 per kWh for electricity sold, and that the battery is charged with electricity that otherwise would have been fed to the grid for 200 of the 365 yearly cycles, then the net energy costs for the property owner is reduced by €340 per year (after accounting for the cost of losses).

In this example, the stacked business use case combining the enabling of load surges and DER self-consumption still does not break even. The pay-back time is reduced to about 13 years (24000/(1560+340)).

In this example, the property owner must value the back-up services that the battery can provide to at least €900 per year (2 800 – (1560+340)) for the business use case to deliver a positive return.

**Business Use Case 2 – Apartment building supporting the TSO**

**Service stack:** Load shaping + DER self-consumption + frequency regulation

*Description of use case*

This use case targets real estate owners who are subject to time-of-use electricity prices and who has some distributed energy production. To provide an additional revenue stream, the battery energy storage also offers frequency regulation services to the TSO, via an aggregator.

For this use case to be applicable, the real estate owner must face electricity prices that are (1) higher for electricity bought from the grid than for electricity supplied back to the grid, and (2) based on time-of-use pricing that makes electricity more expensive during peak load hours (such as early evening hours). The first condition is necessary for financially justifying the DER self-consumption service, and the second for the load shaping service. Further, these two services have a potential to complement each other if the production from the DERs tends to take place during low-price off-peak hours. If this is the case, then the same battery cycle could provide two values by both increasing self-consumption and reducing the load during high-priced peak hours.

The value of providing load shaping and DER self-consumption varies over time, depending on weather conditions and load patterns. Therefore, the battery could supply frequency regulation at times when the value of load shaping and DER self-consumption is likely to be low. It is likely possible to predict times when the load shaping and DER self-consumption services are not needed, which could provide windows of time during which frequency regulation could be provided.

To provide frequency regulation, an aggregator intermediary is needed. The adaptive control system of the battery would need to predict the hours during which it would be more profitable to offer frequency regulation, such that the aggregator can place bids for this capacity in the capacity markets. An alternative arrangement would be for the aggregator to own the battery (and keep the revenues from the frequency regulation), while selling the load shaping and self-consumption services to the owner of the property where it is installed.

It may advantageous to offer frequency regulation as a demand side reduction (i.e. ensuring that the net load for the building is always positive, even when the battery is discharging in response to a frequency deviation). There are two reasons for this: first, a price difference between electricity bought from the grid and electricity sold back to the grid makes it financially more beneficial to maintain a positive net load, and second, some TSOs (such as the Swedish TSO) are currently unable to accept some frequency regulation services from resources that switch back and forth between consuming and producing electricity. For these reasons, it may be beneficial if the real estate has a relatively large load.

**Baseline use case:** The single-service baseline for this stacked business use-case is the case where the battery is used only for DER self-consumption.

*Illustrative financial example*

In this use case, electricity prices facing the real-estate owner (both for electricity bought from the grid and for electricity supplied to the grid) differ from hour to hour, with higher prices during peak hours. The difference in price between electricity bought and sold, which is due to taxes, network fees and other levies, remains constant from hour to hour. We here assume that the later price difference is €0.07 per kWh.

It is here assumed that the DERs in question are solar PVs, and that the battery therefore is charged during mid-day hours and discharged in the evening. The building is a residential building, meaning that loads are typically higher during mornings and evenings, and lower in the mid-day. Some of the power produced by the solar panels during mid-day hours would therefore be fed back to the grid, unless it could be stored in a battery.

As in the previous section, we here consider an investment in a 20 kW / 40 kWh battery. With a battery investment cost of €24 000, a 6% discount rate, 10 years expected lifetime, and a residual value of 25% of the initial investment, we get an annualized investment cost of about €2800.

200 of 365 days per year are assumed to have the right weather and load conditions to enable a cycle where the battery is charged using electricity that otherwise would have been fed to the grid. Assuming a full depth of charge cycle on such days, the increased self-consumption of solar energy would lead to an energy cost reduction of almost €500

per year, after accounting for energy losses in the battery. The DER self-consumption service from the battery is therefore on its own not sufficient to financially justify the battery investment cost. In terms of pay-back time, almost 50 years would be required to pay off the initial investment, far exceeding the expected life of the battery system.

If the real-estate owner faces time-varying prices, then the financial conditions for this use-case can improve somewhat. To begin with, consider the case where electricity prices are lower during the mid-day hours than during evening hours. Then the cost savings from the DER self-consumption service increases, without the need for any additional cycles. Continuing the example from above, if we assume an average price difference of €0.02/kWh between mid-day and evening hours[10] (applied both to the price charged for electricity from the grid and electricity fed to the grid), then the energy cost reduction would increase to around €650 per year.

Further, the battery could be used to benefit from price differences at other times of the day as well. For example, if the prices at night are lower than in the morning, then the battery could do a night-to-morning cycle without limiting the ability of also providing DER self-consumption. If we again assume that the average price difference would be €0.02/kWh and that the battery would perform 200 night-to-morning cycles per year, then this would lead to less than €100 per year in cost savings (after accounting for energy losses).

In total, this means that the combination of DER self-consumption and load-shaping in our example would lead to cost savings around €700-800 per year, which is still far from break even.

Finally, we consider the addition of frequency regulation as an additional service. Specifically, we here consider the provision FCR-N in Sweden. Assuming an average compensation level of €30 per MW and hour, a 20-kW battery could generate about €0.6 per hour in revenues (0.03*20). An aggregator would be needed as an intermediary to sell this service to the TSO, and to provide all necessary additional services regarding communication, metering and pre-qualification. For the purposes of this example, we assume that the battery owner and the aggregator share the revenues equally, meaning that the battery owner in the use case would receive €0.3 per hour for providing FCR-N. If we assume that the FCR service is provided 100 days per year, 12 hours per day, then the annual FCR revenues for the battery owner would be almost €400. This estimate does not take the costs associated with additional battery cycling into account.

Adding all three services together, we arrive at yearly revenues and cost reductions of about €1100 per year, which is still far from enough to break even. The payback-time for the stacked use case would be about 22 years.

**Business Use Case 3 – The sensitive industry**

**Service stack:** Power quality + Peak shaving + DSO peak shaving

*Description of use case*

This use case targets industrial applications with high requirements concerning power quality, e.g. voltage stability. The battery energy storage is used to mitigate temporary power quality issues. The power quality service is complemented with peak shaving, both for the industrial end-user itself, and as a service to the DSO.

[10] This price difference is higher than what is typically observed today in the Nordic wholesale market. It is a more reasonable estimate for markets with a higher share of solar generation.

The peak shaving service requires that the customer is subject to network charges based on peak load. For smaller end-users the load is typically measured at an hourly level, meaning that it is not really referring to a peak power load but rather to the average power consumed during the hour with the highest load (i.e. measured in kWh/h). For the peak shaving service to be attractive from an end-user's perspective, the end-user's load should preferably have relatively short and easy-to-predict spikes. If this is the case, a battery could be used to reduce the peaks. Therefore, for this use case, we assume that the industrial process in question meets this criterium.

The DSO peak shaving service means that the battery energy storage can be discharged based on a need from the DSO to reduce the overall load in the DSO network area. The DSO's incentive to reduce load peaks could, for example, stem from contractual arrangements that the DSO has with overlying network owners, where the DSO needs to pay high penalty fees if the peak load exceeds a certain pre-specified limit.

There are many options for what the relationship between the industrial owner of the battery and the DSO could look like. The DSO would like the battery to be fully charged and available when a load peak is likely, and then activate the discharge when the load reaches a critical peak level. A relatively simple arrangement would be for the DSO and the battery owner to agree on a bilateral contact that guarantees the DSO access to the battery for activation a certain number of times per year. Another option is for the DSO to bid for the service on a case-by-case basis, either directly or through an organized flexibility marketplace.

If one individual battery energy storage system would not be large enough to make a significant difference for the DSO, then an aggregator may be needed as an intermediary to offer DSO peak shaving from a portfolio of distributed assets.

**Baseline use case:** The single-service baseline for this stacked business use-case is the case where the battery is used only for power quality services.

*Illustrative financial example*

The value for the end-user of a higher power quality is highly case-specific and depends on the type of damage that power quality variations might inflict. Instead of directly estimating a value of this service, we here begin by providing a financial estimate for the peak shaving services, which provides a basis for evaluating what the power quality service would have to be worth for the use case to be financially attractive.

In this example, we consider the case where the industrial end-user is charged a monthly peak power charge of €7 per kWh/h, based on the average load during the end-user's peak load hour for each month.

The end-user invests in an 80 kW / 160 kWh battery energy storage system at a cost of €80 000 (€500 per kWh). Assuming a 6% discount rate, 10 years expected life-time, and a residual value of 25% of the initial investment, we get an annualized investment cost of about €9400.

The load profile of the end-user is here assumed to be such that this battery is sufficient to reduce the monthly peak load by 40 kWh/h on average. For this to be possible, it must be that the load peaks do not last more than a couple of hours and are sufficiently infrequent that the battery has time to recharge. The network charge cost savings from these peak load reductions are, given the assumptions above, €280 per month, or about €3400 per year.

For the DSO peak shaving service, we consider the case where the DSO has to pay an overdraft fee of €40 per kW and year if the yearly peak load for the DSO as a whole exceeds the amount that the DSO has contracted for with the overlying grid owner. We further assume that the DSO contracts for an amount that equals the expected peak load, and that there is a 50% probability that the peak load will exceed the contracted amount in a given year.

We here assume that the DSO peak loads are sufficiently predictable and short-lived that the full 80 kW battery capacity effectively reduces the peak load. This means that the value for the DSO in terms of potential cost savings that the battery can deliver is €3200 during a year when the peak load exceeds the contracted amount. In expectation, this means that the value for the DSO of the peak shaving service is €1600 per year. Assuming that the DSO and the battery owner share this amount equally, the DSO would be willing to pay €800 per year to the battery owner for the service. Even though this is not a very high yearly value, very few battery cycles would be needed, meaning that the value per cycle is high.

The two peak shaving services are here generating cost savings and revenues for the battery owner of about €4200 per year. In terms of pay-back time this corresponds to about 19 years, which is longer than the assumed battery life. For this financial example to reach break-even, the battery owner must value the power quality service at about €5200 (€9400 - €4200) per year.

**Business Use Case 4 – Apartment building supporting the DSO**

**Service stack:** Investment deferral + DSO peak shaving + Peak shaving + DER self-consumption

*Description of use case*

This use case involves behind-the-meter energy storage that supplies services both to the real estate owner where the battery is installed, and to the DSO.

For the DSO, flexibility services such as investment deferral and DSO peak shaving is supplied. From the perspective of the battery, the investment deferral and DSO peak shaving services are quite similar. In both cases, the DSO needs access to a flexible resource that can be activated when the load in the DSO area (or a part thereof) reaches a critical level. Depending on the case, the need for this flexibility might be quite infrequent.

For the investment deferral service, it could be that only a small amount of flexibility is needed in a specific location, in which case the battery on its own may be large enough. Alternatively, it could be that a larger area is affected, and that the battery is part of portfolio of flexible assets. In either case, an aggregator may be needed as an intermediary between the DSO and the real estate owner. An aggregator handles the interaction between the DSO and the real estate owner and provides the real estate owner with a revenue stream for providing the services to the DSO.

The DSO services are complemented with services that provide benefits to the real estate owner directly. In this use case, the real estate owner benefits from peak shaving and DER self-consumption services. If the DER in question is a solar PV installation, then the combination of peak shaving and DER self-consumption can be especially valuable for residential applications where the load is likely to be low in the middle of the day and high in the evening. We therefore here consider the case where the battery energy storage is installed behind-the-meter in a building with residential load and solar PV.

**Baseline use case:** The single-service baseline for this stacked business use-case is the case where the battery is used only for peak shaving.

*Illustrative financial example*

We here consider a case where the real estate owner invests in a 20 kW / 40 kWh battery system, which is used to shave a daily load peak that occurs in the evening. The cost of this system is assumed to be €24000. As in previous examples, we assume a 6%

discount rate, 10 years expected life-time, and a residual value of 25% of the initial investment, which leads to an annualized investment cost of about €2800 per year.

In this example, because it is assumed that the DSO charges a network fee based on peak load, the variable network fee is assumed to be lower (€0.01 per kWh instead of €0.04 per kWh). Therefore, the price for electricity supplied from the grid is assumed to be €0.09 per kWh instead of €0.12 per kWh. Assuming a battery efficiency of 92.5%, this means that the yearly energy cost of losses in the battery would be about €100 with one full battery cycle per day.

We assume a monthly peak power charge of €7 per kWh/h, based on the average load during the end-user's peak load hour for each month. If the battery can reduce the load peak by 10 kW on average per month, this leads to savings around €70 per month, or €840 per year. The peak shaving service alone is therefore not sufficient to justify the investment cost.

Next, we add the DER self-consumption service, meaning that the battery is charged with self-generated solar electricity during mid-day hours. On 200 days per year, it is assumed that the self-generated solar would have exceeded the property load, meaning that the real estate owner would have sold power to the grid for which it would have received €0.05/kWh. With these assumptions, the yearly value of the increased self-consumption is about €220, after accounting for the cost of energy losses.

The combined value of peak shaving and DER self-consumption in this example is therefore around €1100, which is less than half of what is needed for break even.

We next turn to the services targeting the DSO. Starting with the DSO peak shaving service, we use the same assumptions as in the previous use case (overdraft fee of €40 per kW and year and a 50% probability of exceeding the limit in a given year). The expected yearly value in terms of cost savings for the DSO if the full battery power capacity can be used to reduce the DSO load peaks is therefore €400, of which we assume the battery owner will receive €200.

The value from the investment deferral service is highly case-specific. In order to provide an estimate for the potential financial value of investment deferral, we follow the case described in [7]. In that case, a relatively large (6 MW / 10 MWh) battery storage system was used to defer a network reinforcement by about 10 years. The cost of the deferred network reinforcement was in that case estimated to be about €7.25 million. With a 6% discount rate, the annual value of the investment deferral was therefore €435 000.

In our example, we consider a distributed solution where a similar service is provided by many small batteries instead of one large. Since the battery in our example has a capacity of 20 kW, about 300 batteries of this size would be needed to provide a total capacity of 6 MW. Therefore, the per-battery cost savings from the investment deferral service is estimated to be €1450 per year (435000/300). Again, assuming that the battery system owner receives 50% of this amount, the battery owner would receive €725 per year for the investment deferral service.

It is here assumed that the DSO peak shaving and investment deferral services have operational priority over the peak shaving and DER self-consumption services, but that the DSO peak shaving and investment deferral services require infrequent cycling the battery. Therefore, these services would not interfere much with each other. This is especially true if the network area peak is likely to coincide with the load peak for the end-user.

In total, all four services provide cost savings and revenues of about €2000 per year, which is not quite enough to reach break-even in our example. The pay-back time would be around 12 years.

## ACES BILLING SOFTWARE ARCHITECTURE AND INTERFACES

The project uses a lean, iterative approach on the development of the ACES software system and its components. In work package WP3 the overall system architecture and the interfaces between the software components have been defined – please refer to WP 3 project documentation. This section describes a subset of software components and actors necessary to run a prototype of the ACES solution to demonstrate core features at the demo sites. Figure 11 describes the software architecture with focus on the Billing System (colored in red) and its interfaces to software components provided by the other ACES project partners.

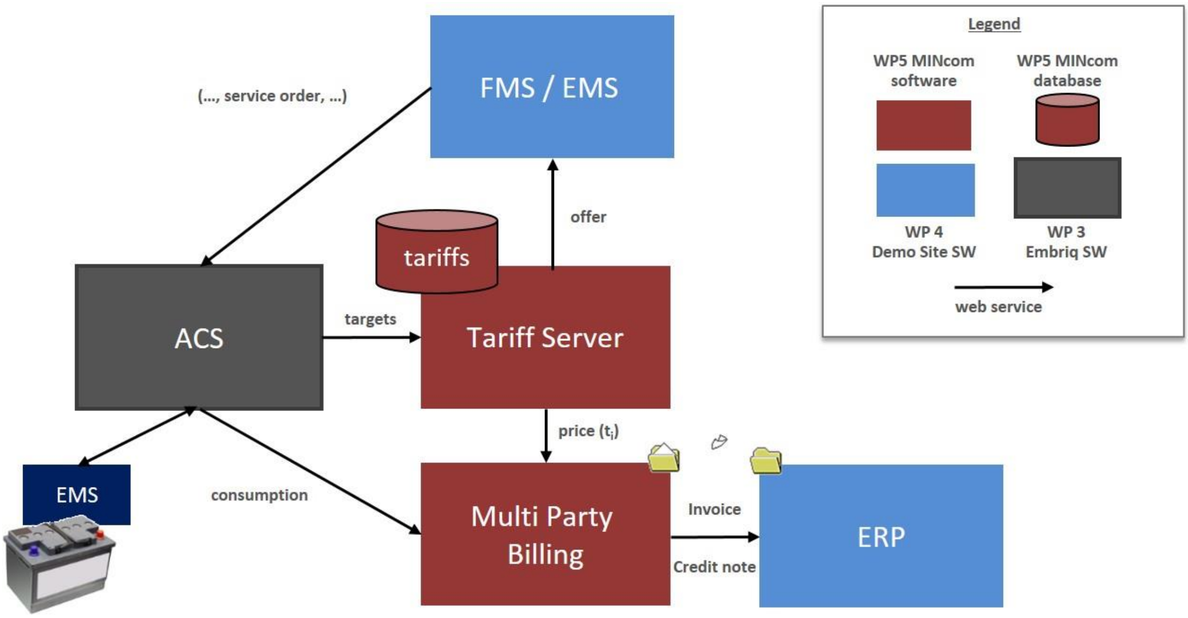


*Figure 11: ACES ICT architecture and interfaces focusing on the Billing System*

As described in the use cases section above facility managers, grid or micro-grid operators, or even e-car fleet owners will want to use their FMS/EMS systems (blue) to manage the flow of energy in order to shave and shape peak loads, provide power quality, increase self-consumption of their RES installations, or amongst others would like to maximize profit by flexibility trading based on variable energy prices. In this context the ACS component (grey) manages all battery service requests from multiple customers and triggers the Billing System (TS component) to send an offer based on the contract between customer and battery owner (dark blue). After successful execution of the battery service by ACS the Billing System (BS-component) is triggered to issue an invoice or credit note for the services provided. Figure 12 provides a more detailed description of the information flow.

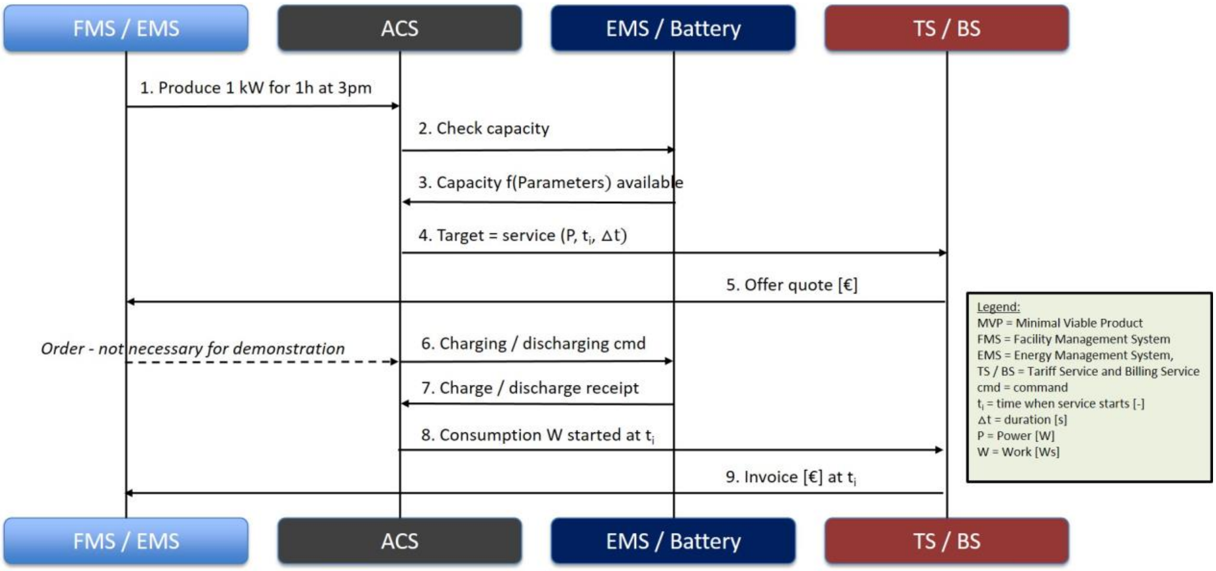


*Figure 12: generic ACES flow chart (simplified) – charging / discharging request and processing*

## BILLING APPLICATIONS AND DEMONSTRATORS

For market adoption, i.e., the willingness of market players to deploy new storage, a reliable investment case is key. In the pilots, the different business models will be configured on an industrial strength billing and clearing system. Savings, earnings and cost of the multiparty services provided by the storage devices will be calculated according to the dynamic market conditions and accounted for all concerned stakeholders in the billing and clearing system. This serves as a deployable storage-to-cash solution that eases market adoption. In addition, the experience gained in multiservice pilots will be captured in business case templates that allow for a better return-on-investment prediction on battery storage investment.

Figure 13 defines the basic principal to do business with battery services. Any business depends on the equation ROI(t) = Revenue(t) - Costs(t), where both revenue and costs are related to the specific application of how(usage) and where(market) the intelligent ACES battery shall work. CAPEX and OPEX have to be calculated to get costs. The achievable price or tariff model has to be designed to receive revenue. In this context it is also important to clearly define roles and cash flow to develop a realistic business model for such a specific application. At least the following roles shall be defined:

a) Customer ~ User of ACES battery services

b) Owner ~ investor

c) Operator

d) Supplier, Subcontractor (e.g. ACES software as a service)

e) Optional: Aggregator

f) Optional: retailer

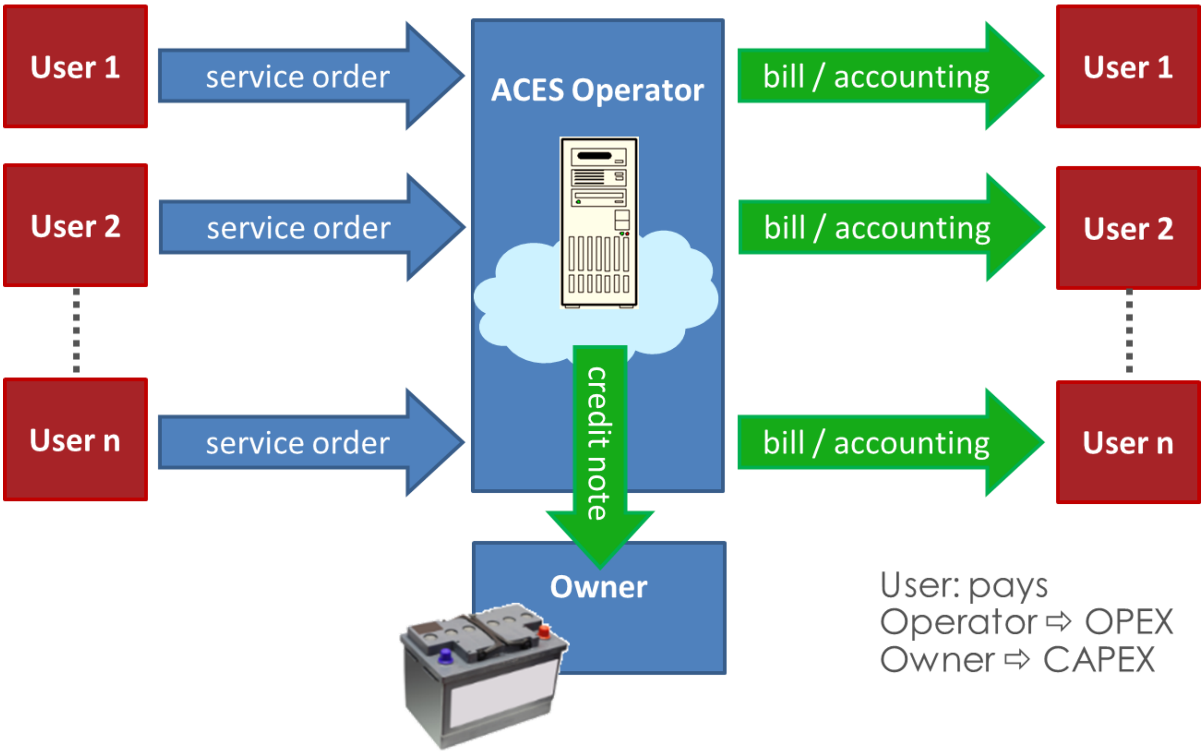


*Figure 13: How business with ACES solutions works – Roles*

Two examples how to calculate ROI:

(i) EV charging: if the intelligent ACES battery is used to guarantee charging of multiple EVs with different charging requirements. In this case CAPEX depends on the specific load / charging profiles during the week; OPEX strongly depends on energy purchasing costs and revenue depends on how much the EV owner is willing to pay for charging.

(ii) Battery as UPS: A completely different calculation has to be done if the battery would be used as an UPS, then CAPEX is based on the power required to cover a possible outage, OPEX in this case is close to € 0,- (because the battery is in standby mode), revenue or price for such UPS battery service can be derived from the potential damage caused by power outages (see Figure 14: Costs and losses from a power-outage can be read from the performance curve  Figure 14) and the probability of such an event – insurance companies provide algorithm and calculation models to define related tariff models.

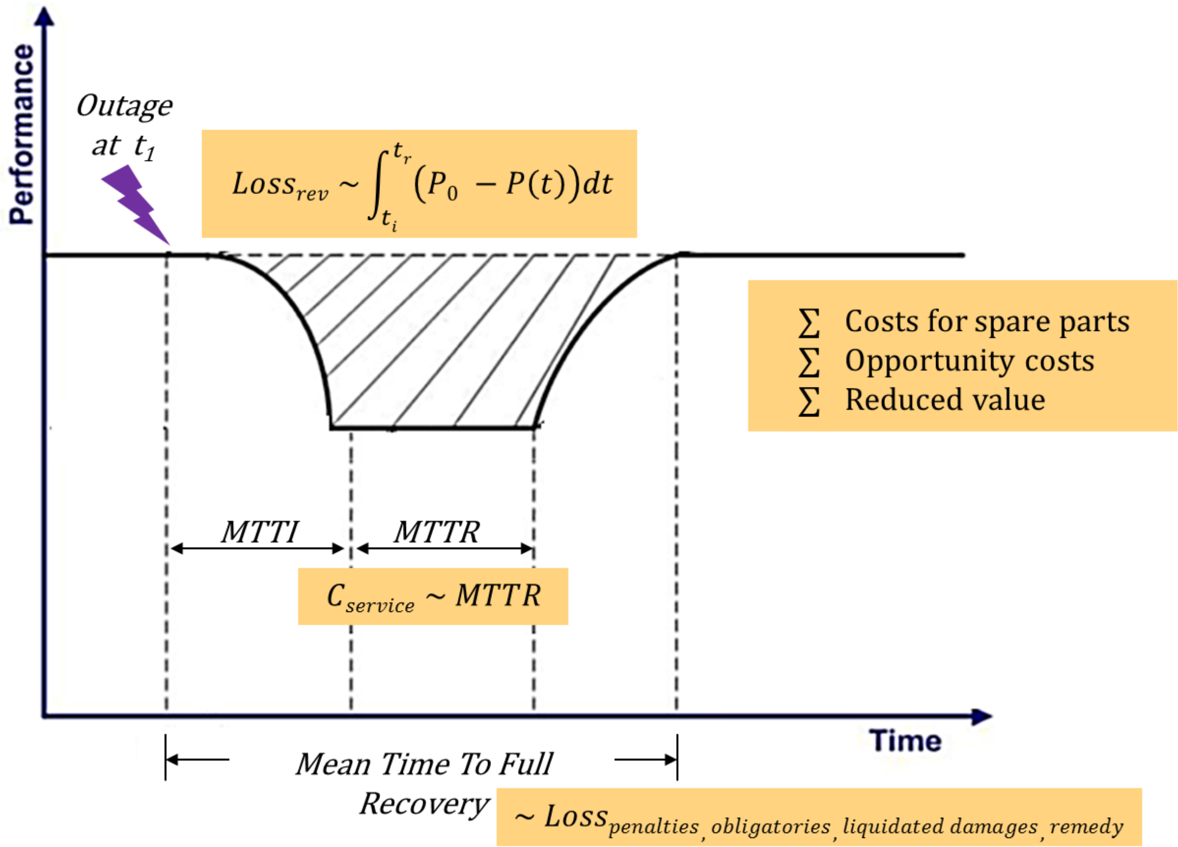


*Figure 14: Costs and losses from a power-outage can be read from the performance curve [42][11]*

**Demonstration Pilot and Business Model at Fraunhofer IFF[12]**

In the coming years there is expected a tremendous growth in the usage of electric vehicles (EV). The result will be an increasing amount of EV charging operations, where requirements for charging management strongly depend on frequency, power demand and time of charging. A high simultaneity factor of the charging processes together with inherent high and constant load demands can lead to a higher stress on grid assets and in extreme situations to violations of grid operation constraints. The costs to guarantee availability of charging capacity according to mobility requirements on the one hand and the need to protect the assets of the charging infrastructure on the other have to be calculated and covered by the EV user. Intelligent load management using batteries for load balancing including also the ability to invoice charging services would be suitable and beneficial to owners of said charging infrastructure.

The following business has been specified and will be demonstrated to potential owners / investors of charging infrastructures at Fraunhofer IFF in Magdeburg. In Figure 15 the principle layout of the demonstration scenario is described. The roles of the chosen business scenario are defined as follows:

---

[11] ISBN 978-3-8007-4505-0; https://www.vde-verlag.de/proceedings-de/454505022.html

[12] Please note: the business model describing e-car charging in this demo is a theoretical example.

**Owner** (investor): Logistic company – we used a real German company called DB-Schenker

**Operator:** Logistic company – DB Schenker

**User** (beneficiary and receiver of invoices): (i) cost account of DB-Schenker's fleet, (ii) subcontractors extending the fleet of DB-Schenker, (iii) employees, (iv) visitors & guests.

The assets used are (i) roof top PV, (ii) battery, (iii) MV/LV micro- grid and the connection to the public energy network, (iv) 1 … n charging station, (v) mini CHP, and (vi) 1 … m EVs. The software for energy management, charging operations and the billing / accounting solution shall be provided as a service and thus shall be a part of OPEX.

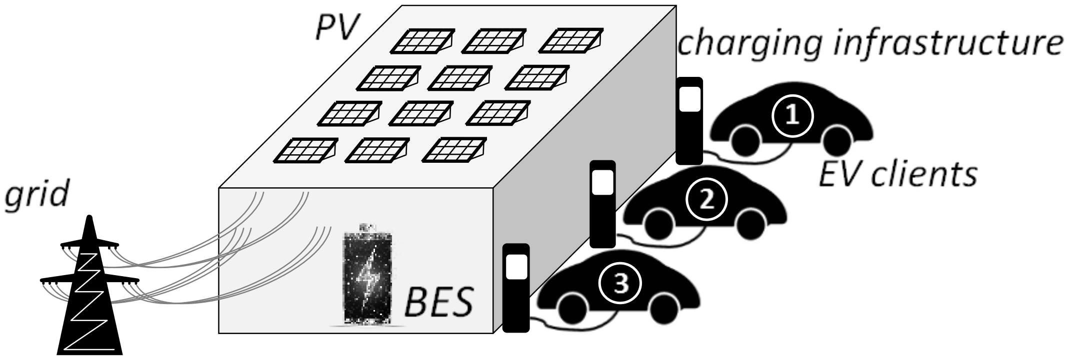


*Figure 15: Demonstrator FhG IFF (Magdeburg) logistic company with own EV fleet and charging infrastructure*

The system can be classified as MicroGrid. It generates its own cheap energy from PV and CHP. The generation characteristics cannot be controlled or can only be controlled to a limited extent for the CHP unit. PV is dependent on meteorological factors and is a strongly fluctuating and difficult to predict variable. The generation curve of the CHP is subject to seasonal and day-dependent fluctuations. Electricity generation can be better predicted. The site-specific electricity demand consists of office buildings including personnel, production - printing plants, logistics - electric vehicles. The charging processes of visitors and logistics service providers must also be taken into account.

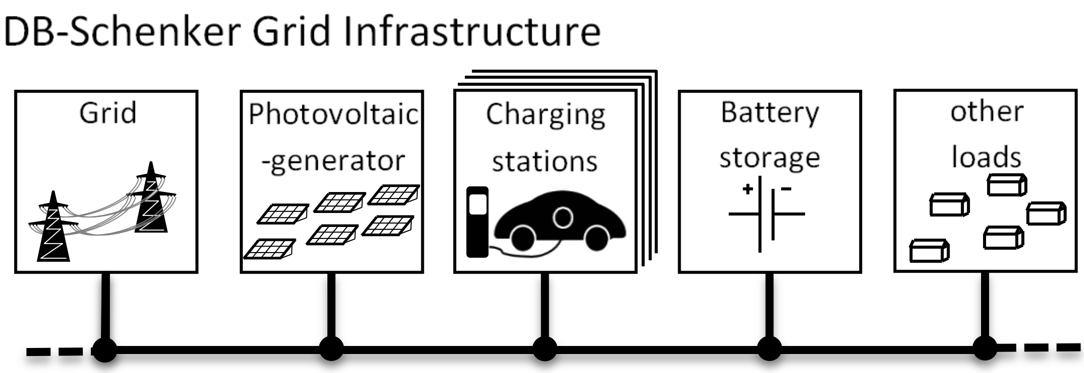


*Figure 16: ACES managed components of the demo scenario at FhG IFF in Magdeburg*

A battery storage is used for the following target functions of the MicroGrid according to The following ACES business use cases can be demonstrated by this application:

- **Avoidance/reduction of peak loads:** For commercial user in Germany, the electricity price consists i.a. of energy price and power price. The power price is based on the maximum peak power of a billing period. This can extend over a year, a quarter or a month. Typically, it is one year. In negative scenario, the simultaneous charging of electric vehicles and peak consumption may lead to a one-off large peak load, which causes very high fixed annual costs. Therefore, the economic potential of battery storage application for peak load reduction/ avoidance results from the local power price.
- **Avoidance of grid feed-in:** There is a lower remuneration for the energy feed-in into the grid than the electricity purchase costs. Own generation needs to be matched to the electrical demand. The economic potential results from the difference between the electricity remuneration according to feed-in tariff and the electricity purchase costs.
- **Sale of electric energy at the charging stations:** At the charging stations, electrical energy from the company's own production facilities is mainly to be sold. This presupposes that there is overproduction that covers the demand or is stored in the battery buffer to be sold to the charging station user. It is also possible to charge the vehicles in a controlled way in order to adapt they consumption to the generation – see Figure 17.
- **Resale of electrical energy:** If the demand cannot be covered by own production, it is purchased from the grid and resold.
- **Avoidance of reactive power costs:** The reactive power purchase is invoiced by the mains supply. This reactive power can be provided by compensation systems. It is also possible to use inverters (PV or battery) for this purpose. In the future, electric vehicles or DC charging stations can also be used for this purpose.

Figure 17 and Figure 18 give an example on how above mentioned business use cases will be invoiced or accounted.

**DB Schenker-Magdeburg**
Saalestraße 35 a
39126 Magdeburg
Germany

eCar User
Saalestraße 1 test
39126 Magdeburg
Germany

Draft Invoice

| Description | Quantity | Unit Price | Taxes | Amount |
|---|---|---|---|---|
| *Charge class used Medium 11kWh,<br>Price for selected class is 0.02€/min VAT exl* | | | | |
| Charge station 001 at 09.09.2019 07:38<br>Time in front of charger 158 min. | 158.000 | 0.02 | 19% USt | 3.16 € |

| | |
|---|---|
| **Subtotal** | 3.16 € |
| USt 19% | 0.60 € |
| **Total** | 3.76 € |

*Figure 17: Sample invoice EV charging - output of the ACES Billing System*

**Fraunhofer**
IFF
Fraunhofer-Institut für
Fabrikbetrieb und -automatisierung IFF
Sandtorstraße 22
39106 Magdeburg, Deutschland

*Städtische Werke Magdeburg GmbH & Co. KG*
*Am Alten Theater 1*
*39104 Magdeburg*
*Deutschland*

# Rechnung: 02020-12

**Rechnungsdatum:**
27.10.2020

| Beschreibung | Ausgangsdokument | Menge | Preis pro Einheit | Steuern | Betrag |
|---|---|---|---|---|---|
| Bereitgestellte Blindleistung | | 1,000 | 19,95 | 19% USt | 19,95 € |

Bereitstellung von Blindleistung um 26.10.20, 00:00. Energiemenge 375 kVAh r plus Steuer 19%. Ihr Preis für diese Operation beträgt 23,74

| | |
|---|---|
| **Zwischensumme** | 19,95 € |
| USt 19% | 3,79 € |
| **Gesamt** | 23,74 € |

*Figure 18: Sample invoice Reactive Power compensation - output of the ACES Billing System*

## Demonstration Pilot and Business Model at GLAVA Karlstad[13]

HSB a regional facility management company and housing organization has motivated a couple of their clients (private house owners) to invest into roof top PV and electric batteries in order to maximize self-sufficiency in energy consumption.  From the ACES project HSB has learned that it was possible to make more use of said batteries by providing peak shaving capabilities and services to the regional DSO KarlstadsEnergi. This extra service of the battery will be remunerated by KarlstadsEnergi by sending a credit note to HSB, who after deduction of their operational costs may refund battery owners by another credit note to their regular energy bill.

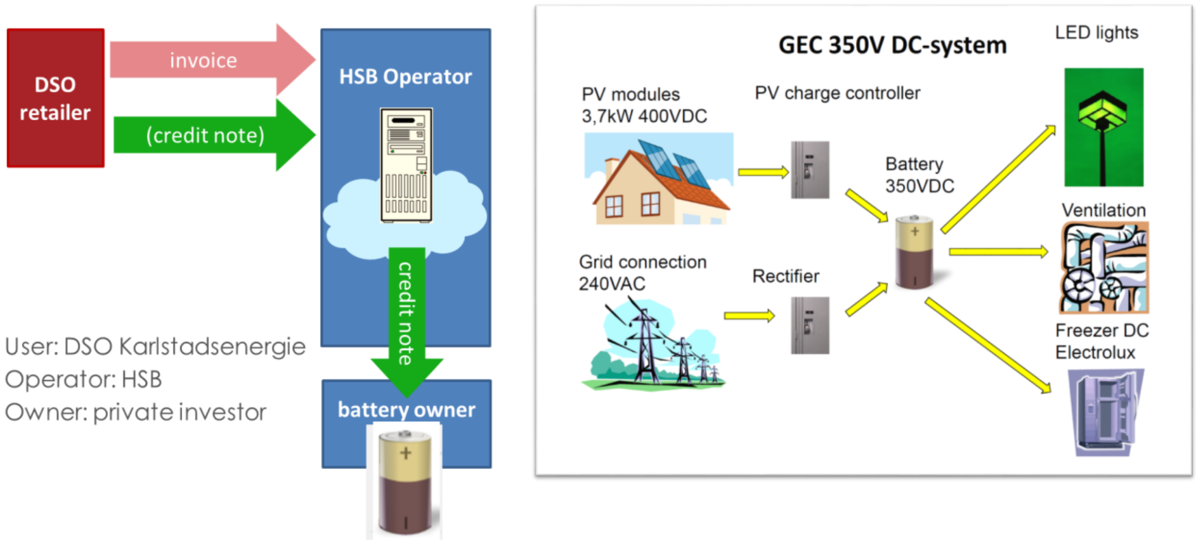


*Figure 19: Demonstrator Glava (Karlstad) and system configuration*

HSB facility management and housing organization provides DSO peak shaving services to KarlstadsEnergi using private owned batteries of their clients. The demonstrator at Glava covers two business models:

*Peak Shaving (behind the meter service) business model*

In the simple case of a standard peak power tariff between the retailer Karlstad Energi and the facility manager HSB, the battery owner [14]provides the capability to HSB to perform peak shaving to reduce HSB's energy bill. HSB measures the maximum peak reduction achieved by the battery discharge within a period and provides a credit note for a percentage of the savings to the battery owner. Using a separate credit note allows HSB to keep their standard energy billing in place without changes.

The roles of the chosen business scenario are defined as follows:

[13] Please note: The business model described here is a theoretical example. Yet, no market place exists at Karlstad.

[14] Of course, this model can be extended to several batteries operated as a local VPP

**Battery Owner (owner, investor):** private capital, here: house owner. The ownership could also be shared between multiple residents who choose to invest in a battery. In a different role assignment, the battery owner could be a different unit [15]of the facility manager HSB or a third party, e.g. a neighbouring company that wants wo make more use of its battery.

**ACES Service Provider (Operator):** "Power services unit" of HSB, a regional facility management and housing organization. In a different role assignment, the ACES services may be provided by a third party "power services" company.

**ACES Service Receiver (user)**: "Facility manager" unit of HSB

*DSO Peak Shaving business model*

KarlstadEnergi charges the highest peak power in the monthly period. Savings are calculated as the difference between the highest peak power at any time in the month and the highest peak power in a time when the "limit consumption" request is active. This difference times the value of a peak power unit is paid out to HSB via a credit note. The amount can be directly paid out to the battery operator HSB "power services" or to HSB "facility management" and then transferred to HSB "power services". The roles of the DSO peak shaving business scenario are defined as follows:

**Battery Owner (owner, investor):** private capital, here: house owner.

**ACES Service Provider (Operator):** "Power services unit" of HSB

**ACES Service Receiver (user)** – KarlstadEnergi DSO

Only the power peak in times with a "limit consumption" request count. Compared to the static peak power tariff, the retail/DSO business customer pays a lower or equal amount. In many countries, the bundling of retail and DSO services in one contract and invoice is problematic. So a static peak power tariff and a credit note for the dynamic reduction of the power peak is more flexible:

- The static tariff invoice can be produced by a legacy billing system, while the credit note is produced by a flexible new billing system.
- The static invoice and the credit note can be produced by different contract partners

Figure 20 and Figure 21 give an example on how above mentioned business use cases will be invoiced or accounted.

[15] "power services unit", may be a separate entity or just a profit-loss account

Energi
Hedvagen 20
Karlstad 654 60
Sweden

HSB
c/o HSB Värmland ek för BOX 141
Karlstad 651 04
Sweden

Credit Note

| Description | Quantity | Unit Price | Taxes | Amount |
|---|---|---|---|---|
| Your flexibility performance | 1,000 | 154,08 | 15.00% | 154,08 kr |

*Dynamic peak shaving tariff; peak was on 17.09.2019*
*12,8*53,13 with Tax15% = 782.07 kr*
*Your regular invoice with standard peak shaving was 959.26 kr*
*Your flexibility performance is difference in standard and dynamic price*
*782,07- 959.26*

| | |
|---|---|
| Subtotal | 154,08 kr |
| Tax 15% | 23,11 kr |
| Total | 177,19 kr |

*Figure 20: Sample credit note from DSO to facility manager for flexible peak shaving*

HSB – där möjligheterna bor

**HSB**
c/o HSB Värmland ek för BOX 141
Karlstad 651 04
Sweden

Battery Owner
Ulvsbygatan 01A
Karlstad 654 64
Sweden

Credit Note

| Description | Quantity | Unit Price | Taxes | Amount |
|---|---|---|---|---|
| Your flexibility performance | 1,000 | 127,51 | 15.00% | 127,51 kr |

*Dynamic peak shaving tariff; peak was on 04.09.2019*
*3,2*53,13 with Tax15% = 195,52*
*Your regular invoice with standard peak shaving was 342,16 kr*
*Your flexibility performance is difference in standard and dynamic price*
*195,52 - 342,16*

| | |
|---|---|
| Subtotal | 127,51 kr |
| Tax 15% | 19,13 kr |
| Total | 146,64 kr |

*Figure 21: Sample credit note from facility management (HSB) to battery owner*

### Demonstration Pilot at VänerEnergi and Digital Twin at Umeå Energi

The demonstrator at VänerEnergi aims to use battery storage and H2E system for peak shaving and DSO peak shaving, as well as local power quality services. The demonstrator is an industrial facility with solar PV generation and a power-to-hydrogen and fuel cell installation – see Figure 22. Therefore, services have been adapted to the local circumstances. The H2E system is designed to both serve the power grid (DSO peak shaving) and optimizing self-consumption to produce hydrogen and the operating power of the

HRS and even internal peak shaving. Refer to [28] or to work package WP 4 final report to receive further information of the business use case and the demonstrator installed at Mariestad. For testing reasons a virtual demonstrator (digital twin) will be installed and tested under the direction of leading partner Metrum.

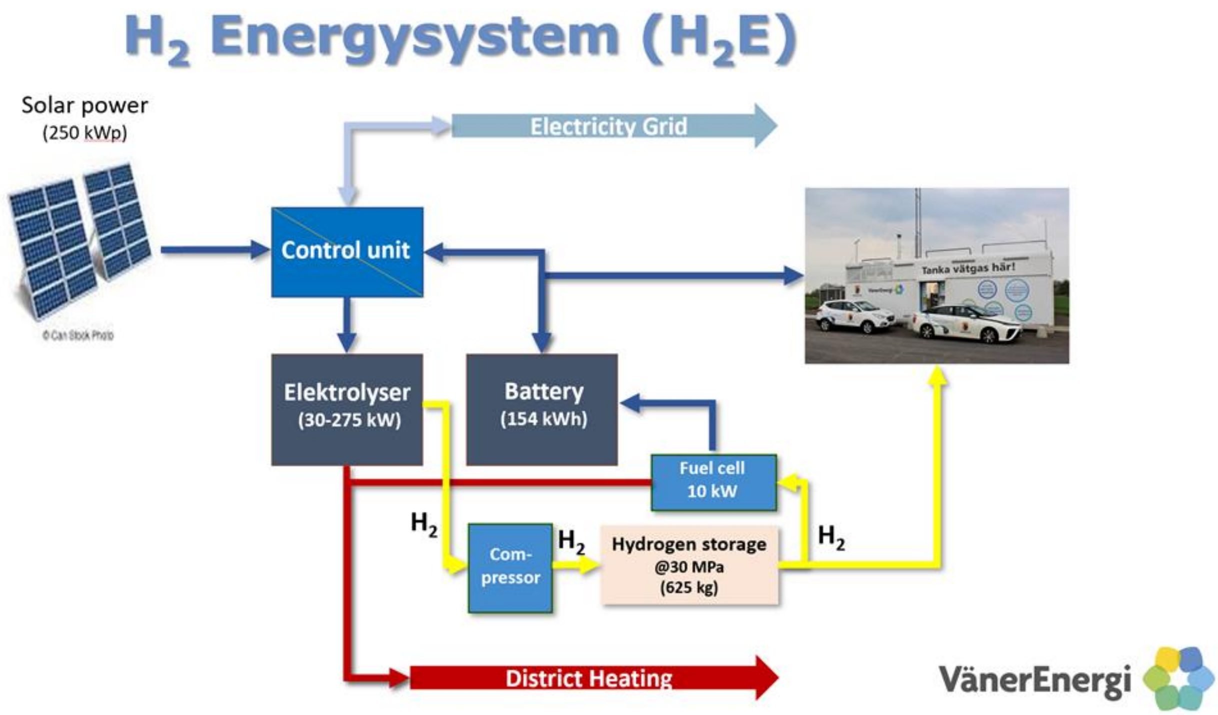


*Figure 22: Schematic overview of the H2E energy system as established in Mariestad*

In the demo application and show case the ACES battery services are used for grid stability and power quality issues. There is no internal billing or accounting right now. In the business model the investment into ACES solution – including battery, IT infrastructure and software licenses – will become a part of the VänerEnergie assets. Interests, depreciation and operational costs will simply be added to general costs, which then are covered by the network charge added by a factor to the consumer’s energy bill. The roles of the chosen business scenario are defined as follows:

**Battery Owner (owner, investor):** DSO VänerEnergi

**ACES Service Provider (Operator):** DSO VänerEnergi

**ACES Service Receiver**: DSO VänerEnergi

Revenue flow - billing relationships: Transfer of service fees between internal accounts could be shown, but this is not planned at present.

## BUSINESS MODELS EVALUATION AND VERIFICATION

The methodology for the business model evaluation is to calculate the profitability of the peak-shaving algorithm utilized as the control in the battery or energy storage based on different tariff structures. For this evaluation five different tariffs have been studied, 1 based on average consumption, 2 based on monthly peak(s) in load and 2 time-of-use tariffs. The applied tariffs concern the grid fees for end-users, electricity retail prices are included in the tariffs.

The economic evaluation is based on one week of data provided from the BMS operation. In Fig. 24 below the input data for the analysis is presented. The data was collected from 2020-11-04 10:00 to 2020-11-11 07:00 (UTC). Missing datapoints were interpolated from the previous values.

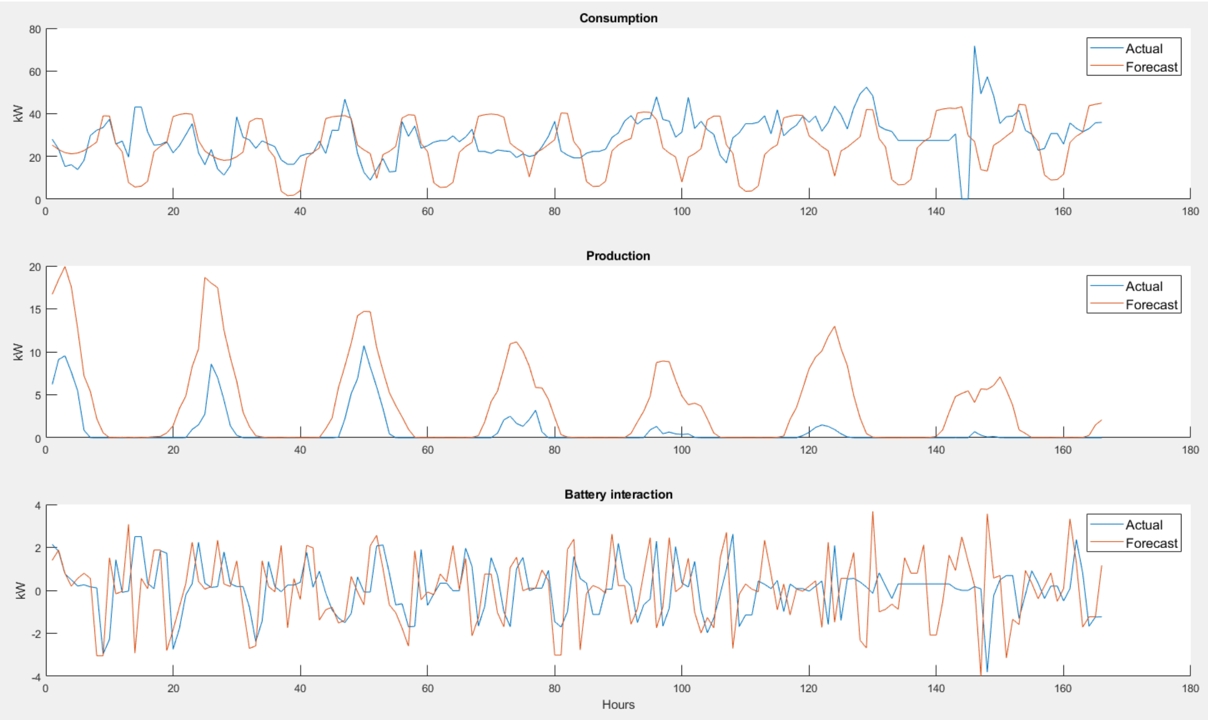


*Figure 24: Input data for the evaluation of the BMS.*

The upper plot is the actual and forecasted load consumption, the center plot is the actual and forecasted PV production and the bottom plot is the actual and forecasted battery running schedule.

To make an economic analysis, a baseline is required as a comparison to see the impact of the BMS running schedule. Fig. 25 below shows the impact of solar production and battery interaction on the overall load profile.

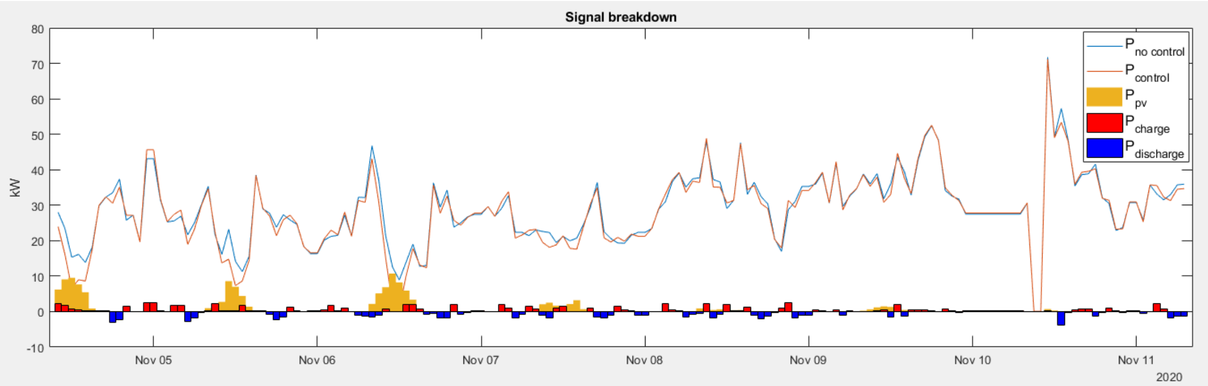

*Figure 25: Signal breakdown of the load profile.*

The figure above describes the signal breakdown, where the blue graph is the actual load signal without any control, the red graph is the combined load, PV and battery interaction. The PV and battery interaction are illustrated as bar plots to better show the charging and discharging. Since tariffs are billed monthly, the data was extrapolated to one month as shown in Fig. 26 below.

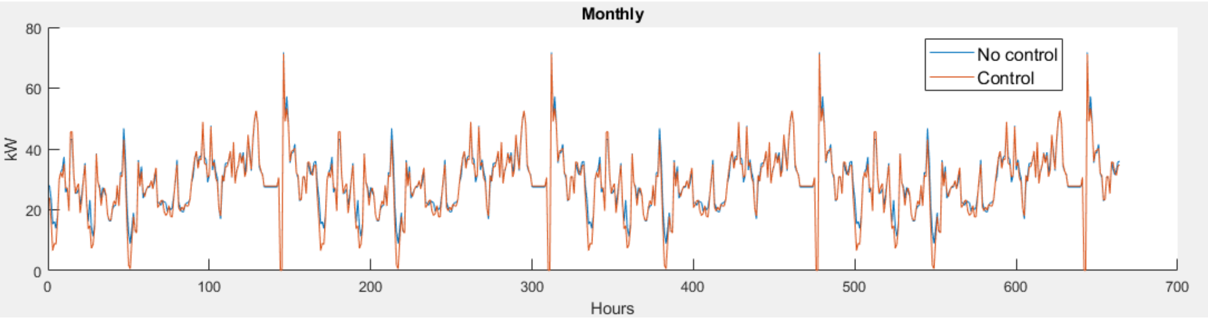

*Figure 26: Monthly extrapolation of load data.*

The five different grid tariff structures used to evaluate the two different modes of operation (No control/Control) are described in the Table 2 below.

| Tariff no. | DSO | Description of grid tariff elements |
|---|---|---|
| 1 | Göteborg Energi (GE) [43] | Fixed fee 2085 SEK/year. Energy fee: 0.28 SEK/kWh. |
| 2 | Partille Energi (PE) [44] | Fixed fee 1350 SEK/year. Energy fee: 0.235 SEK /kWh. Peak power fee: 26.25 SEK/kWh/month. |
| 3 | Sollentuna Energi (SE) [35] | Fixed fee 14535 SEK/year. Energy fee: 0 SEK/kWh. Average peak power fee (3 peaks, 7-19 weekdays): 55.75 SEK/kW/month (apr-oct), resp 111.50 SEK/kW/month (nov-mar). |
| 4 | Vattenfall – N3T (VF-1) [45] | Assumed >80A southern Sweden. Fixed fee 4125 SEK/month. Monthly power fee 35 SEK/kW/month, high load fee 88.75 SEK/kWh/month, low load 0.1125 SEK/kWh, high load (6-22 and nov-mar) 0.28 SEK /kWh |
| 5 | Vattenfall – N4 (VF-2) [45] | Assumed >80A southern Sweden, fixed fee 481.25 SEK/month, monthly power fee 50 SEK/kW/month, high load fee 0 SEK /kW/month, low load 0.18 SEK/kWh, high load (6-22 and nov-mar) 0.65 SEK /kWh |

*Table 2: Five different tariff structures studied from Swedish DSOs.*

The economic outcomes based on the different tariff structures for the cases with and without the proposed control are presented in Fig. 27.

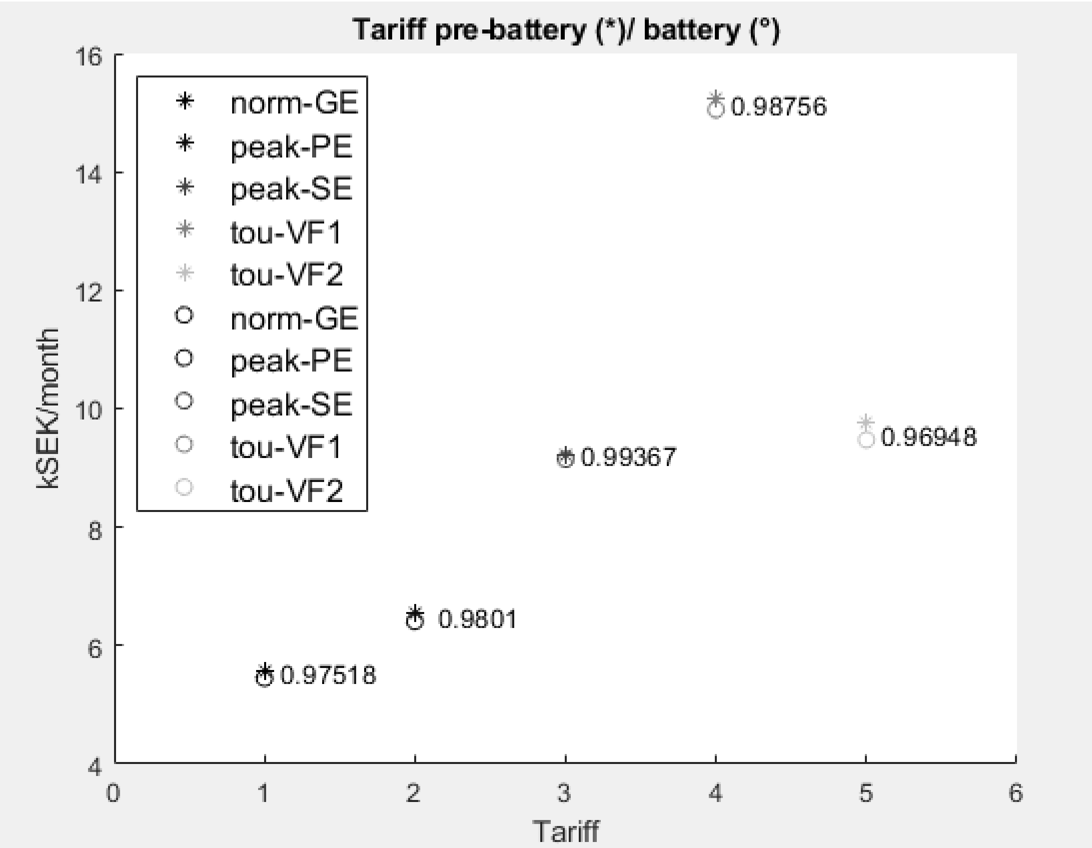


*Figure 27: Evaluation of battery dispatch based of different tariff structures.*

In the figure, (*) indicates the costs before the control is implemented (only load) and (°) represents the costs with implemented control (load, PV and battery). Of primary interest here is the relative cost difference between the two modes of operation. On average the cost savings are 2% of the total cost over the five different tariff structures studied. It can be noted that tariffs 1 and 2 have lower costs due to being based on average consumptions. Also, tariff 2 has a lower peak cost than 3. The gap between tariffs 4 and 5 can be explained by the high load fee of tariff 4.

A sensitivity analysis was performed based on the same battery control but with a simulated higher battery power. From Fig. 25 the maximum power from the battery is 4 kW which is about 4/70 = 6% of the maximum power of the load.

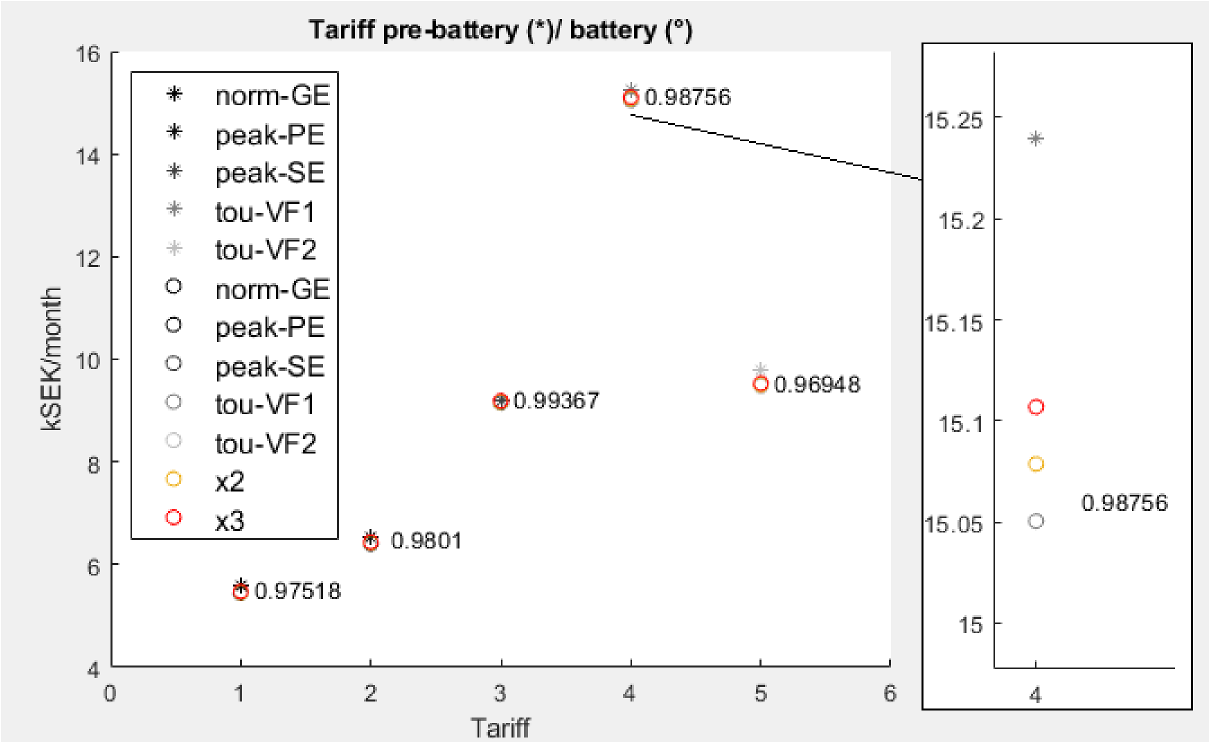


*Figure 28: Battery power sensitivity analysis*

Fig. 28 illustrates a month of battery control with three different levels for the battery power maximum output. The levels are scaled with factors 1, 2, and 3 respectively, representing maximum output levels of 4 kW, 8 kW and 12 kW. The difference between a lower and higher battery power is that the price is higher for that month. In practice, this means that the control strategy cuts more power, but also draws more power when charging the battery from the grid. The negative trend in terms of resulting in higher cost can be explained by that the control strategy creates its own load peaks while it cuts others. An example of this is indicated in Fig. 25, where for hour 00:00 on Nov 5, 2020, showing a peak in battery charging.

# 6. DISCUSSION – New Business Models in a regulated environment

This Chapter provides two slides which MINcom have presented and explained in the Stakeholder Meeting in Paris November 14th, 2019 – see Figure 23 and Figure 24. No further explanations will be provided here due to confidentiality reasons. At their own discretion MINcom is willing to disclose information on request about market details, stakeholders and customer applications regarding its Billing Solution. In parallel to the market research within the ACES project MINcom has done a lot of marketing research looking at potential new customers, competitors, competing or alternative technologies, grid environment and energy policy. A thorough SWOT analysis will be the basis for MINcom's dissemination and exploitation activities.

With demo-site partners we have discussed a new business model, which uses dynamic peak power tariffs. With a high percentage of renewable energy, a static peak power tariff component is not very useful. In this model, the DSO enhances the peak power tariff by telling the business customers[16] whether he wants them to limit consumption in the next hour.

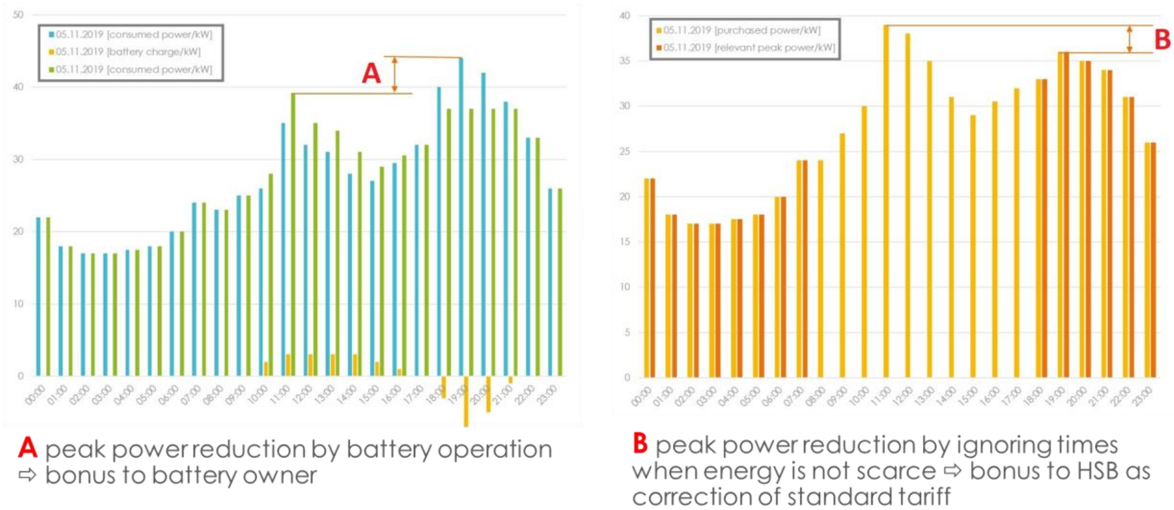


*Figure 23: Present and future flexibility billing*

[16] This information can be sent as a notification (push) or made available on the DSO website. The information can also be localized depending on the load in different parts of the DSO's distribution network.

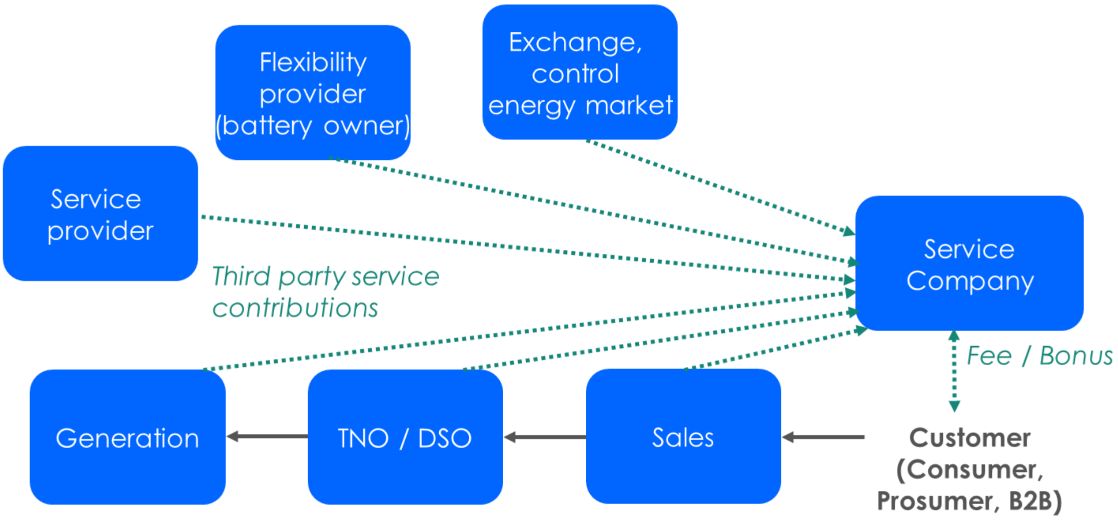


*Figure 24: New billing approaches must separate regulated and unregulated (new) business.*

# 7. Conclusions and Lessons Learned

Work package WP 5 has investigated the market for a "Storage to Cash Solution" and has developed a software component, which monitors and invoices the services provided by the ACES solution. The billing solution developed is a very generic software tool which can be applied to a high variety of business cases not just limited to those described in above. As payment transactions and billing solutions are becoming increasingly important in the energy business and future energy market places. There is an increasing demand for "energy-to-cash" solutions, e.g. for load balancing, for e-car charging, for power quality, for SMEs providing local RES production, and other energy related services. Additionally, new regional market places for local energy trading will emerge, which would require billing services to handle flexibility and flexible tariffs on demand and on production side.

The following results have been achieved:

- The ACES Billing System has been developed for all business cases described in Chapter 5.
- Application and testing have been done for peak shaving and DSOA peak shaving.
- use-case economic evaluation is based on BMS dispatch.

## REPORT CONCLUSIONS

All components of the ACES solution have been developed and tested by independently acting and self-organizing teams – see Figure 25. This methodology is reasonable where requirements rapidly change or where requirements are vaguely specified – e.g. unclear environmental conditions or changing priorities or personnel. After having specified the interface between EMBRIQ's ACS software MINcom was able to develop the billing module independently just checking from time to time if there were any changes to the requirements from the ACES demo-site partners requested. This independence has also given MINcom the freedom to keep close contact to utilities and DSOs from their customer base in order to collect and add further requirements to the Billing System. In the end, MINcom was able to develop a market oriented solution that can easily be adapted to any kind of end customer.

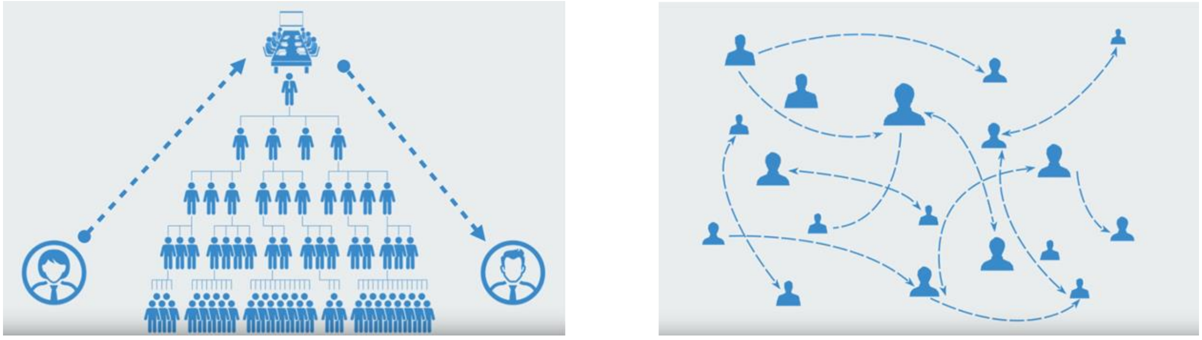

*Figure 25: In hierarchical organisations, the flow of information is hindered by structural barriers. Whereas in self-organising teams, the flow of information can develop freely[17].*

## RECOMMENDATIONS FOR FUTURE STUDIES

Work package WP5 invites interested parties to receive a demonstration on features and performance of the Billing System developed. Potential customers, investors, operators and end-users will be supported by our experts to get our billing solution integrated and applied to any specific IT environment, regardless which kind of ERP system – like SAP, Schleupen, … – they might have in use.

Especially in Germany there are more than 800 utilities and hundreds of companies operating small energy distribution grids. Many of them are SMEs which neither have the budget nor the resources to use available billing solutions for the many new energy services evolving. The logical step should be to launch a new project to achieve the following: (i) applicability of the ACES storage-to-cash solution to customers with low number of transactions or clients (<< 100 000); (ii) fast installation capabilities – plug & play (<< x weeks); and (iii) provide ACES billing functionality as a service.

Interesting would be also to launch an ACES open source project, which would make the results of the ACES software developments to a broad community, which definitely in the end would lead to a better adoption of the ACES results.

[17] Screenshot taken from https://www.youtube.com/watch?v=BatkSenrN0k

# Table of figures

# References

[1] W. Bühring, M. Reinhart, H. Golle and G. Kleineidam, "The Cellular Approach – Business Models Using Efficient Smart Buildings to Push Renewable Energy," in *proceedings of the int. ETG-Congress 2019*, Esslingen, ISBN 978-3-8007-4954-6, 2019.

[2] International Energy Agency, "World Energy Investment 2020," 2020.

[3] IRENA, "Electricity storage and renewables: Costs and markets to 2030," 2017.

[4] Australian Energy Market Operator, "Initial Operation of the Hornsdale Power Reserve Battery Energy Storage System," 2018.

[5] Arevia Power, "Gemini Solar Project," [Online]. Available: https://www.geminisolarnv.com/. [Accessed 08 06 2020].

[6] Southern California Edison, "Submission of Pomona Battery Storage 1 Contract for Expedited Review and Approval by September 15, 2016," 2016.

[7] A. S. Sidhua, M. G. Pollittb and K. L. Anayab, "A social cost benefit analysis of grid-scale electrical energy storage projects: A case study," *Applied Energy,* vol. 212, pp. 881-894, 2018.

[8] "Stem case studies," [Online]. Available: https://www.stem.com/case-studies/. [Accessed 20 11 2018].

[9] "Sonnen," [Online]. Available: https://sonnen.de/. [Accessed 20 11 2018].

[10] "Directive 2009/72/EC of the European Parliament and of the Council of 13 July 2009 concerning common rules for the internal market in electricity and repealing Directive 2003/54/EC," *Official Journal of the European Union,* vol. L 211, pp. 55-93, 2009.

[11] "Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market for electricity and amending Directive 2012/27/EU," *Official Journal of the European Union,* vol. L 158, p. 125–199, 2019.

[12] Council of European Energy Regulators, "Implementation of TSO and DSO Unbundling Provisions - Update and Clean Energy Package Outlook," CEER Status Review, 2019.

[13] Swedish Energy Markets Inspectorate, "Marknadsförutsättningar för elektriska batterilager – principiella utgångspunkter och möjligheter," 2016.

[14] Energimarknadsinspektionen, "Ren energi inom EU - Ett genomförande av fem rättsakter," 2020.

[15] Commission Staff Working Document , "Country Reports - Progress towards completing the Internal Energy Market," European Commission , 2014.

[16] B. Malmendier and J. Schendel, "Unbundling Germany's Energy Networks," *Journal of Energy & Natural Resources Law ,* vol. 24, no. 3, pp. 362-383, 2016.

[17] G. Brunekreeft, M. Goto, R. Meyer, M. Maruyama and T. Hattori, "Unbundling of electricity transmission system operators in Germany: An experience report," Bremen Energy Working Papers, No. 16, 2014.

[18] "Regeringens proposition 2017/18:294 Vissa kontrollfrågor och andra frågor på punktskatteområdet," 2018.

[19] J. Malinen, *Personal communication [e-mail],* Swedish Energy Agency, 2018.

[20] BDEW Bundesverband der Energie- und Wasserwirtschaft e.V., "BDEW-Strompreisanalyse Januar 2019," Berlin, 2019.

[21] C. Pape, N. Gerhardt, P. Härtel, A. Scholz, R. Schwinn, T. Drees, A. Maaz, J. Sprey, C. Breuer, A. Moser, F. Sailer, S. Reuter and T. Müller, "Roadmap Speicher," Fraunhofer-Institut für Windenergie und Energiesystemtechnik, 2014.

[22] M. Klausen, "Market Oppurtunities and Regulatory Framework Conditions for Stationary Battery Storage Systems in Germany," *Energy Procedia,* vol. 135, pp. 272-282, 2017.

[23] Lazard, "Lazard’s Levelized Cost of Storage Analysis - Version 4.0," 2018.

[24] Bloomberg New Energy Finance, "New Energy Outlook 2018," 2018.

[25] Open Utility Ltd, "Piclo Flex," [Online]. Available: https://picloflex.com/. [Accessed 25 06 2020].

[26] NODES Market, "A fully integrated market for flexibility," 2018.

[27] CoordiNet, [Online]. Available: https://coordinet-project.eu/. [Accessed 25 06 2020].

[28] M. van Asseldonk, A. Holmer and et.al., "ACES Requirement Specification V2.0 - ERA-NET Smart Grids Plus - Project Deliverable," ERA-Net SES - https://www.eranet-smartenergysystems.eu, 27-11-2019.

[29] DNV GL, "Energy Storage Use Cases," 2016. [Online]. Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/554467/Energy_Storage_Use_Cases.pdf. [Accessed 27 11 2018].

[30] G. Fitzgerald, J. Mandel, J. Morris and H. Touati, "The Economics Of Battery Energy Storage," Rocky Mountain Institute, 2015.

[31] U.S. Energy Information Administration, "U.S. Battery Storage Market Trends," 2018.

[32] D. Frankel and A. Wagner, "Battery storage: The next disruptive technology in the power sector," 06 2017. [Online]. Available: https://www.mckinsey.com/business-functions/sustainability-and-resource-productivity/our-insights/battery-storage-the-next-disruptive-technology-in-the-power-sector. [Accessed 27 11 2018].

[33] G. Kleineidam, G. Jung and A. Woeltche, "Cost Impact Simulation of Blackouts within the Electrical Grid," in *International ETG Congress*, Bonn, Germany, 2017.

[34] Sandviken Energi AB, "Avgifter för effekt 35A-63A," [Online]. Available: https://sandvikenenergi.se/elnat/elnatsavgifter/3563a.4.1f5212510751e1938e8000514.html. [Accessed 25 03 2019].

[35] Sollentuna Energi & Miljö AB, "Nätavgift," [Online]. Available: https://www.seom.se/elnat/villkor/natavgift/. [Accessed 25 03 2019].

[36] E.ON Energidistribution, "Elnätsabonnemang för regionnät," [Online]. Available: https://www.eon.se/content/dam/eon-se/swe-documents/swe-prislista-regionnat-syd-190101.pdf. [Accessed 25 03 2019].

[37] Energimarknadsinspektionen, "Normvärdeslista elnät 2020-2023 (xlsx 127 KB)," [Online]. Available: https://ei.se/Documents/Forhandsreglering_el/2020-2023/Dokument/Normvardeslista_elnat_2020-2023.xlsx. [Accessed 25 03 2019].

[38] Ellevio AB, "Elnätspriser för Västra Svealand-Västergötland från och med 1 december 2017," [Online]. Available: https://www.ellevio.se/globalassets/uploads/dokument/prislistor-2019/prislistor-privat-2019/sakr_vsv_171201_v19.pdf. [Accessed 25 03 2019].

[39] E.ON Energidistribution, "Våra elnätsabonnemang för företag," [Online]. Available: https://www.eon.se/content/dam/eon-se/swe-documents/swe-prislista-foretag-lag-syd-190101.pdf. [Accessed 25 03 2019].

[40] Svenska kraftnät, "Primärreglering," [Online]. Available: https://mimer.svk.se/PrimaryRegulation/PrimaryRegulationIndex. [Accessed 25 03 2019].

[41] E. Enhörning and E. Odehed, "Power flow control strategies for an energy storage in a solar powered DC microgrid," Department of Electrical Engineering, Chalmers University of Technology, Gothenburg, Sweden, 2018.

[42] G. Kleineidam, G. Jung and A. Wöltche, "Cost Impact Simulation of Blackouts within the Electrical Grid," *proceedings International ETG Congress 2017,* pp. 125-130, 28-29 November 2017.

[43] G. E. Elnät, "Göteborg Energi Elnätsavgifter," [Online]. Available: https://www.goteborgenergi.se/privat/elnat/elnatsavgiften .

[44] P. Energi, "Partille Energi Elnätavgifter," [Online]. Available: https://partilleenergi.se/elnat/.

[45] V. Eldistribution, "Vattenfall Eldistribution Elnätspriser," [Online]. Available: https://www.vattenfalleldistribution.se/el-hem-till-dig/elnatspriser/.