e-book

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The NETfficient Handbook: Aggregated Energy Storage for Smarter Communities

Grid Integration of Distributed Energy Storage Using an Aggregation Platform

NETfficient
Storage for Life

Andrea Immendörfer (Lead author)

The NETfficient Handbook

Steinbeis-Edition

Project funded by the European Union's Horizon 2020 research and innovation programme under the Grant Agreement no. 646463.

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1st edition, 2018 | Steinbeis-Edition, Stuttgart
ISBN 978-3-95663-201-3

Layout: Steinbeis-Edition
Cover picture: FotoIdee/shutterstock.com
This book is also available as printed version. ISBN 978-3-95663-200-6

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206041-2018-12 | www.steinbeis-edition.de

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2LEV	Second-Life Vehicle Batteries
A	Ampere
AMM	Acquisition Management Module
BMS	Battery Management System
BTM	Behind-the-meter
CMMS	Computerised Maintenance Management System
DER	Distributed Energy Resources
DDO	Design-Decide-Operate
DMS	Distribution Management System
DSO	Distribution System Operator
EEX	European Energy Exchange
EMG	Energy Management Gateway
EMP	(NETfficient's) Energy Management Platform
EPEX	European Power Exchange
EV	Electric vehicle
ESS	Energy Storage System
FOMS	Forecast-based optimal Management System
FTM	Front-of-the-meter
HESS	Hybrid Energy Management System
HV	High voltage
iNMS	Intelligent Node Management System
LFP	Lithium iron phosphate
LV	Low voltage
MPPT	Maximum Power Point Tracking
MV	Medium voltage
PV	Photovoltaic
TSO	Transmission System Operator
UPS	Uninterruptible power supplies
VPP	Virtual power plant
WAN	Wide area network

1 Introduction to NETfficient

NETfficient is a visionary project, bringing together 13 partners from seven countries to implement a pilot for a future-proofed energy system on the German island of Borkum.

This pilot is designed to tackle some of the most pressing energy challenges:

- to promote a mostly renewables-based energy supply
- to improve exploitation of existing renewable energy
- to deal with time-shift between availability of renewable resources and demand peaks.

Energy storage and smart energy management are considered to be the missing link in meeting these challenges and in empowering citizens and businesses to become active prosumers, thus involving them in the energy value chain and ultimately, to attain a better living and working environment. One main objective of the project is to develop and test different applications for energy storage systems in a real environment. Central to this endeavour is the development of an Energy Management Platform, which can be used by utilities to manage the energy from renewables and storage devices. This means that clean and sustainable energy, which exceeds the immediate demand, will be stored in the island's electric grid when it is available, to be distributed at a later point in time, when there is demand for it.

The real-life demonstration on Borkum is driven by five different applications for storage, covering a wide range of functionalities in the low voltage and medium voltage grid.

The NETfficient-Handbook presents key results from the project with particular emphasis on integration of small-scale storage technologies into the grid, by connecting them to a management platform. This publication is complementary to the dissemination material already available on the project website www.netfficient-project.eu, and will provide information to facilitate market uptake.

As part of the project a number of extensive studies on storage integration have been undertaken alongside the real-life pilot, covering a wide range of aspect and providing the contents of the publication at hand. Studies on markets integration and the regulatory environment by Fraunhofer ISE and on environmental impacts over the life cycle by Swerea IVF in particular provide the backbone of this handbook. These are framed by detailed descriptions of the hardware and software solutions developed in the project.

As the pilot installations were all based in Germany there is a strong focus on the German context for energy storage, be it the regulatory framework or economic situation. Lessons from analysing these however are considered to have relevance beyond Germany.

Figure 1: NETfficient consortium (Source: NETfficient project).

The NETfficient Consortium

Ayesa Advanced Technologies SA, Spain
www.ayesa.com/en

Ayuntamiento de Santander, Spain
www.santander.es

Centro di Ricerca, Sviluppo e Studi Superiori in Sardegna, Italy
www.crs4.it/

Fraunhofer Institute for Solar Energy Systems ISE , Germany
www.ise.fraunhofer.de/en

PowerTech Systems, France
www.powertechsystems.eu/en/

Schneider Electric GmbH, Germany
www.schneider-electric.com

Steinbeis-Europa-Zentrum, Germany
www.steinbeis-europa.de/

Swerea IVF AB, Sweden (from 1.10.2018: RISE)[1]
www.swerea.se/en/

Università degli Studi di Cagliari, Italy
www.unica.it/unica/en/homepage.page

Williams Advanced Engineering Limited Ltd., United Kingdom
www.williamsf1.com/advanced-engineering

Nordseeheilbad Borkum GmbH, Germany
www.stadtwerke-borkum.de

Vandenborre Energy Systems NV, Belgium
www.vdbenergy.com

ZIGOR Research & Development A.I.E, Spain
www.zigor.com/

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[1] RISE Research Institutes of Sweden is a group of companies with several subsidiaries, including Swerea IVF AB. As of 1 October 2018, RISE Research Institutes of Sweden AB is, indirectly, the only shareholder in Swerea IVF AB, which will then change its company name to RISE IVF AB.

1.1 Challenges and Opportunities for a Future Proofed Energy System

Generating energy, be it electricity, heating or cooling, still causes high CO_2 emissions – a main factor for anthropogenic climate change. It is therefore a matter of safeguarding the well-being of current and future human generations, to replace carbon-intensive fossil fuels with more sustainable technologies for energy generation. This is now universally acknowledged and also enshrined in long term EU-strategies, such as the EU-Energy-Roadmap[2] and reflected in targets for 2020[3] and 2030[4], ultimately aiming for a reduction in greenhouse gas emissions by 80–95 %, when compared to 1990 levels, by 2050.

Renewable energy resources including wind and solar offer great opportunities for reducing CO_2 emissions and increasing the efficiency of electric power generation. However, EU-citizens are depending on the energy system in Europe being reliable, affordable and functioning efficiently as the basis of their standard of living. A large number of interconnected distribution grids, providing electrical power, and energy for heating and cooling have to be coordinated and integrated in order to achieve the pan-European sustainable energy system reflected in EU-policies.

The intermittent nature of renewable power generation poses a significant challenge that has to be tackled with new and distributed storage technologies. In this context greater efficiency in the generation of electric power, consumption of energy and management of the grid is crucial.

The challenges posed by an increasing share of renewables within the grid stretch across all voltage levels. When focusing on behind-the-meter distributed energy generation (DER), such as photovoltaic (PV)-installations on res-

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[2] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Energy Roadmap 2050 /* COM/2011/0885 final */

[3] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions Energy 2020 A strategy for competitive, sustainable and secure energy /* COM/2010/0639 final*/

[4] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: A policy framework for climate and energy in the period from 2020 to 2030 /* COM/2014/015 final */

idential and non-residential buildings, the challenges namely for energy companies include a lack of control and real-time visibility over the DER and the fact that there are many different types of generation and storage technologies at end user level, which are spread over a wide geographic area. They represent a large number of resources to be controlled (potentially thousands), so traditional strategies for large scale centralised generating capacity are not valid. Furthermore they can lead to power quality issues such as reverse flows, voltage imbalances, etc. And in themselves, these DERs are not able to participate in electricity markets.

However, these challenges correlate to a number of potential opportunities, which distributed energy generation can bring about, and which thus must influence how the challenges are dealt with. First and foremost DERs help to increase the share of overall renewable generation in the grid. Local DERs can reduce peak demand on the grid by meeting demands locally. Network upgrades at transmission and distribution level may therefore be deferred. Furthermore, DERs have the potential to provide ancillary services and also back-up power. DERs provide synergies with direct and reverse demand response. All in all, DERs can provide added value to connected services to customers.

These challenges and opportunities set thus the scene in which the NETfficient project operates, maximising the opportunities while addressing the challenges.

1.2 Objectives and Mission of NETfficient

The project developed a range of technology packages for typical applications, which were tested on the island during the demonstration phase of the project. It is designed to reflect and tackle the challenges of a mainly decentralised, renewables-based energy system. The decentralised storage solutions and the aggregation solution implemented on Borkum are briefly sketched as follows:

At the heart of the installations on Borkum, the Energy Management Platform (EMP) connects all distributed energy generation and storage units.

A 1 MW / 500 kWh Hybrid Energy Storage System (HESS) consisting of Li-ion Batteries and ultracapacitors balances out peaks in the energy demand and variations in renewable energy production in the medium voltage grid.

40 home-systems were implemented consisting of PV, smart meters and storage systems, including Li-ion batteries, HESS-systems, second life vehicle batteries and hydrogen storage (power-to-gas).

PV and lithium-ion batteries or HESS for 5 non-residential buildings were installed.

50 energy efficient LED street lights are now powered by a 4 kW photovoltaic system and a 15 kWh lithium-ion batteries storage system.

Two large, low-temperature thermal storage tanks powered by PV maintain the temperature for the fish tanks at the “Nordsee Aquarium Borkum”. The tanks are regulated by two cooling units. Hence the thermal capacity of water is used for storage.

Distributed energy storage and energy monitoring were each integrated in order to provide services to Borkum’s grid on the one hand and as a means of opening new revenue potentials on the other. Developing and installing all components of such a system requires interaction with a wide range of stakeholders from industry suppliers, installer-SMEs, the local authority and policy makers on Borkum and finally to end-users and the wider public on Borkum and beyond.

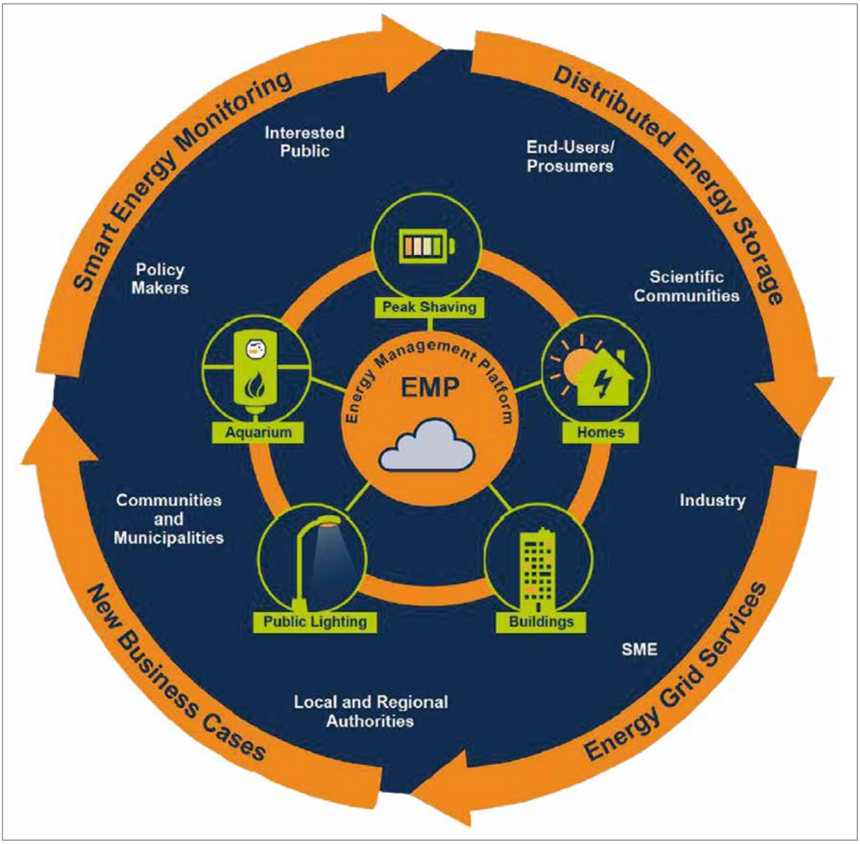

Figure 2: NETfficient Value Chain (Source: NETfficient project).

The project was shaped and observed by representatives of the scientific community, within the project consortium and outside of it. These interactions and relationships around the NETfficient project are illustrated in the NETfficient Value Chain (Figure 2).

All of the component packages developed for these applications are presented in detail in the Chapter 3. Data on individual components are provided in Chapter 2.

1.3 Why Focus on Energy Storage?

The integration of renewable energy production into the electricity distribution grid has introduced strong variability and intermittency in power generation, making it increasingly difficult to maintain the balance between production and consumption of energy for distributors. Energy forecasting and electrical storage technologies are promising innovations for reducing the negative impact of the variability of renewable energy production.

Battery systems and other storage systems have the potential to lower the costs associated with the electrical grid connection of newly built houses or to avoid costs for upgrading existing grid connections. At the same time challenges on the energy system arising from the move towards electric mobility need to be considered. In the case of operating charging stations for EV, the maximum power for the total load allowed for a domestic house, may be reached quickly. Either a very restrictive load management or an extension of the grid connection power becomes necessary. The use of batteries temporarily allows loads exceeding the maximum connection power, thus avoiding costs for upgrading the mains connection. Furthermore, renewable energy output currently has to be curtailed at certain peak times in Germany, thus limiting the utilisation of the installations. The use of energy storage can again offer preferable alternatives.

1.4 Why Aggregate?

Flexibility in the electrical energy system increases in importance and value due to the aforementioned challenges arising from intermittent DERs. In the wake of progressing digitalisation, costs are falling for aggregation, flexible generation capacity and storage, as well as for demand-side management. In order to aggregate DERs and / or distributed storage, the units need to be connected to a management system, which can control them remotely, while also respecting local demands on the systems. A Distributed Energy Management System (DERMS) is required. In NETfficient the relevant software tool is called Energy Management Platform or EMP.

In NETfficient the aggregated distributed storage is used in the first instance to provide flexibility and services at local level, such as increasing the local share of self-consumption. This is economically attractive, especially if the grid does not have to be used. By aggregating diverse technologies and identifying and using flexibilities, the storage aggregator is able to tailor energy products and services to the needs of various customers, through levelling out fluctuating generation from intermittent renewable energy resources, varying consumption needs and limiting predictability of some of the resources.

In addition, aggregated balancing services can be offered to the wholesale market for electricity. There is scope for viable business models for providing Primary Control Reserves – as proven by the strong growth in utility scale batteries, which all offer Primary Control Reserves. Based on a broadened services portfolio, a synergy effect can be generated by combining compatible services (e. g. energy supply and provision of balancing and ancillary services).

Whereas utility scale batteries are usually designed specifically to interact with the energy wholesale market, this is not the case with smaller scale distributed storage (behind-the-meter). It is only through pooling these resources, thus aggregating them that new economic potentials can be accessed. Although locally the DERs will have enough intelligence to decide when to store, generate or disconnect from the grid, it is necessary to use an aggregated and centralised system that remotely indicates the demand and monitors the status of the DERs.

1.5 Why on an island?

In very general terms, islands can be seen as small-scale models of national systems, as they comprise all essential infrastructure and administrative facilities, which would normally be spread over a number of institutions and a large geographical area. These would normally be managed by a large number of people and institutions. Islands however, tend to be managed by a small number of people and institutions. Everyone knows everyone else and islanders tend to have a much closer connection to their institutions as well as a greater direct influence on them. Compared to their mainland counterparts, islanders tend to have a much more acute understanding of dependencies, of what can be provided locally and what has external dependencies. Hence it will be easier to find or support acceptance for solutions, which minimise dependence.

Testing out solutions for electrical grids on Islands has further advantages in energy terms as well. Island grids represent small models of national grids, regardless of whether they are truly independent of the national grid or connected to the mainland. They provide a manageable scale for recording and understanding what energy is entering the system and how it is distributed and consumed, as there will be one or only a small number of entry points, be it the port taking in diesel deliveries or the connection point of a cable from the mainland. The latter is the case in Borkum. Islands can be seen as models of the final state of an energy system, which no longer has easy options for dealing with energy excesses and shortfalls, whereas mainland grids currently still prioritise trading across national boundaries to deal with excess and shortfalls.

NETfficient developed a generic approach for energy systems. This approach is based on an island distribution grid connected to the mainland. Energy islands in regions with low population density may be able to directly transfer insights from NETfficient, thus providing replication potential. Furthermore, outcomes lend themselves to being transferred to industrial mini-grids, district sub-networks and off-grid systems.

1.6 Why Borkum?

Borkum is a German Island in the North Sea. In summer, during tourist high season, the energy consumption grows exponentially and reaches the highest levels of net consumption, i. e. consumption minus generation. The number of people residing on the island multiplies fivefold. However, in addition to a number of Combined Heat and Power Plants (CHPs), Borkum has a comparatively high penetration of PV and wind energy. Peaks of PV generation occur at the same time of year as consumption peaks.

During high season, the main objective is to reduce the maximum amount of energy used by the island, thereby reducing the maximum load. If this maximum load is reduced, the local utility “Stadtwerke Borkum”, which procures energy from the large utility EWE and resells it to the islanders, may be able to renegotiate their contract, reducing ultimately the price per kWh to end-users.

The aim is, therefore, to align the particular characteristic of renewables and the particular consumption patterns of a tourism-dominated island. This constellation of dependence on summer tourism on the one hand, and availability of renewable resources on the other, applies to many islands. At the same time tourism destinations often have energy-intensive specialist applications such as pools, leisure centres, aquariums etc., which lend themselves to sustainable energy solutions, including storage. The current interest in Green Tourism represents a strong driver to explore such solutions.

1.7 Characterisation of Energy on Borkum

The 20 kV medium voltage grid on the island of Borkum is connected to the EWE-Electrical network via the transmission substation “Reede”. It has a length of 82 km. It is the highest voltage level on Borkum and is responsible for the supply of all loads via the connection to the external grid and delivery of power from production sources to energy consumers.

The MV grid has five metering points and is fed at six points by low-carbon local energy sources, i. e. wind and CHP. Furthermore, there are 102 points from PV sources and CHP production via the LV-network through 20 kV / 400 V substations.

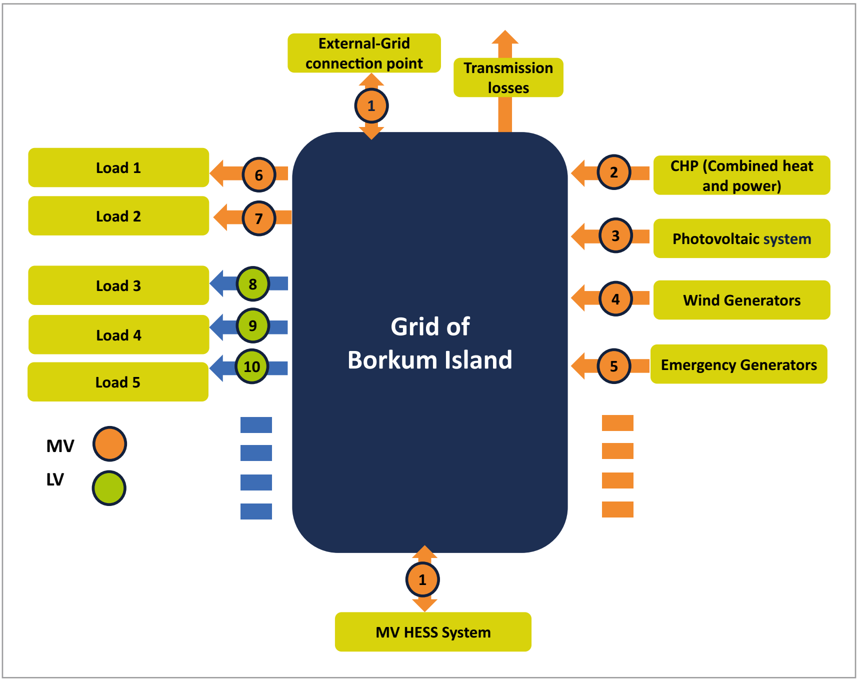

Figure 3: Grid of Borkum (Source: NETfficient project).

The wind turbines installed on the island of Borkum use synchronous generator technology and have a fully rated converter design. The most important parameters are:

- Rated power: 1 800 kW
- Diameter: 70 m
- Swept area: 3 848 m^2
- Power density: 2.1 m^2 / kW
- Number of blades: 3

The existing PV-Farm on Borkum is located in the centre of the island on a former landfill site. The farm has nominal DC-Power of 1 387 kWp and consists of about 7 704 PV modules. There are two outdoor central inverters. The plant has its own MV transformer. The inverter Parameters are[5]:

- Rated AC power: 630 kVA
- AC voltage: 315 V / 3 Phase
- European Efficiency rating: 98.5 %

Furthermore, there are three industrial CHPs and seven home CHPs connected to the low voltage grid in Borkum, ranging from 140–377 kW.

NETfficient added to that 279 kWp of PV, 1 118 kWh of battery storage, 100 kWh of hydrogen storage and two thermal storage tanks for the Seawater Aquarium.

Figure 4: Existing wind turbine on Borkum (Source: Annette Hurst, SEZ).

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[5] http://www.solarpark-borkum.de/technik.php, retrieved 11.11.2018

Figure 5: Existing PV-farm on Borkum (Source: Annette Hurst, SEZ).

NETfficient Catalogues

2 NETfficient Component Catalogue

This section introduces the main hardware and software components used for the pilot on Borkum. Chapter three shows how these are combined into packages of energy storage solutions.

2.1 Lithium-Ion Batteries by PowerTech Systems

The storage solution by PowerTech Systems, named PowerRack is a powerful and scalable solution for a wide variety of applications: stationary, residential, commercial, industry, uninterruptible power supplies (UPS), telecommunications, weak-grid, off-grid and self-sufficiency systems. PowerTech Systems have rigorously selected and tested best-in-class lithium iron phosphate cells that are assembled in this product in order to provide high lifespan and performance. Lithium iron phosphate (LFP) is currently the best solution for storing energy, because of its durability, its high security and its technical superiority compared to other technologies on the market. The Battery Management System (BMS) embeds core intelligence of the PowerRack system. The BMS is also equipped with a built-in multi-protocol communication module (CAN, CAN open, RS232, ModBus) to back up all operating information for external monitoring, or for integration with other systems. Modularity and scalability of PowerRack system offer a wide range of configurations:

- PowerRack supports a range from one single module, up to 500 modules.
- Storage capacity energy can vary from 2.5 kWh to 1.250 MWh.
- Nominal voltage range from 51.2 V to 1024 V.

Figure 6: PowerRack system composition (Source: PowerTech Systems).

2.2 Second-Life Electric Vehicle Battery Storage Solution by Williams Advanced Engineering Limited

As the electric vehicle (EV) market grows, a sizeable supply of second life EV batteries is becoming available. These batteries have significant value and offer the opportunity to be repurposed as cost effective, resource-efficient stationary energy storage solutions. Williams Advanced Engineering is using its technology to repurpose a 20 kWh second life EV battery for a residential energy storage system, interfacing with a LV grid. Williams Advanced Engineering has thus developed stationary storage including BMS as a full system which comprises:

- A second life EV battery
- Grid-Tied inverter
- Battery charger
- Williams control electronics
- Williams safety electronics
- Embedded PC for communication
- Remote Telematics System for diagnostics

Figure 7: Williams Advanced Engineering 2nd life EV based storage system (Source: Williams Advanced Engineering Limited Ltd.).

2.3 Converters by ZIGOR Research & Development A.I.E.

The following converters, all supplied by partner ZIGOR Research & Development A.I.E., are used within the NETfficient project:

- Converters for homes and streetlighting (LV),
- Converters for buildings (LV),
- DC / DC converter for MV-HESS,
- Solar inverters.

Converters for Homes and Streetlighting are 5 kW single phase PV-inverters, which have a modular design including:

- Photovoltaic (PV) converter (2 MPPTs),
- Battery charger / discharger (multi-chemistry),
- Ultracap converter (only HESS),
- Grid connected inverter (compatible off-grid),
- Isolation transformer,
- Cabinet includes battery and ultracaps.

Figure 8: Converter for homes and streetlighting (left), inverter for non-residential buildings (right) (Source: ZIGOR Research & Development A.I.E).

They have two working modes: standalone (autonomous) or EMP controlled (aggregated). They communicate with the smart meters for power regulation at the point of connection (POC), and have embedded energy priority algorithms. They allow for flexible configuration (PV, battery, etc...) for accommodating different needs. The converters for non-residential buildings have much the same features as those for homes and street lighting, however, they are 20 kW three-phase converters and where they are used as part of a HESS-system, ultracap converters are external.

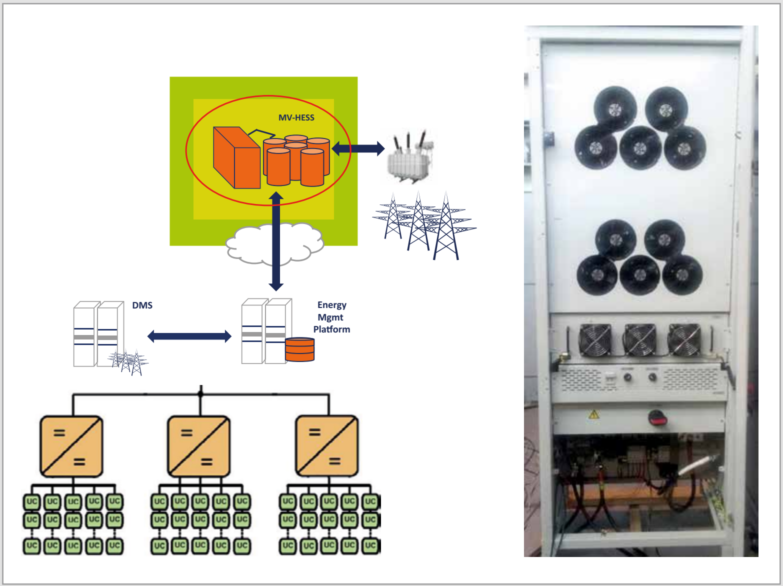

Figure 9: DC/DC-Converter for MV-HESS ultracaps (Source: ZIGOR Research & Development A.I.E).

The Aquarium uses a 20 kW three-phase compact grid-connected inverter including PV converter (3 MPPTs) and communication with EMP.

The medium voltage HESS has DC / DC-converter to hybridise utracaps and batteries. It is also suitable to hybridise different types of batteries, utilising a parallel design: 333 kW per cabinet and is controlled by the energy Management System, provided by Fraunhofer ISE. The converters integrate an ultracap management system, discharging resistors and protection (battery and ultracaps side).

2.4 Ultracapacitors by ZIGOR Research & Development A.I.E.

Ultracapacitors or ultracaps are a short-term storage technology providing high power / low energy. They are intended to limit short-term power peaks to batteries. They have very high energy efficiency (>99 %). They come as integrated modules with built-in balancing system. They can be provided in flexible configurations to match specific needs of applications and can be integrated into cabinets or racks. They have protection against excess voltage and excess temperature.

Figure 10: Ultracap close-up and rack with ultracaps (Source: ZIGOR Research & Development A.I.E).

2.5 Hydrogen Storage by Vandeborre Energy Systems NV (VES)

Vandenborre Energy Systems NV (VES) with registered offices in De Meere 10, 2460 Kasterlee, Belgium is a Belgian company active in the R & D, design, manufacturing and distribution of hydrogen-based products and services. The business of Vandenborre Energy Systems mainly consists of:

- Electrolysis-based hydrogen generation equipment for residential and industrial applications,
- Hydrogen-based energy storage solutions for renewable energy applications,

- Working with European private and government bodies to realise energy storage projects for coupling with renewable energy based on hydrogen, both directly and with partner firms.

The actual main product is the Solenco Powerbox™ (SPB™). The Solenco Powerbox™ (SPB™) is an energy storage device and functions as part of an integrated solution. Solar panels function as the sole source of energy. The SPB™ can work both on-grid and off-grid, hence, there is no strict need for a grid connection. There is no need for a natural gas network connection either as is the case for competing solutions.

Electricity needs are covered by the solar panels during daytime and only the surplus is sent to the SPB™ to be stored as hydrogen. When there's no sunshine, electricity and heat are produced by the SPB™ from the stored hydrogen. Electricity and heat generation taken together have an efficiency of 95 %. Heating demand for both space heating and domestic hot water use can be covered. If there is more than required, heat will be stored in a hot water tank. In case the required heat is higher than the production, additional heat will be produced through a catalytic burner. The latter is a high efficiency burner (97 %) with no flame, using hydrogen as energy source. The system is designed to be intelligent. It will monitor all energy flows in the house.

The whole system has a CO_2 production of 0 gram. The product is therefore triple-zero-carbon, since neither the production, distribution, nor use of the hydrogen generates greenhouse gases. The product is currently at Technology Readiness Level 7, with the product both validated and demonstrated in a relevant environment.

Unlike battery systems SPB™ can store energy for hours to months without degeneration / degradation as it uses compressed hydrogen gas as energy storage or alternatively a metal hybrid Store. This allows storage of energy from one season to another. The basic form of storage, hydrogen, can be shared between houses as well or be used as zero emission fuel in hydrogen powered cars.

The systems used in NETfficient have a 3 kW fuel cell and electrolyser with 500 Nl / hour @ 30 bar. Hydrogen is either stored in a metal hybrid Store (up to 24 kWh) or in an H_2-tank (up to 75kWh).

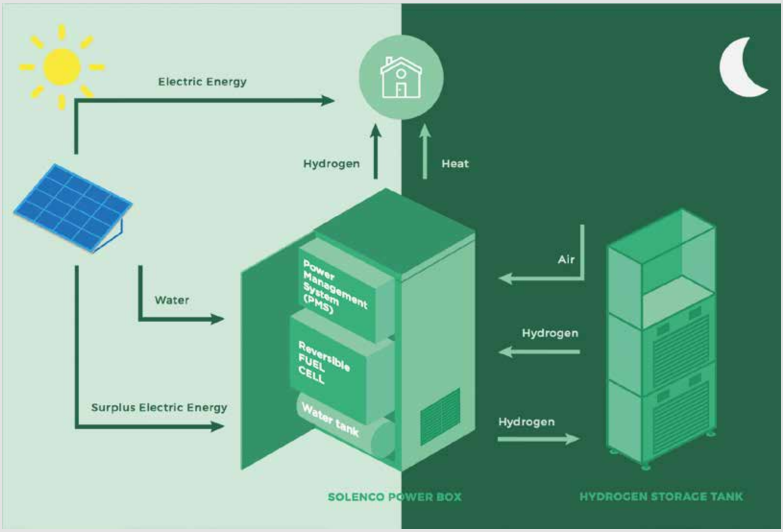

Figure 11: Schematic representation of hydrogen storage (Source: © Vandenborre Energy Systems NV 2018).

Hydrogen basics

Hydrogen is a very small molecule with low viscosity – and therefore prone to leakage. Hydrogen is also known to absorb into certain metals, which can lead to embrittlement and structural failure. So, Solenco Powerbox$^{\text{TM}}$ (SPB$^{\text{TM}}$) has been designed with leak detection and sufficient ventilation. Moreover, materials have been selected that will not suffer hydrogen embrittlement. Hydrogen has a high energy content by weight – but not by volume, which is a particular challenge for storage. In order to store sufficient quantities of hydrogen gas, it is compressed and stored for mobile applications at high pressures (up to 700 bar). For increased safety, hydrogen tanks for vehicles are equipped with pressure relief devices that will prevent the pressures in the tanks from becoming too high. In the confined space of the SPB™, hydrogen can accumulate and reach a flammable concentration. Therefore, appropriate ventilation and the use of detection sensors are installed to mitigate these hazards. Hydrogen has a low minimum ignition energy in ideal combustion concentrations. Like today's gasoline systems, the SPB™ is designed with earthing to prevent ignition by static charge. And because hydrogen is lighter than air and will quickly rise if released, electrical equipment is not placed directly above a potential source of hydrogen.

The storage technology used for a residential application is based on so called metal hydrides. These alloys act as a metallic sponge for the hydrogen gas.

Safety aspects

For over 40 years, industry has used hydrogen in vast quantities as an industrial chemical and fuel for space exploration. During that time, industry has developed an infrastructure to produce, store, transport and utilise hydrogen safely. Hydrogen is no more or less dangerous than other flammable fuels, including gasoline and natural gas. In fact, some of hydrogen's differences actually provide safety benefits compared to gasoline or other fuels. Hydrogen is the lightest and smallest element, and a gas under ambient conditions. It is 14 times lighter than air, which means that when it is released, it typically rises and diffuses quickly. Hydrogen is a colourless, odourless and non-toxic flammable gas. However, all flammable fuels must be handled responsibly. Like gasoline and natural gas, hydrogen is flammable and can behave dangerously under specific conditions. Hydrogen can be handled safely when simple guidelines are observed and the user has an understanding of its behaviour. Therefore, handling of hydrogen must conform to applicable regulations. It is envisaged that in close collaboration with KIWA, Apeldoorn, The Netherlands (www.kiwa-erp.com) and TÜV (Technischer Überwachungsverein) SÜD, Germany (www.tuev-sued.de) the SPBTM will be put in operation.

An explosion cannot occur in a tank or any contained location that contains only hydrogen. An oxidizer, such as oxygen must be present in a concentration of at least 10 % pure oxygen or 41 % air. Hydrogen can be explosive at concentrations of 18.3–59 % and although the range is wide, it is important to remember that gasoline can present a more dangerous potential than hydrogen since the potential for explosion occurs with gasoline at much lower concentrations, 1.1–3.3 %. Furthermore, there is very little likelihood that hydrogen will explode in open air, due to its tendency to rise quickly. This is the opposite of what we find for heavier gases such as propane or gasoline fumes, which hover near the ground, creating a greater danger for explosion.

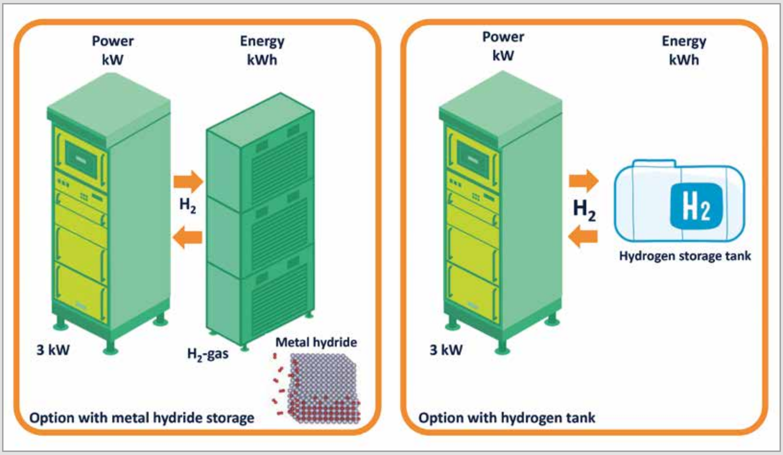

Figure 12: Solenco Hydrogen Power Box with metal hydride storage and with hydrogen storage (Source: © Vandenborre Energy Systems NV 2018).

2.6 Home Automation and Energy Management by Schneider Electric GmbH

Schneider Electric GmbH's technologies connect the infrastructure to the EMP, create a user interface for house owners and provide full control for residential buildings including heating. The algorithms and visualisations are designed for adaption to the user's behaviours.

The main component "homeLYnk"[6] is a logic controller, which allows a connection to different standards and protocols for home automation and energy metering. Residential buildings are equipped with units for energy production, smart meters and battery storage units. Energy production and consumption is managed via the EMP. HomeLYnk connects the different devices and acts as a central controller. It is also connected to the EMP and uses its data input. The homeLYnk visualises relevant energy data of the buildings, which can be accessed through web-browser or any mobile device.

Schneider Electric GmbH also provide transducers measuring at the grid connection point for effective power, apparent power and reactive power for all three phases in larger buildings, as well as energy meters in all areas working as sub-meter.

Intelligent street lighting is made possible through installation of KNX Products and HomeLYnk, in particular supporting grid stability and providing maintenance support through visualisation and remote access.

Data from the temperature measuring process in the sea-water-aquarium, is forwarded via the HomeLYnk and KNX actors to the EMP. KNX Analog actors control the valves.

Figure 13: homeLynk (Source: Schneider Electric GmbH, Germany).

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[6] The name of the controller has changed during the course of the project and is now called "Wiser for KNX".

2.7 MV-HESS Inverter by Fraunhofer Institute for Solar Energy Systems ISE

This is an inverter for connecting DC sources such as batteries or Photovoltaic modules to the electrical grid. Due to the newest technologies the inverter is very compact and is 2-4 times smaller than state of the art products, designed for applications were size matters. It fits into a row with typical battery racks and can be used inside a sea container. Due to fast reaction and high efficiency it is suitable for PV and battery inverters. The nominal power is 1000 kW (modular, 8 slots, with 125 kW each) with an efficiency of up to 98,9%. It features the latest silconcarbide MOSFET semiconductors, high switching frequency of 40 kHz, water cooled semiconductor, push in technology (slot can be removed during operation), advanced chokes build out of iron powder material in tablet form and predictive Control Algorithms for fast and smooth reaction to set point changes and disturbances.

Figure 14: MV-HESS-inverter, single module and rack (Source: Fraunhofer Institute for Solar Energy Systems ISE).

2.8 EMP by Ayesa Advanced Technologies SA with Algorithms from CRS4 and University of Cagliari

It is necessary to find new ICT solutions in order to be able to manage geographically distributed energy resources and the storage solutions introduced in the preceding paragraphs, in a way that optimises their local operation, but also enables new roles and revenue streams for them.

Thus, the Distributed Energy Resource Management System (DERMS) developed in NETfficient by Ayesa Advanced Technologies SA is able to provide a solution for the monitoring, optimisation, management, control and autonomous automated exploitation of DER. Forecasting algorithms have been contributed by the Department of Electrical and Electronic Engineering (DIEE) of the University of Cagliari and the Center for Advanced Studies, Research and Development in Sardinia (CRS4). The resultant DERMS is named EMP (Energy Management Platform), it is modular and extensible, supports behind-the-meter (BTM) and front-of-the-meter (FTM) DERs and furthermore, supports different energy services and revenue streams. The EMP essentially allows for DER and distributed storage to be operated as Virtual Power Plan (VPP).

The EMP is central to the NETfficient project and is explained in detail in Chapter 4.

3 The NETfficient Catalogue of Energy Storage Solutions

NETfficient developed a number of technology-packages for the different applications addressed. These are represented in this chapter in a generic way, but are representative of what has been installed on Borkum (allowing for minor adjustments to meet local conditions).

3.1 Hybrid Energy Storage for Medium Voltage Systems (MV-HESS)

Components:

- HESS-Management System
- High-capacity storage system
- High power storage system Ultra Capacitor + DC-DC converter
- HESS-inverter with MV transformer
- Control electronics hardware
- Interface to the EMP, including weather and demand forecasting

Technical Description:

This storage and management solution connects a high-capacity storage system to the medium voltage grid in order to improve efficiency and stability of the grid. The storage is designed to perform peak shaving and to avoid problems caused by rapid power changes from renewable energy sources. Furthermore, the system is able to provide primary and instantaneous reserve for the electrical grid. This can, in particular, be used for cases when feed-in from prosumers exceeds the demand and public RES have to be curbed. The core of this solution is the HESS. The EMP or the Distribution System Operator (DSO) communicates with the HESS by means of the intelligent Node Management System (iNMS). The EMS gathers all HESS information via the iNMS and is able to communicate with the three main elements of the HESS System. It aggregates a number of distributed energy storage units and generators and is also able to perform peak shaving and medium voltage ride-through. It visualises forecasting of building consumption / production (incl. overall interface to devices). It uses an optimised forecasting algorithm and HESS real-time power profile. It is suitable for a smart grid setting. It facilitates integration of RES into the market in a profitable way, providing information to the operator. It optimises the CAPEX / OPEX in comparison with Li-ion-only.

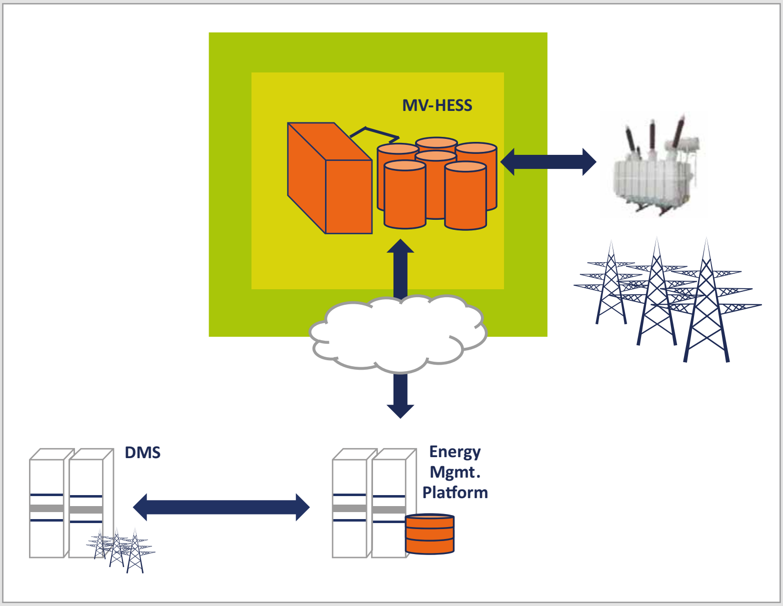


Figure 15: Diagram of MV-HESS (Source: NETfficient project).

Potential Applications / End-Users:

The main area of application for the MV-HESS will be to serve the primary reserves market. It can be used in combination with renewables such as on-shore wind farms or PV installations, either pools of roof-mounted PVs or PV-farms, or equally for a conventional power generation fleet. Suitable applications are:

- Medium scale electricity systems seeking energy self-sufficiency,
- Smart Cities projects,
- Industrial or business estates and ship yards striving for energy self-sufficiency,
- Large consumers such as business parks, offices, public buildings, campus-like settings (educational, hospitals), large scale housing providers (public / private / charitable), including sheltered housing,
- Electric mobility aggregators.

3.2 Lithium-Ion Battery Electricity Storage for Homes

Components:

- Li-ion Battery 5 kWh for homes
- PV / battery-inverter (home, LV)
- HomeLYnk – for
  a) stand-alone use OR
  b) aggregated use
- KNX power-supply
- Smart meter with KNX interface
- Stand-alone home control panel
- For b) interface to EMP, forecast based optimisation, building energy management, local and stand-alone energy management)
- Control electronics hardware
- Stand-alone home control panel

Third-Party Generic Components:

- PV panels 4 kWp
- IoT device
- Tablet
- KNX smart meter interface for homes

Technical Description:

The chemistry of the batteries is based on lithium iron phosphate. The single phase on-grid inverter integrates PV (or other renewable energy source) and battery storage. Battery modules are included into a cabinet. The nominal power is 5 kW. It includes battery and AC protection. The system is capable to work off-grid in case of black-out. It can work in stand-alone configuration or EMP controlled.

The system is designed to be part of a community of aggregated prosumers, managed by the EMP.

Potential Applications / End-Users:

- Single family houses
- Small businesses

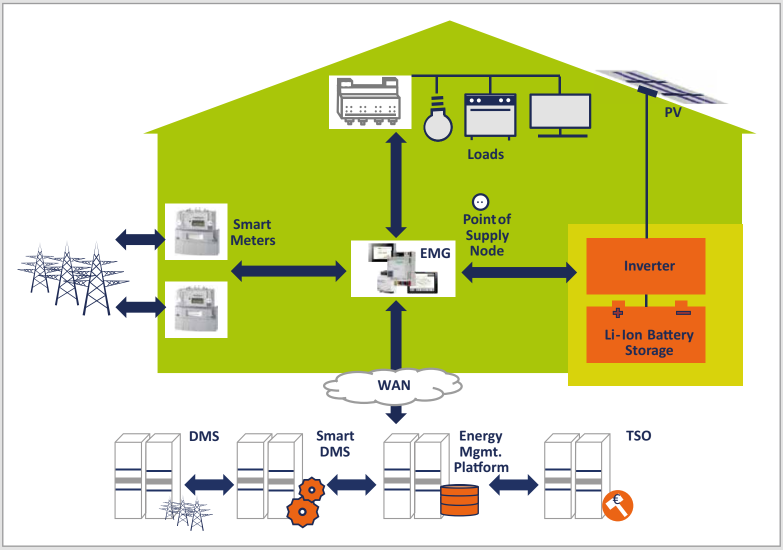


Figure 16: Diagram of lithium-ion battery electricity for homes (Source: NETfficient project).

3.3 2LEV Electricity Storage for Homes

Components:

- 2LEV battery 5 kWh including inverter
- HomeLYnk for stand-alone use
- KNX power-supply
- Stand-alone home control panel
- Control electronics hardware

Third-Party Generic Components:

- PV panels 4 kWp
- Tablet
- KNX smart meter interface for homes

Technical Description:

Storage consists of Second-Life Vehicle Batteries (2LEV), inverters and BMS. The 2LEV technology repurposes a 20 kWh second-life EV battery for a residential energy storage system, interfacing with a LV grid. The system can produce power from both the solar panels and battery if the load consumption demands it. Its supervisory controller for the energy storage system utilises smart algorithms and dedicated hardware to ensure an optimised function.

The system intelligently monitors power generation and consumption by measuring power demand from the home or business (i. e. load), the power produced by solar panels and the available capacity of the battery. The information thus generated can then be communicated via an internet connection to embedded PCs and remote telematics system for GPS tracking and data collection.

Potential Applications / End-Users:

- Single family houses
- Small businesses

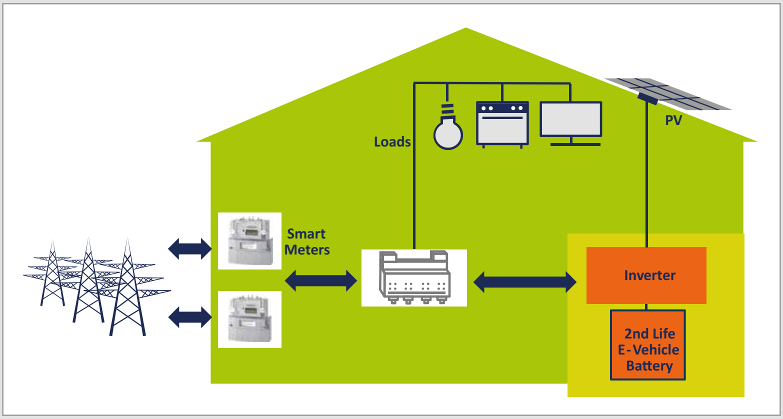


Figure 17: Diagram of 2LEV-electricity storage for homes (Source: NETfficient project).

3.4 HESS Electricity Storage for Homes

Components:

- Li-ion Battery combined with ultracap for homes
- PV / battery-inverter (home, LV)
- HomeLYnk – for
  - a) stand-alone use OR
  - b) aggregated use
- KNX power-supply
- Smart meter with KNX interface
- Stand-alone home control panel
- For b) interface to EMP, forecast based optimisation, building energy management, local and stand-alone energy management)
- Control electronics hardware

Third-Party Generic Components:

- PV panels 4 kWp
- Tablet
- KNX smart meter interface for homes

Technical Description:

LV-HESS – The hybrid solution demonstrates a breakthrough via the combination and optimisation of multiple types of energy storage, adapted to the home's needs. Ultracaps modules are used for short-term peak power. The hybridisation of ultracap and battery can increase the lifetime of the latter. Ultracap modules are composed of a series of connections of individual cells, which include cell equalising electronics.

The hybrid solution is designed to provide an optimal high power and high energy density response with the following advantages:

- Maximum lifetimes of the energy storage system, thanks to decreased degradation
- Continuous high quality supply
- Ability to provide simultaneous grid services as opposed to traditional energy storage systems which can only provide one
- Ability to enhance the distribution grid

This system can optionally be part of a community of aggregated prosumers, managed by the EMP.

Potential Applications / End-Users:

- Single family houses
- Small businesses

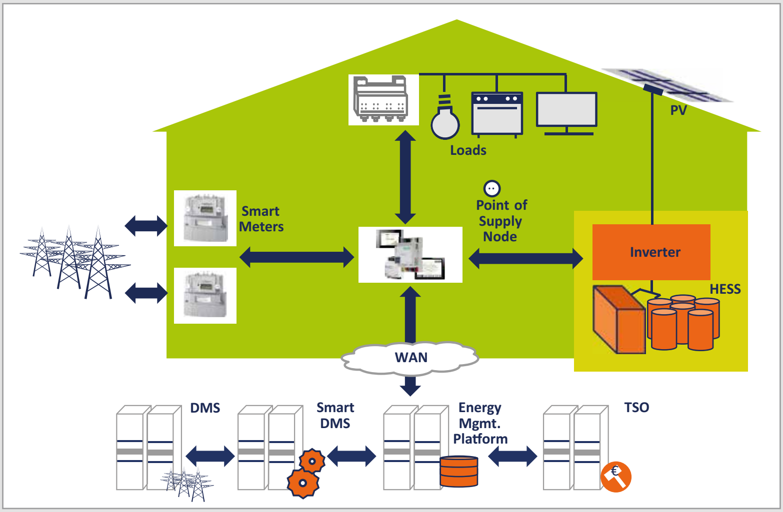


Figure 18: Diagram of HESS – electricity storage for homes (Source: NETfficient project).

3.5 Home Energy Storage Based on Hydrogen Technology

Components:

- Electrolyser
- Hydrogen energy storage (2 alternatives):
  - a) Metal hydrides
  - b) Pressurised hydrogen
- Fuel cell for electricity production
- Control electronics hardware

Third-Party Generic Components:

- PV panels 4 kWp
- Solar Charger
- PV Inverter

Technical Description:

The central component of the system is the Solenco Power Box. It is an energy storage system based on hydrogen technology. Hydrogen is produced from water using the electrolysis principle. It can then be stored either in a pressurised tank or in a metal hydrides store. Using the fuel cell principle electricity and heat and power can be produced. The system is charged by electrical power from a renewable source (typically solar PV). It stores energy when available to be used whenever needed. It provides a one-stop solution for both heating and electricity needs and, if appropriately sized, can eliminate the need for a grid connection. Unlike battery systems it can store energy over many days, even months without losses as it uses compressed hydrogen gas or a metal hydride storage unit. The system thus allows interseasonal energy storage. The basic form of stored energy, i. e. the hydrogen, can be shared between many houses or even be used as zero emission fuel in hydrogen powered cars. The management system is intelligent and monitors all energy flows in the house.

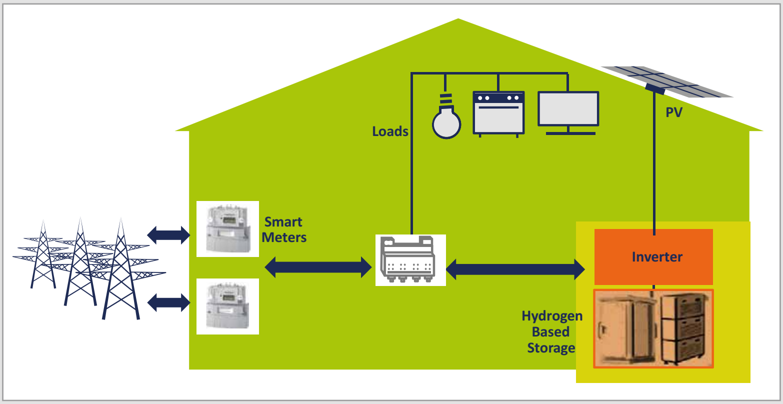


Figure 19: Diagram of home energy storage based on hydrogen technology (Source: NETfficient project).

Potential Applications / End-Users:

- Remote / rural residential (off-grid) properties
- Private home owners striving for energy self-sufficiency
- Small businesses in rural / remote areas (off-grid)
- Agricultural facilities (off-grid)
- Grid balancing

3.6 Lithium-Ion Battery Storage for Larger Buildings

Components:

- Li-ion Battery (75 kWh) for larger buildings
- Inverter for PV with storage (battery, larger building, LV)
- HomeLYnk for aggregated use with interface to EMP
- KNX-power supply
- Power meter with Modbus interface (“Modbus-Energiezähler”)
- Current transformer for power meter
- Control electronics hardware
- Connection to EMP

Third-Party Generic Components:

- PV-Array 20 kWp for large buildings
- KNX smart meter interface

Technical Description:

The chemistry of the batteries is based on lithium iron phosphate.

For this application a mid-size battery storage System (20 kWh–75 kWh) is used which is modular and scalable up to industry-scale lithium-ion battery systems. The system is very flexible regarding different PV or battery power.

20 kW Inverter can be used. Lower cost and lower spacial requirements are achieved through economic and compact power electronics.

This system is designed to be part of a community of aggregated prosumers, managed by the EMP. A compact three-phase, on-grid inverter integrates PV (or other renewable energy sources) and battery storage with a nominal power of 20 kW. It can work in stand-alone configuration or be controlled by the EMP.

Potential Applications / End-Users:

- Blocks of flats (in private, public or charitable ownership)
- Sheltered or social housing
- Office buildings
- Supermarkets
- Hotels
- Educational buildings (schools, universities)

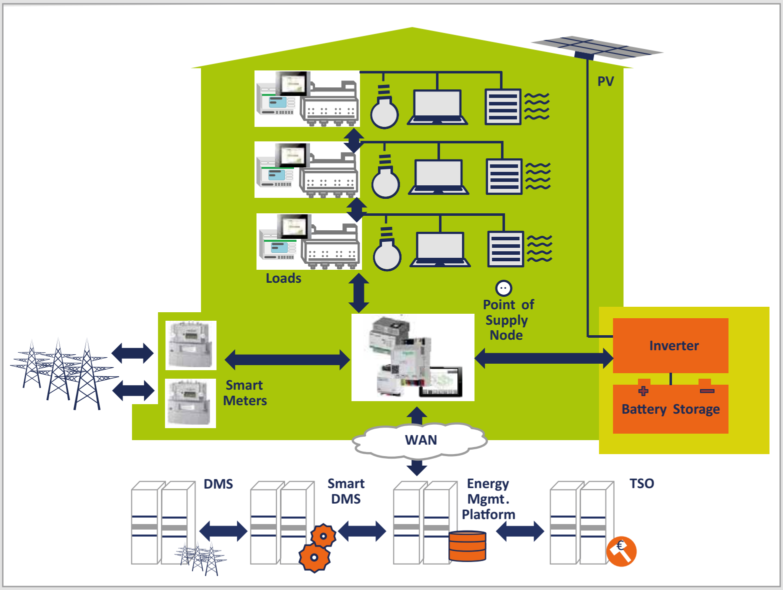


Figure 20: Diagram of lithium-ion battery storage for larger buildings (Source: NETfficient project).

3.7 HESS for Larger Buildings

Components:

- Li-ion Battery 75 kWh for larger buildings
- Ultracap (larger building, LV)
- Inverter for PV with storage (battery and ultracap, larger building, LV)
- SpaceLYnk for aggregated use with interface to EMP
- KNX-power supply
- Smart meter with KNX interface
- Power meter with Modbus interface (“Modbusenergiezähler”)
- Current transformer for power meter
- Control electronics hardware
- Connection to EMP

Third-Party Generic Components:

- PV-Array 20 kWp for large buildings
- KNX smart meter interface

Technical Description:

LV-HESS – This hybrid solution demonstrates a breakthrough via the combination and optimisation of multiple types of energy storage, adapted to the home’s needs. Ultracap modules are used for short time peak power. The hybridisation of ultracap and battery can increase lifetime of the latter. Ultracap modules are composed of a series of connections of individual cells, which include cell equalising electronics.

The hybrid solution is designed to provide an optimal high power and high energy density response with the following advantages:

- Maximum lifetimes of the energy storage system, thanks to decreased degradation.
- Continuous high quality supply

- Ability to provide simultaneous grid services as opposed to traditional energy storage systems which can only provide one
- Ability to enhance the distribution grid

This system is designed to be part of a community of aggregated prosumers, managed by the EMP. A compact three-phase, on-grid inverter integrates PV (or other renewable energy source) and battery storage with nominal power 20 kW. It can work in a stand-alone configuration or controlled by the EMP.

Potential Applications / End-Users:

- Blocks of flats (in private, public or charitable ownership), sheltered and social housing
- Educational buildings (schools, universities), office buildings
- Supermarkets
- Hotels

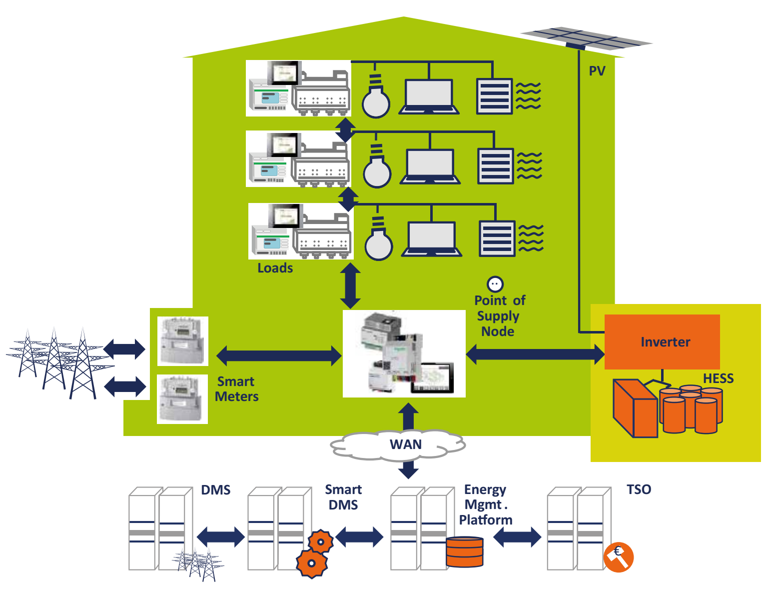


Figure 21: Diagram of HESS for larger buildings (Source: NETfficient project).

3.8 Storage for Street Lighting

Components:

- PV-inverter with storage (15 kWh, Li-ion Battery, LV)
- KNX Power Supply
- Smart meter with KNX interface
- KNX-switch actuator
- KNX-weather station
- Interface to EMP

Third-Party Generic Components:

- PV-array for large buildings
- KNX smart meter interface

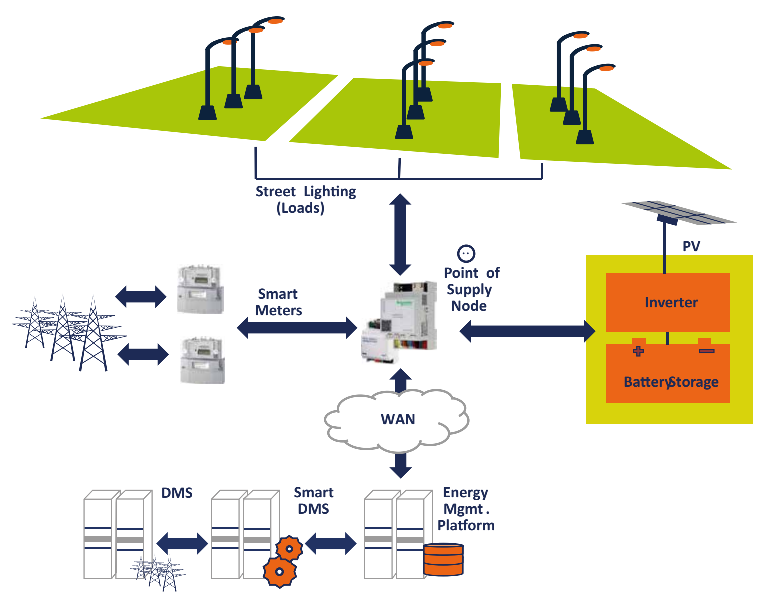


Figure 22: Diagram of storage for street lighting (Source: NETfficient project).

Technical Description:

The Energy Management Gateway (EMG) connects smart street lighting devices to the energy service application, which balances storage, photovoltaic generation and consumption. Smart Grid control will be supported by the energy service applications. The main idea for this use case is to consume the energy supplied by the sun during daytime for lighting at night, while opening up other options of storage use, such as services to the local grid. The integrated weather station collects local weather data for validation of the weather forecast. The system is furthermore designed to improve the street lighting system maintenance service. Therefore, an EMG will collect information from the devices to enable preventative repairs and maintenances, addressing the following two objectives:

- Appropriate maintenance
- Detection of a failure in a section

Potential Applications / End-Users:

- Street lighting of local authorities
- Privately run street lighting on private estates and carparks (industrial, residential, gated communities…)
- Add-on to storage projects for public buildings (e. g. in offices or leisure centres)

3.9 Thermal Storage Solution for Low-Temperature Heating

Components:

- Inverter for aquarium, LV
- Heat management for aquarium CHP and pools
- Heat pumps and heat exchanger
- Management system
- Interface to the EMP
- Control electronics hardware
- KNX-power supply, KNX-Analogue input, KNX Analogue output

Third-Party Generic Components:

- PV panels
- KNX smart meter interface
- Thermal storage vessels for aquarium
- Heating / cooling system for aquarium: heat pumps and heat exchanger

Technical Description:

This system is designed to provide constant water temperatures at fairly low level. The system performs the following tasks:

- Heating up aquarium water – cooling down aquarium water
- Cooling thermal energy storage using
  a) PV production
  b) Grid consumption, if insufficient solar power
- Switching between summer and winter mode
- Feeding PV production surplus into grid

The Energy Management Gateway (EMG) is the core for the communication between the EMP, the DER and the smart meter ("DER Control"). The system is designed to be part of a community of aggregated prosumers, managed by the EMP.

A thermal storage system is central to this solution and is split into a daytime and a night time storage vessels. The temperature of the thermal storage system is regulated by two cooling units (these could be heating units, depending on application). The EMG is used to transport the temperature measured in the installations to the EMP for supervision. It also controls the switching-on / off of the CHUs.

Key features:

- Solar Grid Tie Inverters, remote control inverter integrated in smart grid
- Forecast-based optimal management system (FOMS): FOMS interfaces with the EMP in order to provide suitable forecasted profiles
- Power profile in real-time, to account for different scenarios
- Historical energy and current and historical weather data to forecast PV-production and energy consumption

Potential Applications / End-Users:

- Pool operators, leisure centres
- Zoos, aquariums
- Low-temperature heating systems for ultra-efficient buildings using large scale buffer tanks

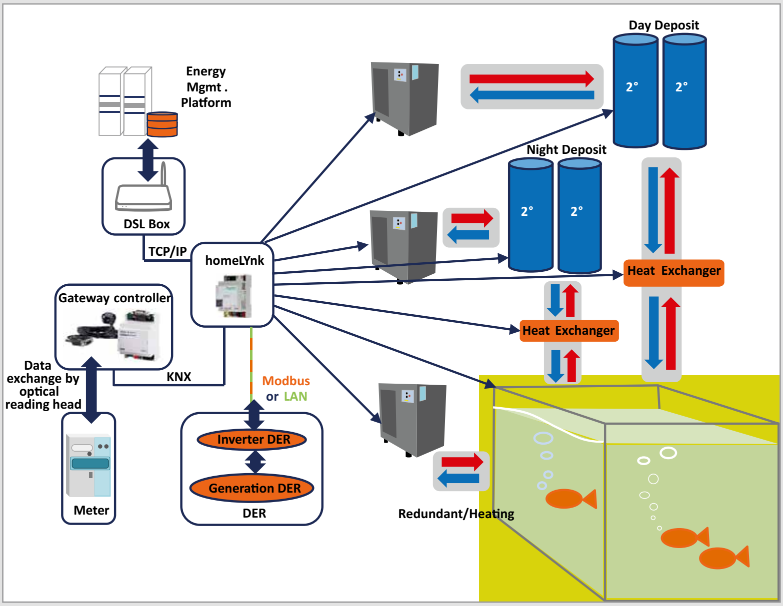


Figure 23: Low temperature heating for aquarium (Source: NETfficient project).

4 The EMP – a DERMS Software

The NETfficient storage system and PV-installations are designed to be part of a community of aggregated prosumers, managed by the EMP (except for a small number operated independently for comparison purposes).

4.1 Challenges and Opportunities of Renewables

Bearing in mind the challenges and opportunities posed by DER outlined in Section 1.1, it is necessary to find new ICT solutions in order to be able to manage geographically distributed energy resources. NETfficient goes one step further and aims at operating these DERs in a way that internal operation behind the meter is optimised, but in addition, DERs can be used to provide an aggregated and reliable source of energy services.

By aggregating the various technologies used and identifying and utilising their flexibilities, the aggregator business (e. g. the operator of a virtual power plant) is able to tailor energy products and services to its customers' needs. It levels out fluctuating generation from renewables, varying energy demand and limited predictability of some of the resources. The EMP is the key tool for aggregating these distributed resources.

The EMP is designed to address the specific range of challenges and opportunities posed at all voltage levels by behind-the-meter DERs, as summarised in Table 1.

Challenges	Opportunities
▪ Lack of control and real-time visibility over the DER, ▪ Many different generation and storage technologies at end user levels, ▪ Power quality issues (reverse flows, voltage imbalances, zero islands, etc.), ▪ Wide geographic distribution and consequent maintenance costs, ▪ Large number of resources to be controlled (potentially thousands), so traditional strategies for large scale centralised generating capacity are not valid, ▪ Inability to participate in electricity markets with DERs.	▪ Contribution to increasing the share of over-all renewable generation, ▪ Reduction of local peak of demand, ▪ Deferring of network upgrade at transmission and distribution level, ▪ Potential to provide ancillary services, ▪ Potential to provide back-up power, ▪ Synergies with direct and reverse demand response, ▪ Provision of connected added-value services to customers.

Table 1: Challenges and opportunities of DER (Source: NETfficient project).

The potentials set out above can only be fully exploited and maximised by aggregating of DERs. There is a need for new solutions to manage behind the meter DERs, and also in front of the meter. Universal guideline and rules to the DERs are necessary to achieve meaningful aggregation, to provide the best use of the energy for the aggregated community and to reserve the energy for sale in the energy balancing markets. The DER Energy Management System developed by NETfficient is a tool to manage and control DERs. The resultant DERMS is named EMP (Energy Management Platform).

The EMP is able to manage the aforementioned guidelines and rules related to energy management, but also the full range of activities throughout the whole DER life cycle, from its grid installation to its final disconnection. The EMP maximises the profitability of DERs by exploiting their full technical potential and enables new business models. Services through the operation of DER, both FTM (Front the meter) and BTM (Behind the meter) are achieved with individual operation, but also with autonomous operation piloted by economic optimisation algorithms.

Thus, the Distributed Energy Resource Management System (DERMS) developed in NETfficient is able to provide a solution for the monitoring, optimisation, management, control and autonomous exploitation of DER. The EMP is modular and extensible, supports behind-the-meter (BTM) and front-of-the-meter (FTM) DERs and furthermore, supports different energy services and revenue streams. These include:

- **Day-Ahead energy market and real-time algorithms:** The EMP is able to provide support for Day-Ahead market integration. Once the energy profile is committed to the market, the autonomous operation of the system is calculated by the real-time operation optimisation. These algorithms calculate the connection power that the systems should track and the commands to the smart appliances in order to meet with committed Day-Ahead curves. This operation allows peer-to-peer trading among DERs.
- **Implicit demand response:** the system analyses user consumption habits and requirements imposed by them with the aim of providing recommendations on the best times to use the devices within a DER.
- **On-demand energy services:** peak shaving, frequency regulation, explicit DR (sending a direct demand response order to a DER)
- **Other possible optimised and autonomous services:** frequency regulation, energy trading (Intraday).

4.2 Functionalities of the EMP

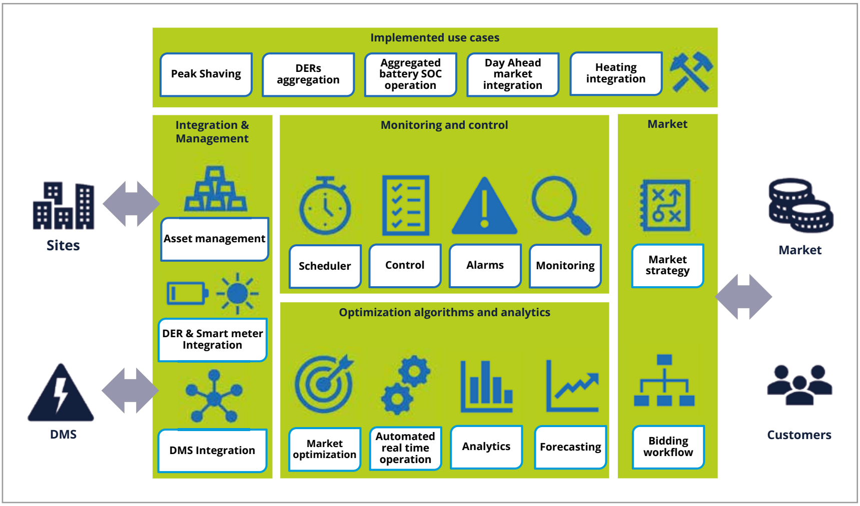


Figure 24: Schematic architecture of the EMP (Source: NETfficient project).

The EMP has these five main functionalities:

- **Integration and measurement module:** allows the data collection from different brands, models and protocols from FTM & BTM devices. This module is also in charge of asset management and integration with the Distribution Management System (DMS) belonging to the utility that is part of NETfficient.
- **Monitoring and control, in charge of alarms, schedulers, monitoring and control of DERs:** This module allows the user to set up alarms, notifications through SMS or email, acknowledge alerts, etc… Another functionality of paramount importance is monitoring, being able to monitor DERs and store the information in a historical database and in-memory database. The control module allows the system to send commands to DERs and track the correct delivery of these commands, that can have different levels of complexity. The scheduler is the module that allows to setup periodic control orders to DERs, taking into account constraints such as the physical limitations of DERs.

- **Techno-economic optimisation and autonomous operation:** The platform is able to provide support for Day-Ahead market integration. Once the energy profile is committed to the market, the autonomous operation of the system is calculated by the real-time operation optimisation. These algorithms calculate the connection power that the systems should track and the command to the smart appliances to conform with the committed Day-Ahead curves.
- **Market module:** The market module is responsible for the integration with the energy market and the bidding automation. Additionally, the market strategy feature allows to manage several offer templates to appraise the best economic optimisation result obtained by the last module. Moreover, it provides other advanced functionalities such as the possibility of scheduling energy services during certain periods of time. It is also able to detect collisions, thus not allowing the overuse of same DER or not allowing the use of a DER by a non-authorised user or service.
- **Billing:** Customer management and billing for the revenues generated by the operation. This module allows to define different billing models in order to look into the best profitable business model.

4.3 Architecture of the EMP

In order to allow aggregation of a wide range of DERs, the cloud-based EMP uses a scalable architecture and is able to support a large number of configurations and functionalities. Therefore, it can support different protocols such as IEC 60870, DNP3, KNX, Modbus, OPC DA / UA o IEEE 2030.5.

In order to achieve real-time supervision of DERs and aggregation, The EMP is integrated with smart inverters, home automation systems and smart meters. It thus is able to provide energy dispatch commands to either individual DERs or to the aggregated level.

It also allows integration with operations of the DMS of local grid operator, generation and / or consumption power limits and energy plans, which reduce the impact of variable renewable generation.

4.4 DER and Smart Meter Integration

The platform is able to aggregate new communication protocols, brands and models of new devices. New types of measures, installations, element configurations and appliances can be monitored thanks to an easily customizable telemetry model. The platform supports typical AMM (Acquisition Management Module) features with gap detection & edition (import / export). This means that the platform enables the user to fill in the gaps. It also allows the user to establish each telemetry resolution. For example, when a certain telemetry starts to be controlled it may be necessary to increase telemetry resolution in order to carry out better control. Additionally, certain control algorithms can change this resolution automatically. Measures are registered considering their local time zone. This is relevant for load curve comparison among installations located in different time zones.

The platform supports several protocols, such as KNX-JSON, IEC60870-104, TCP / MODBUS, OPC, DNP3, Web Service. Additionally, for each protocol, different datasheet versions can be managed simultaneously. The platform can provide additional telemetry information to the DMS. All assets are located in a tree below a grid root node. This allows aggregated queries and analysis.

The platform can register outages which will be taken into consideration by the control algorithms. The DMS can create demand and response campaigns in order to modify owner consumption and generation.

The platform offers a schematic site overview, for each kind of installation (homes, buildings, etc.). Grid monitoring can be configured specifically through aggregation monitoring. The EMP can also be seen as “Platform as a service" because it is ready to be adapted to interfaces and requirements of different companies.

The Interoperability model is based on the European Guide for Smart Grid Architecture Model.

4.5 Alarms, Scheduling and Monitoring

A number of alarm functionalities have been developed for the EMP. The idea is that the user can define alarms indicating thresholds by a global or concrete telemetry by DER type, grid node or Scope. The user can decide on the type of output notification (email, SMS, banner, alert) and the message body can be customised.

Additionally, the user can indicate a work order template in order to generate a work order which will be assigned to the installation responsible. The work order module offers a complete management of asset maintenance: budgets, (aggregations of installations), warehouses, providers, etc.

The platform also has asset management capabilities which support information associated with different kinds of installations and elements. The information can be defined at brand and model level in order to fill in catalogue information which will be fixed to all elements used in the same installation.

This functionality is used to manage typical tasks of electricity suppliers and Computerised Maintenance Management System (CMMS) software with the EMP, such as storing historical data from customers, elements (i. e. DER components), properties and details of installations (i. e. DERs).

Via the Scheduler, the platform allows to manage services planning. For example an order can be scheduled to take action within 2 hours or at a given time. Thus, an operator could program a battery to fix the state of charge (SOC) to 100 % starting at 12 in the night, when energy prices are favourable. This planning takes into account technical constraints due to the fact that certain control services and basic orders cannot be executed simultaneously by the same site. For instance, a "fix SOC" order cannot be implemented by a site that is currently involved in an offer of energy committed to the market. Considering the huge number of installations and their individual control behaviour, the platform allows configuration of these constraints by use of collision matrixes.

In order to provide monitoring, the platform allows the energy service progress report. It is possible to view the current DER status, malfunction, bad performance and outages. Through the sophisticated interface of the schematic site overview, the platform visualises the current installation state nearly in real-time. This schematic site overview can be customised for all installations belonging to the same kind or a single specific installation. Comparison curves can be generated using received telemetries, orders sent, forecast measures or theoretical curves.

Robust control algorithms are another important feature of the platform. This is achieved using a scalable solution. Implemented control algorithms support different complexity levels. The most advanced level allows a global control over a set of sites establishing individual behaviours according to the aggregation aims. Different types of algorithms that can be used are:

1. Adaptive reaction considering real-time values (setpoint),
2. Adaptive reaction considering a theoretical curve,
3. Following a schedule,
4. Advanced predictive control,
5. Aggregation / disaggregation support.

These algorithms can be applied to individual sites or to a set of them. It is important to consider that when a policy is applied to a certain aggregation it can happen that, for a certain period of time, a specific site shows behaviour that is contrary to what is generally desired.

4.6 Market Integration and Billing

A number of services were developed for NETfficient in order to allow market integration for distributed renewables and storage, including related billing.

A facility for energy sales to the Day-Ahead market was developed. However, no actual market access was possible within the project as the threshold of minimum generating capacity was not reached with the 36 residential houses and five non-residential buildings, which form part of the aggregated system (N.B. the remaining installations were run in stand-alone mode for comparison purposes).

Tertiary control and imbalance settlement services can be offered in on-demand mode through a manual control order sent by the platform. Peak shaving is also ordered by a manual control, as an experimental option. Generation load limitation and feed-in limitation are services required by German grid operators and have to be accepted by owners of DER as a matter of course (see also section 8.3). Asset maintenance services are managed by the platform and charged to the owner, for example, if a smart meter requires a firmware update, this work can be registered as a work order and then included in the bill of the smart meter owner.

Possible services which may require billing through the EMP are:

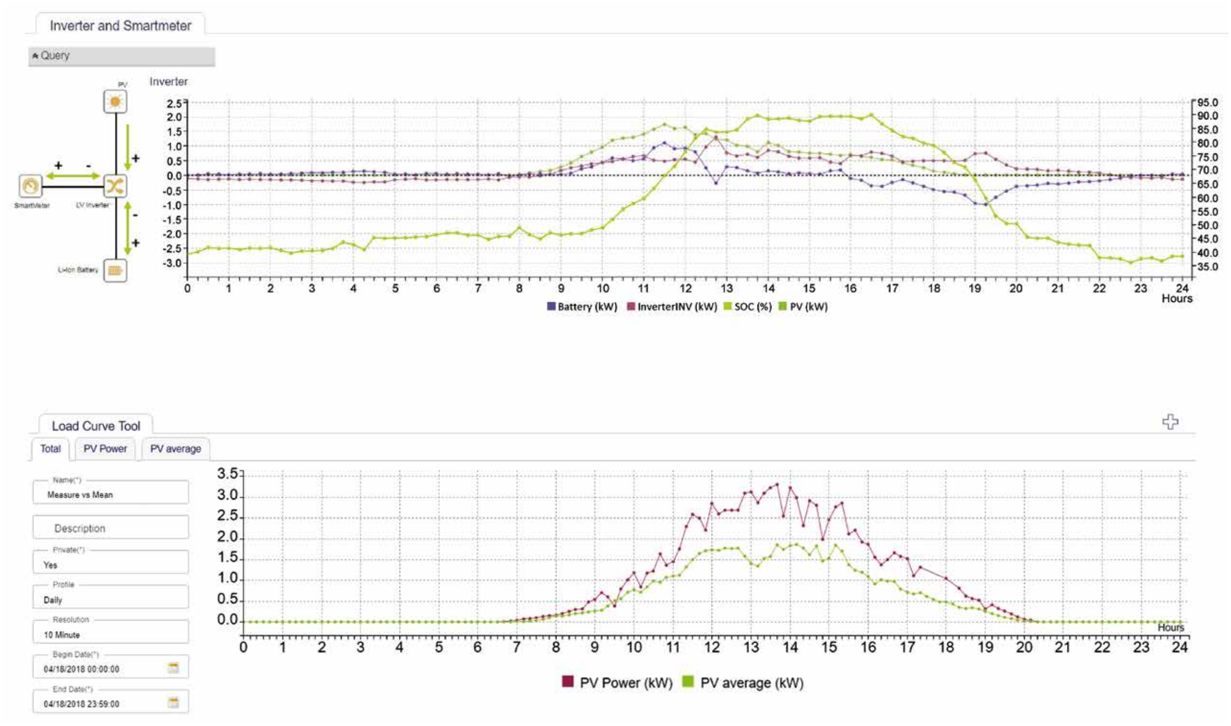
- Won bid offers, if the company managed by the platform assumes the market agent role,
- Peer-to-peer agreements for sold or bought energy,
- Billing for use of the platform on behalf of third parties,
- Invoices or a credit statements to participating DER-owners,
- Efficiency management services for buildings, factories, industries.

The platform supports all these services thanks to an open agreement model and Big Data processes, involving massive data storage and analytics. Big Data processes are needed for figuring out tariff counters, and they involve massive data storage and analytics.

4.7 Trends and Analysis

Trends are available showing what occurs around the inverter – whether generated PV-energy exists or not, when PV is being sent to the house or to the battery, etc.

Two different time series can be superimposed for performance analysis – e. g. generation over one day superimposed over mean values of the preceding average for seven days. This way, the analyst can compare a certain day with the average of seven days and evaluate whether any action is required or not.



Name(*)
Measure vs Mean

Description

Private(*)
Yes

Profile
Daily

Resolution
10 Minute

Begin Date(*)
04/18/2018 00:00:00

End Date(*)
04/18/2018 23:59:00

Figure 25: Trendlines 1+2 (Source: Ayesa Advanced Technologies SA).

4.8 Forecast Algorithms

In order to make all NETfficient functionalities possible, a number of intelligent forecast algorithms has been implemented.

4.8.1 Energy Forecasting Service

The technology developed is based on a multi-model, multi-technology approach, which takes advantage of knowledge of weather forecasting models and machine-learning techniques.

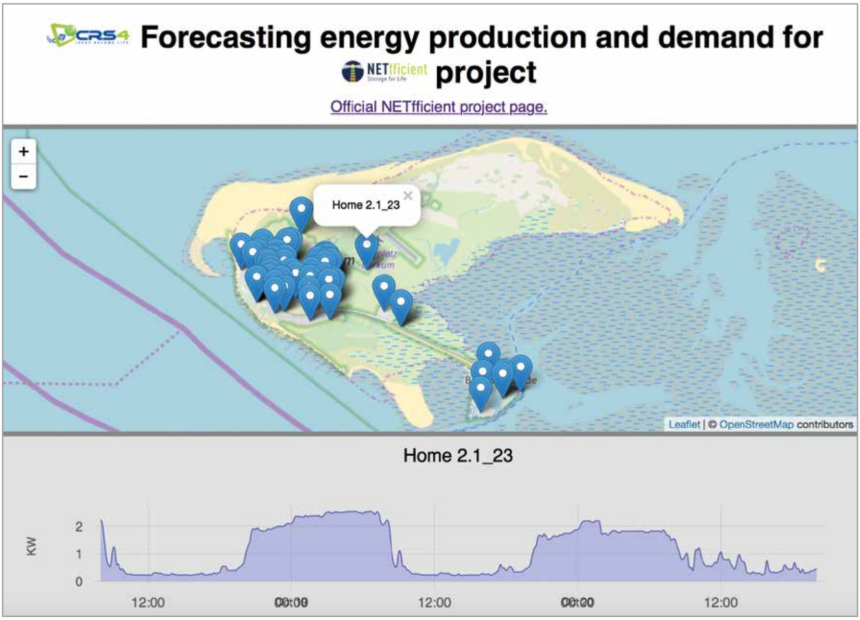
The models are based on the machine learning algorithms that use power consumption and generation data, historical data and the latest weather forecasts as a source of information. On the basis of this information, mathematical models are developed for:

- The consumption made by an electric user, learning the consumption habits relative to each single user,
- The electrical power obtained from the domestic photovoltaic panels, deriving from the analysis of production data and the comparison with weather conditions,
- The characteristics of the plant, such as its actual capacity and its orientation,
- The power exchanged between the microgrid of Borkum with the grid on the mainland, through the learning of consumption habits of the population combined, and through the learning of the generation capacity of renewable energy plants on the island, such as wind turbines, the medium-sized photovoltaic plant, and the set of domestic photovoltaic panels already installed.

The models developed in this way are used to produce forecasts of energy production and expected consumption for the next day. This information, together with energy price forecasts, enables cost-effective and efficient management of energy storage systems aggregated by the EMP, both at household and grid level.

The development of the energy forecasting system focused on the resilience of the system, its robustness, since the application of advanced techniques of machine-learning and the processing of large volumes of data can expose the service to errors in the data supply necessary to achieve the forecasts.

The system is therefore composed of several models at different levels of accuracy, which learn and are continuously improved by an automatic procedure and are activated in sequence in order to obtain the most accurate prediction possible with the available data, and to obtain a prediction in any case, whatever the state of the system for measuring and communicating data.


Forecasting energy production and demand for NETfficient project

Official NETfficient project page.

Figure 26: Forecasting of energy production and demand (Source: Centro di Ricerca, Sviluppo e Studi Superiori in Sardegna).

4.8.2 Key Achievements Regarding Forecasting

The fully operational energy forecasting system provides a forecast at least one day in advance of consumption and electricity generation for the Borkum network and for individual users. The system developed is accessible through a web interface and is constantly being improved, thanks to the continuous learning system of the machine learning algorithms that form the basis of the system. The development has highlighted the need to build a robust system that can deliver the service reliably, even in the absence of a clean and reliable dataset as those commonly used for research applications.

The research carried out made it possible to obtain significant scientific results for photovoltaic and wind energy production forecast technologies, and for the forecast of consumption in a grid with a strong component of generation from renewable sources such as those on Borkum. As this is a real-life application, it is certainly of interest to the scientific community as it is not frequently found in literature.

4.9 Market Integration – Day-Ahead

The Day-Ahead service workflow can be illustrated as follows: the platform carries out all offers planned according to a market strategy. The market strategy defines what grid partition will be involved in each offer. At this step, the DER electrical capabilities are considered, in particular. For example, for a specific offer all the DERs below a grid partition node using DERs with lithium-ion battery may be selected.

As a next step the constraints phase appraises if DERs are involved in other offers, a scheduled service or are affected by an outage. Furthermore, the collision matrix and also owner preferences have to be taken into account. Thus, the platform takes decisions regarding what nodes can or cannot be included in the bids.

After that, three forecasts are used to create a streamlined offer: market price, consumption and generation forecasts. This offer can be reviewed before being sent to the Virtual Power Plant's market.

4.10 DDO for Optimisation and Autonomous Operation

The EMP uses Design-Decide-Operate (DDO) algorithm architecture in order to achieve technical and economic optimisation. The design of the algorithms related to Day-Ahead and real-time energy services have the objective of calculating the optimum number and type of clients (i. e. DERs) to be aggregated, the infrastructure sizing and the prices.

The market trading algorithms calculate the Day-Ahead curves of power to optimise economic benefits of the aggregation. To that end, the algorithms deal with the prediction of prices, loads and generation.

The demand response algorithms calculate the optimal schedule of smart appliances including charging of electric vehicles to maximise the economic benefit of the market trading while ensuring the comfort conditions of the end-users.

The autonomous operation of the system is calculated by the real-time operation optimisation. These algorithms calculate the connection power that the systems should track and the command to the smart appliances to meet with the Day-Ahead curves.

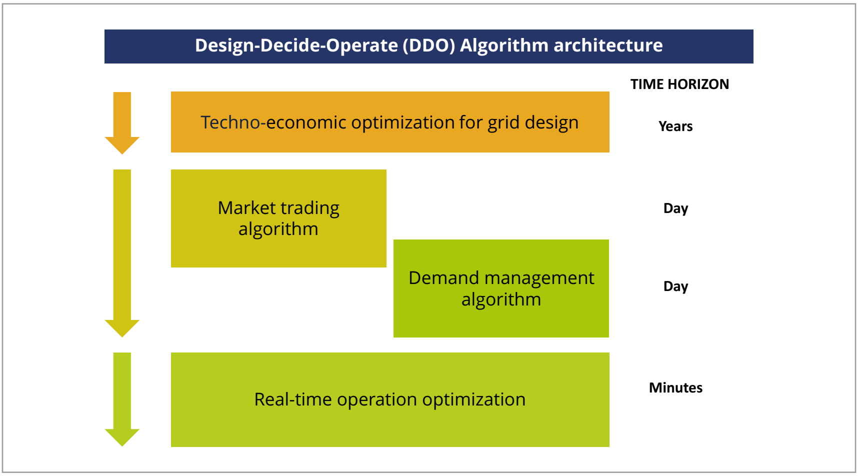


Figure 27: Design-Decide-Operate (DDO) algorithm architecture (Source: Ayesa Advanced Technologies SA).

4.11 Day-Ahead Bids

In Figure 28, an offer to the market encompassing 11 houses is visualised. Different colours show how much each system involved in the offer is contributing to the total. In order to understand this graph, it must be explained that what is below zero represents power consumption from the grid and above zero is injected power into the grid. The EMP is able to manage either forecasts generated by the EMP itself or forecasts originating from third parties.

For eleven installations chosen for a market offer, the EMP queries the forecasts of the relevant installations, which include prices, consumption of the houses and generation. Based on these forecasts, the EMP generates the energy profile that can be committed to the market for the next day.

- Once the Day-Ahead offer is validated by the market, the real-time process runs providing the visualisation in Figure 28, which shows in how far the whole offer complied with the forecast made the day before. The Blue represents the previous day's commitments to the grid: when above zero, the aggregation of the eleven houses is injecting into the grid, when below zero, the house are consuming from the grid.

- Orange represents the real behaviour of the whole system. In this example, at 3 a.m. the system did not consume all the expected energy, but it is visible that the commitments along the day were met in most cases.
- The black lines represent energy price prediction versus real values.
- The purple line represents forecasted energy generation
- The grey line represents forecasted energy consumption

Figure 29 shows the behaviour of a selection of individual DERs towards meeting the commitment.

These disaggregated graphs show in step-shaped lines the desired setpoints. Dotted lines show what happened in reality. Normal behaviour would be that the site tries to follow the setpoint. The battery's state of charge can be useful for analysis, so it is represented with a dotted black line.

Greater consumption than forecast took place in the early hours because the system considered the insufficient state of charge of the batteries. So, the system sends a request to the batteries to charge in order to ensure enough energy is available to inject into the grid later in the same day, to ensure the commitment to the market will be fulfilled successfully. The system tries to consume between 08:00–10:00, because it – again – pre-empts having to inject into the grid.

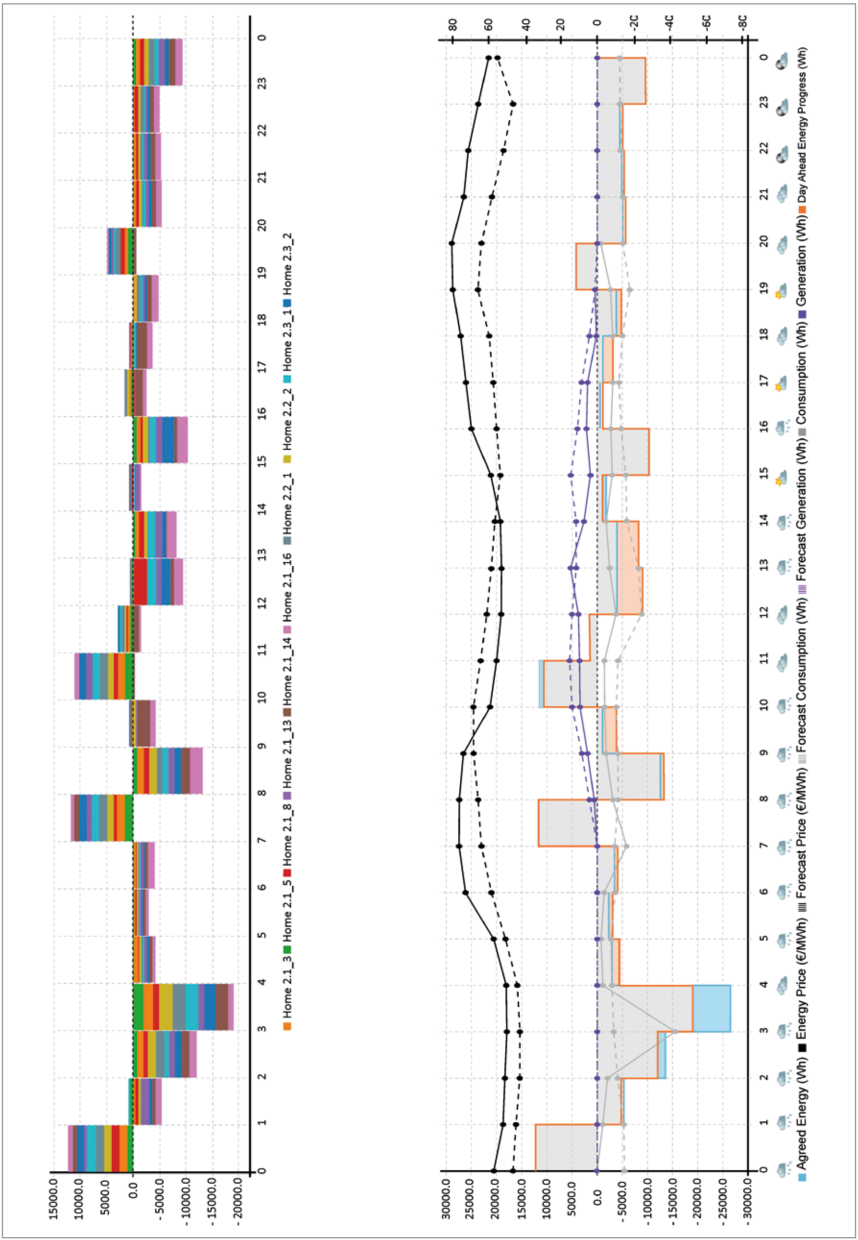


Figure 28: Visualised Day-Ahead offer showing contribution of eleven houses and aggregated data (Source: Ayesa Advanced Technologies SA).

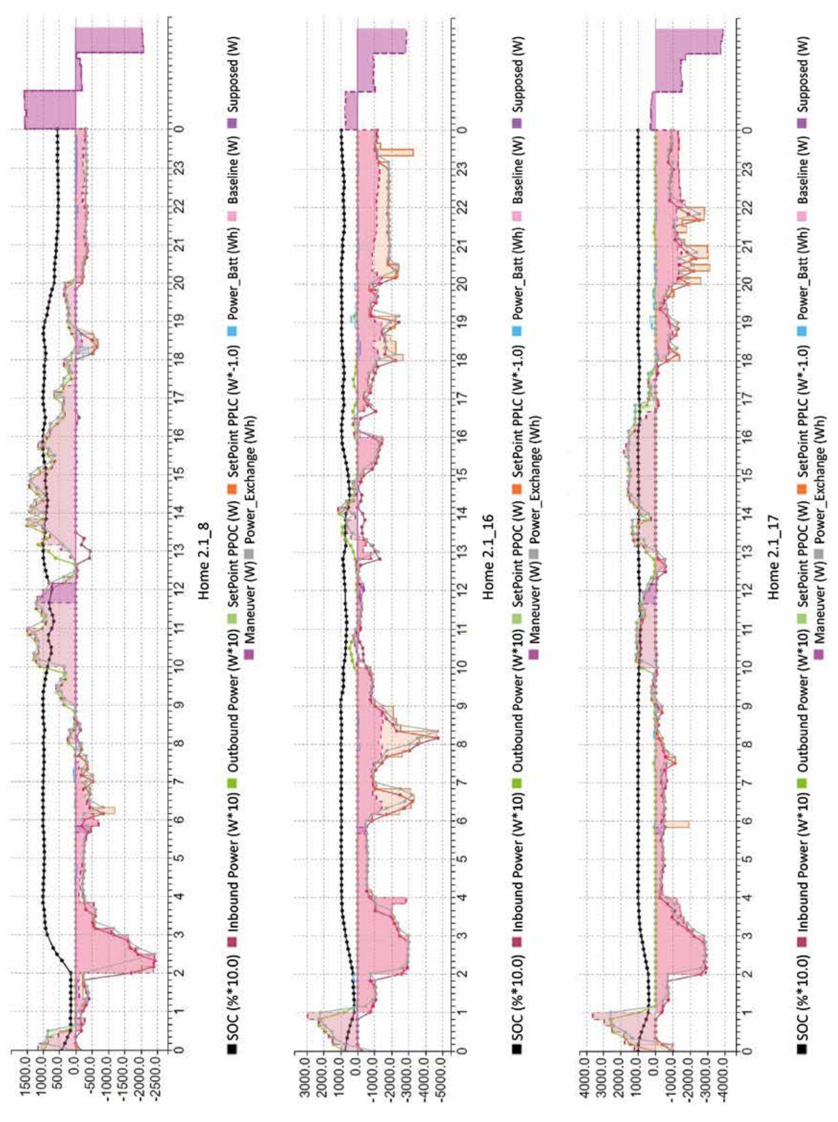


Figure 29: Behaviour of individual DERs towards commitment (Source: Ayesa Advanced Technologies SA).

4.12 Market Dashboard

Figure 30: Market Dashboard (Source: Ayesa Advanced Technologies SA).

The market dashboard visualises comparisons of real energy flows versus commitments vs. real, hourly progress, forecasts for the next day. At the bottom optimised revenues due to improvements in forecasting are shown.

5 National Regulation on PV, Storage and Direct-Supply

Self-consumption of locally generated electricity has been recognised as a promising approach for promoting the European energy transition processes towards a low-carbon energy system. This will be reflected in the revised version of the Directive of the European Parliament and of the Council on the promotion of the use of energy from renewable sources (draft version: February 2017 [7]). Particular reference is being made to the need for setting a regulatory framework for self-consumption and facilitating generation, storage and sale of electricity without facing disproportionate barriers. It also requires that communal self-consumption should be allowed in certain cases so that citizens living in apartments can benefit from consumer empowerment to the same extent as households in single family homes, e. g. as explained in Section 6.2.1. Currently, the handling of electricity generated by smaller units is typically regulated by national bodies. Especially for small installations, regulatory treatment and technical requirements differ greatly between countries, reaching from being allowed to plug in the generation units without formal permission or without particular technical measures for grid connection on the one hand, and very restrictive approaches, requiring explicit contracts to run grid coupled generation units on the other hand.

Key features of legislation and regulation relating to PV self-consumption, storage and direct supply have been compiled for a number of countries represented by NETfficient project partners from Spain, the UK, Germany and Sweden. An overview and comparison between these countries is provided in Table 2. Key characteristics and impacts are given in the following sections. Regulations take a long time in the making and updating. Therefore they are continuously in flux. The information provided will give an initial impression and starting point for further research. It has to be complemented with additional checks for more recent information.

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[7] European Commission (2017). Proposal for a Directive of the European parliament and of the Council on the promotion of the use of energy from renewable sources (recast), Brussels. EC.

		Germany	Spain	
			Below 100 kW	Above 100 kW
PV Self-consumption	Right to self-consume	Yes	Yes	Yes
	Revenues from self-consumed PV	Savings on the electricity bill	Savings on the electricity bill	Savings on the electricity bill
	Charges to finance T&D	None	Yes (“solar tax”)	Yes (“solar tax”)
Excess PV electricity	Revenues from excess electricity	Feed-in tariff or feed-in premium	None	Wholesale market price minus taxes
	Maximum timeframe for compensation	Real-time	Real-time	Real-time
	Geographical compensation	On site only	None	None
Other system characteristics	Regulatory scheme duration	20 years (feed-in tariff)	Unlimited	Unlimited
	Third party ownership accepted	All	None	Yes
	Grid codes and additional taxes/fees	Grid codes compliance and partial EEG-surcharge	Above 10kW (*)	Yes (*)
	Other enablers of self-consumption	Battery storage incentives	None	None
	PV system size limitations	Minimum 10 % self-consumption	100 kW but below or equal to capacity contracted	Below or equal to the capacity contracted
	Electricity system limitations	52 GW of PV installations	Distributer’s License	Distributer’s License
	Additional features	EEG levy must be paid anyway by the prosumer (above 10 kW)	Taxes on batteries	Taxes on batteries

		Sweden		UK
PV Self-consumption	Right to self-consume	Yes	Yes	Yes
	Revenues from self-consumed PV	Savings on the electricity bill	Savings on the electricity bill	Savings on the electricity bill + Generation Tariff
	Charges to finance T&D	None	None	None
Excess PV electricity	Revenues from excess electricity	Various offers from utilities + 0,6 SEK/kWh + Green certificates	Wholesale electricity price	Generation Tariff + Export Tariff
	Maximum timeframe for compensation	1 year	Real-time	Real-time
	Geographical compensation	On site only	On site only	On site
Other system character-istics	Regulatory scheme duration	Subject to annual revision	Unlimited	20 years
	Third party ownership accepted	Yes	Yes	Yes
	Grid codes and additional taxes/fees	Grid codes requirements and VAT registration	Grid codes requirements and VAT registration	None
	Other enablers of self-consumption	Time-of-use Tariffs	Time-of-use Tariffs	None
	PV system size limitations	Below 100 A Maximum 30 MWh / year for the tax credit.	Above 100 A	30 kW
	Electricity system limitations	None	None	None
	Additional features	None	None	None

Table 2: Comparison on regulation on key issues according to Masson at all (2016); T&D = Transmission and Distribution (Source: Masson, G., Briano, J. I., & Baez, M. J. (2016). Review and analysis of PV self-consumption policies. IEA-PVPS T1-28).

5.1 Regulations in Germany

This section refers to aspects of small scale renewable energy generation not covered in Section 6.2.1 on tenant direct supply in apartment blocks. The regulation regarding decentralised generation in Germany distinguishes between two general situations:

Situation 1: Electricity produced by distributed generation is fed into the grid and thus immediately assigned to a third party (typically the distribution system operator). The owners / operators of the DG unit do not have any rights to consume this energy themselves.

In almost all cases in which operators of DER units receive payments based on feed in tariffs (as regulated by the German Renewable Energies Act (EEG) or German Combined Heat and Power Generation Act (KWKG)), situation 1 applies. All generated electricity must be fed back to the public grid. Also for situations for selling generated electricity directly to the wholesale market (also regulated by the above laws), self-consumption without compensation measures is obviously not possible.

Situation 2: In all other cases self-consumption is allowed. This right of self-consumption means “real-time” consumption requiring immediate consumption (or local storage) of generated electricity. The applicable laws allow a fairly dynamic allocation of distributed generators (or even parts of them) for feed-in payments (situation 1) or self-consumption (situation 2).

Net-metering is usually not allowed in Germany. The reasons being the strict approach to unbundling between generation and consumption. Therefore direct offsetting at the local grid connection points is not permitted. The German regulatory body requires the separate metering and handling of energy fed back and energy consumed[8]. Nevertheless, in the past some DSO tolerated the

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[8] Bundesnetzagentur (24.11.2015): Strombezug von PV Anlagen, retrieved 21.04.2017, from https://www.bundesnetzagentur.de/DE/Sachgebiete/ElektrizitaetundGas/Unternehmen_Institutionen/ErneuerbareEnergien/Photovoltaik/Strombezug_von_PVAnlagen/Strombezug_von_PV-Anlagen.node.html

installation of single meters without backstop for very small PV installations, thus leading to unofficial net-metering situations.

For owners of PV it is important to clarify additional taxes and levies they need to pay either in the case of self-consumption or in the case of receiving feed-in tariffs. So there is an obligation for consumers of self-consumed PV energy to pay a reduced rate of the renewable energy levy ("EEG Umlage"), which co-finances renewable generation sold by the German TSOs as part of the feed-in law mechanism. PV systems smaller than 10 kWp are exempt from this levy for the first 10 MWh of self-consumption. This reduced levy for self-consumption is currently in the range of 2,5 cent / kWh, i. e. 40 % of the full levy. In many cases it is also necessary to pay taxes for self-consumption. The calculation of these taxes depends on many aspects such as the legal status of the owner, the way the PV installation has been declared to the local tax authority and the purpose of the self-consumption (e. g. private or business).

A rough estimation is: 19 % taxes on the number of kWh x 20 cent / kWh. Similar taxes (except "EEG-Umlage") also have to be paid for feed-in tariffs with different tax categories being applicable depending on the status of the system owner (private / commercial, employed / self-employed, married, …)

5.2 Regulations in Spain

During recent years a radical reform of Spanish electricity regulation has been undertaken. The cornerstone of this reform is the new Power Sector Law 24 / 2013 (spa. "Ley del Sector Eléctrico"), approved by the Spanish Parliament on December 26th, 2013. The reform touches on a large number of issues and, for the first time in Spain, regulates self-consumption, although it does not in itself set specific self-consumption regulations. These have been laid out in the Royal Decree RD 900 / 2015 approved by the Government in October 9th, 2015[9].

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[9] Aragonés, V.; Julián, B.; Alba, J. (2016): The new Spanish self-consumption regulation, Energy Procedia 106, 245–257.

The decree does not introduce any taxation on distributed generation, yet it prescribes a methodology for defining other system costs and energy policy charges. There was wide and strong opposition to the Royal Decree. According to Spain's Photovoltaic Union (UNEF), the new law requires owners of systems for self-consumption to pay the same grid charges that all electricity consumers in Spain pay, plus a so-called 'sun tax'[10]. This "sun tax" is officially referred to as backup charges (esp. "peajes de respaldo") or also as self-sufficiency charges (esp. "cargos al autoconsumo") – it only recently has been abandoned. Key points of the RD 900 / 2015 regulations are[11, 12]:

- Installations smaller than 10 kW are exempt from the backup charges.
- The new law prohibits PV systems up to 100 kW from selling electricity.
- Owners of PV up to 100 kW are required to donate the extra electricity to the grid for free.
- Systems over 100 kW must register in order to sell electricity in the spot market for the excess power they generate.
- For PV systems up to 100 kW, the owner of the installation must be the party having the contract with the electricity company.
- Community ownership is prohibited altogether for all sizes of self-consumption systems.
- Permissions need to be obtained before installation takes place. Every grid-connected electricity system requires authorisation from the relevant electricity supplier and the Spanish Government.
- The installation of storage units is explicitly allowed as long as they are installed with the specified protection and as long as they share a metering system with the generating unit. In other words, only the storage device may be installed between the generating unit and the meter, no other loads of any kind.

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[10] Mariscal & Abogados (2016): Sun Tax on Photovoltaic systems in Spain, retrieved 14.06.2017, from http://www.mariscal-abogados.com/sun-tax-on-photovoltaic-systems-in-spain/

[11] Mariscal & Abogados (2016): Sun Tax on Photovoltaic systems in Spain, retrieved 14.06.2017, from http://www.mariscal-abogados.com/sun-tax-on-photovoltaic-systems-in-spain/

[12] Ministerio de Industria, Energía y Turismo (10.10.2015): Real Decreto 900/2015, BOE-A-2015-10927, Spain, retrieved 09.11.2017, from https://www.boe.es/buscar/pdf/2015/BOE-A-2015-10927-consolidado.pdf

Although the installation of storage units is allowed, there are barriers for their use in the context of self-consumption.

Battery owners cannot benefit fully from reduction in maximum power (kW), on which their contract with their utility is based. Since the largest part of the Spanish residential energy bills is related to the contracted power rather than the actual electricity use, this makes it harder for battery owners to recoup the cost of their investment. Further barriers are:

- Customers have to pay fees
- Laborious legal procedure takes around seven months – these are the same for all systems, implying proportionally higher costs for smaller systems

There are also a number of more general barriers for the PV sector in Spain:

- There is no regulatory certainty regarding PV, leading to considerable decrease of implementation of PV projects.
- Having more than one supply contract is not legally permitted.
- Net-metering is not possible.
- Obtaining grid access permits from DSOs is difficult.

Self-consumption in buildings in multiple ownership

In apartment blocks and in non-residential buildings which are held in multiple ownership or which are occupied by more than one tenant, the consumer of the generated energy and the owner of the system have to be the same legal entity. Hence, for such buildings the only option is to use the PV electricity for landlord-use, i. e. for energy consumption in common spaces. Alternatively, permission can be given to just one of the occupants to install PV for their own self-consumption and for feeding in excess energy to the grid, by selling to an aggregator and paying generation tax.

5.3 Regulations in Sweden

Self-consumption of PV electricity is allowed in Sweden. Since 2016, the Swedish government negotiates measures to reach the national target of 100 % renewable energy supply by 2040. Behind this framework there is the intention to make small-scale electricity production and self-consumption easier, especially for PV systems. This started with the exclusion of systems smaller than 255 kW from the Swedish energy consumption tax, if energy is self-consumed. There are current plans to reduce this tax by 98 % for generators over 255 kW, thus effectively cancelling the tax for all solar power systems. This new regulation is about to start in November 2017[13]. In addition, the Swedish government signalled plans to implement regulatory changes that could allow homeowners to install PV modules without first obtaining a special permit.

No national net-metering system exists; however, several utilities offer various agreements, including net-metering for the excess electricity of a micro-generators[14].

Sweden has introduced a support system to facilitate the deployment of home energy storage in 2016[15]. The scheme started in November 2016 and covers up to 60 % of the system costs, up to a maximum of SEK 50,000. Under terms of the scheme, this grant can go towards the battery, wiring, control systems, smart energy hubs and installation work for houses with PV.

5.4 Regulations in the UK

Self-consumption in the UK is allowed. In October 2015, the UK government announced a change in its self-consumption scheme with a major decrease of

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[13] Bellini, E. (21.03.2017): pv magazine, retrieved 23.06.2017, from Sweden's plan to reduce tax for self-consumption by 98 % moves forward: https://www.pvmagazine.com/2017/03/21/swedens-plan-to-reduce-tax-for-self-consumption-by-98-movesforward/

[14] Lindahl, J. (2015): National Survey Report of PV Power Applications in Sweden, Stockholm: Swedish Energy Agency.

[15] Steel, W. (26.10.2016): Renewable Energy World. from Sweden Set to Launch Residential Energy Storage Scheme: http://www.renewableenergyworld.com/articles/2016/10/sweden-set-to-launch-residentialenergy-storage-scheme.html, retrieved 03.07.2017

the generation tariff. Residential solar systems can currently access the following revenue[16]:

Generation tariff: This is paid for every kilowatt-hour generated, regardless of its destination. It is currently set at £0.0414 / kWh and is indexed to the UK inflation rate.

Export tariff: In theory, this is paid for the electricity fed into the grid. For installations smaller than 30 kW the government assumes for the time being that half of the kilowatt-hours generated are exported. Currently, the export tariff is set at £0.053.

Self-consumption benefits: This financial benefit refers to the reduction in the customer's bill due to the avoided electricity consumption from the grid. Residential customers in northern Europe are typically only able to use about 20–30 % of the electricity produced by their own solar system without storage or significant behavioural changes. Assuming 20 % self-consumption and an electricity tariff of £0.12 / kWh, a solar system owner would save the equivalent of £0.024 per kWh generated. During the recent months there were intensive discussions in the UK about a solar tax hike resulting from a business rate hike for self-consumption from rooftop solar power. There are around 44,000 micro generators in the UK[17] which currently pay no business rates on their PV-installations and which may receive an unpleasant surprise with the rate rise. The same source also reports uncertainty about the domestic solar VAT and the VAT treatment of storage.

There are furthermore a number of "Code of Practice" documents addressing metering of circuits for different purposes, which can be found on the ELEXON web-portal[18]. Installations with a total installed capacity of 30 kW or less are not required to have an export meter to receive feed-in tariff payments for exported energy. Instead the export payments can be deemed[19].

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[16] Labastida, R. R. (27.04.2017): Navigant Research, retrieved 10.11.2018, from Can Batteries Save the UK Solar Market?, https://www.navigantresearch.com/news-and-views/can-batteries-save-the-uk-solar-market

[17] Solar Trade Association. (03.07.2017): Chancellor urged to drop the solar tax hike, http://www.solar-trade.org.uk/chancellor-urged-drop-solar-tax-hike/, retrieved 11.11.2018

[18] https://www.elexon.co.uk, retrieved 11.11.2018

[19] https://www.ofgem.gov.uk/consumers/household-gas-and-electricity-guide/understand-smart-prepayment-and-other-energy-meters/onsite-generation-and-metering, retrieved 10.11.2018

6 Storage, The Prosumer and Self-Sufficiency Market

6.1 The Prosumer

The business model of electricity suppliers had remained more or less unaltered over the last century. Until a few years ago it mainly consisted of generating power and selling it to their customers. These customers simply consumed energy. Hence, the flow of energy was strictly one way from generation to load. Demand was relatively straight-forward to predict.

In recent years, the business model of utilities has been facing a paradigm shift. With the emergence of advanced, smarter technology, consumers can now make more informed choices about energy use. They can act as energy producers and storage operators – thus becoming so-called “prosumers”. A bidirectional flow of energy is the result. Consequently, the energy industry is currently undergoing rapid and fundamental changes. These affect generation, transmission, distribution and most importantly also the role of the end-user.

While the pace of change has accelerated throughout the entire value chain, changes are most pronounced in the rather immobile utility industry. Changes include substantial increases in DERs, particularly rooftop solar PVs, but also include improvements in energy efficiency and the emergence of energy storage.

The former allows prosumers to generate more of the energy they need, the latter means they need less energy. This leads to a number of impacts on the technical as well as the business side. Utility sales and revenues, based on per-unit tariffs are falling. On the technical side two-way energy management is required, dealing with a range of scenarios. Local generation may at times be able to directly meet local demand. At other times, feed-in peaks may strain local infrastructure.

The technologies developed and implemented in NETfficient have the prosumer model at their core – each participating installation includes distributed generation (using PV) and distributed storage.

6.2 Drivers for Prosumers to Invest in Storage

In general terms, owners of generation systems are either motivated by a desire to increase self-consumption or by maximising income from feed-in tariffs, thus feeding all of the energy generated back into the grid. The choice between these models depends on the relation between local per-kWh tariff for electricity bills on the one hand and feed-in tariffs on the other. The higher the retail price of electricity and the lower the feed-in tariff, the more lucrative self-consumption becomes. Thus, increasing self-consumption tends to be the main driver for most consumers for investing in storage technologies, which allow the shifting of electricity consumption or feed-in times (see also section 8.1).

6.2.1 Tenant Direct-Supply for Apartment Buildings

In addition to single family dwellings, larger blocks of flats can present an additional new market for DERs and storage. Often blocks of flats have large suitable roof areas for PV, which however are owned by either a landlord company or the community of individual owners of apartments, which may either live in their apartments or rent them out. While long-term tenants may wish to benefit from renewables, they are not involved in the decision-making process, whereas their landlords have no interest to invest, as they will not reap any benefit or receive a pay-back – it would be the tenant benefitting from lower bills. Hence the prosumer-model has to be adjusted to meet this split-incentive situation. Further difficulties arise in sharing renewable energy fairly between those wishing to participate. In response the so-called "Mieterstrom"-model (tenant direct-supply model, "neighbour solar supply model") has emerged in Germany, together with the necessary legislation for administrating it.

Relevant legal instruments in Germany are stated within the Renewable Energy Act (EEG 2017)[20]. "Mieterstrom" is now to be treated equally to self-consumption solutions[21]. Corner stones of this act are:

- Funding of PV system owners for delivering electricity to other local tenants with 2.75 ct / kWh to 3.8 ct / kWh. The funding depends on the size of the installation and only new installations up to 100 kWp are eligible.
- The electricity price the providers can charge to the tenants must be less or equal to 90 % of the local standard electricity price.
- Tenants still retain the freedom to choose their preferred electricity supplier (this means, they might opt out from the direct supply).
- Contractual relationship of the players in the German "Mieterstromkonzept" are shown in Figure 31.

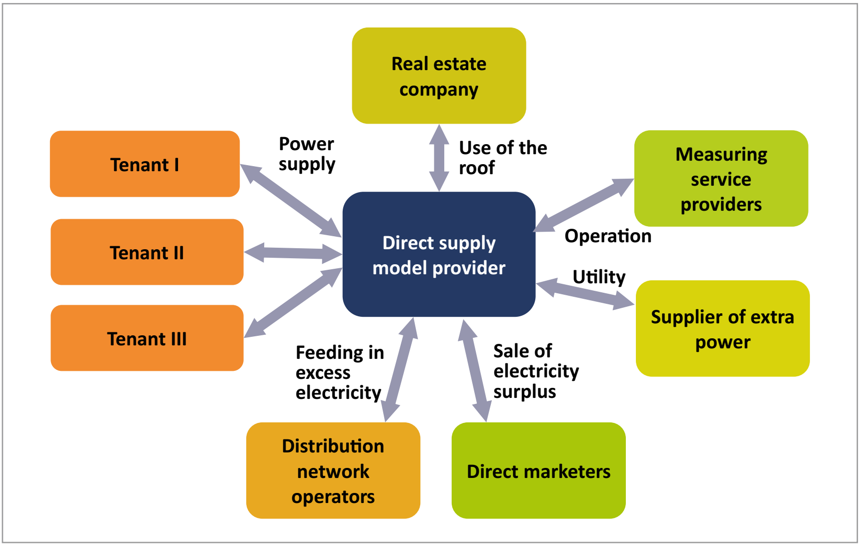

Figure 31: Relationships within a tenant direct supply model (Source: Redrawn based on Aguilar, L. (2016). The neighbor solar supply model in Germany – "Mieterstrom". Project Report "PVFINANCING". Brussels: BSW-Solar).

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[20] Gesetz für den Ausbau erneuerbarer Energien

[21] Gesetz zur Förderung von Mieterstrom und zur Änderung weiterer Vorschriften des Erneuerbare-Energien-Gesetzes, 17.07.2017, Bundesgesetzblatt, Bundesanzeigerverlag

The payments PV owners receive partly compensate taxes and levies that have to be paid when delivering electricity to other customers. Nevertheless, the end user's free choice of electricity supplier still applies. The supplier could be changed annually, thus posing a significant economic risk to the PV system owner.

In fact, one of the most relevant business opportunities of electricity storage systems in buildings in Germany are within tenant direct-supply schemes. During recent years, such applications received more and more public attention driven by decreasing feed-in tariffs for RES energy and the need to develop new business options for smaller and decentralised generation. Another driver is the goal to relieve the public grid from peak powers generated by fluctuating DER generation.

However, regulation / metering concepts are relatively complex, having to be fair to all occupants, be they owner-occupiers or tenants in such buildings.

6.2.2 Metering of Direct-Supply

As explained above, often a direct-supply-provider will act as an electricity supplier, supplying for the entire power needs of the tenants. Hence the direct-supplier has to procure the short fall. The use of storage may help optimise the procurement strategy.

There are huge differences between countries in the EU. However, where such applications are supported by the necessary regulations they can represent a potential incentive to increase RE generation in urban areas. It can be an opportunity to increase urban grid supporting PV installation and it is therefore also a potential market for mid-sized storage systems, which could also be attractive for pooling strategies.

There are no binding regulations regarding the metering concept. Certainly all metering solutions need to account for energy consumed from the public grid as well as energy produced locally, and correctly assign the energy volumes to customers participating in the direct supply model, while taking into account those residents remaining with other utilities. Figure 32 shows a frequently used metering model for direct-supply which adds up all individual meters.

Providing local renewable electricity to tenants in apartment buildings is difficult and complex from a regulatory point of view in most countries. In Germany, progress has been made in that regard in 2017 with the "Mieterstromgesetz" mentioned previously.

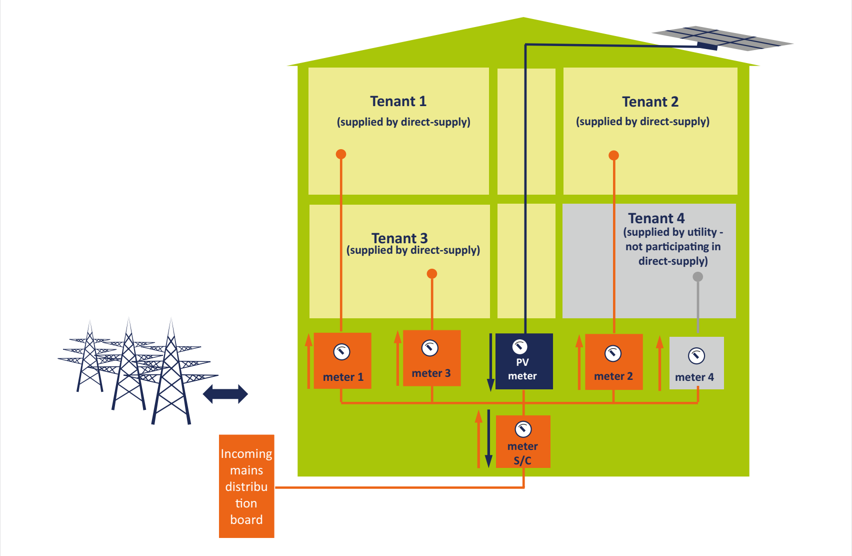

Figure 32: Metering concept for houses applying the "Mieterstromkonzept" (Source: Redrawn based on: EnergieAgentur.NRW (2017). Mieterstrom kurz erklärt – Neue Perspektiven für Vermieter und Mieter. Düsseldorf: EnergieAgentur.NRW GmbH).

Each tenant receives an individual electricity bill, issued by the operator of the direct-supply-scheme for tenant 1, 2 and 3, and from the utility for tenant 4. The utility also determines the difference between local electricity generation and local energy consumption by subtracting the energy measured for tenant 4 from the total energy consumption from the public grid (supply / consumption meter). This amount of energy is charged to the operator of the direct-supply, to pass on to its end-customers.

Once smart-metering systems have been implemented across the board, it will be possible to determine the energy flows accurately at each instance and consequently incentives can be offered to those customers aligning their personal consumption profiles to the availability of local energy.

6.3 Other Applications for Storage

Revenue potentials from offering energy as balancing or ancillary services (see section 8.6) open up further options for profitable storage applications, in addition to those in residential buildings, as detailed previously.

In particular, those revenue options which require an interaction with the energy wholesale market are suited to utility scale batteries. The medium-voltage HESS prototype developed for NETfficient is connected to the MV-grid and specifically designed to perform peak shaving. These applications are only as a secondary consideration now also attractive for pools of small-scale storage and VPPs.

Drivers for low temperature storage systems such as that developed for the Seawater Aquarium meet very specific challenges and differ from those for building integrated storage. However, they can also be integrated into storage pools and used for additional peak-shaving potential.

7 Business Models and Ownership Models for Energy Storage

7.1 Basic NETfficient VPP-Model for Homes and Larger Buildings

A detailed analysis of markets and revenue potentials for aggregated storage is an important part of the NETfficient project. The business model assumed for most of this analysis is one close to the set-up created on Borkum. The operator of the EMP would in effect acts as a Virtual Power Plant (VPP) – this term is used in the following for the storage aggregator business, which would probably aggregate associated PV-output at the same time.

The model would mainly apply to homes and larger buildings, but it could also include the streetlighting system and aquarium.

7.1.1 The Value Proposition of the VPP

The VPP turns the flexibility potentials of aggregated storage into financial benefits and also qualitative benefits for its customers, consisting of:

- Lower energy imports from grid (higher self-consumption), hence lower bills from main supplier,
- Lower losses due to feed-in peak shaving,
- Payments for avoided grid utilisation charges,
- Share of earnings from reserve power sales,
- Share of earnings from selling flexibility,
- Customer tailored energy services, considering the customers’ needs and behaviour.

7.1.2 The Customer and the Customer Relationship

The VPP would need to recruit owners / operators of distributed storage and / or DER-capacity, it would not supply and own the storage itself. Target groups are owners of private and small commercial buildings, preferably with local generation (e. g. PV, CHP). They are referred to in the following sections as the customer.

The customers of the VPP are thus owners of the storage units, who often (but not always) also own the houses or buildings they are located in. Customers of the VPP could therefore be private persons, smaller businesses.

Sufficient incentive has to be offered to storage owners to take part in the storage pool. This incentive would be made up in parts of optimised self-consumption for the storage operator through the management system. Possibly a small share of the profits obtained on the energy wholesale market for selling flexibility would have to be offered in addition, thus making up for potential restrictions on storage use and possible shorter life-span of the storage unit due to higher usage. In addition, idealistic values such as participation in a green energy transition can also be considered as incentives, at least in in the current German climate.

7.1.3 Key Business Activities of the VPP

The VPP assumed for the analysis of revenue potentials in Section 8 is a service provider aggregating technical flexibilities from storage systems and other components. It does not act as primary energy supplier nor does it own the storage units. The VPP sells flexibility products on the relevant markets and to customers, leading to financial revenues. The main activities the VPP would need to undertake are:

- Scheduling and operation management of the distributed storage systems
- Aggregation of storage capacities and flexibilities
- Sales on the wholesale energy market

- Participation in balancing energy markets and marketing of ancillary services
- Metering and billing actions not covered by DSO

7.1.4 Costs and Revenues

The main cost items and revenues set out in Table 3 illustrate roughly the functioning of the VPP business considered in this chapter.

Cost to the VPP	Revenue
▪ up-front capital cost (e. g. server, software, communication equipment…) ▪ interest payments ▪ cost for ongoing monitoring, maintenance and management (personnel, materials) ▪ cost for trading on energy markets ▪ cost for communication, metering, billing ▪ cost for incentives to storage owners (share of earnings)	▪ revenues from energy-sales on wholesale markets (benefiting from prize differences) ▪ revenues from participating the balancing market and ancillary services ▪ revenues from grid services (e. g. flexibility for grid operator)

Table 3: Main costs and revenues of VPP (Source: NETfficient project).

7.2 Ownership Models and Contracting Solutions

Though the VPP assumed here does not own nor procure the storage units, other models for ownership of the aggregated storage capacity are conceivable. In particular leasing and energy contracting models are possible. The most important business models are summarised briefly below.

- **Financial contracting (third-party-financing):** The storage units are operated by the customer of the scheme. Ownership of the installation is retained by the contractor. Mutual agreements can be made regarding operation management, maintenance and repairs involving corresponding service payments.

- **Operation management contracting:** The contractor is assigned a defined number of tasks related to the technical unit including operational management, maintenance and repair work.
- **Energy saving contracting / energy supply contracting:** While the first two versions of contracting presented above focus on the specific technical unit, energy savings contracting and energy supply contracting are performance based, with specific performance targets written into the contract. In an energy saving contracting solution, the contractor endeavours to lower the costs for fuels and energy for the customers and typically receives a certain percentage of these savings in return. For energy supply contracting the customer will finally be provided with electricity, heating or cooling with the contractor having a large degree of freedom to achieve this by utilising the local resources or own investments.
- **Leasing:** Leasing contracts are close to contracting models with the exception of the risk being solely taken by the customer. Mostly the customer is given some hardware for his own use and must pay fixed instalments for a defined period. This contractual situation is less suitable for a VPP, as it would not normally have access rights to the hardware in that case.

If the VPP owns the storage capacity, recouping the initial capital cost or interest rates have to be factored into the business plan.

8 Selling Flexibility – Revenue Options for VPPs

NETfficient aggregates flexibility to provide services to local customers, to grid operators and to the wholesale market simultaneously. These target markets offer a range of revenue potentials, which are analysed in this chapter. As part of NETfficient, Fraunhofer ISE have undertaken extensive modelling and analysis to identify revenue potentials.

Starting point for revenue streams related to energy trading is the assumption that the customer only partly self-supplies with local generation and thus needs contracts with energy suppliers trading energy on the energy markets. The main interest of the customer is either to use as much as possible of his locally generated energy (self-consumption) or to buy electricity from the market for a low price. Having a storage unit in between the market and the electrical consumer enables intelligent energy management to make use of the market price dynamics and allows increasing energy consumption. For a VPP able to buy and sell energy at the market, an additional option is to utilise market price differences by intermediate energy storage.

Besides the exchange of energy via the electricity supply system, grid operation requires a number of services in order to remain stable, reliable and affordable. An especially critical aspect is the specification of grid components which are able to withstand peak power situations resulting from loads or generators. The reduction of peak-loads is a very efficient way to lower costs for grid operation or grid reinforcement. Such services can alleviate stress on grid infrastructure and avoid or postpone grid extension or reinforcement. Therefore, a number of incentives exist to motivate consumers or generators to contribute to local peak-reduction.

The most relevant revenue potentials are:

- Increasing self-consumption
- Local system services
  - Peak load reduction
  - Feed-in peak shaving
  - Avoided grid utilisation charges
- Exploiting wholesale market price dynamics
- Reserve power markets

8.1 Increasing Self-Consumption

Self-consumption means that an owner / operator of distributed generation device consumes some or all of the energy at their own premises. The term self-sufficiency reflects that a good part of self-consumption could be delivered by own resources. Sometimes self-sufficiency is considered by the customer as a value in itself, thus opening up a value proposition of helping the customer to achieve or increase self-sufficiency, even 100 % self-sufficiency. From a purely economic point of view, normally the increase of self-consumption is the more relevant target if energy imports were more expensive than own consumption.

In a number of EU countries (including Germany) the retail electricity price is significantly higher than the feed-in tariff thus motivating self-consumption of local generation by the customer, rather than selling it to markets or third parties (see Figure 33). The financial advantage results from the saved costs for buying energy of the grid minus the cost for local generation and necessary operational management, which may include storage.

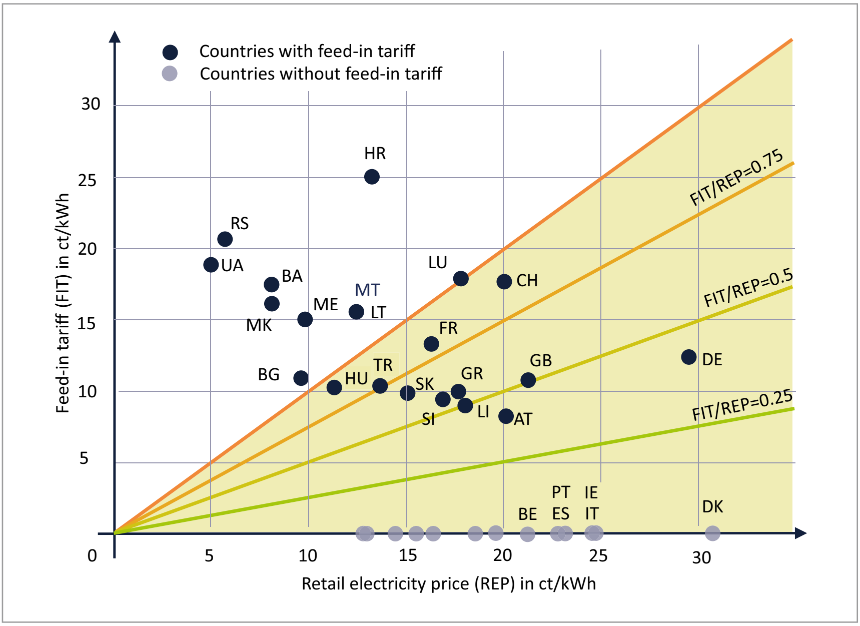

Figure 33: Comparison of retail electricity price and feed-in tariffs for European countries according to Tjaden & Weniger (Source: Redrawn based on Weniger, J.; Bergner, J.; Tjaden, T.; & Quaschning, V. (2016). Effekte der 50 %-Einspeisebegrenzung des KfW-Förderprogramms für Photovoltaik-Speichersysteme. Berlin: Hochschule für Technik und Wirtschaft Berlin).

Increasing self-consumption requires a forecast of times of excess local generation and the shifting of surplus generation to times of generation short-falls, using either storage or energy management techniques. Therefore controllable generation should be adjusted, if possible and flexible loads should be shifted towards times of excess electricity production. Figure 34 illustrates the approach of using a storage system to shift PV-generation peaks to times of no PV generation (e. g. night-time).

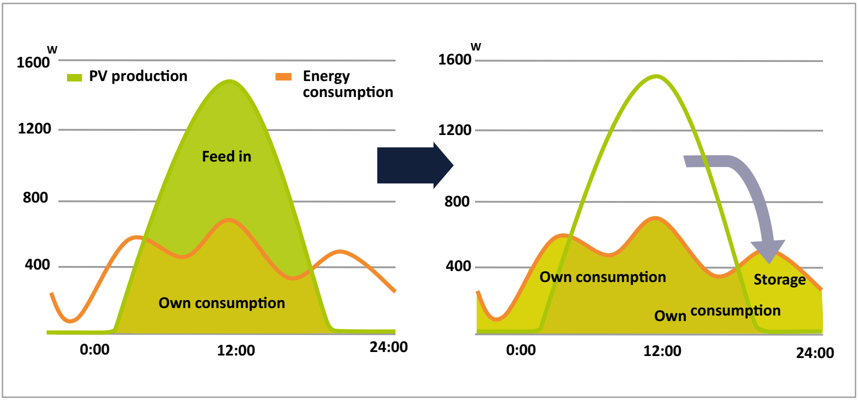

Figure 34: Approach for increasing self-consumption by using battery storage (Source: Redrawn based on red electrical. (2014). Self consumption of solar PV yields. https://www.redelectrical.co.uk/self, retrieved 10.11.2018).

Value Proposition: Avoid expensive energy imports for the customer (or improve level of "self-consumption", as a qualitative criterion).

Method: Adjust operational management of the pool of flexible generation, storage and load units in a way leading to increased self-consumption over-all for the pool.

The potential for financial benefits from self-consumption depends on the relation between local generation, local loads, storage capacity and storage power. A simulation analysis has been performed to analyse the sensitivities for self-consumption and self-sufficiency for PV home storage systems.

A typical example for a private customer with a PV system of up to 20 kWp, leading to an added value of self-consumption of about 15 cent / kWh. A typical example for a small business may include a PV system with up to 50 kWp, with an added value of about 8 cent / kWh. A large industrial example with very large PV-installations may lead to an added value of up to 4 cent / kWh.

Figure 35 shows the share of self-consumption for four individual single-family houses, with variations in annual electricity consumption (ranging from 2 225 kWh / a to 6 507 kWh / a) and related variations of sizes of the PV-installations (i. e. 2 kWp, 6 kWp, 10 kWp) and the capacity of the battery in a range up to 10 kWh. One important aspect of this graph is the relatively high "natural" self-consumption without using any storage or intelligent load management. The financial benefit from additional self-consumption achieved through aggregation and operational management is limited to that on top of the "natural" self-consumption.

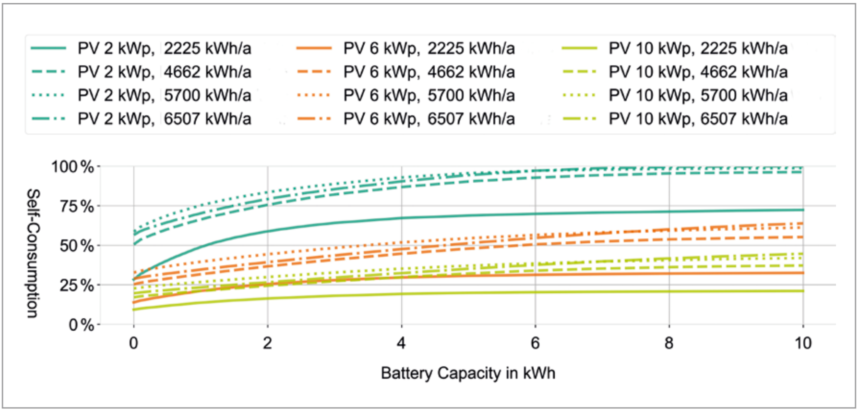

Figure 35: Share of local PV consumption of PV power depending on battery size and nominal PV power and load for single-family houses with an annual electricity consumption of 2 225 kWh to 6 507 kWh (Source: Fraunhofer Institute for Solar Energy Systems ISE).

The data given in Figure 35 allows a rough estimation about the total financial benefit achievable. If a house owner operates a PV-installation of 10 kWp using a battery of 10 kWh capacity, this will increase the self-consumption by about 25 %, which for an annual generation of 10 000 kWh results in 2 500 kWh. With an added value of 15 cent / kWh this amounts to an annual profit of 375 Euros. With capital costs for the 10 kWh battery of 10 kWh × 1 000 € / kWh = 10 000 € payback of the battery would be after 27 years.

8.2 Peak Load Reduction

Value Proposition: Electricity bills of non-residential customers usually contain a price component related to the power rating. Peak shaving often can be a viable secondary service on the local level in addition to other services for the grid or the markets.

Method: Offer owners of storage units being in the pool of the VPP to run their units in a way to avoid generating new local peak loads and help to lower the expected default peak load, which is relevant for the power price component in the electricity bill. It requires intelligent forecasting of consumption / generation and appropriate energy management systems.

Financial benefits from peak load reduction result from lowering the power price component in the electricity tariff of some commercial customers. For smaller commercial and private customers peak-load reduction is not applicable. Time resolved consumption data is not being metered by conventional household meters.

The majority of non-residential electricity customers pay a price for electricity that depends on both the maximum power (kW) and the amount of energy (kWh). For smaller customers this is often not transparent since their tariffs include a flat part for the maximum connection power. When requiring significant extra power (e. g. when wanting to install fast EV chargers) this may become relevant for them, too. Most commercial and industrial customers have a tariff with charges made up from the maximum power and the amount of kilowatt hours. Depending on the national regulation and the type of contract the relevant peak power is the maximum power drawn during a given quarter of an hour in a certain time interval (month, year). This moment on its own determines the power price the customer has to pay for the whole supply period. For customers with significant variation in power consumption it is therefore lucrative to take measures to predict the peaks and avoid peak consumption by intelligent energy management, storage or other kinds of flexibility.

As part of its services, using its aggregated storage capacity, the VPP can also offer solutions for local peak loads, as long as the necessary data is available. This way an additional financial benefit can be offered.

The specific electricity contracts and tariffs of relevant customers have to be analysed, and potential for lowering the peak loads established.

In order to quantify the financial benefits for a realistic case a simulation of loads has been carried out for a supermarket (Figure 36). For the example load the reduction of the peak loads up to approximately 5 kW is possible with very few measures (Active Time and Energy Demand, Figure 37). Above 5 kW, the energy involved and the hours a peak reducing unit would be active increase fast. The figures in the plot show the numbers for a peak load reduction of 10 kW. A high share of the 9 371 kWh would necessarily have to be provided in winter (see peaks above horizontal red line in Figure 36).

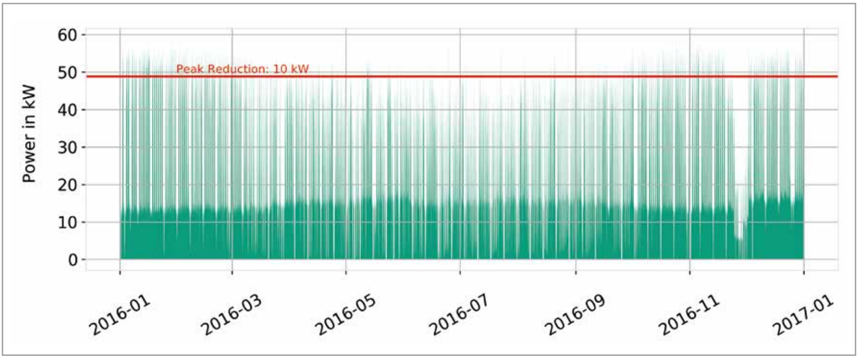

Figure 36: Exemplary supermarket load in Germany for the year 2016 in quarter hourly resolution, the red horizontal line represents an exemplary peak reduction value of 10 kW (Source: Fraunhofer Institute for Solar Energy Systems ISE).

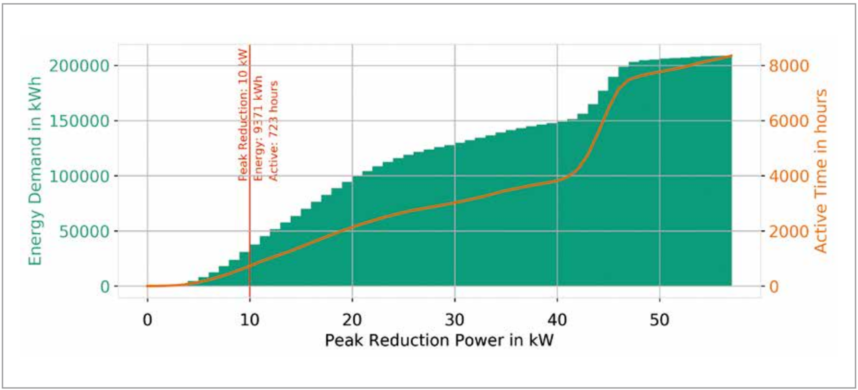

Figure 37: Necessary energy and necessary time to generate energy locally to reduce the peak load at the grid connection point, the red vertical line represents an exemplary peak reduction value of 10 kW with the resulting energy and time values (Source: Fraunhofer Institute for Solar Energy Systems ISE).

8.3 Feed-in Peak Shaving

Value Proposition: Customers have lower losses using feed-in peak shaving.

Method: Perform storage management in a way to avoid losses of energy revenues to the customer by charging the storage during times of feed-in power shedding and shifting this energy to high-load times or times with lower feed-in power.

The integration of fluctuating RES into the grids in Germany increasingly leads to grid problems because of overload of cables and transformers. Because of the intermittent character of PV generation, overload periods are short and occur only in a few instances each year. Simulations have shown that a shaving of feed-in peaks could increase the capacity of existing grid infrastructure towards DER generation units significantly with limited energy content in these peaks.

Based on this knowledge the German regulatory body and the German government started to set incentives for peak shaving of feed-in peaks:

- Small PV installations below 30 kWp have a choice of either installing costly remote-control equipment (obligatory for all PV installations) or to limit feed-in power to 70 % of the nominal power.
- There are several funding programmes for PV batteries combined with the requirement of limiting the peak feed-in power. The large funding programme of the German KfW Bank contains an obligation to limit the feed-in power from the installation of the PV-battery-system to 50 % of the installed PV power for the whole lifetime of the PV installation (regardless of the lifetime of the battery)[22].

With a hard 70 % feed-in power curtailment without battery storage, up to about 3–5 % of the annual yield will get lost depending on the PV plant configuration. The alternative is to adjust battery management so as to store excess energy during times of high generation and shift the consumption of this energy to times with low generation and / or high load. If applicable, controllable loads can be adjusted accordingly.

For example intelligent energy management and forecasting limits the PV's feed-in to the grid and increases own consumption. Figure 38 shows a PV home storage system, which provides self-sufficiency increase and at the same time peak shaving. Based on the findings of a German study[23] the implementation of such a strategy can increase the local grid capacity by 66 %.

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[22] KfW (2018). KfW-Programm Erneuerbare Energien "Speicher". Frankfurt: KfW.

[23] Hollinger, R., Wille-Haussmann, B., Erge, T., Sönnichsen, J., Stillhahn, T., & Kreifels, N. (2013). Speicherstudie 2013 (im Auftrag von BSW-Solar). Freiburg: Fraunhofer-Institut für Solare Energiesysteme ISE.

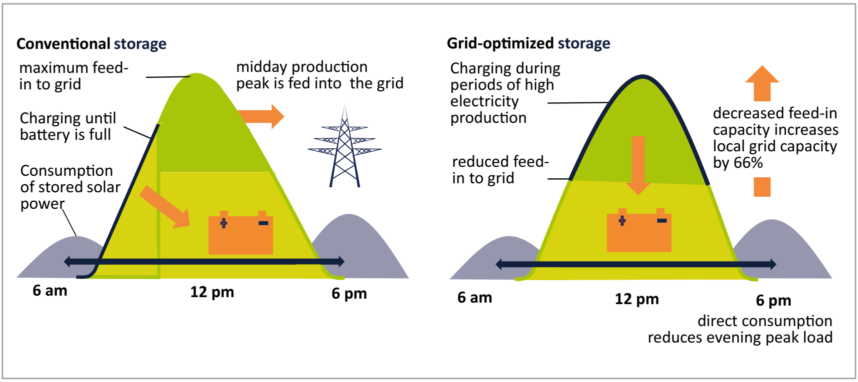

Figure 38: Comparison conventional vs optimised storage (Source: Redrawn based on Hollinger, R.; Wille-Haussmann, B.; Erge, T.; Sönnichsen, J.; Stillhahn, T. & Kreifels, N. (2013). Speicherstudie 2013 (im Auftrag von BSW-Solar). Freiburg: Fraunhofer-Institut für Solare Energiesysteme ISE).

Feed-in peak shaving avoids the shedding of generated PV energy above certain generation levels. These levels depend on the reason for peak shaving. This may be a condition on receiving battery funding, or as a means of avoiding installation of costly control equipment. Currently curtailment levels at 70 % or at 50 % are most relevant.

Example Calculation:

When receiving a feed-in tariff of e. g. 12 ct / kWh, for a 6 kWp system that would sum up within 20 years to

20 years x 6 kWp x 1 000 kWh / year x 12 ct / kWh x 5 % = 720 Euro.

For a 10 kWp system the annual loss would be 500 kWh or 60 Euro.

If with the help of a battery this curtailed energy could be used for self-consumption, this sum will double to 1 500 Euros for an electricity price of about 25 ct / kWh. This money could be spent to install equipment for battery management avoiding the loss of generated energy.

A 50 % feed-in curtailment, which is the funding condition of the German battery subsidy programme, and a simple combination between local load, PV system and battery shall be considered. A “basic” battery charging algorithm operates on the basis of “charge as soon as you can, discharge as soon as you can". This will lead to curtailment losses of about 12 % of the annual PV generation. In the example calculation above this would correspond to a value of about 3 600 Euros. By applying predictive charging, the losses could be lowered 10 % down to about 2 %, leaving 3 000 Euros for investing in the predictive charging management system for the battery.

8.4 Avoided Grid Utilisation Charges

Value proposition: Increase payments to the owner of the units resulting from avoided grid utilisation charges.

Method: Run units in a way feeding back power to the grid during times of forecasted high grid load.

The idea of paying avoided grid utilisation charges results from the perspective of decentralised generators at low voltage level alleviating the grid load in the grid segments they are connected to and thus lowering the energy transmissions required from higher voltage grid levels. Based on the German regulation §18 StromNEV the operators of the units where assigned payments depending on their contribution to lower the maximum grid load for a certain time period (e. g. year). Thus, intelligent operation and energy management coupled with forecasting the time of maximum grid load open up the opportunity for additional profits in the same way as it has been described in section 8.3 regarding lowering peak loads. Therefore the value proposition is similar.

The calculation rules for avoided grid utilisation charges are complex. They are specified in the German Standard[24]. Payments are calculated from grid charges actually avoided and determined individually for each grid- or transformation level in the corresponding year. A separation is being made for avoided grid use between energy (in kWh) and avoided power (in kW). Customers equipped with quarter hourly power meters can choose between two general calculation methods: actual avoided power, or average avoided power. Only the

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[24] VDN. (2007). Kalkulationsleitfaden §18 StromNEV. Berlin: VDN.

first method offers the opportunity for increasing revenues by shifting actual feed-in power to the times of maximum grid load.

Feed-in voltage Level	unit	LV	LV / MV	MV	MV / HV	HV
set price	EUR / kWa	53.99	37.43	30.68	25.30	21.54
scaling factor		0.998	0	0.976	1	0.268
factor for regular down payment		0.7	0.7	0.7	0.7	0.7
resulting down payment	**EUR / kWa**	**37.72**	**0.00**	**20.96**	**17.71**	**4.04**

Table 4: Down-payments for avoided grid utilisation depending on the voltage level of feed-in (NS = low voltage, MS = medium voltage, HS = high voltage) for customers (Source: Own table according to RNG Rheinische Netzgesellschaft).

As an example, Table 4 shows the down payments the grid operator Rheinische NETZGesellschaft is paying to customers feeding-in electricity to their grid and receiving avoided grid utilisation charges[25].

The payments are of the same order of magnitude as the financial benefits from peak load reduction. This is to be expected since both approaches target the reduction of peak loads in the grid. The payments vary significantly from grid operator to grid operator, being typically in the range between 30 € / kW to 100 € / kW. One reason for this broad range are significant variation of grid charges customers have to pay in different geographic regions and special contractual specifications.

To quantify the financial benefits for a typical application, a simulation has been carried out for an example distribution grid in a quarter hourly time resolution. Within this distribution grid there is a huge amount of renewable generation (esp. wind and PV), therefore the residual load is often negative (feed-in from this distribution grid into the grid layer above). In this example a 520 kW generator (battery) has been used to reduce the peak load of the distri-

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[25] RNG Rheinische NETZGesellschaft (2017): Vermiedene Netzentgelte 2018, RNG.

bution grid. Throughout the year it was possible to reduce the grid load by the technical maximum of 520 kW (see distance between the upper two red lines in Figure 39). The relevant peak loads occurred in January and in February; one in each month (in Germany peak residual loads typically occur in winter times). The financial benefit as compared to no residual peak load reduction for the operator of the generator is 49 977 € / a (with a power price of 96.11 € / kW for this exemplary distribution grid). The simulation also shows, that for the decrease of the residual load (and by this the increase of avoided grid utilisation charges) by only 520 kW the generator is being activated only twice in the given year for this specific grid. Obviously far more operations are necessary if the technical power was much greater (as compared to the grid load) to use the full technical potential (e. g. several hundred hours of operation to reduce to below 6 000 kW). Therefore, the risk of not being operational with full power at the relevant times has to be analysed on a case by case basis.

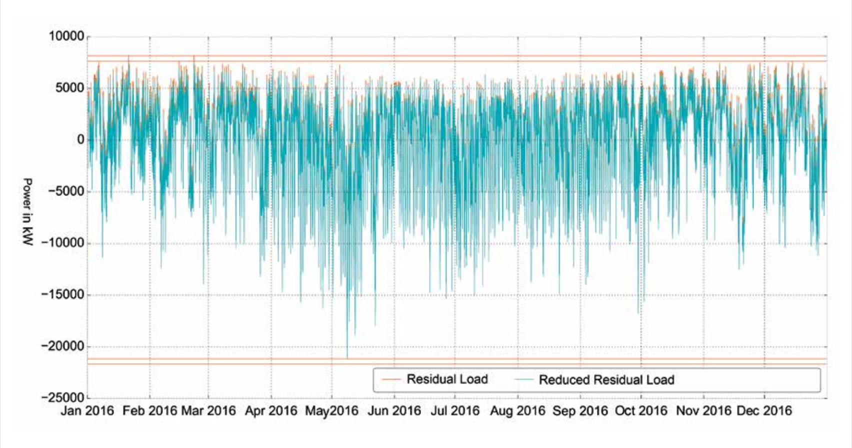

Figure 39: Residual load of a German distribution grid with and without a flexibility of 520 kW, operated to reduce peak residual load to maximise income from avoided grid charges (Source: Fraunhofer Institute for Solar Energy Systems ISE).

8.5 Exploiting Wholesale Market Price Dynamics

Companies supplying electricity to customers usually buy all of the required electricity or any deficits resulting from the difference between local / own generation and consumption on the energy markets. Thus, either they themselves or associated service providers have market licences to offer or sell electricity on the wholesale market. There are different market products for electricity and different price building mechanisms attached to them. Figure 40 summarises the most relevant EPEX trading processes on the Day-Ahead and Intraday time scale.

Value Proposition: Generating income on the wholesale market and offering storage owners / operators a share of electricity trading revenues.

Method: by adjusting operation and management of the storage units connected to the EMP in a way that allows them to import cheap electricity (market price low) and if applicable exporting electricity at high market prices. Achieving this by forecasting of loads, local generation and market prices, and adjusting operation management and contract negation accordingly.

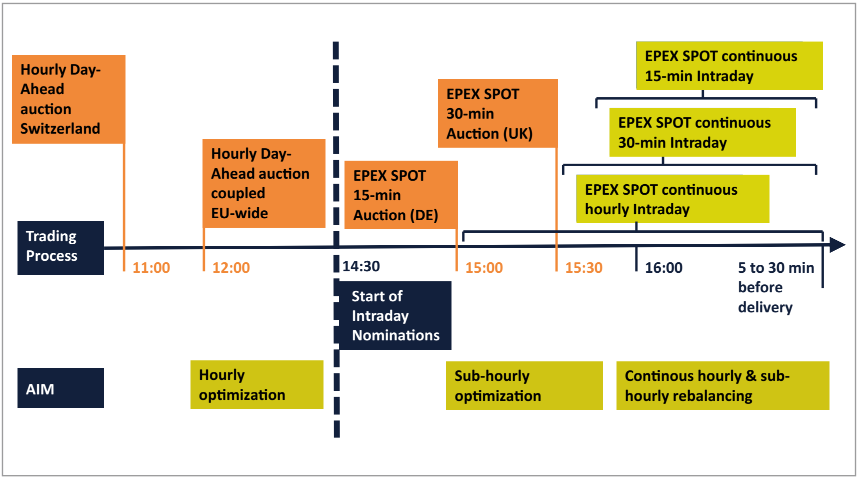

Figure 40: The wholesale energy trading process (Source: Redrawn based on: EPEX SPOT (2018). Trading on EPEX SPOT. Paris, France: epexspot).

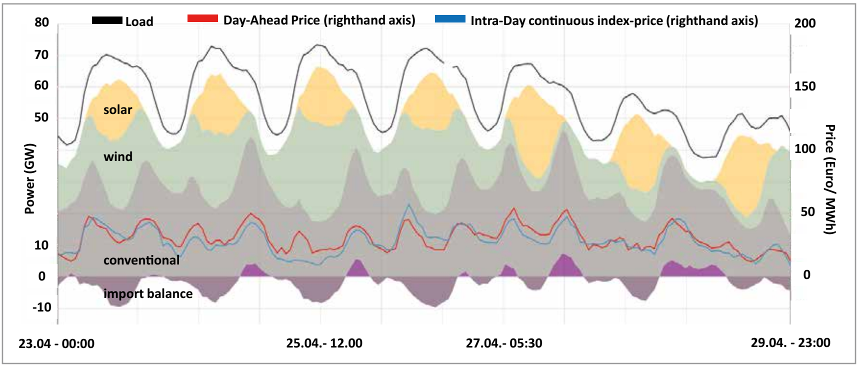

Figure 41: Energy generation and market prices based on German TSO-data (Source: Generated using Fraunhofer ISE Energy Charts Tool at https://www.energy-charts.de/, retrieved 16.10.218).

Electricity stored in distributed energy storage as well as that generated by associated PV installations can be traded on the wholesale Market in more or less the same way as electricity coming from conventional power stations. There are several markets / products to trade energy. There is always price volatility. Figure 41 illustrates highs and lows in market prices in relation to the energy generation mix. Daily peaks from PV generation are clearly discernible.

On the forward and future markets, there are long-term and seasonal volatilities as well as differences between base and peak products (the latter are referring to time of day or working day / non-working day). In the Day-Ahead market there are fluctuations based on predicted loads and fluctuating generation on an hourly basis. The Intraday market shows spontaneous volatility based on prediction errors, which are traded on a quarter hourly basis.

Forecasting errors which are not balanced on this short-term market lead to the need for balancing energy, which is organised by the TSOs – see Section 8.6 on Control Reserve.

Short term markets are showing higher price spreads, high and low price periods are shorter and the traded products have a higher time resolution than on long term markets. This makes them especially interesting for short term storage, as addressed in NETfficient. It is important to notice that both for the Day-Ahead and the Intraday trade there are auctions with merit order price building mechanism. Additionally, there is the continuous trading on the Intraday market where the momentary price strongly depends on the momentary liquidity of the market. Even though a large percentage of energy trading happens as OTC or peer-to-peer trading, normally the prices are linked to the spot market prices (compensation trading is common and results in equalisation of prices on other markets).

Findings of an analysis of an ideal yearly profit potential for storage on the German Day-Ahead market by mixed integer linear optimisation:

- The income potential is limited to 15 553 € per year per MWh of storage capacity
- With an average of 3.6 full cycle equivalents per day
- Both are significantly reduced with reduced power as compared to the capacity (C-Rate: Power / Energy; e. g. 0.5 MW and 1 MWh represents a C-Rate of 0.5 and charging or discharging completely takes at least 2 hours)
- A C-Rate of 1 is the maximum considered since faster charging or discharging doesn’t increase profit or cycles due to the hourly time resolution of the Day-Ahead product at the EEX
- The income potential from optimal scheduling based on wholesale market prices often does not allow for a sufficient business case because of a low frequency of high price spread situations.

Barriers for utilising price spreads at power retail markets are:

- Minimum bid size and increment size (requires sufficient aggregation)
- Market and trading fees for direct participation
- Energy losses and aging when using batteries for temporary balancing of local generation and consumption (in order to follow the price curve at the market).
- Price uncertainties when participating in merit-order-markets

Revenues Wholesale Market Price Dynamics:

A number of simulations have been carried out on the basis of a data set of historic annual price data for EPEX SPOT both for Intraday and Day-Ahead auctions and continuous Intraday trading. The time period considered is the year 2017. For the simulations a 1 MW / 1 MWh battery store was considered, solely buying and selling electricity from and to the EPEX SPOT market.

Figure 42 shows the optimisation of financial gains resulting from buying and selling electricity at the Day-Ahead electricity market EPEX SPOT, taking into account the State of charge. During hours of the lowest market price the battery is being charged completely. At the next opportunity with high market price the battery completely sells this electricity on the market, thus being discharged completely.

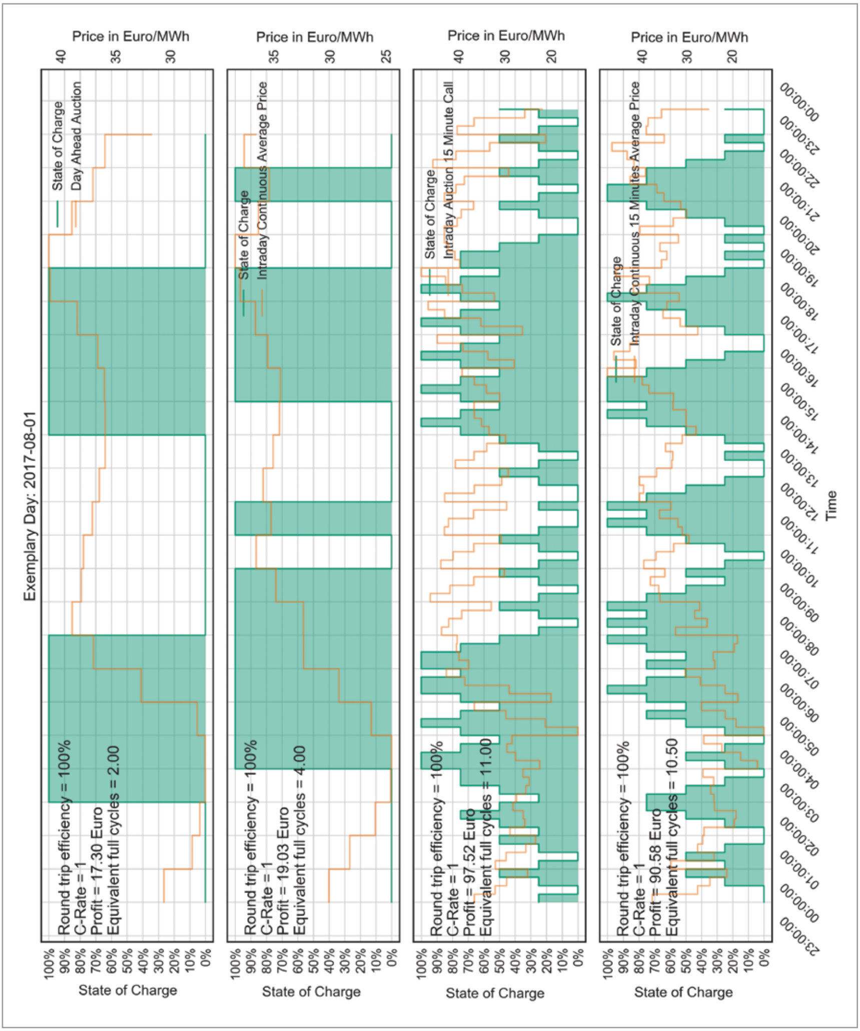

Figure 42: Sample day for simulating the financial profits for storage units buying and selling in optimal way at the Day-Ahead EPEX SPOT market (without losses). (Source: Fraunhofer Institute for Solar Energy Systems ISE).

Making use of the wholesale market price dynamics at the EPEX SPOT market with a battery, expected yearly profits are in the order of magnitude of up to 12 000 € / MW in the Day-Ahead market and up to 107 000 € / MW for the Intraday market. At the Intraday markets high C-rates (up to 4-C) result in a significant increase in absolute income potential but also require increase in cycling. Different operation management strategies are required for the different market products. Incorrect forecasts of the market prices and volumes for each single product slice will strongly influence the achievable profit. The latter is especially significant in the Intraday continuous market.

The annual maximum potential profits are in the order of magnitude of a tenth of the battery costs of about 1 000 T€ / MWh. Taking into account the high amount of cycles it can be assumed, that the lifetime of the battery will not reach ten years (or more than 50 000 cycles) thus battery storage systems will not pay-off by utilising this business approach alone.

8.6 Reserve Power Markets

Value Proposition: Pay the customer a share of revenues received from reserve power sales.

Method: Aggregate a number of storage systems and controllable generators and or loads and determine flexibilities not conflicting the regular operation which the units are designated for at their respective locations. Offer these flexibilities at the tendering platform for balancing power and receive payments for reserve power.

While system services discussed in Section 8.1 to 8.4 were focussed on local aspects being mostly relevant for the local DSO and specific parts of the local distribution grids, there are also system services less dependent on the specific geographic location of the customer in the grid. The most important service is reserve power being provided for an entire control area of a TSO. There are also situations requiring the DSO to lower the aggregated energy import from a higher grid level without any preference from which part of its grid those adjustments emanate. Such services can be an important source for revenues for the VPP.

Control Reserves products are traded on the wholesale market. Control Reserve balances generation and consumption physically, thus ensuring a stable grid frequency (in central Europe: 50 Hz). There are three products which mainly differ in terms of speed of activation:

- Frequency Containment Reserve (FCR)
- Frequency Restoration Reserve (FRR)
- Replacement Reserve (RR)

To participate in Control Reserve trading a prequalification has to be obtained. Batteries today only provide FCR (due to the limited capacity), whereas power-to-heat (e. g. as demonstrated in NETfficient's low temperature thermal storage aquarium-application) and power-to-hydrogen (e. g. as demonstrated with NETfficient's hydrogen-based home storage system) applications are potentially also able to participate in FRR and RR.

Potential income from power price for all products in Germany are shown in Figure 43. In Germany about 1 / 3 of PCR is provided by lithium-ion now. Potential decreased significantly for many products between 2011–2016. Nevertheless, the participation in Control Reserve power (esp. fast products) can be an attractive option.

In Primary Control Reserve, such as the German FCR, there is only one product for a whole week, with provision in both directions – the so-called product NEGPOS_00_24.

In Secondary Control Reserve, such as the German FRR, there are four products for negative ("NEG", increased consumption or decreased generation) and positive ("POS") provision as well as low price time ("NT") and high price time ("HT").

In Tertiary Control Reserve, such as the German RR, there are products for each 4 hour block (e. g. "00_04") of the day, positive and negative.

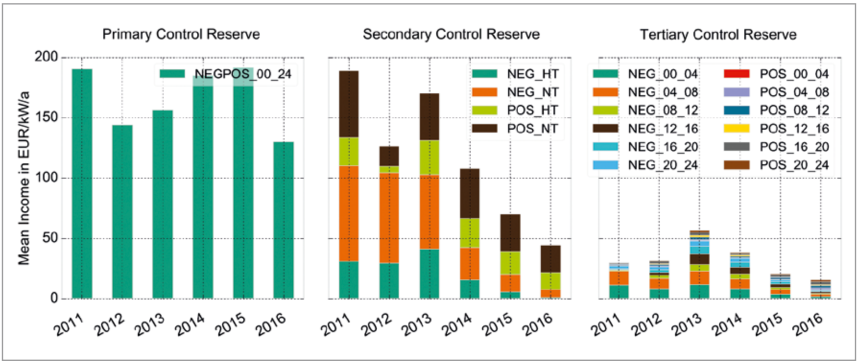

Figure 43: Income potential – Control Reserves (Source: Fraunhofer Institute for Solar Energy Systems ISE).

Offering positive or negative balancing power, however, requires the ability to deliver or import a certain amount of power at completely unpredictable times with extreme reliability and for a rather long delivery period, as specified for the corresponding type of balancing power. Thus, the pool of technical units which are to be selected for physical delivery of balancing power must sustain the required level of flexibility for all of the time period balancing power has been sold.

8.6.1 Convergence and Differences in the EU

There is still huge diversity in the regulation of the electrical energy systems and markets within the EU.

Income potentials differ significantly in terms of time bands and terminology between the different products in Control Reserve and the different countries, as shown in Table 5. Even though the EU strives towards convergence, there are still significant differences between products in Control Reserve.

	Primary Control	**Secondary Control**	**Tertiary Control**	
EU	Frequency Containment Reserve	Frequency Restoration Reserve		Restoration Reserve
		Automatic	Manual	
Germany	Primary Control Reserve	Secondary Control Reserve	Minute Reserve	N / A
Spain	Primary Regulation	Secondary Regulation	Tertiary Regulation	Deviation Management
Sweden	FCR-Disturbance	FRR-A	FRR-M: Fast active reserve (forecast, disturbance and counter trading) and Slow active reserve	N / A
	FCR-Normal			
Great Britain	Primary, secondary and high response (Mandatory and Firm)	N / A	Fast Reserve	Short Term Operating Reserve, Demand Turn Up and BM-Startup
	Enhanced Frequency Response			

Table 5: Control Reserves – national differences (Source: Fraunhofer Institute for Solar Energy Systems ISE).

To illustrate this in greater detail: Frequency Containment Reserve as the most important product for lithium-ion storage has been selected to show the diversity and the importance of analysing business models on a national level in great detail to support decision making. There are differences in parameters in regulation e. g. full activation time (first line in Table 6) on the one hand. On the other hand, there are also differences in control design (e. g. different deadbands, different degrees of freedom).

Parameter	**Germany**	**Great Britain**		**Sweden**	
	PCR	FFR	EFR	FCR-N	FCR-D
Full Activation Time	50 % in 15 s, 100 % in 30 s	Primary: 10 s Secondary: 30 s High: 10 s	< 1 s	63 % in 1 min, 100 % in 3 min	50 % in 5 s, 100 % in 30 s
Minimum Activation Period	With backup unit: 15 min Without backup unit: 30 min	Primary: 30 s Secondary: 30 min High: Indefinite	15 min	15 min	15 min
Full Activation Frequency Deviation	≥ ±200 mHz ≥ ±100 mHz, > 5min ≥ ±500 mHz, > 10min	±500 mHz (or specified in capability data tables)		±100 mHz	±500 mHz
Deadband	±10 mHz	None	Wide: ±50 mHz Narrow: ±15 mHz	±10 mHz	±100 mHz (activation frequency deviation)

Table 6: Different Parameters of Frequency Control in Regulation (Source: Fraunhofer Institute for Solar Energy Systems ISE).

Consequently, the profit from individual products in different countries for Lithium batteries in Frequency Control Reserve varies hugely, as illustrated in Figure 44.

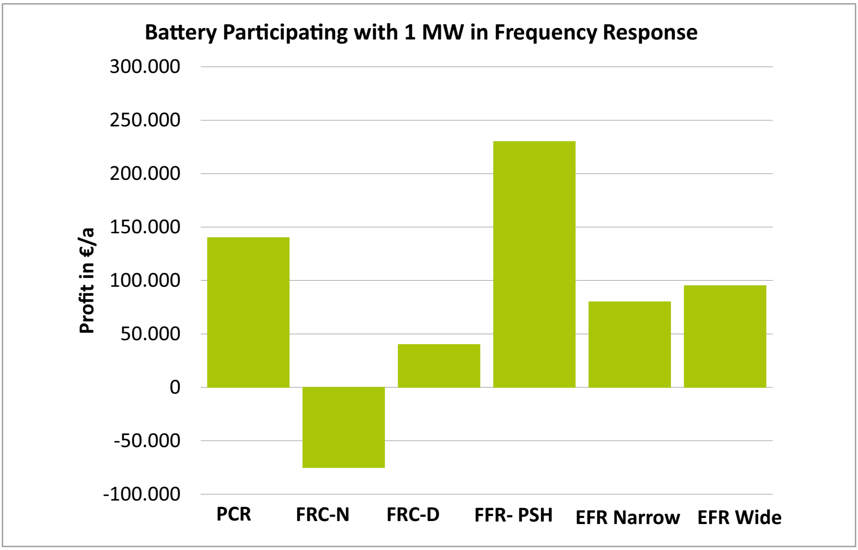

Figure 44: Profit potentials battery participating with 1 MW in Frequency Response (Source: Fraunhofer Institute for Solar Energy Systems ISE).

Comprehensive technical requirements and regulations for the provision of Control Reserve by using battery systems are still immature or non-existing in most EU countries (because of the limited and fluctuating energy capacity of batteries the existing regulations for generators are mostly not applicable).

Regulations and income potentials change fast and have to be analysed continuously on national levels.

NETfficient modelling of storage participating in the market for primary reserve power suggests annual financial gains in the region of 100 to 150 € / kW / year for reserve power provision. As of today, battery storage units cannot be pre-qualified for secondary or tertiary control. Nevertheless, in a pool with flexible generators and loads, participation could be reasonable also for storage units with limited energy capacity.

8.7 Combination of Services

Individual services and products presenting income potentials have been discussed in isolation thus far. The key competence and competitive advantage of a VPP is the ability to combine a number of these potentials in order to build a diverse yet complementary and flexible over-all service, thus maximising benefits and profits both for the storage owners / operators and the VPP.

In most cases individual services can be combined with each other, as long as the required technical flexibility can be ensured.

When combining a number of compatible services with each other, the challenge is to determine the priority of the various services to be performed at any given time. This priority might change rapidly from one period to the next. For illustration one could consider a day with strongly varying grid load. During times of low grid load, management for a battery does not take into consideration payments for avoided grid utilisation at all. Thus, the operation scheduling will prioritise other services. As soon as the grid load rises sharply the strategy of the operation optimisation will change taking into account the opportunities for increased feed-back during times of high grid load.

Thus, marketing a pool of flexible technical units for a collection of combined services requires a highly flexible and adaptive optimisation algorithm "knowing" all the opportunities and challenges of the individual services.

The following Table 7 gives a rough assessment of the compatibility of different services. Compatibility "P" means that this combination requires a combined adaptation of the whole pool of technical units. If for example at the location of one technical unit the maximum peak power of consumption is reached, this unit should not be used to provide negative reserve power and should be replaced in the virtual pool providing the reserve power service by another unit (which is entirely legal). Almost all services for the Spot Market and the Reserve Power Market could be assigned flexibly to individual technical units as long as there are corresponding power reserves available in the pool. However, the exact details of contracts and conditions relating to the product need to be considered.

	Wholesale Market	Self-Con-sumption	Peak Load reduction	Avoided Grid Use Payment	Reliability of Supply	Reserve Power Market	Flexibility for Grid Operators
Wholesale Market		p	p	0	p	+	p
Self-Con-sumption	p		+	+	+	0	0
Peak Load reduction	p	+		+	+	p	0
Avoided Grid Use Payment	0	+	+		+	p	0
Reliability of Supply	p	+	+	+		p	0
Reserve Power Market	+	0	p	p	p		p
Flexibility for Grid Operators	p	0	0	0	0	p	
+ = easily combinable P = combinable if managed in a pool with several technical units 0 = needs a case by case analysis							

Table 7: Options to combine different services with each other (Source: NETfficient project).

In terms of risk assessment, the use of one technical unit for multiple purposes at the same time certainly increases the financial implications of potential malfunctioning. Backup and contingency planning need to be adapted in such cases accordingly.

8.8 Conclusions and Outlook on Revenue Potentials

Currently, there are still significant national (or even regional) differences in legal and regulatory framework, requiring case-by-case evaluations of the business cases and sometimes adaptations of the technical solutions. This is especially the case for the influence of national taxes and levies on the business models of VPPs. There is still some uncertainty in national regulations regarding the classification of batteries as either generators, consumers or something completely new. This has implications on both technical and business concepts.

An aggregator of divers technologies as designed in NETfficient has to handle an enormous complexity and can only utilise its full potential when providing a wide range of services on the local level as well as grid services and trading on wholesale market.

8.9 Lessons for VPP-Businesses

Based on contracts with various customers, where the technical units (storage system, generators, and controllable loads) may be located, and different services, a VPP has the option of either operating these individual units or the pool. The VPP will be able to generate a competitive advantage if, with the help of the EMP, it is able to combine the provision of local services to local customers with aggregated services offered by the aggregated pool. Besides excellent knowledge of the requirements of the individual customers this requires the professional understanding of the market mechanisms of energy and reserve power markets as well as a robust and adequate infrastructure backbone handling all communication and IT requirements (see Chapter 4).

One specific challenge for any VPP will be the choice of appropriate customer groups. There may be a large group of customers composed of owners / users of homes and buildings, owning DER or CHP generation units and having similar interests. It should be relatively easy to offer a standardised service package to these customers, including the same software and hardware solution. However, the profit to the VPP per individual customer is rather low (in the range of 100 € / kW / year) and a large number of customers must be aggregated in order to generate sufficient profit. Therefore, any VPP can add a number of larger customers (commercial and industrial customers, integrated communities) to the portfolio and offer tailor-made solutions to customers. Some local system services such as peak load reduction may become relevant, which are not applicable for most of the small customers.

Costs of the storage system are an important consideration. Even though there is a considerable number of potential customers already owning PV-battery system they, too, will expect the VPP to contribute to the pay-back of their storage systems. Especially if the VPP reserves a part of the storage capacity exclusively for his purposes or if the battery will face increased aging due to a higher number of charging cycles, monetary compensation is necessary. This is also relevant for owners of EVs with battery systems which are able to feed back to the grid or owners of emergency power supply systems.

Handling and maintenance of hardware at the customers' sites, IT-services, forecasting services or direct trading at the energy wholesale market and Reserve Power Markets all carry costs which the VPP has to cover. Considering the relatively low margin predicted, it could be worthwhile to develop internal skills for some of these services with the long-term strategy to sell them independently to other market players.

8.10 Medium to Long-Term Outlook

In the medium term it may well happen that prices for PCR will fall, as has been the case for Secondary Control Reserves and “Minute Reserves”. A higher CO_2 price would help the viability of virtual power stations. So would greater flexibility of electricity pricing, which is to a large degree determined by standing charges (levies and fees) and adaptation of the regulatory framework to emerging developments (esp. the multiple uses of distributed storage)

Regarding the long-term perspective, there may be developments boosting profitability, e. g. falling prices for storage technologies, the need for more technical units balancing fluctuating RES power or the replacement of ancillary services currently being provided by conventional power plants. On the other hand there may be developments that could endanger profitability significantly, such as lowering prices on the markets, restructured tariff systems for energy customers or an implementation of technical regulations requiring some of the services as “mandatory” services to be integrated in the technical units, without payment for them. The best strategy to cope with those risks is to offer a diverse portfolio of services and to carefully watch the political and regulatory developments.

Conclusions for VPP-businesses:

- The most profitable value proposition approaches are an increase in self-consumption, the participation on reserve power markets and the utilisation of price dynamics at the energy spot market.
- Some of the relevant services require pooling of many units with a pool size of multiple MW.
- Any VPP-business will only have a sound economic basis if some of the services are being combined with each other.
- Main customer groups are the many (potential) PV-battery system owners, together with municipal, commercial or industrial enterprises running flexible storage units or other flexible technical units.
- The projected economic margin for contracts with smaller customers is relatively low, requiring many of them to be contracted. Having some commercial / industrial customers with large electrical power units in the pool would ease the situation.
- Besides aspects of competition, the highest risks are of long-term nature, such as the long-term price development on the markets or legal and regulatory changes influencing the value proposition approaches.

9 Environmental Assessment of Storage Solutions

One important aim of NETfficient is to increase the share of renewable energy sources within electricity systems by using energy storage solutions, thus contributing to sustainable development at large. However, storage components such as lithium-ion batteries and corresponding power electronics have to be manufactured and distributed to prosumers. This in itself requires resources and means that components cause an environmental burden. At their end of life (EoL), a dedicated treatment with disassembly and recycling must be organised to ensure that resources are recovered and pollution is minimised.

This constellation, where benefits and drawbacks are expected, can be analysed with a life cycle assessment (LCA). An LCA is an iterative procedure for assessing environmental impacts of products and services in a holistic way.

9.1 Brief Introduction to LCA

The general framework for an LCA procedure is described in international standards and consists of four stages as depicted in the following figure 45.

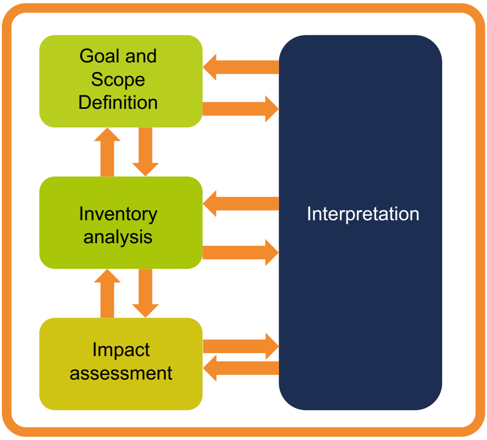

Figure 45: General process for a Life Cycle Assessment (LCA) (Source: NETfficient project).

Collected data for inventory flows are further processed in an impact assessment stage. An LCA provides results for many different impact categories, for example global warming, primary energy demand, acidification or toxicity. Elementary flows from and to the environment that are related to production, operation and recycling of energy systems are assigned to categories (classification) and converted to a common unit within each category (characterisation). Elementary flows are linked to the so-called Areas of Protection (AoPs) via cause effect chains. The AoPs human health, natural environment and natural resources represent the end-points of the assessment (see also Figure 46).

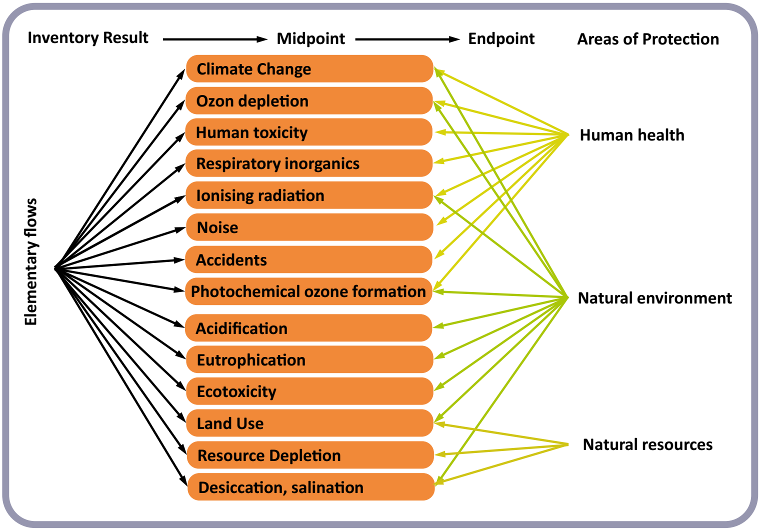

Figure 46: Life Cycle Impact Assessment methods overview (Source: Redrawn based on Joint Research Center – European Platform on Life Cycle Assessment: http://eplca.jrc.ec.europa.eu/?page_id=1159, retrieved 05.11.2018).

9.2 Notes on LCA-Approach for NETfficient

It was not possible during the project to collect sufficient information to estimate longevity and performance of different storage solutions over their lifetime, therefore the analysis is focusing on the cradle-to-gate stages of the life cycle from raw material extraction to assembly and installation at the prosumers' location in Borkum. Estimates for a possible end of life / recycling scenario in the future have been added. Several technology packages have been analysed based on the life cycle assessment (LCA) framework. The environmental assessment considers resource use and expected recovery for components and compares this to the actual benefit which storage components can provide, that is providing electricity from renewable energy sources during their use phase.

9.3 LCA-Analysis for Selected NETfficient Technology-Packages

Material and energy inputs and corresponding emissions for manufacturing, assembly and transport of components to prosumers are included in inventories. Inventory data are then processed in a life cycle impact assessment by classifying them to a set of categories and applying characterisation factors to convert them to a common substance – for example carbon dioxide equivalents for the case of climate change. Full sets of impact categories correspond to different areas of protection, including toxic burden on humans and biosystems, acidification or land use, to name a few. For the case at hand the selected impact categories are related to resource use and emissions of carbon dioxide, as the project aim was to reduce the environmental burden from fossil fuels from conventional thermal power plants in the electricity mix.

Definitions of chosen impact categories and indicators

Contribution to climate change is modelled according to the framework provided by the Intergovernmental Panel on Climate Change (IPCC) with a timeframe of 100 years. Contribution to climate change is measured in kg CO_2 eq.

The cumulative energy demand (CED) is based on calorific values of all materials and processes that are used for processing and assembly, therefore providing a summary of primary energy used. CED is calculated in MJ.

Abiotic depletion potential for finite non-fossil resources is an estimate for the required resources, including among others copper for cables and other equipment. Abiotic depletion is measured in kg antimony equivalents (kg Sb-eq).

In accordance with the goal of the project, namely to provide sustainable electricity, the indicators above have been selected as relevant indicators. The approach is further explained using the example of home systems. Only flows from and to the environment are considered in an LCA. Therefore, the original data items collected for the case, such as for example a specific mass of copper wire, are then combined with background data on copper mining and recycling to consider upstream processes. They are also combined with information on manufacturing processes such as wire drawing to represent flows that are required to provide prosumers with the necessary equipment. This information is complemented with credits for a potential recycling system that needs to be established. Inventory results are then converted to impact assessment results.

Being representative for all applications, homes are equipped with photovoltaic panels with mounting systems, providing options to harvest clean energy. This module as well as connecting infrastructure is considered for all storage options and additionally for a stand-alone PV system with inverter.

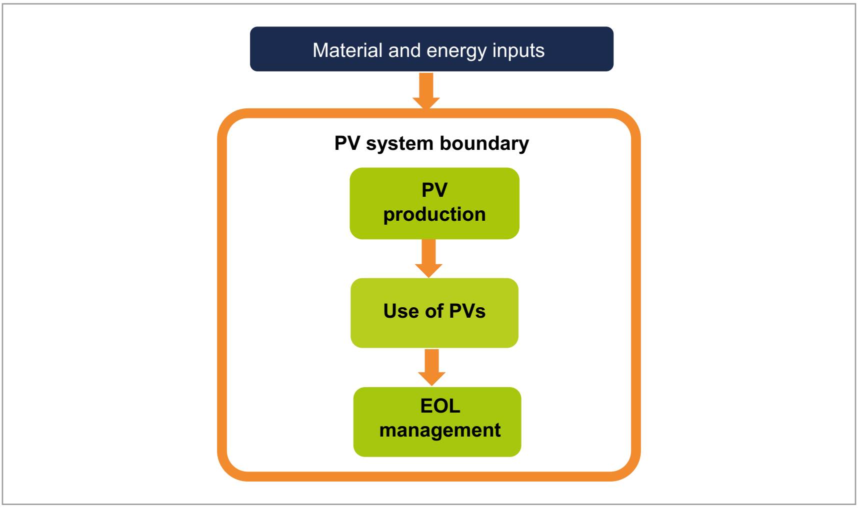

Figure 47: System boundaries photovoltaic home systems (Source: RISE IVF AB).

The storage systems developed for private homes cover a variety of storage options with bespoke inverters:

- Lithium-ion batteries Energy Storage System (ESS),
- Lithium-ion batteries combined with capacitors as a hybrid storage system (HESS),
- Second life vehicle batteries (2LEV) using a traction battery from an electric vehicle,
- Fuel cells combined with two options of hydrogen storage as pressurised storage (H2SS) and as metal hydride storage (MeHSS).

For all storage options, data was collected for the PV system and inverter with boundaries as illustrated in the following system diagram.

Systems and boundaries considered for a complete system with PV and storage units are illustrated in Figure 48 for ESS (Li-ion batteries).

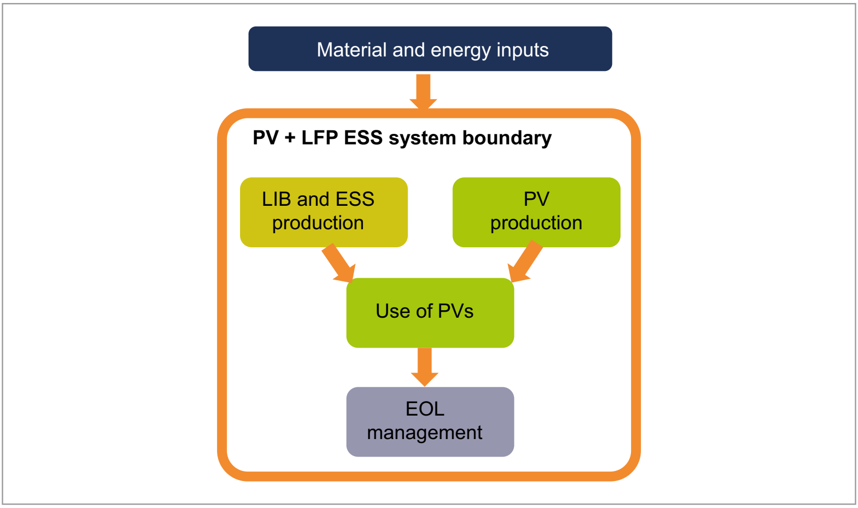

Figure 48: System boundaries ESS home systems (Source: RISE IVF AB).

The system boundaries used for the 2LEV system are illustrated in Figure 49.

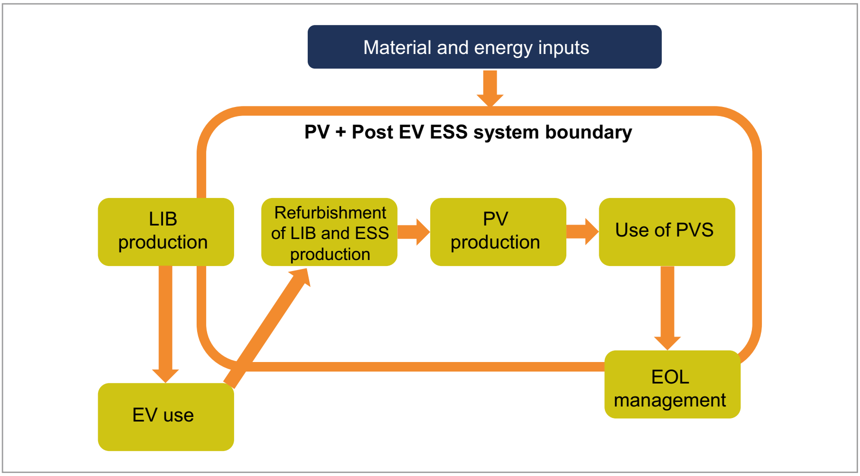

Figure 49: System boundaries 2LEV home systems (Source: RISE IVF AB).

The 2LEV system does not include manufacturing of the batteries themselves, but for refurbishment and for equipment, case and controls which are directly attributed to their application as stationary storage. The refurbishment design is modular, and several batteries can be used in sequence with a single refurbishment. This is not considered in the base model.

The environmental assessment for all systems showed that the storage adds to environmental burden, if compared with a stand-alone PV system. However, the main environmental impact is caused by the PV system itself. This can be shown in a comparison for the indicator cumulative energy demand as illustrated in Figure 50.

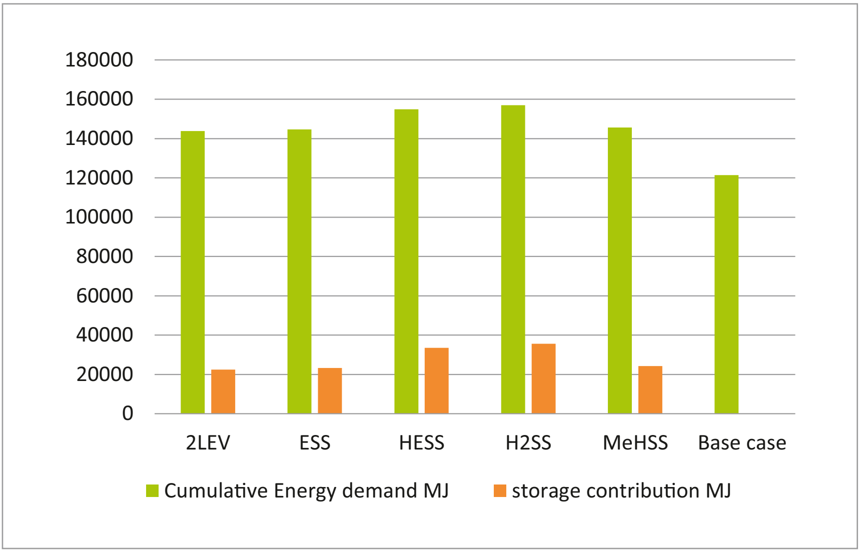

Figure 50: Comparison of CED (in MJ) for all home PV + storage applications and a base case without storage (Source: RISE IVF AB).

For the example of 2LEV ESS and MeHSS, the storage contributes approximately 16 % to the CED of the total system, whereas for H2SS the contribution is 23 %. The increased burden for all storage options can possibly be compensated by an increased utilisation of the PV system. A key factor for that is the longevity of storage options.

For all options the additional CED for the storage was calculated as between 22 500 and 35 600 MJ. The cumulative energy demand per kWh electricity from the German grid, which considers the generation system with shares of fossil fuels and other options, conversion rates, and transmission losses is calculated for the current mix as 10.7 MJ (data from Ecoinvent database).

The results for the converted storage contributions are compared in the following figure 51.

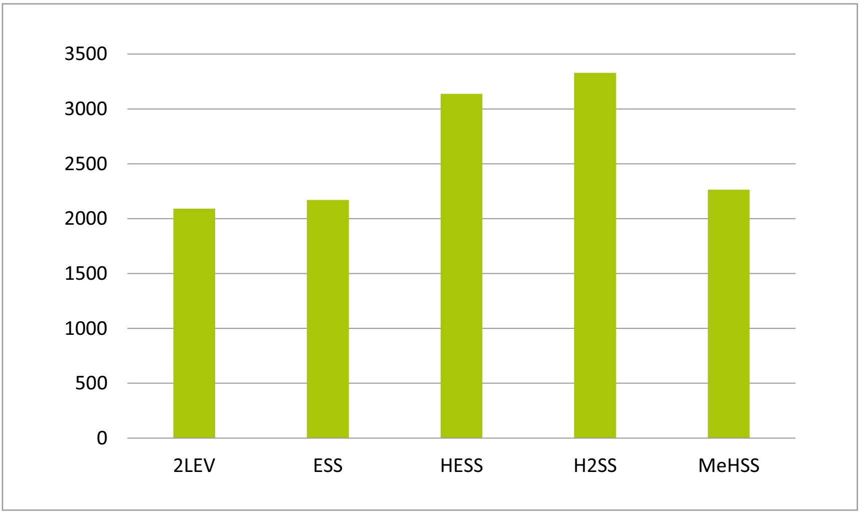

Figure 51: Amount of energy to recover during use phase for energy-break-even (kWh) (Source: RISE IVF AB).

The demands to reach a break-even point from an energy point of view are approximately 2 000 kWh for ESS, 2LEV and the metal hydride hydrogen storage, and approximately 3 000 kWh for HESS and the pressurised hydrogen storage.

This can be interpreted as the amount of grid electricity that has to be avoided by increased utilisation of the PV panel through storage. Since the storage is intended to be used for other purposes also including for local services and trading flexibility, as described in Chapter 8, a direct conversion to charging cycles is not sufficient. Only additional renewable energy, which would not have been available without the use of storage can count towards this energy break-even, i. e. solar energy which may otherwise have been curtailed, due to feed-in regulations (see also Section 8.3). When using the battery to provide negative or positive balancing energy, it would store and release general grid electricity. There may still be an environmental benefit of such services as opposed to having to upgrade the network. However, suitable LCA data for avoided strain on infrastructure or avoided upgrades is not currently available.

Taking into account the above and based on existing experience with longevity of ESS it is realistic to recover the required amount of energy within the life time of the storage unit. For other options the available data are limited. All data are based on non-optimised pilot equipment.

A comparison based on normalised results of different PV systems with storage options for the indicators cumulative energy demand in MJ, global warming potential in kg CO_2 eq and abiotic resource depletion in kg Sb eq shows that all options are in a similar range. Based on data collected for the pilot equipment, the ESS (battery storage) and the 2LEV have slight advantages. For the hydrogen pilots, the MeHSS option shows advantages over the pressurised storage option. Among the reasons for this is that the pressurised storage tank is a polymer composite material, thus fossil resources are considered as input and material recycling is under development. The metal hydride storage consists of metals for which recycling is assumed.

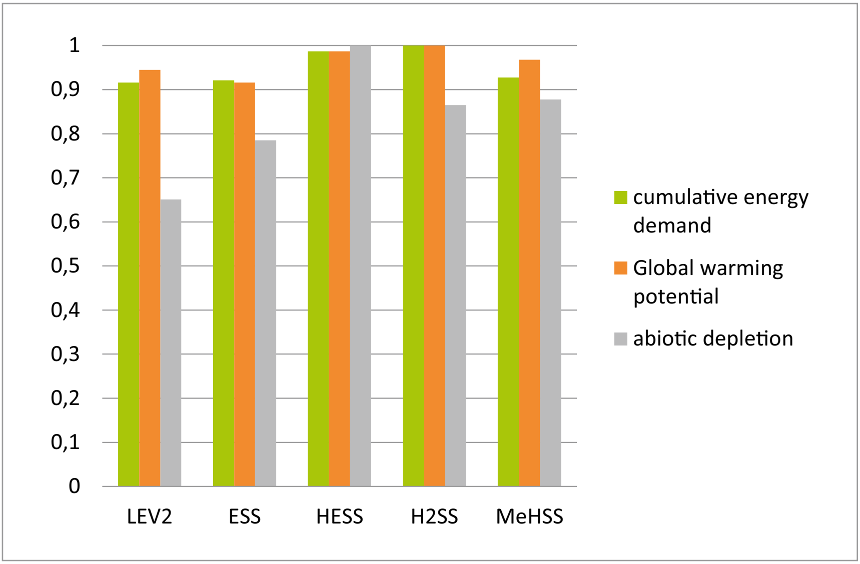

Figure 52: Comparison of normalised environmental burden in three impact categories for technology packages for homes based on cradle to gate + recycling inventories. Largest normalised value per impact category set to 1, all others relative to that (Source: RISE IVF AB).

The normalised results are based on cradle to gate data, differences in performance during the use phase are not considered. The storage capacity of the technology packages varies, but without sufficient information on longevity it is not possible to further evaluate the use phase.

Similar results have been prepared for storage applications in larger buildings and for the medium voltage HESS.

The environmental assessment of the home storage systems shows that the addition of storage to a PV system is beneficial even from the perspective of the prosumer, provided that the longevity of the storage is sufficient and also with the assumption that resource recovery for the components is implemented. From a wider systems and societal perspective, this addition of distributed storage reduces the effort to increase grid capacity.

9.4 Medium-Voltage HESS

In addition to the distributed storage solutions in the low voltage grid a utility scale storage solution based on HESS was also included into the medium voltage grid. The advantage in this case is potentially similar to the case of homes as described above. The municipal utility runs two wind turbines and a large set of photovoltaic panels as publicly owned units. Due to their relevant contribution to feed-in loads, these units have to be curtailed during feed-in peaks. Thus, a storage unit provides similar benefits as for the low voltage cases, an increased utilisation of equipment to harvest renewable energy. The cumulative energy demand for the additional equipment is in this case estimated as equivalent to 250 000 kWh, which corresponds to approximately 500 charging and discharging cycles. Whether this can be achieved depends on a variety of factors including the longevity of the equipment and the demand for curtailing larger units. The storage can also be used to reduce electricity procurement via the cable from mainland, which would mean reduced transmission losses.

9.5 Lessons for Decision Makers

One main purpose for LCA is to support decision making through calculated results for certain indicators on the one hand, but also by revealing impacts and dependencies.

The following lessons from the assessment of NETfficient storage solutions can be summarised:

- **From the perspective of a home owner:** Adding storage to PV systems increases utilisation to an extent that will probably be sufficient to recover additional environmental burden linked to producing, transporting and installing the unit.
- **From the perspective of the municipal utilities:** Encouraging installation of storage is an approach to increase uptake of renewable energy without requiring additional grid capacity.
- **From the perspective of policy makers:** Financial support for storage linked to DER has the potential to be eco-efficient; an integrated energy and waste management policy needs to be established.
- **From the perspective of storage developers:** Longevity of storage components has to be addressed in product development as a requirement to recover initial burden on the environment due to material and energy use for manufacturing; material efficiency in design contributes to reduced environmental burden and shorter energy payback periods.

10 Conclusions and Outlook

The NETfficient project centred around the piloting of energy storage and DER-aggregation solutions, stretching across a wide range of scales and technologies. During the course of the project the energy landscape has moved on – the mega-trends of decarbonization, decentralization, diversity in combination with digitalization are now shaking up the entire energy sector to a much more noticeable degree than when NETfficient was conceived[26]. Consequently, key markets for the technologies, which were developed and brought to maturity during the project now find an exciting global environment in which to spread.

In line with long-term energy strategies, the energy landscape in Europe is undergoing continuous changes, affecting opportunities and viability for energy storage and aggregation. There is an ongoing standardisation process addressing all electricity grid related matters, including regulations, standards and markets. Though challenges currently remain, barriers for aggregated flexibility providing services are expected to fall. This environment will be sketched out in this section, putting previously presented project outcomes into economic and policy context.

10.1 The Challenge Ahead

The cost of new-build renewables has been sinking. Based on figures from the US, the highest-cost solar and wind projects can now produce electricity at least as cheaply as the lowest-cost coal plants[27]. It can therefore be expected that by the early 2020s, renewables will be cheap enough to be more cost effective to build than to operate even an existing coal or nuclear plant[28]. Never-

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[26] Smart Energy International (Journal): #EUW18 – Immerse yourself, p.46, Issue 5 2018

[27] Based a report by Lazard Inc, 2017 as quoted in Fickling, D. (2018). The cost of renewables has been sinking. https://www.bloomberg.com/opinion/articles/2018-05-20/storage-will-be-the-next-biggest-thing-in-energy, retrieved 05.11.2018

[28] Jim Robo, CEO of Florida-based NextEra Energy Inc., during an investor call in January as quoted in: Fickling, D.(2018). Storage Will Be Energy's Next Big Thing, https://www.bloomberg.com/opinion/articles/2018-05-20/storage-will-be-the-next-biggest-thing-in-energy

theless, coal fired plants are still being retained, in particular in Germany for residual load, despite being highly carbon intensive and not well suited to the increasingly dynamic residual load curves. Gas-fired power stations would be far better suited to complement renewables in the short to medium term, as they modulate much more easily and hence be operated in a far more responsive manner than coal fired power stations.

The reasons for coal-fired power stations running regardlessly lie in the "merit order effect", which is a description of the mechanism by which the market price is set at the electricity exchange. It refers to the sequence in which power stations contribute power to the market, based on the cheapest offer made by the power station with the lowest running costs. The growth of renewable electricity with low or zero marginal cost (due to "free" sun/ "free" wind) has led to lower wholesale electricity prices. These set the starting point. The lowering of the entrance price due to renewables pushes more expensive conventional producers down the merit order. This affects the more expensive gas powered plants in particular, leaving coal as the next most cost-effective option in the system.

Due to the inflexibility of coal plants, but also due to local constraints on network capacity and congestion, renewables are being curtailed, thus expelling a proportion of the cheaper generation capacity from the mix, making the grid mix again more expensive than necessary for consumers. If using storage in order to balance variability of renewable energy output this will at the very least have the effect of allowing conventional generators to run more steadily and efficiently, saving a small percentage of CO_2 and cost. Eventually, however, the use of storage in conjunction with renewables will reduce the residual load, ultimately reducing it to what can be covered by biomass and power-to-gas solutions.

Therefore the declared objective for flexibility measures has to be to avoid curtailment of cost-effective low carbon renewables in the first instance, thus to increase their share in the mix, to avoid back-up power and gradually reduce residual power.

10.2 The Bigger Picture: Targets and Drivers

Whereas localised barriers for self-consumption, storage, and DER-aggregation remain, there is currently a discernible mood, that the triumph of these over incumbent energy systems models is unstoppable, with renewables of course being vital for long-term decarbonisation of the EU energy system.

Since 2014 when the target of 27 % renewable energy in the EU was adopted, there have been considerable changes in the energy sector. Cost reductions for key renewable technologies, in particular PV and offshore wind, have been much faster and more extensive than expected, hence increasing the renewable potential that can be harvested cost-effectively. In end-use sectors, too, accelerated technological developments occurred. Electric vehicles are close to commercial maturity and could play a key role in both, the transport and power sectors. At the same time, new information and communication technologies are changing the way energy systems are being designed and operated. With these developments in mind, the EU's 27 % renewable target appears rather conservative.

The report "Renewable Energy Prospects for the European Union" by the International Renewable Energy Agency (IRENA) claims that a faster deployment of renewables by 2030 is technically feasible with today's technologies. The EU could increase the renewable share in its energy mix cost effectively to 34 % in 2030. Indeed, all EU countries have cost-effective renewable potentials at their disposal. Even if leaving aside the considerable economic value of the associated environmental and health benefits, cost-effectiveness is given.

The additional investments required to achieve this share of 34 % by 2030 would support Europe's leading role by creating a new industrial base around the renewables sector, thus benefitting growth and balance of trade, as macro-economic effects. Much broader social benefits for the EU and individual Member States would ensure, boosting economic activity and creating jobs. In addition, the decentralised nature of many renewable energy technologies have the potential to drive economic development in structurally weak regions and rural areas. Combined with energy efficiency measures, renewables can furthermore contribute to reducing energy poverty in the EU[29].

The various weather extremes during the summer of 2018 brought a first taste to Europe of the deleterious economic effects climate change implies, notably in the agricultural and shipping sectors. An accelerated move to less carbon intensive energy systems is imperative, if the EU is to be aligned with a decarbonisation trajectory compatible with the "well-below" 2°C objective established in the Paris Agreement, thus protecting the health and quality of life of its citizens. This can only be achieved, if the long-term goal of an almost complete decarbonization is attained.

Indeed, the trend towards far-reaching penetration of renewable energy sources is undisputed, as it is already enshrined in existing European legislation. As all EU countries gradually phase out fossil-based base loads, importing and exporting will no longer be a viable way of dealing with temporary shortfalls or excess generation. Flexibility options such as storage, in particular as part of VPPs, are thus unavoidable and it is generally acknowledged that energy storage is indispensable. Some would even argue it is simply needed – regardless of cost[30].

10.3 The Global Market Picture

In line with the bigger picture, great levels of growth in related markets are being forecast. The most important global market trends have been compiled based on recent studies.

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[29] European Union and IRENA (2018): Renewable Energy Prospects for the European Union, European Commission, Brussels, February 2018.

[30] Bernhard Rindt at EUW2018, Vienna, Panel discussion "Panel discussion: Integrated storage Applications", ELSA Final Event, 07.11.2018.

10.3.1 Outlook for Storage

It has become increasingly common for TSOs to procure balancing and ancillary services from batteries – be it utility scale batteries or pools of distributed storage in order to deal with grid stability and power quality issues[31]. For DSOs it can be a case of needing more flexibility so urgently, any available flexibility will be bought, in order to save energy, avoid losses, for power balancing, power quality (reactive power) and local peak shaving to reduce strain on infrastructure. Again, the use of batteries is becoming increasingly common[32]. In principle, TSOs and DSOs are technology neutral in their procurement of flexibility – what counts is the best price.

According to a forecast by Bloomberg NEF (BNEF), the investment in battery storage will surge to $ 1.2 Trillion by 2040, reaching a cumulative 942 GW[33]. Energy-storage deployment is expected to exceed 50 GWh annually by 2020 and may be equivalent to 7 % of the world's total installed power capacity by 2040. The Asia-Pacific region is expected to home 45 % of total installations on a MW-basis by 2040, whereas 29 % will be spread across Europe, Middle East and Africa. The remainder will be in the Americas. The majority of storage capacity will be at utility-scale until the mid-2030s. By then behind-the-meter projects at businesses, industrial sites and residential properties may overtake utility-scale storage. China, U.S., India, Japan, Germany, France, Australia, South Korea and the U.K. are considered to represent the most important markets. In addition to the rise of electric vehicles and solar power driving the market, energy access for remote areas also plays an important role. Developing countries in Africa are expected to start playing a role in the storage market, too, as utilities recognize that the combination of PV with batteries in remote off-grid sites is cheaper than extending grid infrastructure or installing fossil-only generators, even where diesel-back-up is required.

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[31] E.g. https://www.pv-magazine.de/2018/10/30/tennet-praequalifiziert-ampard-speicher-fuer-primaerregelleistung/

[32] Various DSOs at EUW2018, Vienna, 07.11.2018.

[33] Eckhouse, B. (06.11.2018): The Battery Boom Will Draw $1.2 Trillion in Investment by 2040, https://www.bloomberg.com/news/articles/2018-11-06/the-battery-boom-will-draw-1-2-trillion-in-investment-by-2040.

It can be expected that eventually most stationary batteries will be second life vehicle batteries[34].

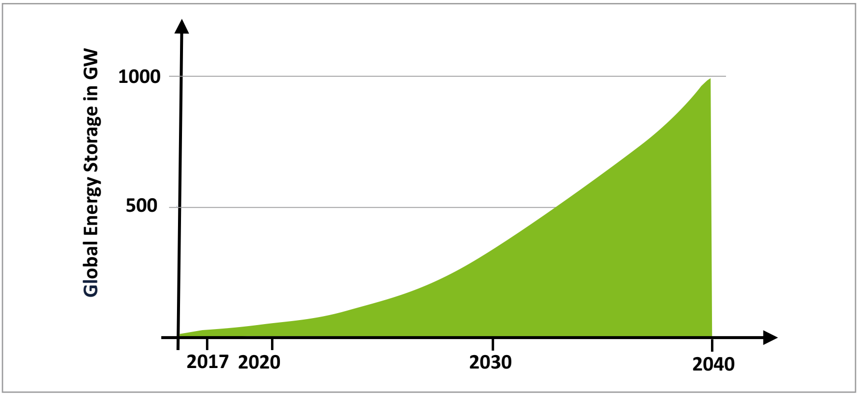

Figure 53: Global energy storage rising to one terawatt in two decades according to Bloomberg NEF[35] (Source: Redrawn based on Eckhouse, B. (6.11.2018). The Battery Boom Will Draw $1.2 Trillion in Investment by 2040).

10.3.2 Outlook for VPPs

Already now VPPs have become a market force to be reckoned with. For example in the UK – the VPP-operator Limejump operates 30 % of all Firm Frequency Response energy supply for the UK-National Grid. They operate a portfolio of flexible resources stretching across 130 sites and including one of the largest battery portfolios world-wide[36].

Globally, the market for virtual power plants is expected to grow by 18.6 % annually and reach $ 5.5 billion by 2023, according to P&S Market Research[37].

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[34] Stringer, D., Ma, J. (27.06.2018): Where 3 Million Electric Vehicle Batteries Will Go When They Retire?, https://www.bloomberg.com/news/features/2018-06-27/where-3-million-electric-vehicle-batteries-will-go-when-they-retire, retrieved 11.11.2018.

[35] Eckhouse, B. (06.11.2018): The Battery Boom Will Draw $1.2 Trillion in Investment by 2040.

[36] Limejump https://www.limejump.com/, retrieved 10.11.2018.

[37] Prescient and Strategic Intelligence (03.2018): Virtual Power Plant Market to Reach $5,510.2 Million by 2023. https://www.psmarketresearch.com/press-release/virtual-power-plant-market, retrieved 10.11.2018.

The increasing penetration of renewable energy sources in the energy mix across different parts of the world, will be the main driver for this market.

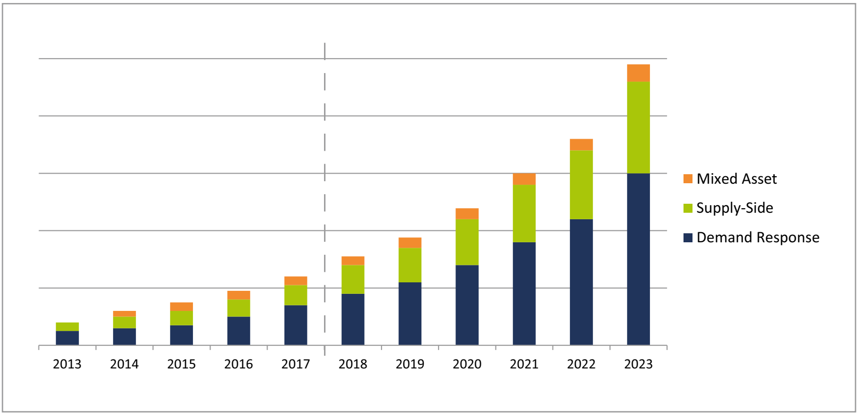

Figure 54: Global virtual power plant market, by technology, MW (2013–2023) according to P&S Research (Source: Redrawn based on https://www.psmarketresearch.com/market-analysis/virtual-power-plant-market).

The market can be broken down into Demand Response, Supply Side, and Mixed Asset. With a revenue contribution of more than 40 % in 2017, demand response is likely to be the most important market globally. It is North America which has been holding the largest share in the virtual power plant market with an estimated contribution of more than 35 % in terms of capacity in 2017. The U.S. is still the most advanced as well as the largest market for VPPs in the world, mainly due to the expanding capacity of renewable power projects in addition to the development of smart grid networks equipped with VPP technology.

Generally, a shift is discernible toward VPPs, which require less capital than conventional power plants and can integrate various distributed energy resources. Countries such as China, the U.S., and Germany have commercially viable VPP pilot projects. Global players such as Tesla Inc.[38] have announced large scale investment plans in setting up virtual power plants. By 2025, the

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[38] Alvarez, S. (24.05.2018): https://www.teslarati.com/tesla-virtual-power-plant-south-australia/, retrieved 10.11.2018.

global investment into implementation of these plants is expected to reach $ 2.1 billion.

Renewable energy ambitions of emerging countries such as China and India will further push growth in this sector. China for example has a target for 2020 to generate 150–200 GW of solar power. The development of renewable energy will generate a large pool of distributed energy which will require appropriate infrastructure in order to ensure a reliable flow of electricity.

At the same time ageing power transmission networks in the majority of advanced countries will underpin the trend towards VPPs. Networks not being capable of accommodating intermittent DERs, frequent network failure, high transmission and distribution losses all cause a decrease in returns to utilities. Through accurate estimation of electricity demand and supply, VPPs can ensure consistent flow of electricity to the power transmission network.

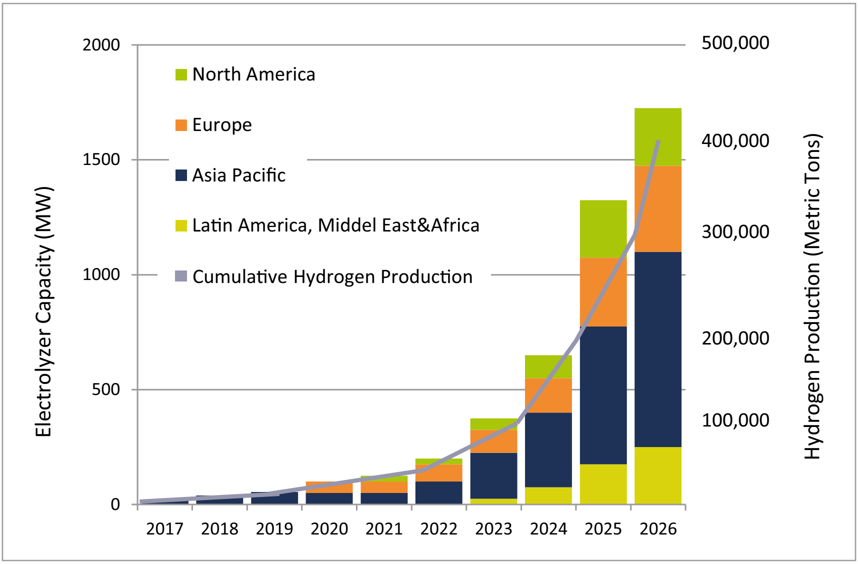

Figure 55: Annual installed power-to-gas capacity and cumulative hydrogen production by region, world markets 2017–2026 according to Navigant Research (Source: Redrawn based on Beez, W. (20.02.2018): The Future of Power-to-Gas Couldn't Be Brighter, https://www.renewableenergyworld.com/articles/2018/02/the-future-of-power-to-gas-couldn-t-be-brighter.html).

10.3.3 Outlook for Power-to-Gas

In order to reach EU-decarbonisation and renewable energy targets, not only electricity generation needs to be tackled. All possible renewable transport options need to be used, and heating and cooling solutions, which make up more than one third of the untapped renewable energy potential, have to be capitalised on[39]. Gas infrastructure and power-to-gas technologies, including smaller decentralized installations as piloted during NETfficient, are likely to play an important role. Variable and intermittent renewable electricity is converted to renewable gases (H_2 or synthetic natural gas) with low carbon footprint. Power-to-gas can be used to decarbonize the gas grid by replacing fossil natural gas – initially as small percentage of hydrogen added to the natural gas. For a larger renewable proportion in the gas grid, hydrogen can be converted to synthetic natural gas. The gases can be stored, transported, and used for mobility or industrial applications (green chemistry). Power-to-gas is able to add flexibility to energy systems and therefore facilitate higher shares of renewables by interlinking the power grid and the gas grid which has ample capacity for storage and transport (sector coupling). The gas grid is being recharged without timing or technical restrictions, thus allowing utilities to generate electricity and store it for a variety of uses at a later time and place. Navigant Research estimates exponential market growth as shown in Figure 55, reaching revenues for electrolysers of $ 2.2 billion in 2026[40].

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[39] European Union and IRENA (2018): Renewable Energy Prospects for the European Union, European Commission, Brussels.

[40] Beez, W. (20.02.2018): The Future of Power-to-Gas Couldn't Be Brighter, https://www.renewableenergyworld.com/articles/2018/02/the-future-of-power-to-gas-couldn-t-be-brighter.html).

10.3.4 The NETfficient message

The NETfficient project has piloted a wide range of storage solutions, including less common technologies such as hydrogen storage and second-life vehicle batteries, which are likely to play an increasing role in the future. The advantages of operating these as an aggregated resource have been studied and analysed in a real-life environment.

The project allowed 13 partners from all over Europe to develop their respective products, skills and knowledge, bringing a number of technologies from prototype stage to maturity. The studies undertaken alongside, feeding this handbook prove that aggregated energy storage has a wide range of revenue potentials, and the energy storage options piloted can have beneficial effects in terms of the environmental impact of the energy systems they sit in. The EMP is a powerful tool for realising these advantages.

Great market growth can be expected for selling flexibility and the components required to provide it.

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Renewable energies are extensively available, but neither easy to predict nor to store. So how can we provide clean, renewable energy for tomorrow's energy demand?

NETfficient is a project funded under the EU's Horizon 2020-Programme for Research and Innovation tackling this question. NETfficient's answer comprises local smart grid solutions and decentralised energy storage for low and medium voltage application in a real environment: the German Island of Borkum. In the endeavour to pilot a future-proofed energy system NETfficient brought together 13 partners from seven countries.

Technologies range from lithium ion batteries, ultracapacitors and second-life vehicle batteries to hydrogen storage solutions and thermal storage, all in connection with photovoltaics. Applications cover single family dwellings, larger buildings, streetlighting, an aquarium and medium voltage peak-shaving. To maximise their technical and economic potential all these distributed energy resources are connected to an energy management platform, turning them into a virtual power station.

The NETfficient Handbook draws on a number of extensive studies on storage integration which have been undertaken alongside the real-life pilot. These cover regulatory aspects, revenue potentials and environmental impacts. These aspects are framed by detailed descriptions of the hardware and software solutions developed in the project.

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