ECES Annex 28
DESIRE

IEA ECES Annex 28

Distributed Energy Storage for the Integration of Renewable Energy

Final Report

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About this Report

To	**International Energy Agency** Executive Committee of the Energy Conservation through Energy Storage (ECES) technology collaboration programme.
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List of Abbreviations

ATES	Aquifer Thermal Energy Storage
BTES	Borehole Thermal Energy Storage
CAES	Compressed Air Energy Storage
CEEP	Critical Excess Electricity Production
CES	Cloud Energy Storage
CO_2	Carbon dioxide
CHP	Combined Heat and Power
COP	Coefficient Of Performance
DES	Distributed Energy Storage
DH	District Heating
DME	DiMethyl Ether
EASE	European Association for Storage of Energy
ECES	Energy Conservation through Energy Storage (an IEA TCP)
EES	Electrical Energy Storage
EFB	Energy Flexible Building
EH	Electric Heating
ENTSO-E	European Network of Transmission System Operators for Electricity
EV	Electric Vehicle
HP	Heat Pump
HUES	Hybrid Urban Energy Storage
ICE	Internal Combustion Engine
IEA	International Energy Agency
O&M	Operation and Maintenance
P2G	Power-to-Gas
P2G2P	Power-to-Gas-to-Power
P2H	Power-to-Heat
PEM	Proton-Exchange Membrane
PHES	Pumped Hydro Energy Storage
PTES	Pit Thermal Energy Storage
PV	Photovoltaic electricity generation (module)
R&D	Research and Development
RES	Renewable Energy Source
SNG	Synthetic Natural Gas (or Substitute Natural Gas)
SOC	Solid Oxide Cell
SOEC	Solid Oxide Fuel Cell
SOFC	Solid Oxide Electrolysis Cell
TCP	Technology Collaboration Programme (of the IEA)
TES	Thermal Energy Storage
TRL	Technology Readiness Level
TTES	Tank Thermal Energy Storage
V2G	Vehicle-to-Grid

Political Statement

The main question of the Annex was: **What can be the contribution of distributed energy storage to the integration of renewables in our future energy systems?** After 4 years of intense discussion and exchange of over 40 experts from 15 countries in 8 meetings the following results could be achieved

- **A large variety of decentralized storages at a high degree of maturity is available** and therefore offer opportunities to improve the operation of energy systems. The diffusion of and expertise on technologies differs in most countries. Transfer of knowledge is therefore necessary.

- Until now, decentralized storage systems are primarily locally optimized. **The increasing deployment of decentralized storages allows for smart and grid-friendly operation in the future without losing the local added value. R&D on intelligent control mechanisms is needed.**

- Although many business models for decentralized storages are already economically feasible or almost feasible and investment costs are constantly decreasing, unfavorable or frequently changing legislative framework conditions hinder extensive deployment. **Therefore, a stable legal framework that also adequately considers decentralized storage is necessary.**

- **Decentralized storage systems are particularly economically advantageous if they are able to address** multiple applications at the same time. Especially **cross-sectoral applications**, i.e. addressing electricity, heating or mobility market, show the highest impact.

    - **Today, power-to-heat is a cost-effective solution** (e.g. heat pump with storage), which not only allows RES to be integrated into the heating sector, but also offers flexibility to the electricity sector. However, a level playing field is necessary for power-to-heat solutions in order to make business cases possible.

    - **Power2Mobility is a future solution integrating RES in the mobility sector (CO2 reduction) and simultaneously offering decentralized flexibility to the electricity sector.** The direct coupling of electricity and mobility (Vehicle to grid, VtG) is even more grid-friendly,

- **A cross-sectoral coupling of different decentralized storage systems offers the highest flexibility to the grid. This requires very fast, intelligent communication and control in a smart network.** Therefore, smart grid technology needs to be addressed in research and brought to the market.

Main Results In a Nutshell

The overall goal of Annex 28 is to foster the role of Distributed Energy Storages, DES, and to better evaluate the potential storage capacities for the integration of renewables at an economical competitive level.

Distributed energy storages (DES) are located at the consumer side. Looking at the electricity grid, this would be the distribution level. This is also the level, where local renewable energy sources should be integrated. In general all types of energy storage technologies can contribute to DES solutions.

Subtask 1: "Storage Solutions for the Integration of Renewable Energies":

- Over 90 different distributed energy storage (DES) configurations – a configuration consist of energy source, energy storage and energy user – have been identified. Most of them are commercially available (TRL ≥ 9).
- About 40 % of the DES configurations are realized by electrical energy storage, 40 % by thermal energy storage and 20 % by power-to-gas installations. In general all types of energy storage contribute to DES solutions.
- Almost all DES configurations operated today are optimized for their local application. Grid (electrical and thermal) services provided by DES configurations are expected to present additional benefits. More R&D is needed to quantify this approach.

Subtask 2: "Economic Analysis & Business Cases"

- There are many business possibilities, although the regulatory framework must be modified to support the large-scale deployment of DES, to harvest its many benefits across market segments.
- Therefore, there is an urgent need for multidisciplinary, and multi-stakeholder R&D concerning the influence non-technical barriers and regulatory framework on the business opportunities of DES.

Subtask 3: "Potential of Distributed Storage Solutions for the Integration of Renewable Energies"

- The potential of DES technologies was modelled in the context of a whole energy system on a national scale. Three indicators were used for evaluation: The annually discharged energy from the DES, the reduction in the total annual CO2 emissions and the total annual socio-economic cost of the system.

- The most feasible technology combinations are those that provide flexibility to the electricity and the heating sector by the implementation of DES solutions (“flexible” sector coupling). In this context thermal energy storage (TES) in district heating (power-to-heat) is a promising approach.

- A redesign of the energy system towards more district heating increases the potential for introducing low-cost distributed energy storage like large-scale thermal energy storages. The same holds for more electric vehicles with smart charging, which introduces a substantial and cost-effective distributed electrical energy storage capacity in the system.

- R&D demand exists concerning simulation approaches, which include local effects and allow quantifying the actual DES potentials in more detail.

Subtask 4: “Control Requirements for Distributed Energy Storages”

- In order to operate distributed energy storage solutions with additional benefits to electrical and thermal networks, intelligent operation and control mechanisms are necessary. This could be realized by e.g. Smart Grid installations.

- A state-of-the-art collection of smart grids including DES showed three main applications: The support of substations and transmission & distribution (T&D) equipment, ancillary services like frequency and voltage control and arbitrage operation caused by fluctuating electricity prices. Mainly electrical DES are suitable for these approaches.

- There is a high R&D demand when it comes to control requirements for more complex energy systems, like coupling of the electricity, mobility and thermal sector and the implementation of DES solutions (e.g. “flexible” sector coupling).

1 Executive Summary

1.1 Objectives, Structure and Approach of the Annex

1.1.1 Objectives

The overall goal of Annex 28 is to foster the role of Distributed Energy Storages, DES, and to better evaluate the potential storage capacities for the integration of renewables at an economical competitive level. For this the following measures are taken:

- Identifying actual applications for DES to integrate fluctuating renewable energy sources into future energy systems

- Examining distributed energy storage technologies and their properties (including mechanical, electro-chemical, thermal and chemical and biogas approaches)

- Reviewing storage properties requirements depending on the different renewable energy sources (wind, PV, solar thermal, …)

- Quantifying potential of DES systems for the integration of renewable energies based on the actual final energy demand

- Promoting best practice and success stories examples

1.1.2 Scope

The scope of this Annex includes all energy storage technologies suitable on the consumer side. Three main fields of application – households, trade and commerce and industry – will be investigated.

The Annex will cover the following topics:

- Assessment of all storage technologies which show a technical and economic potential for distributed applications (e.g. batteries or cold and heat storages) in uni- or bidirectional operation.

- Investigation of system concepts with the temporal mismatch between fluctuating, renewable energy sources (wind, PV, solar-thermal, …) and the corresponding energy demand.

- Evaluation of national energy scenarios of participating countries with focus on the development of renewable energies

1.1.3 Collaboration with other TCPs

Collaboration with other Technology Collaboration Programme (TCP) within the IEA Technology Network is crucial for this Annex.

- TCPs for Renewable energy sources: Wind, PVPS and Solar Heating and Cooling from the Renewable Energy Working Party (REWP)

- TCPs for Applications: buildings, appliances and electric vehicles, (EBC, Heat Pump Technologies, 4E and HEV) and Demand Side Management DSM from the End-Use-Working Party (EUWP)

- Programs for distribution and scenarios: DHC and the International Smart Grid Action Network (ISGAN) as well as ETSAP

1.1.4 Main Question and Definition of „Distributed Energy Storage“

The main question of the Annex is, **what can be the contribution of distributed energy storage to the integration of renewables in our future energy systems?**

This Annex is looking at “distributed” energy storages as storage solutions located at the consumer side of the energy system. Figure 1.1 is visualizing the relation of DES on the consumer side including local renewable energy sources, including the possibility of DES being located directly at the renewable energy source.

The distribution grid is placed on top of this tetrahedron to represent the connection to the higher grid levels with centralized power plants.

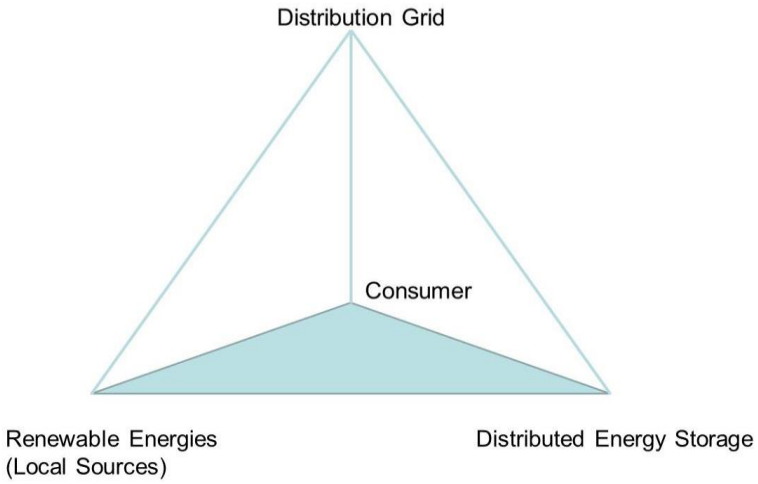


Figure 1.1: Definition of „Distribiuted Energy Storage“, DES

In order to categorize the different possibilities to utilize DES for the integration of renewables the following matrix was developed. It shows the operation of DES systems for the integration of renewable energies on different levels by usage of thermal and/or electrical and chemical energy storage (which is limited to power-to-gas technologies in this context).

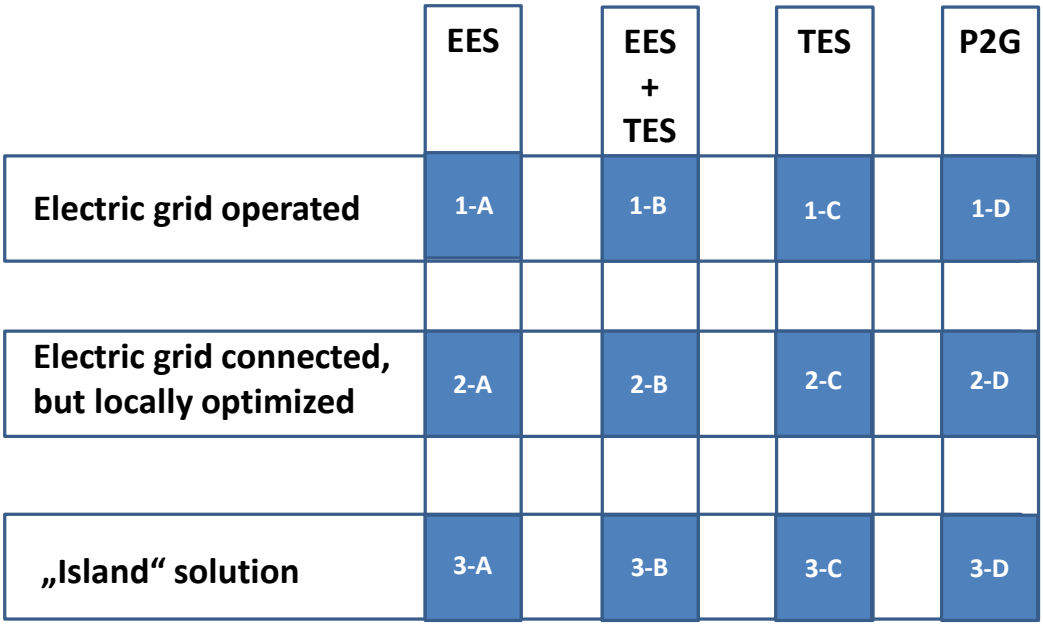


Figure 1.2: Application/ storage technology matrix

1.1.5 Structure and Approach of the Annex

The Annex work is structured in Subtasks. The main question on how much DES can contribute to the integration of renewable energies in future energy systems is approached within Annex 28 from different sides:

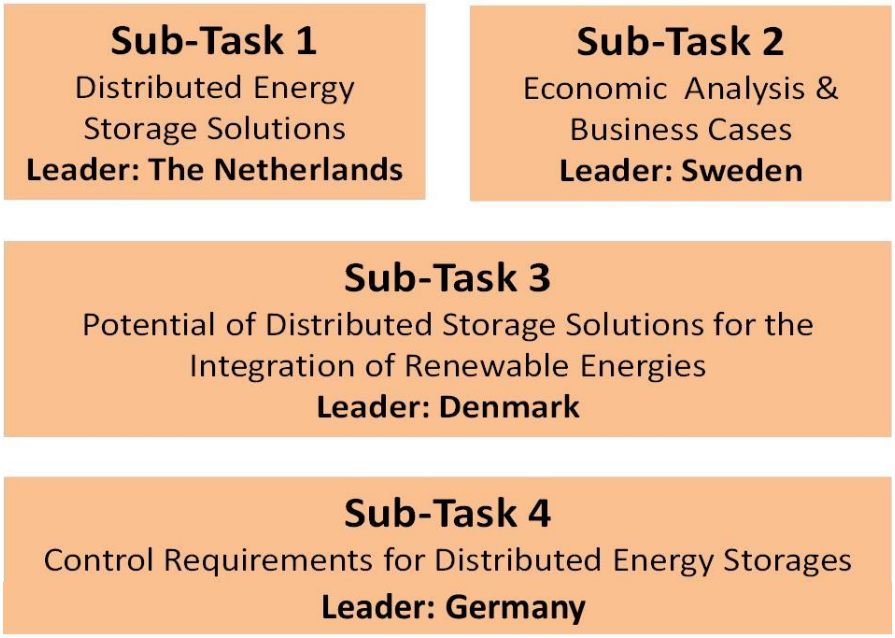
- Bottom-up Approach:

Subtask 1 and 2 start from actual DES technologies and applications – put together in “configurations” – and document the technological and economic state-of-the-art.

- Top-down Approach:

Subtask 3 derives general trends and dependencies for different DES technologies from the modelling of national scenarios.

In Subtask 4 the state-of-the-art of smart grids in connection with DES was explored.



Subtask 1: "Distributed Energy Storage Solutions "

Goal of this subtask is to outline the variety and possibilities of distributed energy storage technologies.

A three step approach covering the definition, description and characterization of DES systems was proposed.

Overview of DES systems:

Systems commercially available & systems under development

Previously defined classification structure for DES within their application (Source – DES – Consumer) will be called "configurations".

Basic system description, including number of systems in operation, detailed technology description, including working principle and Technology Readiness Level (TRL).

Subtask 2: "Economic Analysis & Business Cases"

Goal of this subtask is to show possible business cases and their dependencies on the actual economic conditions.

This Subtask will focus on actual examples of distributed energy storage systems. It will cover real applications which are operated due to economic reasons as well as demonstration plants, which will be able to be operated in the future in an economical way.

The work plan of Subtask 2 comprises the following activities:

- A techno-economic analysis of demonstration projects and commercial installation of DES systems

- Listing of possible business cases for DES configurations following the findings of subtask 1

Subtask 3: "Potential of Distributed Storage Solutions for the Integration of Renewable Energies"

Goal of this subtask is to identify trends of potential DES technologies applications within a national energy scenario. The simulations will be performed based on a model of the German energy system. Variations of the parameters will give information about the impact of the different storage solutions.

The workplan of Subtask 3 comprises the following activities:

• Estimation of feasible total storage capacity within certain boundary conditions.

• Technical potential indicated by surplus RE reduction.

• Economic potential indicated by socio-economic cost of the total energy system.

• Results should indicate most relevant storages to promote in the given context.

Subtask 4: "Control Requirements for Distributed Energy Storages"

Important for the successful operation of distributed energy storage solutions are intelligent operation and control mechanisms. This could be realized by e.g. Smart Grid installations. Existing Smart Grid technologies and future R&D demand should be identified.

- Collecting the state-of-the-art in Smart Grid solutions with possible respect to DES solutions

1.1.6 General Remarks for the evaluation and relevance of DES

- "DES only to evaluate within an actual application"

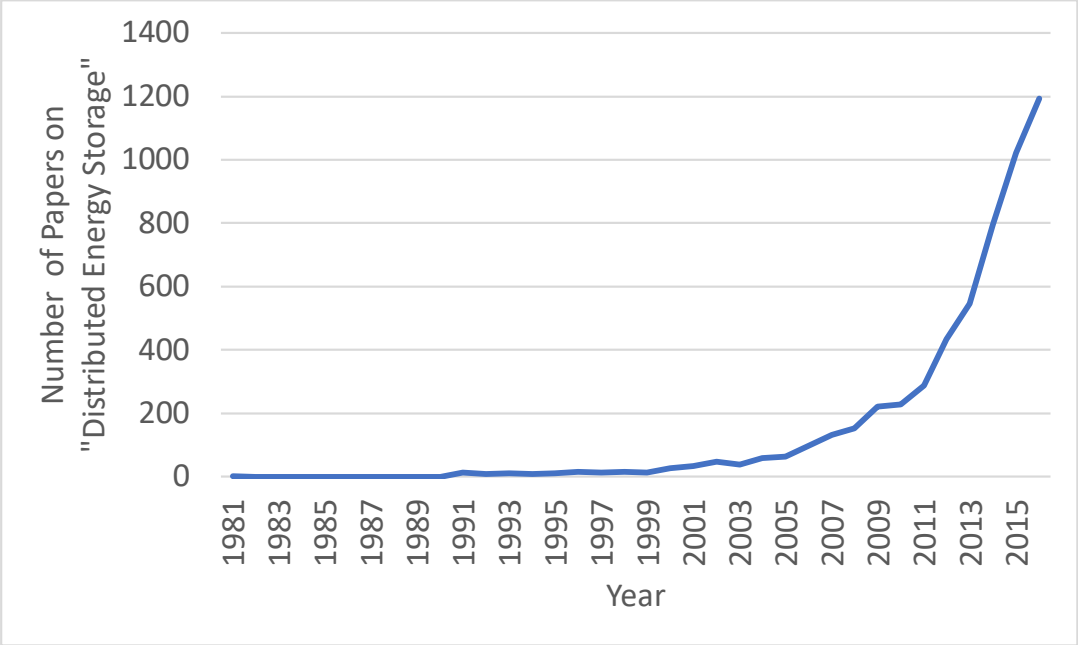
The most important assumption for the work reported here is the fact, that distributed energy storage systems can only be evaluated within an actual application. It is not sufficient to calculate general storage capacity demands (e.g. "…we might need x TWh storage capacity by the year 2015"). It is necessary to identify the real operation conditions – technical and economic – given by the actual application. The requirements for an

energy storage technology described by the application can go from storage cycle numbers over required power output (or input) or storage capacity to remuneration of the actual benefit.

This is the motivation for the Subtask 1 approach to look at DES embedded in “configurations” only.

- Increasing relevance of the topic (Publications)

Since this Annex has started the number of publications in this field has increased immensely. The topic has also climbed up the ladder of importance in the public and political discussion.



1.1.7 Meetings and Participating Countries and TCPs

Eight experts meetings and workshops were held. Every second meeting was scheduled in Paris at the IEA. To the Paris meeting relevant TCPs were invited.

The table below gives an overview of the Annex 28 expert meetings and workshops.

Nr	Location	Country	Date	Participants
1	Bad Tölz	Germany	April 10-11 2014	27
2	Paris	France	October 28-29 2014	28
3	Arnhem	The Netherlands	April 29-30 2015	20
4	Paris	France	October 22-23 2015	21
5	Stockholm	Sweden	April 27-29 2016	19
6	Paris	France	October 20-21 2016	13
7	Copenhagen	Denmark	April 26/27 2017	13
8	Bad Tölz	Germany	October 24-26 2017	12

Active Countries (Subtask leaders):

- Denmark
- Germany
- Sweden
- The Netherlands

Participating Countries:

- Austria
- Belgium
- Canada
- Denmark
- France
- Germany
- Ireland
- Republic of Korea
- The Netherlands
- Norway
- Spain
- Sweden
- Switzerland
- Turkey
- United Kingdom

Participating TCPs:

- ECES
- EBC
- DSM
- H2 IA
- DHC
- SIR

1.2 Subtask 1 – Distributed Energy Storage Solutions

In order to identify the potential role of Distributed Energy Storage (DES) for the implementation of renewables, DES needs to be included in an energy system.

The goals of Subtask 1 are:

- To prepare an overview of DES system configurations. A DES system configuration includes, apart from the energy storage, an energy source and an energy consumer. This overview should include configurations that are commercially available (TRL > 9) as well as configurations under development (TRL ≤ 9).

- To prepare DES system configuration descriptions

1.2.1 Definition of DES system configurations

A DES system configuration consists of an energy source, an energy user, as well as a DES technology with an application in the system. The DES system configuration can be electric grid connected for supply of additional energy or to return surplus energy to the grid. The DES system configuration can also operate as an island system, i.e. without grid connection. See also Figure 1.2.

In this report, DES system configurations will be illustrated by infographics. An example of an infographic for a DES system configuration is shown in Figure 1.3. The general lay-out is as following:

Upper left corner: the energy source, in this example consisting of solar PV panels as electricity source

Top center: the energy user, in this case a single family house as electricity consumer

Bottom center: the distributed energy storage, in this example a battery.

Upper right corner: status of the DES system configuration with respect to grid connection. In this example the house has a connection to the electric grid.

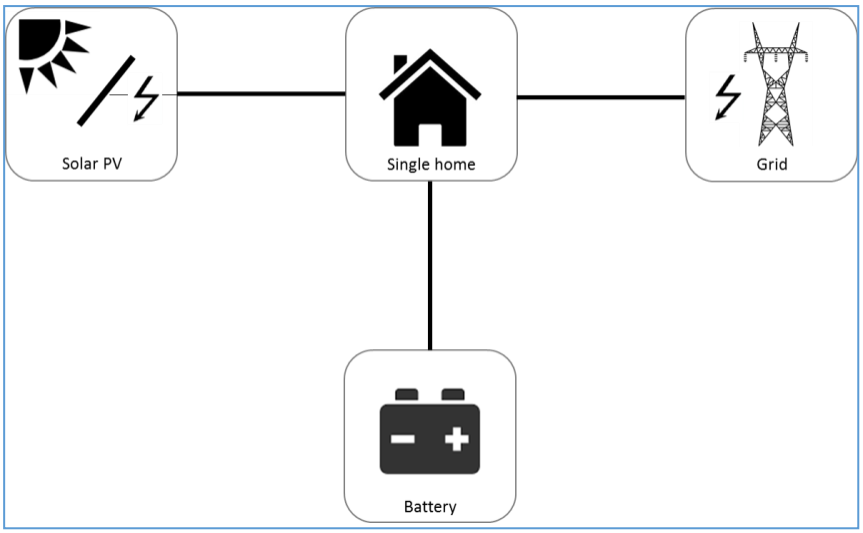


Figure 1.3: PV-Single home-Battery-Grid connected

1.2.2 Overview of DES system configurations

In this report the DES system configurations that are in operation and/or presented in literature, are subdivided by market application, like housing, commercial/institutional buildings, etc. The rationale for this subdivision is that:

- The various market applications have a different load profile and annual energy demand, resulting in different DES solutions.
- DES technologies that are applied in larger scale projects, might not be feasible or technically suitable for small scale applications.
- The decision making process is not the same for all market applications, resulting in different deployment barriers.

The subdivision by market application is given in following points:

- **Residential DES system configurations-single house**

In this group of DES system configurations a single family home is the energy consumer. Both the electricity and thermal demand are relatively small.

- **Residential DES system configurations-housing development**

In this group of DES system configurations a multi-family house (apartment building) or a housing development is the energy consumer. Both the electricity and thermal demand are 1-3 orders of magnitude larger than those for a single house.

- **Commercial/institutional DES system configurations-single building**

In this group of DES system configurations a single building is the energy consumer. This can be a commercial or an institutional building, but not a residential building.

- **Commercial/institutional DES system configurations - multiple buildings**

In this group of DES system configurations multiple buildings are connected to a local electric grid and/or thermal distribution network. This local electric grid and/or DH&C network (with the buildings connectd to it), is the energy consumer in the DES system configuration. In case of a mixed development, also residential buildings will be connected to the local electric grid and/or DH&C network. The peak loads for the grid or network will be significantly lower than the sum of the peak loads of the individual buildings, as a result of load diversity.

- **Industrial DES system configurations - single industry**

In this group of DES system configurations a single industrial building, like a factory, a laboratory, a warehouse or an agricultural building, is the energy consumer.

- **Industrial DES system configurations - industrial area**

In this group of DES system configurations multiple factories and/or industrial buildings are connected to a local electric grid and/or thermal distribution network. This local electric grid and/or DH&C network with the buildings connected to it, is the energy consumer in the DES system configuration. The peak loads for the grid or network will be significantly lower than the sum of the peak loads of the individual industrial buildings, as a result of load diversity.

- **Mobility DES system configurations**

In this group of DES system configurations means of transportation for people, animals and freight and/or the energy supply infrastructure is the energy consumer. So, this can be a private bike, car or boat, but also a commercial bus, truck, train, ship or plane, as well as the infrastructure to provide energy to these means of transportation.

1.2.3 Conclusions

From the assessment of the energy system configurations with distributed energy storage the following might be concluded:

- The number of energy systems enabling the application of distributed energy storage is large: more than 90 DES system configurations have been identified.

- Most of these DES system configurations are commercially available or in the demonstration stage (technology readiness level TRL ≥ 9).

- For larger scale projects, like mixed developments or industrial areas, a combination of several DES system configurations is applied sometimes.

- Several storage technologies might serve the same purpose in a DES system configuration. The choice of the optimum storage technology will depend on system characteristics and local conditions.

- For most storage technologies applied today in DES system configurations, alternatives with improved characteristics are under development (these alternative storage technologies have a TRL ≤8).

- The number of system configurations including electric energy storage is about 40% of the total number of system configurations identified, and about equal to the number of configurations with thermal energy storage. The remaining 20% of the system configuations include gas storage (mainly H2). This is contrary to the general opinion that energy storage is equivalent with electric energy storage.

- Almost all DES system configurations in operation today are locally optimized, not grid operated (optimized). Grid operation of DES systems is expected to provide additional system advantages (grid services). More R&D with respect to this topic is advised in order to quantify the additional advantages, both for electric and thermal grids.

1.3 Subtask 2 - Economic Analysis & Business Cases

The vision of Distributed Energy Storage (DES), of various technology and size, as enabler for implementing large shares of renewable energy in our energy system (local, regional, and global) is firmly put forward by the ECES Annex 28 DESIRE. In Subtask 2, a careful examination of existing business cases has been at the center of attention to: a) bring to attention cost-benefits for various actors, as well as values from a functional point of view, and b) exemplify lessons learned from existing projects and installations.

In addition, the subtask has also been able to compile descriptions of a number of business cases related to DES (see online Appendix).

1.3.1 DES for Heating

Space heating represents more than 40% of the total energy use in households while hot water heating accounts for less than 20% total energy use. However, due to short bursts of hot water use (e.g. showers), instantaneous peak thermal power load for hot water is much higher than that for space heating. Distributed storage that levels out the peak thermal power demand through load shifting and peak shaving may alleviate grid instability and hence strengthen the network. Distributed load-levelling measures, such as DES, will aid in implementing large shares of fluctuating renewable energy in the system. Also, seasonal storage is fundamental for the increased use of solar heat in the energy mix providing comfort heat, since summer heat can be stored for winter use.

1.3.2 DES for Cooling

Comfort cooling, as well as industrial process cooling, are vital services in a modern energy system. In fact, the cooling demand world-wide is growing and this growth is likely to continue in the next decades. Conventional cooling technology rely on electricity, and the demand often co-incides with the hottest hours of a day, and in seasons where heat sinks used in power generation often get too warm for full capacity generation. Cooling is then highly connected to an electricity system. Thinking about levelling the cooling demand over a day, or even seasons, is thus of importance in order to reach sustainability. Cold storage is a key solution and commercial technology exists.

1.3.3 Energy Flexible Buildings

Picking up on one important concept of DES, the IEA EBC Annex 67 is presently investigating the concept of energy flexible buildings (EFB), and their ability to alleviate a part of the forecasted problem with large scale implementation of renewables. Adding load (electrical demand) in an existing system might bring the peak load beyond the maximum possible, despite using “green technology” like heat and electric vehicles (EV). However, buildings carry a certain thermal mass that cost-effectively can be used as “storage of heat” (and cold) – e.g by pre-heating the building excessively (within an allowed comfort range) before the peak hours (approx. 17:00-20:00 hrs), letting the building “free-

float" through peak hours, and then provide additional heat immediately after.

1.3.4 The Electricity Bank – "Die Strombank" – and DES in the Clouds

Just as the financial institutions "banks" manage the flow of money, the electricity bank concept (ger. Die Strombank) proposes an on-site solution for handling on-location storage in an electricity grid where distributed renewable energy is present. The electricity bank consists of a district (de-centralised) battery storage placed on location next to distributed generation (e.g. wind and solar PV) in residential communities and small businesses. The local, distributed placement, helps alleviate the central grid, and reduces transfer losses. In principle, this concept works as a regular financial bank, with surplus electricity generated being stored, and then fed back to the local grid when needed. A "cloud" solution connects prosumers with the storage, and helps manage each individual electricity account.

1.3.5 Distributed Polygeneration

Building on the concept of CHP comes the next generation energy systems termed polygeneration. In these systems, the complete pallet of energy services are addressed in integrated generation system. Polygeneration lends itself well to distributed generation and is large value for implementing large renewable energy fractions in next generation energy services. Aside from delivering multiple energy services (e.g., electricity, heat and cold) polygeneration can utilize a hybrid mixture of energy resources (e.g. solar-PV, wind and fuel-based CHP).

1.3.6 On Policy affecting DES Business Opportunities – regulations and incentives

DES comes with vast opportunities to bring added value in forming a sustainable energy system. Balancing the grid at large fractions of renewable electricity generation, as well as enabling secure, robust, and cost-effective energy services are traits of integrating DES. Despite the increasing awareness of this potential, there are still factors that hinders implementation of keeping up with storage technology developments: administrative barriers, limited access to grids, and excessive fees and charges. DES does not fit into existing regulations, often because the technology provides benefits to several parts of the market, like the supply AND demand side, as well as the transmission AND distribution.

Most documented policy strategies are based on a focus on the electrical network, renewables for electricity generation, and balancing the grid when generating capacity becomes more fluctuating with increasing share of solar and wind. However ST2 has brought forward the interconnectivity of energy services.

1.3.7 Conclusions

- There are many business possibilities, although the regulatory framework must be modified to support the large-scale deployment of DES, to harvest its many benefits across market segments.

- Therefore, there is an urgent need for multidisciplinary, and multi-stakeholder R&D concerning the influence non-technical barriers and regulatory framework on the business opportunities of DES.

1.4 Subtask 3 - Potential of Distributed Storage Solutions for the Integration of Renewable Energies

In subtask 3 of IEA ECES Annex 28, the aim is to identify which distributed energy storage (DES) technologies could be technically and economically beneficial for the integration of fluctuating renewable energy sources (RES) in different types of energy systems. In the subtask, the technical and economic potential for DES solutions is quantified, and it is identified which DES technologies have the largest total (technical and economic) potential. For this, different DES technologies are modelled in the context of a whole energy system on a national scale. For comparison and combination with the DES technologies, energy conversion technologies and other methods for balancing supply and demand in the system are also included in the modelling work.

1.4.1 Methodology

The modelling of the different technologies is performed using a scenario-based approach, where the technologies are modelled one at a time, as well as in some combinations. The modelling is carried out in the settings of five different energy system typologies. For each of the scenarios fifteen variations are introduced, where the electricity generation from fluctuating renewable energy sources (RES) (wind turbines and photovoltaics) is gradually increased with each variation to investigate the performance of the technologies in integrating fluctuating RES. In addition to this, variations in the energy storage or conversion capacity have been carried out for some scenarios, and a sensitivity analysis has been carried out on some of the model input parameters. The modelling has been performed using the energy system simulation tool EnergyPLAN, developed by Aalborg University.

The results of the scenarios are assessed using three indicators. These indicators are used for quantifying the technical and economic impact of and potential for introduction of each technology in the energy system. The indicators are:

- The annually discharged energy (a measure of how well the technology facilitates the integration of fluctuating RES by consuming overproduction and “discharging” it to the system again in another form or at another time).
- The reduction in the total annual CO2 emissions arising from the operation of the energy system.
- The total annual socio-economic costs of the energy system (a measure of how much the operation of the energy system costs society as a whole during one year).

The scenarios are considered feasible if the introduction of the technology simultaneously lowers the CO2 emissions and total system cost and increases the discharged energy, compared to the baseline scenario of the same energy system configuration. The total potential of each technology is assessed based on the combined performance of each technology in the three indicators.

1.4.2 Policy Recommendations

Based on the results of the modelling in this subtask, the following policy recommendations can be given in order to obtain the best integration and the greatest technical and economic benefits of transitioning towards very large capacities of fluctuating renewable energy generation:

1.4.2.1 Recommendations for energy system redesign

- **District heating, with low-carbon heat generation:** A system redesign towards more district heating would be feasible. A conversion away from individual heating towards district heating with low-CO2 emitting heat generation should be prioritised. The redesign towards more district heating increases the potential for introducing low-cost distributed energy storage in the form of large-scale thermal energy storages.

- **Electric vehicles with smart charging:** A system redesign towards more electric vehicles would be feasible. A conversion away from internal combustion engine vehicles towards electric vehicles should be prioritised. To maximize the positive effects of introducing electric vehicles, they should be smart charged. The redesign towards more electric vehicles with smart charging introduces a substantial and cost-effective distributed electrical energy storage capacity in the system in the form of vehicle batteries.

- **Some level of electrical interconnections to island systems can be beneficial:** Going away from island systems towards interconnected systems would be beneficial on all indicators to some extent. This measure, however, has a limited potential with a high penetration of renewable electricity generation. The feasibility of interconnecting current island energy systems to other energy systems should be investigated carefully where this is geographically and technically possible.

- **Less inflexible nuclear power:** A conversion away from inflexible nuclear power towards other forms of low-CO2 emitting power generation or towards very flexible nuclear power generation should be prioritised in energy systems with a large nuclear power capacity, that wish to integrate fluctuating RES.

1.4.2.2 Recommendations for distributed energy storage and conversion technologies

- **Flexible sector coupling:** The most feasible technology combinations are those that provide flexibility both in the electricity sector and the heating sector (district heating), and have a link between the two (power-to-heat). An example of this is a combination of DES and flexible sector coupling; e.g. combinations that include tank thermal energy storage (TTES), heat pumps and flexible electricity demand.

- **Individual heat pumps:** The introduction of heat pumps should be prioritized in order to replace fossil fuelled heat generation in individual heating.

- **Flexible electricity demand:** It should be investigated and tested (e.g. in demonstration projects) to which extent electricity consumers are willing to be flexible and how socio-economically expensive it would be to compensate them for their flexibility.

- **Thermal energy storages:** When thermal energy storages are implemented, connections with the electricity sector through power-to-heat should be looked into for increasing the positive impacts of the TTES. Thermal energy storages in district heating are more economical and can have the potential to provide more flexibility than thermal storages in individual heating.

- **Reduction of electrical energy storage investment costs:** Electrical energy storages, power-to-gas and electrical interconnections are all technically beneficial for the energy system but cause increased total system costs due to high investment costs. Research and development should be prioritized with the goal of reducing the price of these solutions. With the price levels used in this model, the implementation of these technologies should only be prioritized in energy systems where very high integration of fluctuating RES and very large reductions in CO2 emissions are clearly prioritized higher than the minimisation of the total socio-economic energy system costs. The economic feasibility of these solutions may be improved by implementing them in combination with flexible sector coupling.

1.4.2.3 Other policy recommendations

- **Ensure a positive investment framework for technologies that generate and integrate renewable energy:** Measures should be taken to ensure that energy technologies that generate or integrate renewable energy in the energy system have a positive investment environment compared to energy generation based on fossil fuels. This can be endorsed e.g. by removing subsidies for fossil fuel consumption and/or by introducing economic incentives for renewable energy generation and balancing technologies. Such policies would advance the transition towards a CO2 neutral energy supply and make the integration of large amounts of fluctuating renewable energy more economically viable. Higher fuel prices make the introduction of DES and other technologies for balancing energy supply and demand more economically feasible, as shown by the sensitivity analysis of the results.

- **Increase CO_2 emission prices:** Measures should be taken to ensure that for existing polluters, the costs of emitting CO_2 reflect the actual socio-economic costs related to the emissions. This would make the integration of large amounts of fluctuating renewable energy more economically viable and would make the introduction of DES and other technologies for balancing energy supply and

demand more economically feasible, as shown by the sensitivity analysis of the result.

1.5 Subtask 4 - Control Requirements for Distributed Energy Storages

In order to successfully operate distributed energy storage solutions intelligent operation and control mechanisms are necessary. This could be realized by e.g. Smart Grid installations. Existing Smart Grid technologies and future R&D demand should be identified.

Owing to the fact the collaboration with other TCPs like ISGAN in this Subtask could not be realized, the limited goals of this subtask are:

- Collecting the state-of-the-art in Smart Grid solutions

1.5.1 Smart grid applications of DES

Based on previous work in ISGAN Annex 1, the DOE Global Energy storage database and expert interviews three distinct DES applications in smart grids could be identified from 47 DES smart grid examples. The vast majority of the examples identified utilized electrical energy storages in the smart grid applications. The applications were evaluated regarding their systemic, economic and energetic benefits.

- **DES for limited substation capacity/islanding**

The first application of DES in smart grids identified is the possibility to support substations and transmission and distribution (T&D) equipment and possibly run parts of the grid in island mode. Not only high feed-in from renewables but also increasing demands due to new consumption models (e.g. electric vehicle charging) can bring the T&D equipment to its limits. Distributed energy storages can – if intelligently operated – relieve this situation and defer a possibly expensive upgrade in T&D equipment.
The systemic benefits of this application are the stabilization of the grid. Economic benefit is the deferred grid upgrade investment. From an energetic point of view, the increased feed-in of renewables and reduced losses are beneficial.

- **DES for ancillary services**

DES can also be utilized for ancillary services. Frequency control is necessary to keep the frequency of the system constant and to adjust supply and demand to any given time with respect to the active power. Besides frequency control, grid voltage also needs to be controlled within the allowed voltage range. Storages offer reactive power as well as fault power and can control voltage by actively charging and discharging effective power within a grid. Depending on the regulatory frameworks, energy storages need to fulfil prequalification requirements. In the case of DES aggregation of multiple DES systems is necessary to be able to participate in operating reserve markets. The intelligent management of these high numbers of DES plays an important role especially when it come to providing time-critical grid services. The systemic benefit of this application is the stabilization of the grid. Economic benefit is the possible participation and generation of profits in the operating reserve markets.

- **Arbitrage**

The economic value of electricity fluctuates strongly with fluctuating supply and demand. Coming from a fossil fuel based electricity generation these fluctuations were usually limited to night-day shifts due to lower demands during night times. Heading towards systems with high shares of volatile renewable generation the price fluctuations can increase. During times of low demand and surplus from renewables like wind and PV, prices drop and even negative prices are possible. Whereas during peak demand times and simultaneous low availability of renewables or unscheduled power plant outages. For arbitrage intelligent algorithms processing price/weather and consumer data are needed to beneficially operate the respective energy storage. Better data availability automatically facilitates the optimization of the arbitrage operation and hence yields bigger economic benefits.

- **Combination of the above applications**

In order to maximize the benefits, the above applications can also be combined.

1.5.2 Conclusion

- The intelligent management of DES within smart grid applications helps maximize the beneficial operation and can improve system stability.
- Today mainly electrical energy storages are applied in smart operation applications
- Challenges exist regarding the complexity of the interconnection of high numbers of DES in a smart grid application

Final Report

1 Objectives, Structure and Approach of the Annex

1.1 Objectives

The overall goal of Annex 28 is to foster the role of Distributes Energy Storages, DES, and to better evaluate the potential storage capacities for the integration of renewables at an economical competitive level. For this the following measures are taken:

- Identifying actual applications for DES to integrate fluctuating renewable energy sources into future energy systems

- Examining distributed energy storage technologies and their properties (including mechanical, electro-chemical, thermal and chemical and biogas approaches)

- Reviewing storage properties requirements depending on the different renewable energy sources (wind, PV, solar thermal, …)

- Quantifying potential of DES systems for the integration of renewable energies based on the actual final energy demand

- Promoting best practice and success stories examples

1.2 Scope

The scope of this Annex includes all energy storage technologies suitable on the consumer side. Three main fields of application – households, trade and commerce and industry – will be investigated.

The Annex will cover the following topics:

- Assessment of all storage technologies which show a technical and economic potential for distributed applications (e.g. batteries or cold and heat storages) in uni- or bidirectional operation.

- Investigation of system concepts with the temporal mismatch between fluctuating, renewable energy sources (wind, PV, solar-thermal, …) and the corresponding energy demand.

- Evaluation of national energy scenarios of participating countries with focus on the development of renewable energies

1.3 Collaboration with other TCPs

Collaboration with other Technology Collaboration Programme (TCP) within the IEA Technology Network is crucial for this Annex.

- TCPs for Renewable energy sources: Wind, PVPS and Solar Heating and Cooling from the Renewable Energy Working Party (REWP)

- TCPs for Applications: buildings, appliances and electric vehicles, (EBC, Heat Pump Technologies, 4E and HEV) and Demand Side Management DSM from the End-Use-Working Party (EUWP)

- Programs for distribution and scenarios: DHC and the International Smart Grid Action Network (ISGAN) as well as ETSAP

1.4 Main Question and Definition of „Distributed Energy Storage“

The main question of the Annex is, **what can be the contribution of distributed energy storage to the integration of renewables in our future energy systems?**

This Annex is looking at “distributed” energy storage as storage solutions located at the consumer side of the energy system. Figure 1.1 is visualizing the relation of DES on the consumer side including local renewable energy sources, including the possibility of DES being located directly at the renewable energy source.

The distribution grid is placed on top of this tetrahedron to represent the connection to the higher grid levels with centralized power plants.

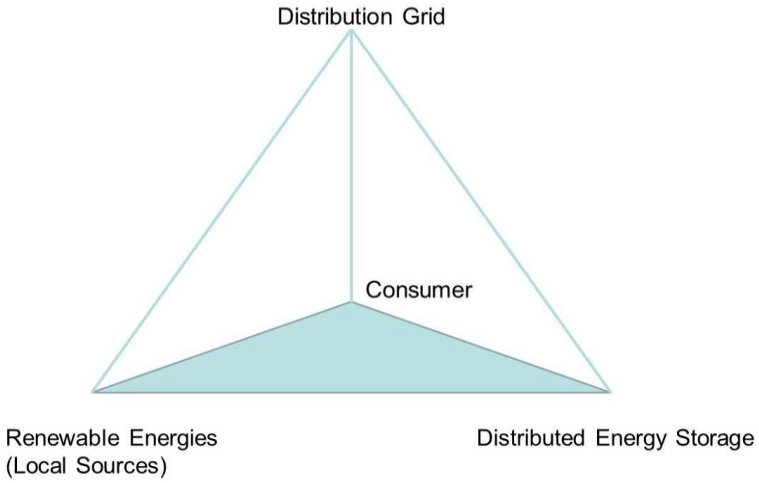


Figure 1.1: Definition of „Distribiuted Energy Storage“, DES

In order to categorize the different possibilities to utilize DES for the integration of renewables the following matrix was developed. It shows the operation of DES systems for the integration of renewable energies on different levels by usage of thermal and/or electrical and chemical energy storage (which is limited to power-to-gas technologies in this context).

	EES	EES + TES	TES	P2G
Electric grid operated	1-A	1-B	1-C	1-D
Electric grid connected, but locally optimized	2-A	2-B	2-C	2-D
„Island“ solution	3-A	3-B	3-C	3-D

Figure 1.2: Application/ storage technology matrix

Basically DES systems can be operated in order to provide grid services, like primary control reserve. This can be found in the application/technology matrix at “Electricity grid operated” in line 1 (see Figure 1.2). The box below shows such an example.

Matrix-Classification 1-A

Batteriepark Schwerin, Germany

5 MW Li-Ion Battery System for Primary Control Power

Technology Status	First Systems in place
Storage Capacity	5 MWh
Electrical Power	5 MW

©Younicos

These Li-ion battery systems can provide primary control services to the grid. Due to their very accurate reaction on frequecy changes these storages are able to replace power plants with much higher power outputs (up to 50 MW).

Links

- https://www.younicos.com/de/case-studies/schwerin-battery-park-germany/

DES installations can also be grid connected, but locally optimized (see line 2 in Figure 1.2). The benefit of such systems is a specific service for the local consumer. In the box below you find an example for such an application/technology combination in Japan.

Matrix-Classification 2-C

Nagoya Station, Japan

Latent Cold Storage for Air Conditioning of an Office Building

Technology Status	Many Systems installed (in Japan)
Storage Capacity	49 MWh_{th}
Electrical Power	7 MW_{th}

This latent cold storage is charged during night time at low electricity tarifs and supplies cold for air-conditioning during the peak hours at high electricity prices. I runs since 1999 commercially and is only one example of many cold storage installations in Japan.

Links

- http://task42.iea-shc.org/Data/Sites/9/documents/events/meeting-12/EM12-Central-Nagoya-Station.pdf

Island solutions however simply support off-grid systems by integrating renewable energies and pprovide the match between supply and demand. The example below (grey box) illustrates DES systems representing line 3 in Figure 1.2 – “Island Solutions”.

Matrix-Classification 3-D

Power Gap Filler, Germany

Power-to-Gas storage for boosting bio gas CHP plant at peak demand

Technology Status	First System installed
Electrical Power (Electrolysis)	20 kW (complete bio gas plant200kW)
Efficiency	75 % (Electrolysis) 95 % (incl. heat utilization)

This power-to-gas storage is combined with a bio gas plant. Hydrogen is mixed with the bio gas (70:30) and burned in a CHP plant. The hydrogen is boosting the CHP performance. Heat from electrolysis and the CHP is used in the buildings and the bio gas production.

Links

- http://www.gp-joule.com/100-renewable/the-power-gap-filler/

1.5 Structure and Approach of the Annex

The Annex work is structured in Subtasks. The main question on how much DES can contribute to the integration of renewable energies in future energy systems is approached within Annex 28 from different sides:

- Bottom-up Approach:

Subtask 1 and 2 start from actual DES technologies and applications – put together in “configurations” – and document the technological and economic state-of-the-art.

- Top-down Approach:

Subtask 3 derives general trends and dependencies for different DES technologies from the modelling of national scenarios.

In Subtask 4 the state-of-the-art of smart grids in connection with DES was explored.

Subtasks

Subtask 1: "Storage Solutions for the Integration of Renewable Energies"

Goal of this subtask is to outline the variety and possibilities of distributed energy storage technologies.

A three step approach covering the definition, description and characterization of DES systems was proposed.

Overview of DES systems:

Systems commercially available & Systems under development

Previously defined classification structure for DES within their application (Source – DES – Consumer) will be called **"configurations"**.

Basic system description, including number of systems in operation, detailed **technology description**, including working principle and **Technology Readiness Level** (TRL).

Subtask 2: "Economic Analysis & Business Cases"

Goal of this subtask is to show possible business cases and their dependencies on the actual economic conditions.

This Subtask will focus on **actual examples** of distributed energy storage systems. It will cover **real applications** which are operated due to **economic reasons** as well as **demonstration plants**, which will be able to be operated in the **future** in an **economical way**.

The work plan of Subtask 2 comprises the following activities:

- A techno-economic analysis of demonstration projects and commercial installation of DES systems

- Listing of possible business cases for DES configurations following the findings of subtask 1

Subtask 3: "Potential of Distributed Storage Solutions for the Integration of Renewable Energies"

Goal of this subtask is to identify trends of **potential** DES technologies applications within a **national energy scenario**. The simulations will be performed based on a model of the German energy system. Variations of the parameters will give information about the impact of the different storage solutions.

The workplan of Subtask 3 comprises the following activities:

- Estimation of feasible **total storage capacity** within certain boundary conditions.

- Technical potential indicated by **surplus RE reduction**.

• **Economic potential** indicated by socio-economic cost of the total energy system.

• Results should indicate **most relevant storages** to promote in the given context.

Subtask 4: "Control Requirements for Distributed Energy Storages"

Important for the successful operation of distributed energy storage solutions are **intelligent operation** and **control mechanisms.** This could be realized by e.g. Smart Grid installations. Existing **Smart Grid** technologies and future R&D demand should be identified.

- Collecting the **state-of-the-art** in Smart Grid solutions

1.6 General Remarks

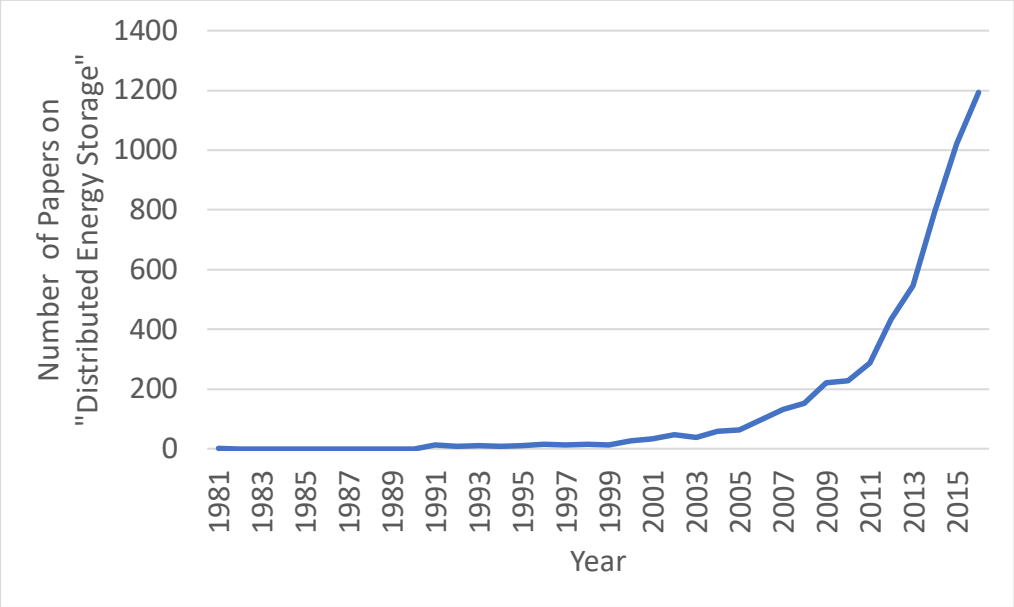
- "DES only to evaluate within an actual application"

The most important assumption for the work reported here is the fact, that distributed energy storage systems can only be evaluated within an actual application. It is not sufficient to calculate general storage capacity demands (e.g. "…we might need x TWh storage capacity by the year 2015"). It is necessary to identify the real operation conditions – technical and economic – given by the actual application. The requirements for an energy storage technology described by the application can go from storage cycle numbers over required power output (or input) or storage capacity to remuneration of the actual benefit.

This is the motivation for the Subtask 1 approach to look at DES embedded in "configurations2 only.

- Increasing relevance of the topic (Publications)

Since this Annex has started the number of publications in this field has increased immensely. The topic has also climbed up the ladder of importance in the public and political discussion.



1.7 Meetings and Participating Countries and TCPs

Eight experts meetings and workshops were held. Every second meeting was scheduled in Paris at the IEA. To the Paris meeting relevant TCPs were invited.

The table below gives an overview of the Annex 28 expert meetings and workshops.

Nr	Location	Country	Date	Participants
1	Bad Tölz	Germany	April 10-11 2014	27
2	Paris	France	October 28-29 2014	28
3	Arnhem	The Netherlands	April 29-30 2015	20
4	Paris	France	October 22-23 2015	21
5	Stockholm	Sweden	April 27-29 2016	19
6	Paris	France	October 20-21 2016	13
7	Copenhagen	Denmark	April 26/27 2017	13
8	Bad Tölz	Germany	October 24-26 2017	12

Active Countries (Subtask leaders):

- Denmark
- Germany
- Sweden
- The Netherlands

Participating Countries:

- Austria
- Belgium
- Canada
- Denmark
- France
- Germany
- Ireland
- Republic of Korea
- The Netherlands
- Norway
- Spain
- Sweden
- Switzerland
- Turkey
- United Kingdom

Participating TCPs:

- ECES
- EBC
- DSM
- H2 IA
- DHC
- SIR

2 Subtask 1 – Energy systems with DES

2.1 Introduction

The potential role of Distributed Energy Storage (DES) for the implementation of renewables has been introduced in Chapter 0. It will be clear that a storage technology always needs to be included in an energy system in order to be useful.

The goals of Subtask 1 are:

- To prepare an overview of DES system configurations. A DES system configuration includes, apart from the energy storage, an energy source and an energy consumer. This overview should include configurations that are commercially available (TRL > 9) as well as configurations under development (TRL ≤ 9).

- To prepare DES system configuration descriptions, including an estimate of the number of systems in operation.

Subtask 1 is not dealing with detailed descriptions of specific energy storage technologies. These descriptions have been made in the past by various institutions and will be referred to where appropriate.

2.2 Definition of DES system configurations

A DES system configuration consists of an energy source, an energy user, as well as a DES technology with an application in the system. The DES system configuration can be electric grid connected for supply of additional energy or to return surplus energy to the grid. The DES system configuration can also operate as an island system, i.e. without grid connection.

In this report, DES system configurations will be illustrated by infographics. An example of an infographic for a DES system configuration is shown in Figure 2.1. The general lay-out is as following:

- Upper left corner: the energy source, in this example consisting of solar PV panels as electricity source
- Top center: the energy user, in this case a single family house as electricity consumer
- Bottom center: the distributed enrgy storage, in this example a battery.
- Upper right corner: status of the DES system configuration with respect to grid connection. In this example the house has a connection to the electric grid.

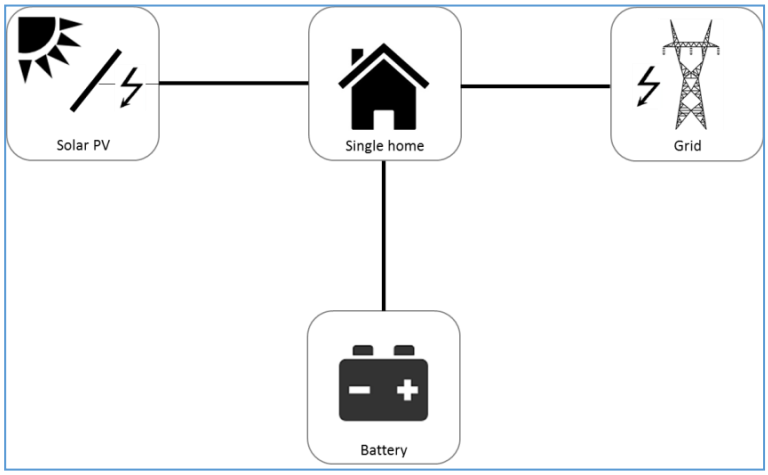


Figure 2.1: PV-Single home-Battery-Grid connected

Quite often, and also in this example, there are several DES technologies that might fulfill the same role in this system configuration, now or in the future. The DES technology (or technologies) that is most common (has the highest TRL) in a given system configuration is referred to as *DES technology-1* later on in this report. An alternative DES technology (or technologies) that might fulfill the same role in the system configuration is referred to as *DES technology-2* and typically is a DES technology in the RD&D stage (lower TRL). In general, the RD&D for DES technology-2 is aimed at eliminating one or more of the disadvantages of the presently applied DES technology-1, like high investment cost, low energy density (thus large weight and volume), low storage efficiency, etc.

2.3 Overview of DES system configurations

2.3.1 Introduction

In this report the DES system configurations that are in operation and/or presented in literature, are subdivided by market application, like housing, commercial/institutional buildings, etc. The rationale for this subdivision is that:

a) The various market applications have a different load profile and annual energy demand, resulting in different DES solutions.

b) DES technologies that are applied in larger scale projects, might not be feasible or technically suitable for small scale applications.

c) The decision making process is not the same for all market applications, resulting in different deployment barriers.

The subdivision by market application is given in following paragraphs. For each market application the DES system configuration are summarized in a table and an example project is included. The tables contain the following information:

1. **Configuration code**. This code is used to order the various DES system configurations and for reference purposes.

2. **Matrix position.** This is the position of the DES system configuration in the matrix that was developed to classify the DES technologies with respect to the level of electric grid integration, see Figure 1.2. This results in DES system configurations that look similar but differ with respect to the level of electric grid integration (e.g. grid connected versus grid operated) and as a consequence might differ with respect to technology readiness level. Remark: The matrix position of a DES system configuration refers to the level of electric grid integration. This implies that thermal DES system configurations with a very low electricity consumption (pumps, controls, etc.) are island systems from the electric grid perspective.

3. **TRL.** The TRL refers to the DES system configuration with the DES technology-1, so not to the storage technology only. DES system configurations that are commercially available already, are indicated by a TRL >9 (TRL=9 refers to "Actual technology proven through successful deployment in an operational setting"). Remark: There are several quite similar definitions of the Technology Readiness Level. The definition of Public Works and Government Services Canada, Office of Small and Medium Enterprises (2011-08-12) is used here.

4. **DES system configuration.** Each DES system configuration is described by the energy source, the application of the energy in the system, as well as the DES technology. The DES technology (or technologies) that is most common in the given system configuration is referred to as DES technology-1. An alternative DES

technology (or technologies) might fulfill the same role in the system configuration and is referred to as DES technology-2. The latter typically is a DES technology in the RD&D stage (lower TRL). In general, the RD&D for DES technology-2 is aimed at eliminating one or more of the disadvantages of the presently applied DES technology-1, like high investment cost, low energy density (thus large weight and volume), low storage efficiency, etc.

2.3.2 Residential DES system configurations-single house

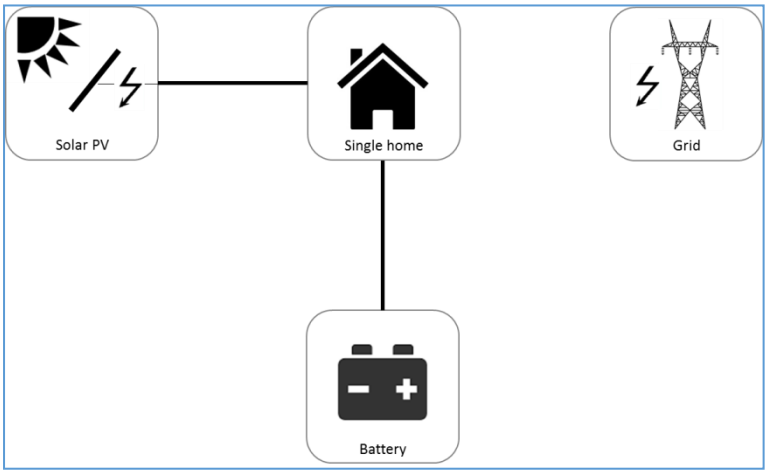
In this group of DES system configurations a single family home is the energy consumer. Both the electricity and thermal demand are relatively small.

Table 2.1 gives a summary of the DES system configurations that are in operation and/or presented in literature. The configurations H1 and H2 only differ with respect to the level of electric grid integration. H3 is a DES system configuration where electric energy from the grid is stored in batteries of individual houses, but fully grid operated (one of the smart grid storage solutions). A more detailed description of each configuration is included in the Appendix.

Table 2.1: Residential DES system configurations-single house

Config. code	Matrix position	TRL	DES system configuration			
			Energy source	Application	DES technology-1	DES technology-2
			Residential DES system configurations-single house			
H1	2-A	>9	Solar PV or wind	Electric consumption	Li-ion or lead-acid battery	
H2	3-A	>9	Solar PV and/or wind	Electric consumption	Li-ion or lead-acid battery	
H3	1-A	8	Electric grid	Electric consumption	Li-ion or lead-acid battery	
H4	1-C	>9	Electric grid	DHW	Hot water tank	
H5	3-C	>9	Solar thermal	DHW	Hot water tank	
H6	2-C	>9	Heat pump-ambient	Space heating and/or cooling	Building mass	PCM increased building mass
H7	2-C	>9	Heat pump-ambient	Space heating and/or cooling	Water tank	PCM or thermo-chemical
H8	1-C	8	Heat pump-ambient	Space heating and/or cooling	Water tank	PCM or thermo-chemical
H9	2-C	>9	Electric grid	Fridge	PCM	
H10	1-C	8	Electric grid	Fridge	PCM	

Example: house in remote area, PV, not grid connected.



Single Home *Matrix-Classification 3-A, Config. Code H2*

PV-Battery Off-Grid (Island-System)

Ostpreußenhütte, Austria

Completely grid-independent energy supply for remote areas

Technology Status	Widespread use
Storage Capacity	38.4 kWh
Electrical Power	0.1 - 10 kW

Alpine System

An island system is used to provide electricity in areas without grid connection. By combining a PV-system and a battery, it is possible to avoid all the issues with the conventional diesel generators, such as constant need for refueling and the environmental pollution and instead provide cheap and reliable electricity around the clock.

Links
https://en.sma-sunny.com/en/worlds-first-three-phase-off-grid-system-with-lithium-ion-battery-supplies-power-to-alpine-cabins/

2.3.3 Residential DES system configurations-housing development

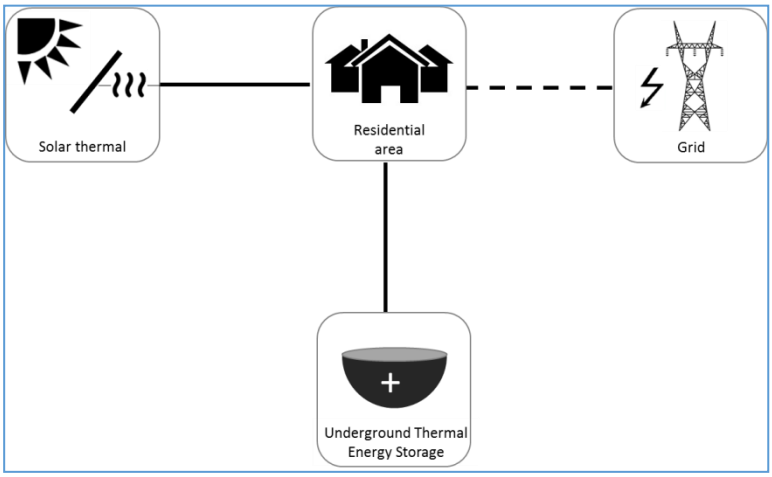
In this group of DES system configurations a multi-family house (apartment building) or a housing development is the energy consumer. Both the electricity and thermal demand are 1-3 orders of magnitude larger than those for a single house.

Table 2.2 gives a summary of the DES system configurations that are in operation and/or presented in literature. In the configurations HD6 and HD8 the scale of a housing development enables the application of seasonal underground thermal energy storage, which is not technically feasible for a single house. A more detailed description of each configuration is included in the Appendix.

Table 2.2: Residential DES system configurations-housing development

			Residential DES system configurations-housing development (DH&C)/apartment building			
HD1	2-A	>9	Solar PV and/or wind	Electric consumption	Li-ion or lead-acid battery	Redox flow battery, HT battery
HD2	3-A	>9	Solar PV and/or wind	Electric consumption	Li-ion or lead-acid battery	Redox flow battery, HT battery
HD3	1-A	8	Electric grid	Electric consumption	Li-ion or lead-acid battery	Redox flow battery, HT battery
HD4	3-C	>9	Solar thermal	DHW (centralized)	Hot water tank	PCM or thermo-chemical
HD5	1-C	>9	Electric grid	DHW (centralized)	Hot water tank	PCM or thermo-chemical
HD6	3-C	>9	Solar thermal	Space heating	UTES/water tank or pit storage	
HD7	2-C	>9	Heat pump-amb. (centralized)	Space heating and/or cooling	Building mass	PCM increased building mass
HD8	2-C	>9	Heat pump-amb. (centralized)	Space heating and/or cooling	UTES/water tank or pit storage	PCM, thermo-chemical, mine water
HD9	2-C	>9	Chiller (de-centr. and centr.)	Space cooling	PCM: ice storage	Thermo-chemical storage
HD10	1-C	8	Chiller (de-centr. and centr.)	Space cooling	PCM: ice storage	Thermo-chemical storage
HD11	3-C	>9	Biomass boiler	Space heating and DHW	Hot water tank	
HD12	3-C	>9	Biomass/-fuel	CHP	Hot water tank	PCM or thermo-chemical

Example: housing development with centralized solar heating system. Remark: The electricity consumption for this thermal DES system configuration is very low (pumps, controls, etc.). Therefore, from the electric grid perspective, this is an island system.



Housing Development *Matrix-Classification 3-C, Conf. Code HD6*

Solar Thermal-BTES

Drake Landing Solar Community, Canada

Solar thermal collectors combined with a local district heating system and a borehole thermal energy storage

Technology Status	Incidental
Storage Capacity	690 MWh
Thermal Power	n.a.

Drake Landing Housing Development

Solar thermal energy is applied for space heating for a 52 home development in Alberta, Canada. By storing thermal energy both for the short term (hot water tank) and over the season (BTES), a solar fraction of over 90% is achieved.

Links
www.dlsc.ca

2.3.4 Commercial/institutional DES system configurations-single building

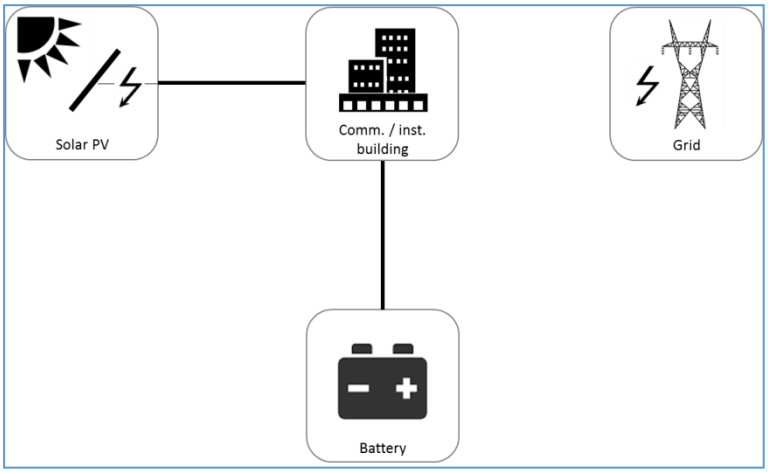
In this group of DES system configurations a single building is the energy consumer. This can be a commercial or an institutional building, but not a residential building.

Table 2.3 gives a summary of the DES system configurations that are in operation and/or presented in literature. A more detailed description of each configuration is included in the Appendix.

Table 2.3: Commercial/institutional DES system configurations-single

Config. code	Matrix position	TRL	DES system configuration			
			Energy source	Application	DES technology-1	DES technology-2
			Commercial/institutional DES system configurations-single building			
B1	2-A	>9	Solar PV and/or wind	Electric consumption	Li-ion or lead-acid battery	Redox flow battery, HT battery
B2	3-A	>9	Solar PV and/or wind	Electric consumption	Li-ion or lead-acid battery	Redox flow battery, HT battery
B3	1-A	8	Electric grid	Electric consumption	Li-ion or lead-acid battery	Redox flow battery, HT battery
B4	3-C	>9	Solar thermal	DHW	Hot water tank	
B5	1-C	>9	Electric grid	DHW	Hot water tank	
B6	3-C	>9	Solar thermal	Space heating	UTES/water tank or pit storage	
B7	2-C	>9	Heat pump-ambient	Space heating and/or cooling	Building mass	PCM increased building mass
B8	2-C	>9	Heat pump-ambient	Space heating and/or cooling	UTES/water tank or pit storage	PCM or thermo-chemical
B9	2-C	>9	Electric grid-Chiller	Space cooling	PCM: ice storage	Thermo-chemical storage
B10	1-C	8	Electric grid-Chiller	Space cooling	PCM: ice storage	Thermo-chemical storage
B11	3-C	>9	Biomass boiler	Space heating and DHW	Hot water tank	

Example: stand alone building, PV, not grid connected.



Institutional Building *Matrix-Classification 3-A, Conf. Code B2*

PV-Battery Off-Grid

Diesel-Hybrid System – Hospital Albert-Schweitzer (Haiti)

Off-grid energy supply by PV-battery system for larger buildings

Technology Status	Incidental
Storage Capacity	227 kWh_{el}
Power	200 kW_{el}

Roof of the hospital

The hospital has 131 beds and used diesel generators, which caused costs of more than 350.000 USD/year. The project aims to reduce that by 250.000 USD/year by combining PV and batteries. This provides independency from fuel, from rising fuel prices and reduces the air pollution.

Links
https://www.qinous.de/de/references/hospital-albert-schweitzer/

2.3.5 Commercial/institutional DES system configurations-multiple buildings

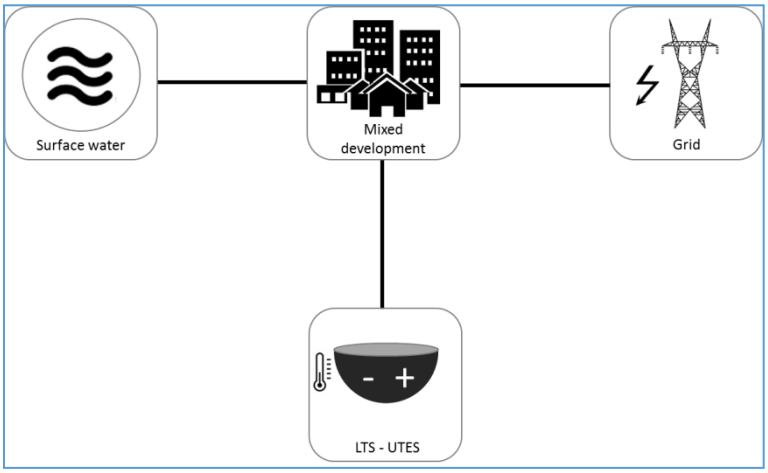
In this group of DES system configurations multiple buildings are connected to a local electric grid and/or thermal distribution network (e.g. a campus with a CHP plant and a distribution network for heating and cooling). This local electric grid and/or DH&C network (with the buildings connectd to it), is the energy consumer in the DES system configuration. In case of a mixed development, also residential buildings will be connected to the local electric grid and/or DH&C network. The peak loads for the grid or network will be significantly lower than the sum of the peak loads of the individual buildings, as a result of load diversity.

Table 2.4 gives a summary of the DES system configurations that are in operation and/or presented in literature. The scale of a multiple building project enables the application of more than one DES system configuration, several renewable energy sources and several storage technologies as compared to a single building or even a housing development. A more detailed description of each configuration is included in the Appendix.

Table 2.4: Commercial/institutional DES system configurations-multiple buildings

Config. code	Matrix position	TRL	DES system configuration			
			Energy source	Application	DES technology-1	DES technology-2
			Commercial/institutional DES system configurations-mixed development/campus (DH&C)			
BD1	2-A	>9	Solar PV and/or wind	Electric consumption	Li-ion or lead-acid battery	Redox flow or HT battery, CAES, PHS
BD2	3-A	8	Solar PV and/or wind	Electric consumption	Li-ion or lead-acid battery	Redox flow or HT battery, CAES, PHS
BD3	1-A	>9	Electric grid	Electric consumption	Li-ion or lead-acid battery	Redox flow or HT battery, CAES, PHS
BD4	2-A	8	Hydropower	Electric consumption	Li-ion or lead-acid battery	Redox flow or HT battery, CAES, PHS
BD5	3-A	8	Hydropower	Electric consumption	Li-ion or lead-acid battery	Redox flow or HT battery, CAES, PHS
BD6	2-C	>9	Heat pumps-ambient	Space heating and/or cooling	UTES/water tank or pit storage	PCM, thermo-chemical, mine water
BD7	3-C	>9	Biomass boilers	Space heating	Hot water tank	
BD8	3-C	>9	Solar thermal	Space heating	UTES/water tank or pit storage	Mine water
BD9	3-C	8	Geothermal-low enthalpy	Space heating	UTES or pit storage	Mine water
BD10	2-D	8	Solar PV and/or wind	Electric consumption	H2 and fuel cell	
BD11	3-D	8	Solar PV and/or wind	Electric consumption	H2 and fuel cell	
BD12	1-D	>9	Electric grid	Electric consumption	H2 and fuel cell	
BD13	2-D	>9	Biomass/-fuel	CHP	Gas storage and/or hot water tank	PCM or thermo-chemical
BD14	3-D	8	Biomass/-fuel	CHP	Gas storage and/or hot water tank	PCM or thermo-chemical
BD15	2-D	8	Hydropower	Electric consumption	H2 and fuel cell	
BD16	3-D	8	Hydropower	Electric consumption	H2 and fuel cell	
BD17	2-A	>9	Electric grid	Electric consumption	Flywheel	

Example: Mixed development, DH&C with heat pumps and surface water.



Mixed development *Matrix-Classification 2-C, Conf. Code BD6*

Heat Pumps/Ambient-UTES

Local DH&C System – Eastern Trade Wharf (Netherlands)

Renewable heating and cooling supply for mixed developments/campuses

Technology Status	Multiple projects
Storage Capacity	3.000 MWh_{th}
Power	3.500 kW_{th}

In total, 160 apartments and about 130.000 m² of commercial building space are connected to the local DH&C network. The heat pumps and the underground thermal energy storage (in this case ATES) are providing all of the cooling and the major part of the heating to the mixed development. Surface water is applied for balancing the annual heating and cooling demands.

Links
http://latent.be/wp-content/uploads/2015/09/CASE-Oostelijke-Handelskade-Amsterdam-2.pdf

2.3.6 Industrial DES system configurations-single industry

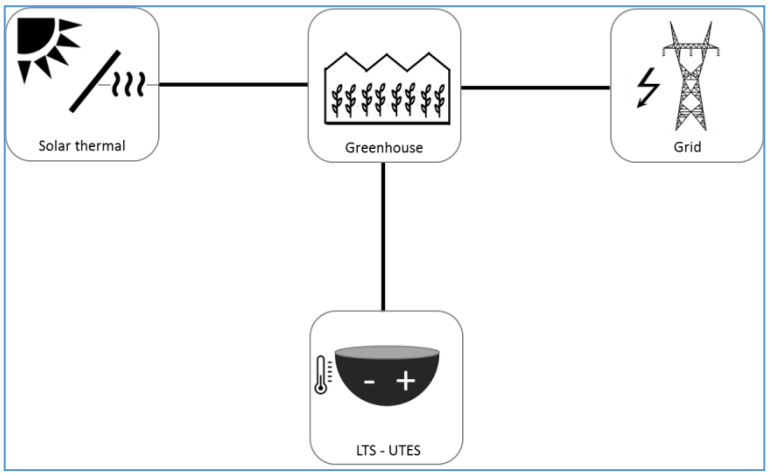
In this group of DES system configurations a single industrial building, like a factory, a laboratory, a warehouse or an agricultural building, is the energy consumer.

Table 2.5 gives a summary of the DES system configurations that are in operation and/or presented in literature. A more detailed description of each configuration is included in the Appendix.

Table 2.5: Industrial DES system configurations-single industry

Config. code	Matrix position	TRL	DES system configuration			
			Energy source	Application	DES technology-1	DES technology-2
I1	2-A	>9	Solar PV and/or wind	Electric consumption	Li-ion or lead-acid battery	Redox flow or HT battery, CAES, PHS
I2	3-A	>9	Solar PV and/or wind	Electric consumption	Li-ion or lead-acid battery	Redox flow or HT battery, CAES, PHS
I3	1-A	8	Electric grid	Electric consumption	Li-ion or lead-acid battery	Redox flow or HT battery, CAES, PHS
I4	2-C	>9	Heat pumps-ambient	Greenhouse climatization	UTES or pit storage	Mine water
I5	3-C	>9	Biomass boiler	Space or process heat LT	Water tank	PCM, thermo-chemical
I6	3-C	7	Geothermal-low enthalpy	Greenhouse heating	UTES or pit storage	Mine water
I7	3-C	>9	Ambient air or surface water	Process cooling	UTES or pit storage	Mine water
I8	3-C	8	Solar thermal-HT	Process heat-HT	Molten salt or solid material	
I9	3-C	8	Biomass boiler	Process heat-HT	Molten salt or solid material	
I10	2-C	8	Electric grid	Warehouse refrigeration	Stored products	PCM
I11	2-D	9	Solar PV and wind	Electric consumption	H2 and fuel cell	
I12	3-D	8	Solar PV and wind	Electric consumption	H2 and fuel cell	
I13	1-D	8	Electric grid	Electric consumption	H2 and fuel cell	

Example: Greenhouse climatization using solar irradiation and heat pumps, grid connected.



Single industry-Greenhouse *Matrix-Classification 2-C, Conf. Code I4*

Heat Pumps/Ambient-UTES

Greenhouse Climatization – Themato, Netherlands

Solar irradiation into a greenhouse combined with an aquifer thermal energy storage to provide low temperature heat for heat pumps in winter

Technology Status	Incidental
Storage Capacity	4.000 MWh_{th}
Power	2.200 kW_{th}

A closed greenhouse of 14.000 m² is cooled by groundwater in summer to prevent over-heating. The thermal energy is stored in an aquifer. In winter this low temperature heat is used for heat pumps, providing heating to a greenhouse area of 54.000 m².

Links
https://nl.wikipedia.org/wiki/Gesloten_kas

2.3.7 Industrial DES system configurations-industrial area

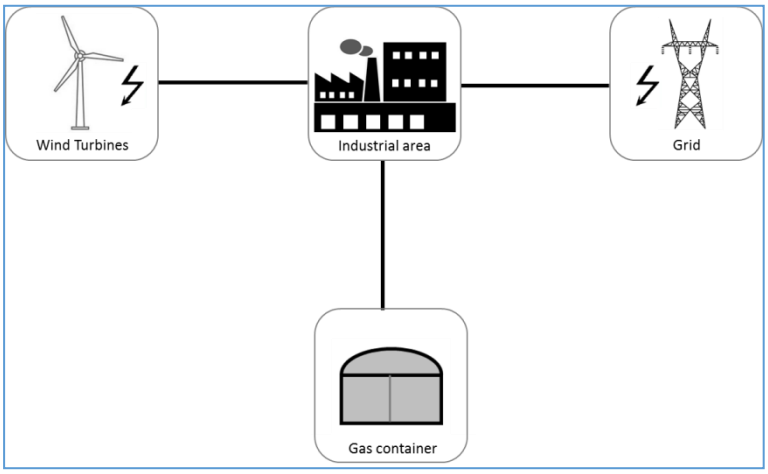
In this group of DES system configurations multiple factories and/or industrial buildings are connected to a local electric grid and/or thermal distribution network. This local electric grid and/or DH&C network with the buildings connected to it, is the energy consumer in the DES system configuration. The peak loads for the grid or network will be significantly lower than the sum of the peak loads of the individual industrial buildings, as a result of load diversity.

Table 2.6 gives a summary of the DES system configurations that are in operation and/or presented in literature. The scale of an industrial area enables the application of more than one DES system configuration, more renewable energy sources and more storage technologies than the scale of a single industrial building. A more detailed description of each configuration is included in the Appendix.

Table 2.6: Industrial DES system configurations-industrial area

Config. code	Matrix position	TRL	DES system configuration			
			Energy source	Application	DES technology-1	DES technology-2
			Industrial DES system configurations-industrial area (DH&C)			
IA1	2-A	>9	Solar PV and/or wind	Electric consumption	Li-ion or lead-acid battery	Redox flow or HT battery, CAES, PHS
IA2	3-A	8	Solar PV and/or wind	Electric consumption	Li-ion or lead-acid battery	Redox flow or HT battery, CAES, PHS
IA3	1-A	>9	Electric grid	Electric consumption	Li-ion or lead-acid battery	Redox flow or HT battery, CAES, PHS
IA4	2-A		Hydropower	Electric consumption	Li-ion or lead-acid battery	Redox flow or HT battery, CAES, PHS
IA5	3-A		Hydropower	Electric consumption	Li-ion or lead-acid battery	Redox flow or HT battery, CAES, PHS
IA6	2-C	>9	Heat pumps-ambient	Greenhouse climatization	UTES or pit storage	Mine water
IA7	3-C	9	Biomass boilers	Greenhouse/space heating	Water tank	PCM, thermo-chemical
IA8	3-C		Geothermal-low enthalpy	Greenhouse/space heating	UTES or pit storage	Mine water
IA9	3-C	9	Ambient air or surface water	Process cooling	UTES or pit storage	Mine water
IA10	2-D		Solar PV and wind	Electric consumption	H2 and fuel cell	
IA11	3-D		Solar PV and wind	Electric consumption	H2 and fuel cell	
IA12	1-D		Electric grid	Electric consumption	H2 and fuel cell	
IA13	2-D	9	Hydropower	Electric consumption	H2 and fuel cell	CAES,PHS
IA14	3-D	8	Hydropower	Electric consumption	H2 and fuel cell	CAES,PHS
IA15	2-D	>9	Biomass	CHP	Gas storage	
IA16	3-D	9	Biomass	CHP	Gas storage	

Example: Industrial area, using surplus wind for power to hydrogen, hydrogen storage.



Industrial area *Matrix-Classification 2-D, Conf. Code IA10*

Wind-Electrolyzer and Hydrogen Storage

Energiepark Mainz, Germany

Multiple hydrogen applications on an industry park to use excess wind energy combined with with hydrogen storage

Technology Status	Pilot system
H_2 Storage Capacity	780 kg / 26 MWh_H
Power (Electrolyzer)	6 MWe

Source: Siemens AG

The PEM-Electrolyzer system is designed to use surplus electricity generation from a co-located wind park for hydrogen production. This approach allows a local grid integration of fluctuating wind energy production. The electrolyzer is designed for flexible operation can also provide ancillary services to the grid. After storage in a pressure vessel, the hydrogen can be provided for different applications including direct hydrogen supply to the industry park (this example), hydrogen feed-in in the natural gas grid and hydrogen supply to a hydrogen fueling station.

Links
http://www.energiepark-mainz.de/projekt/energiepark/

2.3.8 Mobility DES system configurations

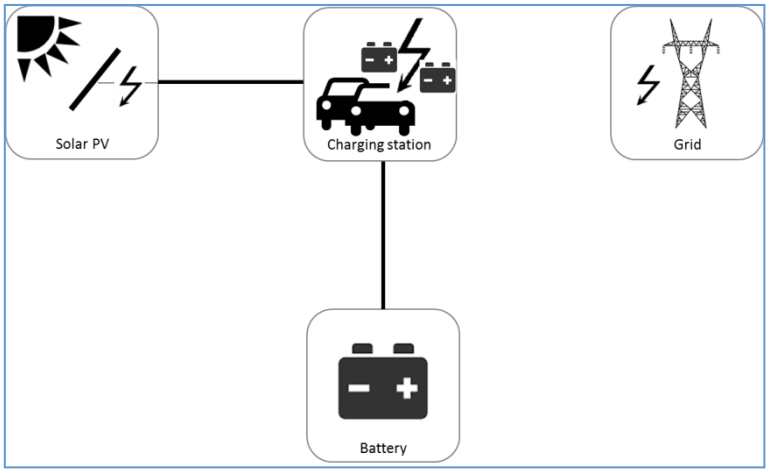
In this group of DES system configurations means of transportation for people, animals and freight and/or the energy supply infrastructure is the energy consumer. So, this can be a private bike, car or boat, but also a commercial bus, truck, train, ship or plane, as well as the infrastructure to provide energy to these means of transportation.

Table 2.7 gives a summary of the DES system configurations that are in operation and/or presented in literature. A more detailed description of each configuration is included in the Appendix.

Table 2.7: Mobility DES system configurations

Config. code	Matrix position	TRL	DES system configuration			
			Energy source	Application	DES technology-1	DES technology-2
			Mobility DES system configurations			
T1	2-A	>9	Electric grid	Bike	Li-ion battery	
T2	1-A	7	Electric grid	Bike	Li-ion battery	
T3	2-A	>9	Electric grid	Car, truck, bus	Li-ion or lead-acid battery	CAES, FES
T4	1-A	9	Electric grid	Car, truck, bus	Li-ion or lead-acid battery	CAES, FES
T5	2-A	9	Electric grid	Train	Li-ion or lead-acid battery	Redox flow battery, HT battery, FES
T6	2-A	>9	Electric grid	Ship	Li-ion or lead-acid battery	Redox flow battery, HT battery
T7	3-D	9	Electric grid	Ship	H2 and fuel cell	
T8	3-D	7	Electric grid	Airplane	H2 and fuel cell	
T9	3-D	>9	Electric grid	Car, truck, bus	H2 and fuel cell	
T10	3-D	>9	Biomass	Car, truck, bus	Gas tank	
T11	2-A	>9	Electric grid	Charging station	Li-ion or lead-acid battery	Redox flow battery, HT battery
T12	2-A	>9	Solar PV	Charging station	Li-ion or lead-acid battery	Redox flow battery, HT battery
T13	3-A	9	Solar PV	Charging station	Li-ion or lead-acid battery	Redox flow battery, HT battery
T14	2-A	9	Electric grid	Railway	Fly-wheel	

Example: charging station, PV, not grid connected.



Mobility *Matrix-Classification 3-A, Conf. Code T12*

PV-Battery Off-Grid

Zero Emission Urban Bus System Münster, Germany

Fast charging station for public buses

Technology Status	Validation
Storage Capacity	112 kWh_{el}
Power	55 kW_{el}

Charging procedure

The ZeEUS project is aimed at testing innovative electric bus technologies with different charging infrastructure solutions in ten demonstration sites across Europe. Thanks to varied geographical and topographical characteristics, the ZeEUS demonstrations validate economic, environmental and societal viability of the electric solutions. At the bus depot in Münster, fast charging is provided by a solar PV and battery storage system.

Links

- http://zeeus.eu//
- http://zeeus.eu/uploads/newspapers/documents/die-elektro-busse-sind-da-munster-von-aa-bis-zoo.pdf

2.4 Conclusions

From the assessment of the energy system configurations with distributed energy storage the following might be concluded.

- The number of energy systems enabling the application of distributed energy storage is large: more than 90 DES system configurations have been identified.
- Most of these DES system configurations are commercially available or in the demonstration stage (technology readiness level TRL ≥ 9).
- For larger scale projects, like mixed developments or industrial areas, a combination of several DES system configurations is applied sometimes.
- Several storage technologies might serve the same purpose in a DES system configuration. The choice of the optimum storage technology will depend of system characteristics and local conditions.

- For most storage technologies applied today in DES system configurations, alternatives with improved characteristics are under development (these alternative storage technologies have a TRL ≤8).

- The number of system configurations including electric energy storage is about 40% of the total number of system configurations identified, and about equal to the number of configurations with thermal energy storage. The remaining 20% of the system configuations include gas storage (mainly H_2). This is contrary to the general opinion that energy storage is equivalent with electric energy storage.

- Almost all DES system configurations in operation today are locally optimized, not grid operated (optimized). Grid operation of DES systems is expected to provide additional system advantages (grid services). More R&D with respect to this topic is advised in order to quantify the additional advantages, both for electric and thermal grids.

3 Subtask 2 - Economic Analysis & Business Cases

3.1 Introduction to Business Cases for Distributed Energy Storage

The vision of Distributed Energy Storage (DES), of various technology and size, as enabler for implementing large shares of renewable energy in our energy system (local, regional, and global) is firmly put forward by the ECES Annex 28 DESIRE. In Subtask 2, a careful examination of existing business cases has been at the center of attention to: a) bring to attention cost-benefits for various actors, as well as values from a functional point of view, and b) exemplify lessons learned from existing projects and installations. The results of this subtask 2 work are presented below.

In addition, the subtask has also been able to compile descriptions of a number of business cases related to DES. Some of them are described further below, whereas a full summary is given in the Appendix.

3.2 DES for Heating

Space heating represents more than 40% of the total energy use in households while hot water heating accounts for less than 20% total energy use [US EIA, 2015]. However, due to short bursts of hot water use (e.g. showers), instantaneous peak thermal power load for hot water is much higher than that for space heating. Distributed storage that levels out the peak thermal power demand through load shifting and peak shaving may alleviate grid instability and hence strengthen the network. Distributed load-levelling measures, such as DES, will aid in implementing large shares of fluctuating renewable energy in the system. Also, seasonal storage is fundamental for the increased use of solar heat in the energy mix providing comfort heat, since summer heat can be stored for winter use. This sub-chapter discusses such concepts further, underlining commercially available storage solutions.

3.2.1 Power to Heat – P2H

The increased share of electricity generated from fluctuating renewable energy sources, like wind and solar-PV, requires storage for balancing. Especially the problems of excess power in the system will be large in the future, since base-load (namely “fossil fuel”- and nuclear-based) generation cannot ramp down sufficiently fast in response to excess power in the grid [Martin, 2016]. Depending on the duration, and quantity, excess electricity may be stored via e.g. batteries, pumped hydro, compressed air energy storage (CAES), and so on. However, when linking to a district energy system the concept of power-to-heat (P2H) is especially promising. One motivating factor is the significantly lower cost of TES, as compared to e.g. batteries: order of 1$/kWh for large-scale TES compared to well over $100/kWh for batteries [Zart, 2017]. The concept of P2H is attracting growing interest in Europe, especially in Germany and Denmark, as recently reviewed by Schweiger et al [2017].

For Germany, Böttger et al [2016] considered the technical potential for P2H in DH systems. Restrictions, as compared to a theoretical potential

of all DH demand, were put to only consider the surplus electricity (also referred to as “negative residual load”) as it coincides with DH demand, in an hourly simulation. Then, around 40% of the surplus occurring could be used in P2H. For 2030 projections, this amounted to 21 GWel, and for 2015 just under 6 GWel. With no doubt, if storage would have been taken into consideration, the amount would be larger. Most DH networks have central storages already in place, and if there are incentives enough, could install additional capacity.

In Sweden, P2H has yet to be established and therefore, the technoeconomical potential for P2H in the Swedish DH system was examined [Schweiger et al, 2017]. For storage, they assumed that all DH networks accommodate a hot water accumulator equivalent to 25% of its mean daily demand, according to said “best practise” in today’s networks. Also, this number was increased to 250% of the mean daily demand, to really assess the opportunities for P2H. Three electricity scenarios were compared: a) a conservative case where the present nuclear power is replaced by new, and wind and solar are not growing that much; b) a high wind scenario, where nuclear power is phased out and solar-PV still is only used to a small extent; and c) a high-wind-high-solar scenario where both wind and solar-PV increase a lot compared to today. With electric boilers to generate the heat, the potential was found to vary between 0.2 and 8.6 TWh/year, depending on primarily the amount of renewable electricity generated. The higher number corresponds to 60+ % of wind and solar-PV. Access to TES, and the amount of waste incineration and/or industrial surplus heat available in the system were other important factors. Waste incineration, and industrial surplus heat (presently available at very low marginal cost, but with low flexibility) was in this study NOT available to be met by P2H. This indicates a sound approach to assessing technical feasibility.

A final example study presented herein explores Finland. The combination of combined heat and power (CHP), DH and P2H via TES has been analysed using theoretical modelling and optimisation for the Finish Energy system [Rinne and Syri, 2017]. In this national-level case study, the results showed that the optimal TES size should increase from today’s 17 GWh up to 100 GWh in order to balance wind power up to 24% of electric power generation.

Based on the above examples, P2H is clearly of interest to regional district systems, and is facilitated by the consideration of hot water accumulators as TES. However, striving for de-centralised generation of all energy commodities (power, heat, cold …), there is of course an opportunity to take the concept further to de-centralised cases. In the optimum design of a 100% renewable, autonomous energy system, wind or solar-PV electricity should at times of surplus be stored with optimal strategies, e.g. in an optimally sized mix of batteries AND hot water accumulator if there is a demand of electricity and heat. This will be further discussed below, in section 3.6.

3.2.2 Seasonal TES

One important step towards increase share of renewable energy on a global level is to bridge the gap in time and in space between available

solar heat and/or industrial surplus heat, and the heating demand. Seasonal TES systems are often used, with commercial technologies being underground TES: primarily fields of boreholes(BTES), and aquifers (ATES). Recently, it has been documented that 2800 ATES exist worldwide allowing 40% to 70% energy savings as compared to no storage scenarios [Fleuchaus, et al., 2018].

Merging technology is e.g. thermochemical storage, which has been evaluated in many cases. The technical bottleneck on heat and mass transfer inside the reactor, as well as economic factors still limit the widespread implementation of this technology [Krese, et al., 2018].

Perhaps the most publically known commercial installation of seasonal TES is the Drake Landing Solar Community in Alberta, Canada [Drake Landing Solar Community, 2018]. A local heating network is servicing 52 homes with heat, of which approximately 90% is solar heat. The solar collectors (glazed, flat plate) are installed on the garage roofs, and a BTES is installed for storage. This BTES consist of 144 holes, 35 m deep. The system is schematically described in Figure 3.1.

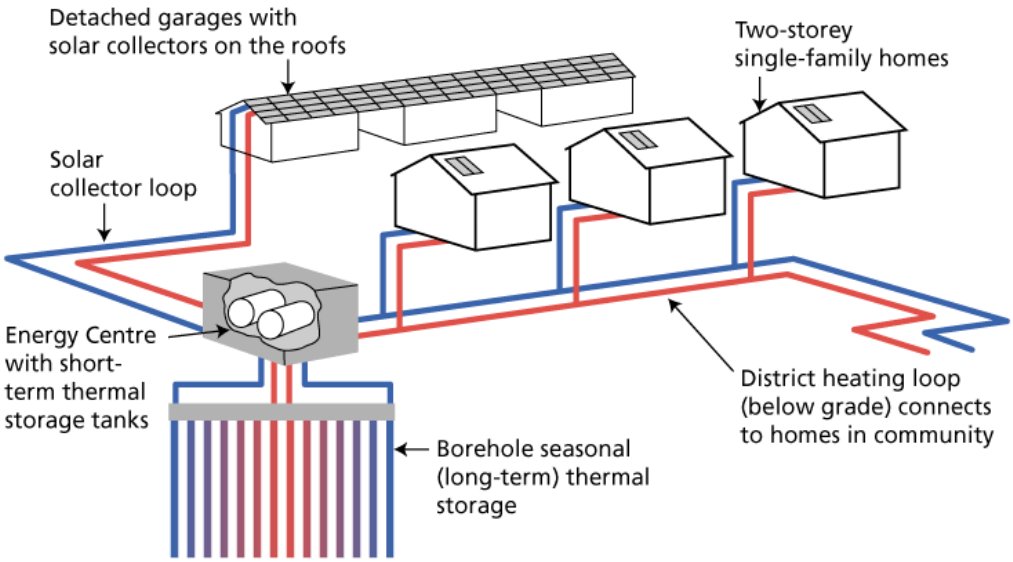


Figure 3.1: Drake Landing Solar Community – schematic Layout (taken from [Drake Landing Solar Community, 2018])

As shown, a short term water storage (240 m3) interconnects the seaqsonal storage with the local heat network. During five years of operation (2007-2012), between 2000 and 3000 GJ/year has been injected annually to the BTES [Sibbitt et al, 2012]. The BTES core temperature has gradually increased and is reported to e.g. 58 °C in March 2016 [Drake Landing Solar Community, 2018]. Worth noting for this installation is the design temperature of -31 °C.

An alternative layout of a local solar thermal heating network is that of Attenkirchen, north of Munich, Germany. In this concept, a cylindrical

concrete tank for stratified storage is surrounded by a borehole field [Reuss, 2015]. A schematic is shown in Figure 3.2.

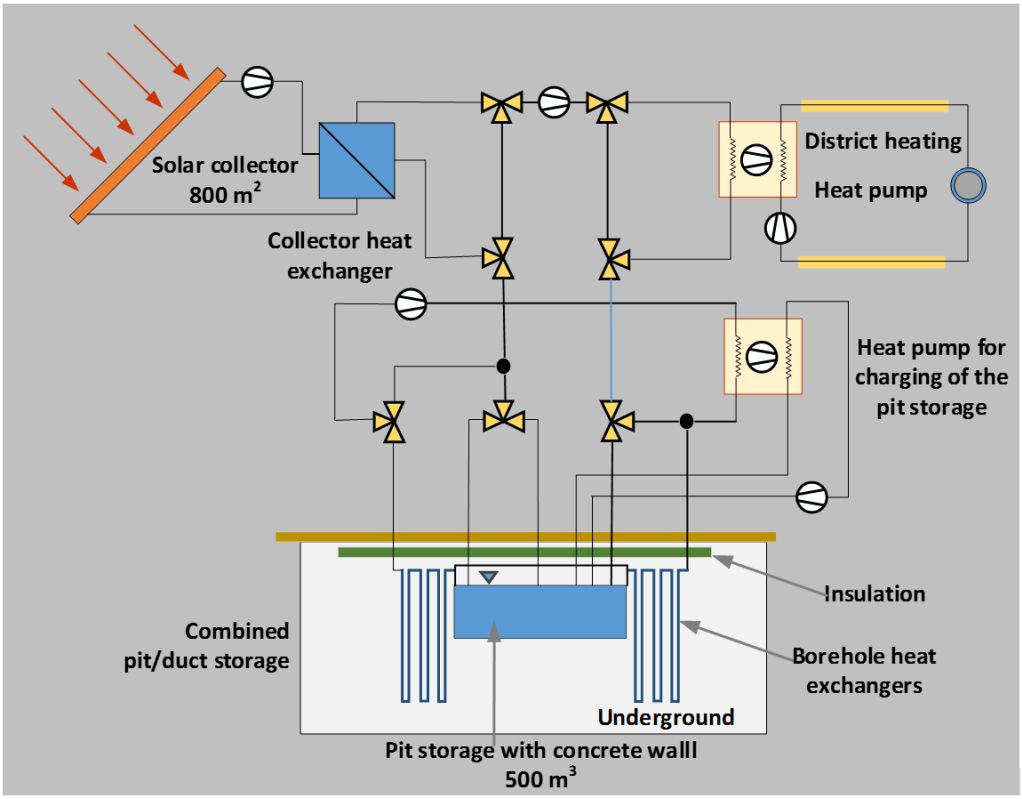


Figure 3.2: Attenkirchen local solar heating network (from [Reuss, 2015])

In this concept, the heat losses through the walls and bottom of the tank (pit) storage are then “charged” into the borehole field and can be recovered. With the tank, the system obtains flexibility in power (discharge and charge rate) since BTES are comparably slow in heat transfer and the power properties are limited. The concrete water storage is 500 m3, and insulated on top with polystyrene [Reuss, 2015]. Heat pumps are intergrated in the system to aid in mastering the required temperatures in the heating network.

Of equal interest to increasing the use of solar heat, is the use of industrial surplus heat. At Xylem Water Solutions Manufacturing plant, in Emmaboda Sweden, a high temperature BTES (designed for 60/40 °C temperature) is installed to balance the long and short term heating and cooling demand in manufacturing, without a heat pump [Andersson and Rydell, 2018]. The physics of the storage is 300000 m3 in volume, based on 140 holes drilled to 150 meters, and with a storage capacity of 3800 MWh. The BTES was taken into operation in 2010 and experiences show that it is difficult to obtain temperatures over 50 °C, so the next actions are to integrate a heat pump and decrease the operating temperature to 40/20 °C. Then, the thermal losses from the store will decrease, and the cooling function of the manufacturing process will be improved.

3.3 DES for Cooling

Comfort cooling, as well as industrial process cooling, are vital services in a modern energy system. In fact, the cooling demand world-wide is

growing and this growth is likely to continue in the next decades. Conventional cooling technology rely on electricity, and the demand often coincides with the hottest hours of a day, and in seasons where heat sinks used in power generation often get too warm for full capacity generation. Cooling is then highly connected to an electricity system. Thinking about levelling the cooling demand over a day, or even seasons, is thus of importance in order to reach sustainability. Cold storage is a key solution and commercial technology exists, as outlined below.

3.3.1 Ice Storage

Ice storage, for moving cold in time is nothing new. Historically, harvesting ice on lakes and rivers during winter, and storing it until the summer was a common technology. Ice blocks were shipped long distances, e.g. from the north in the US to the Caribbean Islands. However, as refrigeration technology and electricity moved into the market, thinking about ice storage became obsolete and in many cases the concept was phased out [Weightman, 2004]. However, with increasing demand for comfort and process cooling, the storage of cold in ice for securing cost-effective cooling during e.g. peak hours, are again a conventional solution in many places of the world. The reasons are: a) alleviation of peak electricity demand – an important action for stabilizing the electricity grid; and b) cost effectiveness – less installed chiller capacity can be used.

In Japan for example, distributed cold storage (often ice-based TES) alleviates about 2 GW of peak cooling demand [HPTCJ, 2018]. As depicted in the Figure 3.3, below, the need for less installed chiller capacity is promoted towards the demand side. However, incentives in terms of supporting lower night-time electricity tariffs is also of interest for increasing the amount of storage installed and maximising the peak demand reduction.

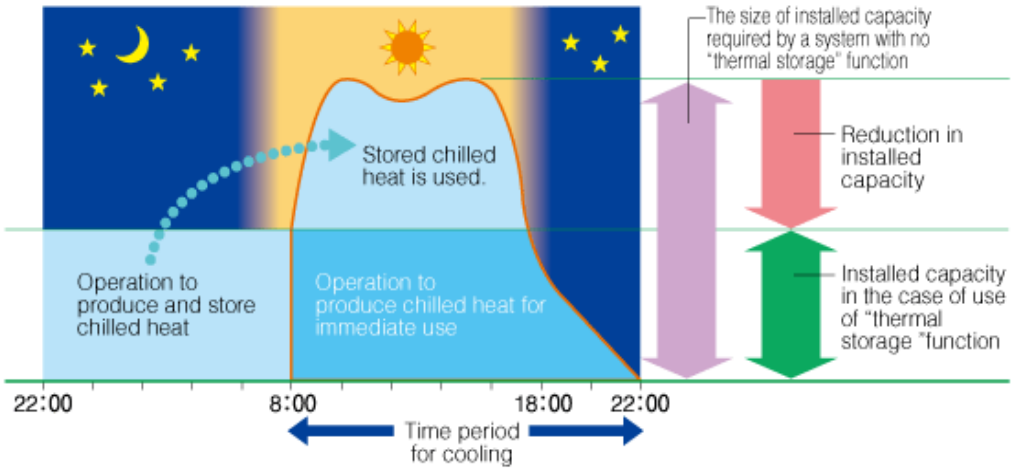


Figure 3.3: The concept of utilising cold storage in air-conditioning for peak-shifting the load (from [HPTCJ, 2018])

Today, a variety of commercial ice storage technologies exists, and it is not the task for this report to promote any particular kind or company. However, a few concepts are described schematically with keywords search such as: ice storage, ice bank, ice storage installations, etc. The

reader may carry out the search similarly to find the details on technologies. Some conceptual Ice Storage Configurations are summarized in Figure 3.4.

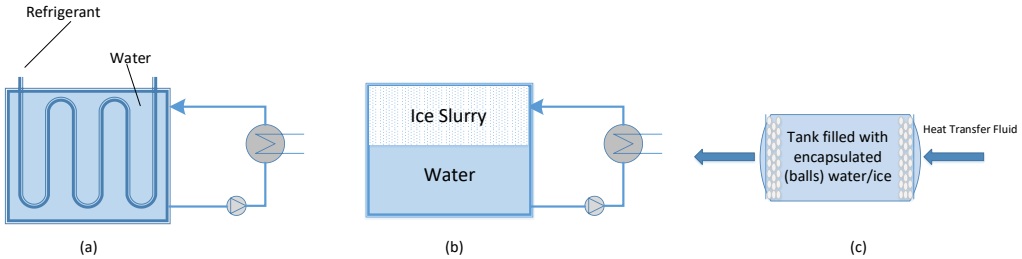


Figure 3.4: Examples of commercial concepts of ice storage: (a) ice-on-coil; (b) ice-slurry; (c) encapsulated storage tank.

In the ice-on-coil configuration (Figure 3.4a), a cold carrier (refrigerant) circulates through pipes sub-merged in a water filled tank. Ice builds directly on the coils, and the thickness of the ice layers grows as the storage is charged. Figure 3.4b depicts an ice slurry storage, where small ice crystals are dispersed in water. This concepts has some advantages as compared to more static ice storage solutions: it provides a pumpable storage capacity which renders flexibility in installation, and also good power properties. However, the storage density (kWhth/m3) may be lower than the static solutions.

A special case of “ice storage” is the snow storage installation in Sundsvall Central Hospital, Sweden [Nordell and Skogsberg, 2005]. This is an “open-pond” type of storage owned and operated by the regional county council. It is designed to hold up to 60000 m3 of snow, cleared from roads, or, if needed, generated from artificial snow-making machines (COPel well over 50). During above freezing temperatures, the melting from the pile is slowed down by a 0.2 m layer of insulating wood-chips. The melt water exchanges “cold” with the cold carrier servicing the hospital. In addition to over 90% electricity savings, as compared to conventional cooling, this snow storage facilitates snow-clearing in the winter, and makes it possible to purify the snow melt water from road contaminants, before it is dispatched to nature. The system is schematically illustrated in Figure 3.5.

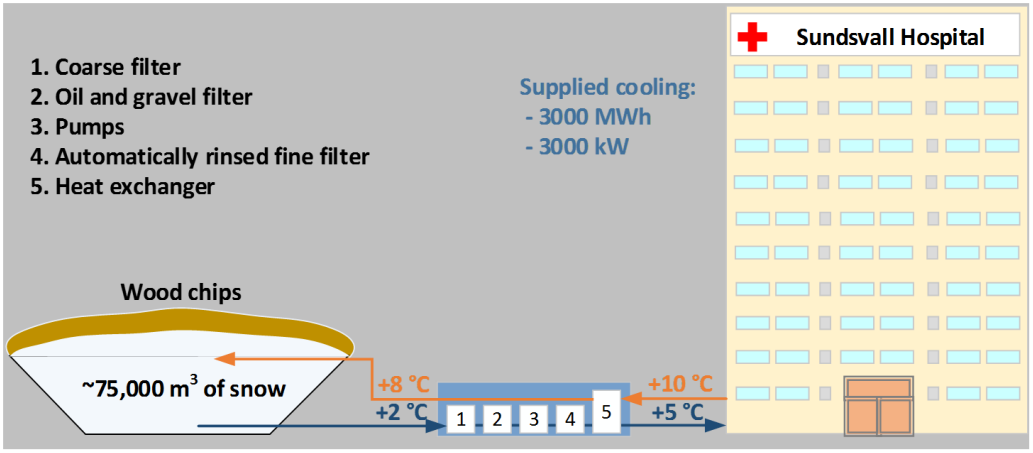


Figure 3.5: Seasonal storage of snow for cooling Sundsvall regional hospital in Sweden (from [Nordell, B., 2015])

Hamada et al [2012] presented results from an evaluation of a snow storage in Asahikawa City, Japan. Here, an existing building was renovated to make use of an old parking floor (previously for postal delivery trucks) as snow storage. The concept is described in Figure 3.6.

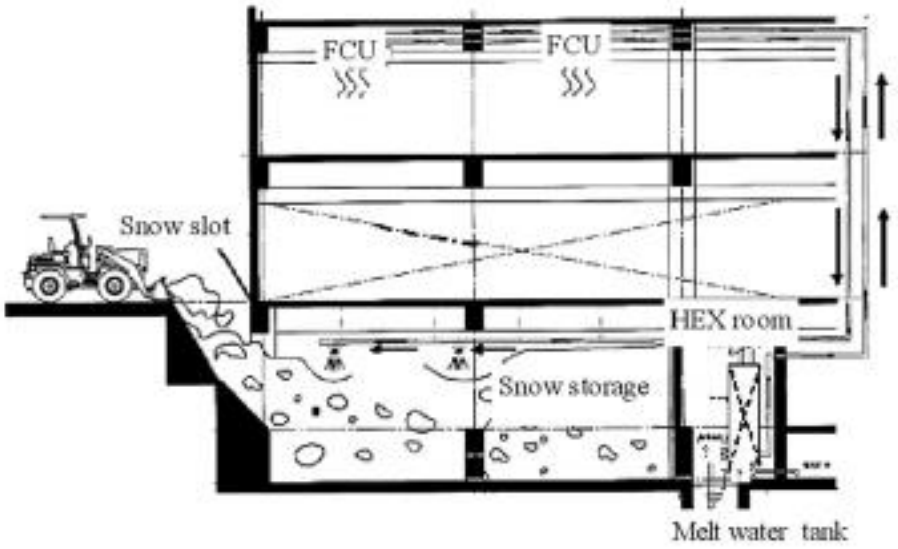


Figure 3.6: Snow storage in renovated building, Asahikawa City, Hokkaido, Japan (from [Hamada et al., 2012])

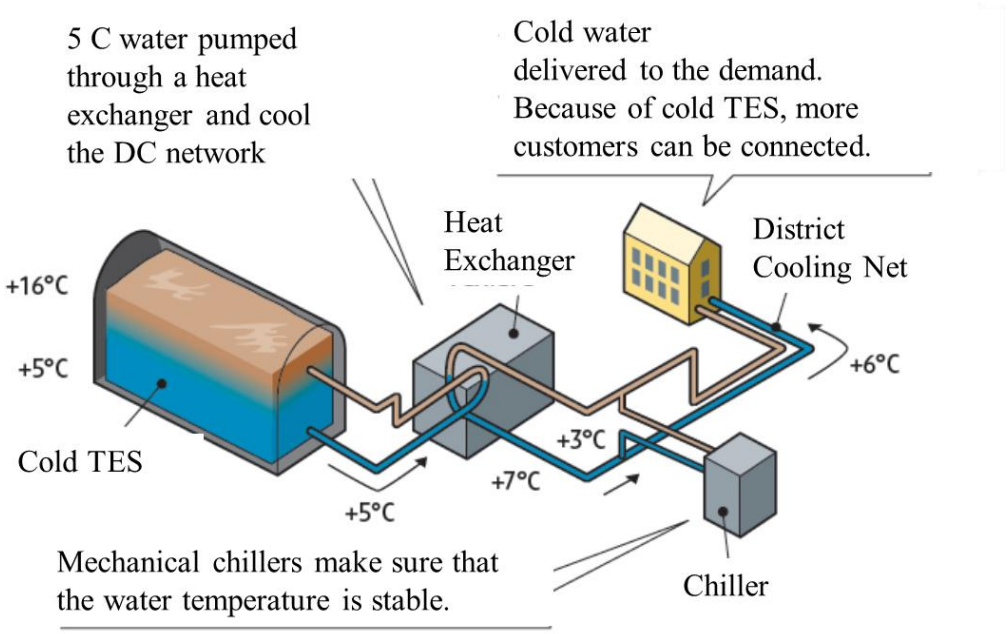
Results showed that over 50% of the initially stored snow was recovered as useful cold, and the primary energy consumption was reduced by over 70% as compared to a conventional chiller system.

3.3.2 Distributed Cold Storage in District Cooling

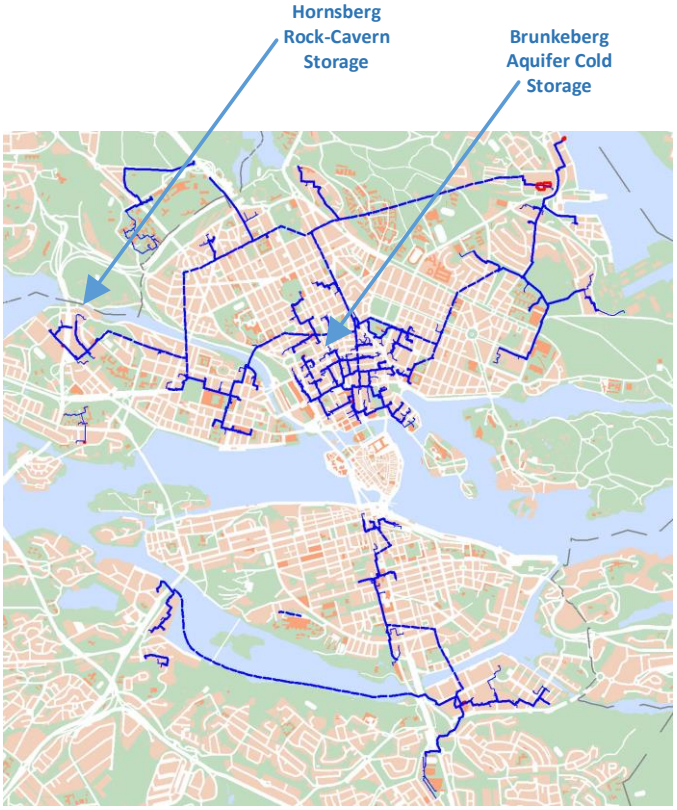
Sweden accounts for 926 GWh of yearly district cooling delivery in 2015 with an annual average increase of 8% since year 2000 [Statistics Sweden, 2016]. Due to small allowable temperature differences between supply and return, the district cooling network would reach its peak capacity during peak demand periods [Werner, 2017]. Several utility companies hence have adopted the distributed cold storage operation where the common technology is cold water stored during off-peak hours in downstream sensible heat storage units. These are stratified cold water storages, either above ground in tanks or underground caverns. The stored cold thermal energy is then distributed to the users during peak hours.

In 2010, a 45’000 m³ underground sensible heat cold water storage cavern was commissioned in Hornsberg, Stockholm, Sweden, see Figure 3.7, showing the Stockholm District Cooling Network. The storage provides daily cycles where stratified cold water may be unloaded at maximum 5’000 m³/hr, the thermal power capacity is rated at 80 MWth with a supply-return temperature difference of 14°C [Termoeknonomi AB, 2009]. The principle of the Rock Cavern Storage is described in Figure 3.7a. The utility company Stockholm Exergi AB (owned 50 % by Fortum, and 50% by the City of Stockholm), bring forward that this particular installation leads to 30 000 tonnes/year reduced CO2 emissions [Stockholm Exergi, 2018]. An earlier installation of cold storage involves an

aquifer underground thermal energy storage (ATES). The geographical storage placements are shown in Figure 3.7b.



(a)



District Cooling Net -- Stockholm

- ”Free-Cooling” from the Baltic Sea
- ”Waste Cooling” from Electrical Heat Pumps
- Conventional Compression Chillers

(b)

Figure 3.7: Stockholm District Cooling System: (a) principle of the Hornsberg Rock Cavern storage; (b) overview of network including distributed cold storage. (based on [Stockholm Exergi, 2018])

The rock cavern storage was a new installation as it was blasted into the underground rock. The “innovation” needed for this concept was specially designed diffusers for distributing the in- and out-flow during operation. Maintaining stratification of water, with a temperature difference of only 10-15 °C is a challenge.

It is also possible to use existing caverns, like in a recently reported prestudy presented by Chiu et al [2018]. In 2017 an abandoned oil cavern of the size 28’000 m³ in Sundbyberg, Stockholm, Sweden was evaluated as a potential cold water storage for use in alleviating district cooling network peak load [Chiu et al, 2018]. Its placement, in relation to the utility is rather central, as depicted in Figure 3.8.

At any rate, the concept could just as well be de-centralised in a larger district cooling system – it all depends on the location of the existing cavern. Through numerical modelling, an assessment showed promising results demonstrating thermal cline zone of maximum 1 meter at 1800 m³/hr. For a supply-return temperature difference of 10°C, this storage may provide a maximum rating of 20 MWth. Again, one of the challenges with this cold storage is to maintain a thermocline and good stratification in the cold storage, even though the temperature difference during operation is less than 10 °C. Through a careful design of the inlet and outlet diffusion system in the storage, this is possible to achieve. Exemplifying results are shown in Figure 3.9.

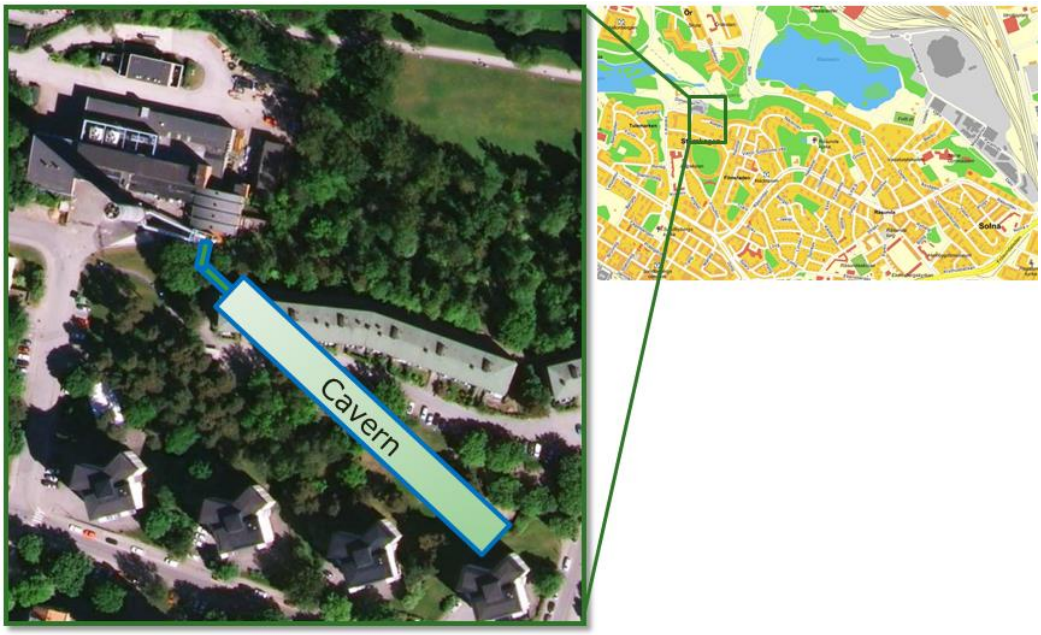


Figure 3.8: Potential cold storage in existing Rock Cavern, Sundbyberg, Sweden.

No decision on an actual installation has been made at the present time, as practical installation considerations, like how to best make the installation in this water filled (with oil residual settled) cavern.

A new Swedish project on distributed cold storages also started in May 2018. This is a collaboration between KTH, RISE, Profu, and NorrEnergi

AB. The project is mediated by Energiforsk[1] and is co-funded by the Swedish Energy Agency, within the TERMO program as part of the project "Thermal energy storage - the solution for a flexible energy system". This distributed cold storage project will investigate how integrating various cold storages into the district cooling networks can contribute to consistent and efficient cold production that maximizes the proportion of natural cooling in the system, while securing quality delivery of cold. This particular project will continue to collaborate with, to DESIRE, IEA ECES follow-up annexes.

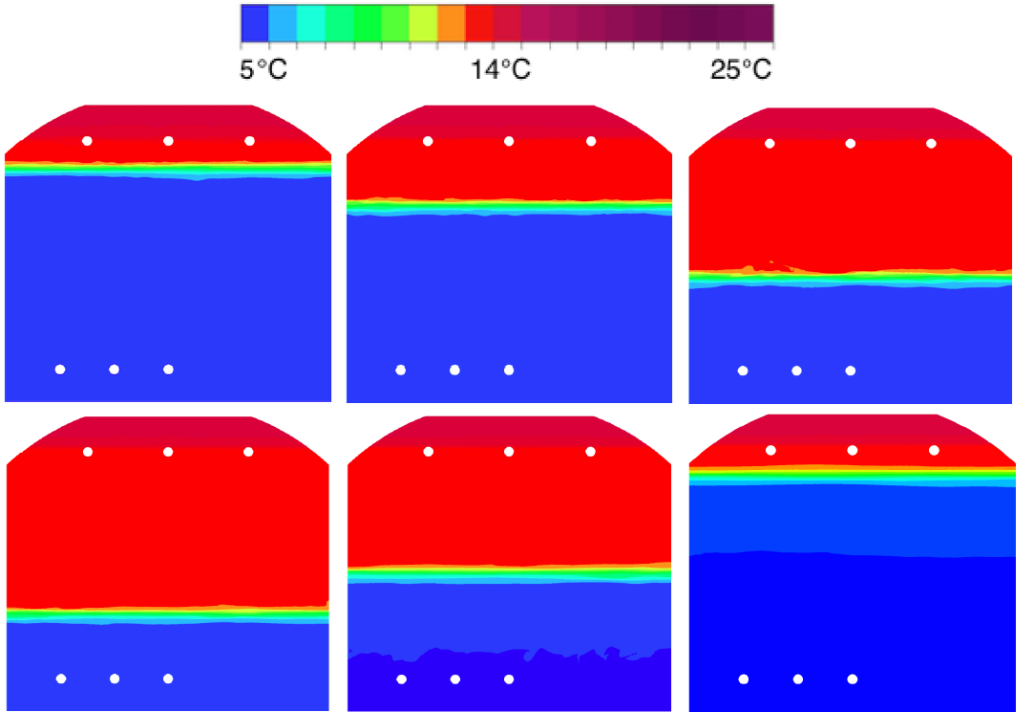


Figure 3.9: Thermocline depths during charging (top) and discharging (bottom) cycles [Chiu et al, 2018].

3.4 Energy Flexible Buildings

Picking up on one important concept of DES, the IEA EBC Annex 67 is presently investigating the concept of energy flexible buildings (EFB), and their ability to alleviate a part of the forecasted problem with large scale implementation of renewables [Jensen et al., 2017]. To illustrate EFB, one example to contemplate was presented, which is here re-illustrated in Figure 3.10. This figure shows how adding load (electrical demand) in an existing system brings the peak load beyond the maximum possible, despite using “green technology” like heat pumps (approximately 2/3 geothermal heat) and electric vehicles (EV) (Figure 3.10a). However, buildings carry a certain thermal mass that cost-effectively can be used as “storage of heat” (and cold) – here, by pre-heating the building excessively (within an allowed comfort range) before the peak hours (approx. 17:00-20:00 hrs), letting the building “free-float” through peak hours, and then provide additional heat immediately after (Figure 3.10b).Also, the EV-charging must be controlled (ICT emphasized) to

[1] www.energiforsk.se

keep the power demand below the maximum allowed, to avoid the installation of additional voltage capacity in existing systems.

In the scope of the this IEA EBC Annex 67, the potential of such building flexibility, along with controlling the flexibility without loss of comfort, is at the heart of the work plan. In their latest newsletter [IEA EBC Annex 67, 2018], among other things the stakeholders' perspective was highlighted, since to fully capture the value of EFB, there is a need for a number of changes:

- Energy retailers must adapt their business models
- Occupants must be willing to change their behaviour
- And relations among actors will need to change towards increased collaboration

A readiness for EFB adoption is, according to stakeholder perspectives, given by factors such as:

- For buildings:
    - Automation
    - Flexible devices
    - Distributed energy resources
    - Refurbishment
    - Comfort
    - Return of investment
- For grid and market:
    - Grid condition
    - Market requirements
    - Real-time price
    - Tariffs and tax
- Along with an effective two-way communication between building and grid

A number of ongoing projects related to EFB were also discussed, and they are summarized in Table 3.1, below.

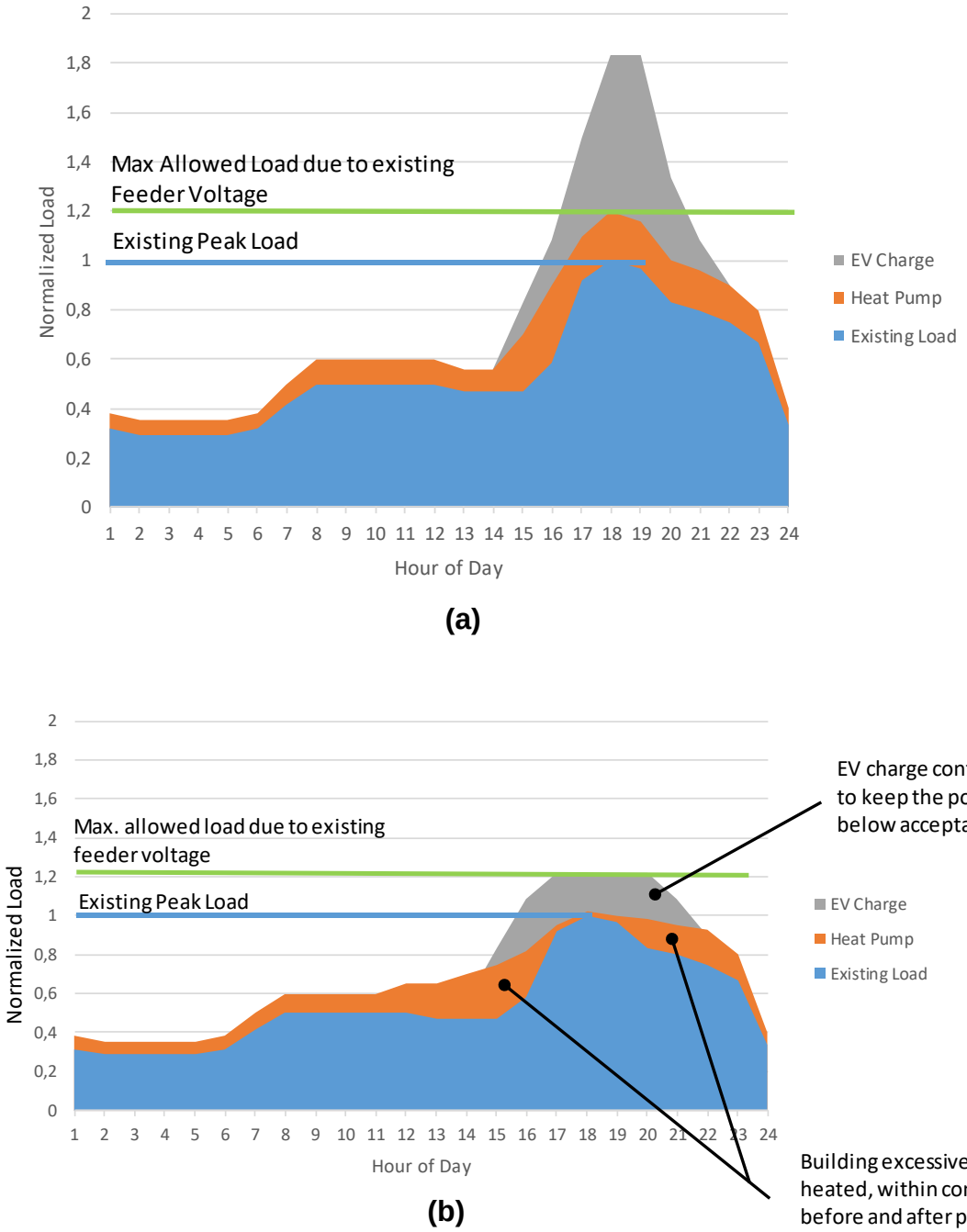


Figure 3.10: Example of introducing heat pump and electric vehicle in existing voltage outlet/feeder: (a) through un-planned installation, the peak load is increased beyond the existing voltage feeder; (b) with excessive heating of the building, before the peak hou

Table 3.1: Examples of projects related to Energy Flexible Buildings

Project Acronym/Name	Essence of Scope	Project website
ForEVER/ Flexibility potential of building technology in electrical distribution networks (Germany)	"the flexibility potential of buildings to stabilize the electrical distribution networks"	http://www.ebc.eonerc.rwth-aachen.de/cms/E-ON-ERC-EBC/Forschung/Forschungsprojekte2/Projekte-Urbane-Energiesysteme/~mqly/FoR-EVER/?lidx=1
IEA HEV Task 28 Home Grid and V2x technologies	The use of electric storage from plug-in electric vehicles (PEVs) demands other than powering the vehicles.	http://www.ieahev.org/tasks/home-grids-and-v2x-technologies-task-28/
INCITE/ Innovative controls for renewable source integration into smart energy systems (H2020 ITN-ETN)	"innovative solutions for the challenging work of controlling and designing the future electrical networks"	http://www.incite-itn.eu/
InterHUB/ Intermittent Energy –Integrating Household, Utilities and Buildings (Denmark)	Integrating buildings to the energy system via understandings from interdisciplinary research on e.g. technical R&D along with actors' decision motivators and communication.	https://www.strategi.aau.dk/Forskning/Tv%C3%A6rviden-skabelige+forskningsprojekter/interHUB
SABINA/ SmArt BIdirectional multi eNergy gAteway (H2020)	"…develop new technology and financial models to connect, control and actively manage generation and storage assets to exploit synergies between electrical flexibility and the thermal inertia of buildings."	http://sabina-project.eu/

3.5 The Electricity Bank – "Die Strombank" – and DES in the Clouds

Just as the financial institutions "banks" manage the flow of money, the electricity bank concept (ger. Die Strombank) proposes an on-site solution for handling on-location storage in an electricity grid where distributed renewable energy is present [Thomann, 2018]. The electricity bank consists of a district (de-centralised) battery storage placed on location next to distributed generation (e.g. wind and solar PV) in residential communities and small businesses. The local, distributed placement, helps alleviate the central grid, and reduces transfer losses. In principle, this concept works as a regular financial bank, with surplus electricity generated being stored, and then fed back to the local grid when needed. A "cloud" solution connects prosumers with the storage, and helps manage each individual electricity account. The concept is schematically described in Figure 3.11. During the project period, the concept was tested at a MVV Energie Site in Rheinau-Süd, Germany.

Aside from the above example, there exist many other initiatives along the same line. For example, the EWE Group of Germany offers "a storage in the cloud" (CES for Cloud Energy Storage) solution to bring to-

gether existing storage solutions in local networks and residential installations. Similarly to “cloud computing”[2] , storage installations are then managed centrally, via the cloud, and make them available in a combined manner. The aim is for CES to optimise the utilisation of installed DES capacity. This concept is promoted under the acronym green2store [EWE AG, 2018]. In the sonnenCommunity [Sonnen GmbH, 2018], their batteries are offered into a digital power sharing platform for small-scale, decentralised renewable energy electricity plants. All members of the sonnenCommunity are able to share their self-generated electricity, without involving large utility companies. Depending on the individual member’s need she can feed or withdraw electricity into/from the community.

All of the above are in fact business cases for DES in Renewable Energy systems. However, as an alternative to DES, there is of course more centralised energy storage solutions that could come with an “economy of scale”, but may not alleviate the grid for transmission to the same extent as the Energy Bank. One merging concept of CES, which sets a good example of the possibilities through “economy of scale” and its opportunity to work with “best-for-purpose” storage technology, is the one presented by Liu et al [2017], in this report denoted CES-Liu. In the CES-Liu, one central energy storage facility replaces DES, as customers are offered a “virtual Battery” via an internet interface. Simulating a case study in Ireland, Liu et al showed that the CES-Liu-concept can provide the same quality service as DES, but at a lower cost. The lower cost comes from taking advantage of the fact that not all CES-users have the same load patterns – the shared storage resources can thus be optimized, including the possibility for the CES-operator to also purchase electricity from the grid, if needed. Also, the economy of scale of storage, as well as making use of “fit-for-purpose” storage technologies in the central facility are important for the cost advantages of the CES-Liu. “Fit-for-purpose” storage technologies can e.g. be a matter of using high power density power capacitors for peak power, and flow batteries or even CAES for high energy density and shifting large quantities of energy in time. [Liu et al, 2017].

[2] Cloud Computing is the concept of an IT strategy that enables universal access to shared pools of computer resources and services, source e.g.: https://en.wikipedia.org/wiki/Cloud_computing

In Sweden, the CODES project (financed by the Swedish Energy Agency, the City of Örebro, and InnoEnergy), will develop and test a battery management system for distributed batteries [CODES Project, 2018]. In the demonstration phase, batteries of 10-50 kWh will be installed in 3-6 apartments in the city of Örebro. The frequency regulation will be evaluated.

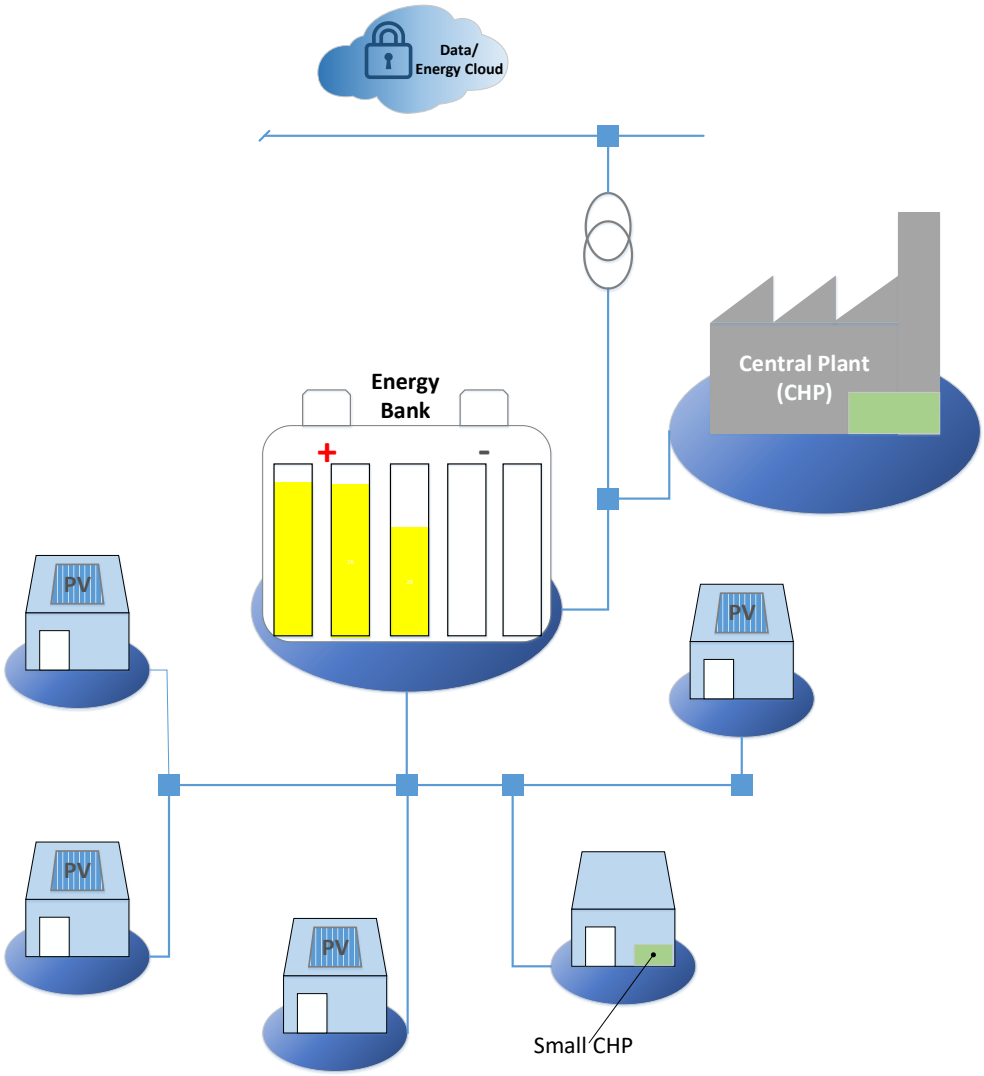


Figure 3.11: Conceptual schematic of the Energy Bank, based on [Thomann, 2018].

3.6 Distributed Polygeneration

So far, this report has discussed either thermal networks or electrical grids, and only slightly touching on the fact that energy services in a system are inter-linked. Building on the concept of CHP comes the next generation energy systems termed polygeneration. In these systems, the complete pallet of energy services are addressed in integrated generation system. Polygeneration lends itself well to distributed generation and is large value for implementing large renewable energy fractions in next generation energy services [Ghaem Sigarchian, 2018]. Aside from deli-

vering multiple energy services (e.g., electricity, heat and cold) polygeneration can utilize a hybrid mixture of energy resources (e.g. solar-PV, wind and fuel-based CHP). One example layout is shown in Figure 3.12.

As shown to the right in the figure, electric, heating and cooling load are

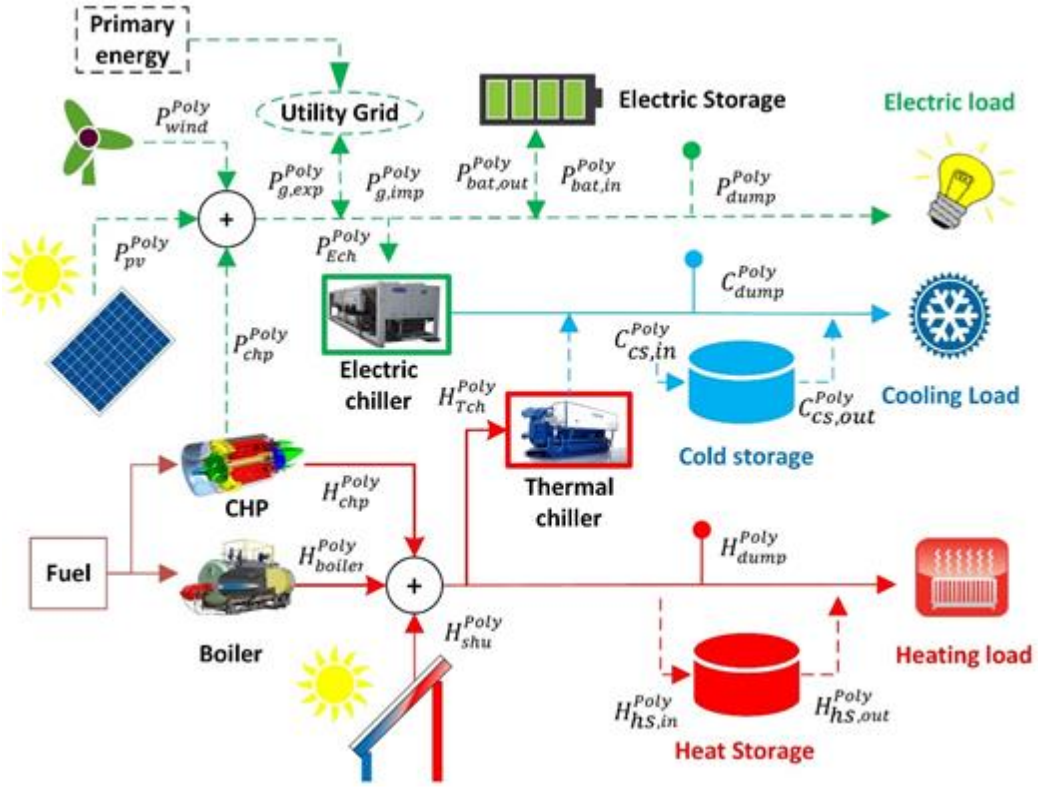


Figure 3.12: Conceptual schematic of a distributed (grid connected) polygeneration system (from [Ghaem Sigarchian, 2018]).

considered using a holistic energy supply chain. There are also storage for these three commodities. On the supply side (to the left) PV, Wind and a CHP and or boiler is integrated for electricity and heat generation. Cold production is done via electric and/or thermal chillers, and excess electricity can in fact be used to generate extra cold and heat stored in the thermal storage capacity, as well as store the excess electricity in batteries. Depending on application conditions, an optimisation will reveal which units are of use in each particular case. A recent study of this particular system concluded that batteries are seldom part of an optimal solution putting equal weight on minimizing the fuel (for CHP/boiler), economy and environmental impact. Storage is managed through the thermal technologies, using micro-CHP for base-load with added solar-PV in addition [Ghaem Sigarchian, 2018].

Below, a few real installations along the same concept are discussed.

3.6.1 Hybrid Storage Solutions – the example of a Self-Sustaining Apartment Complex in Brütten, Switzerland.

The first self-sustained (in energy – not sewage included) multi-family (nine apartments) building was inaugurated in Brütten, Switzerland, in 2016. A façade entirely covered in solar panels, sand-blastered to reduce glare, is the core of the electricity production, along with battery storage. However, a power-to-hydrogen electrolyser system, hydrogen storage, fuel cell micro-CHP, underground thermal energy storage, and heat pumps for hot water generation are also included [Umwelt Arena, 2018]. The installation is shown in Figure 3.13.

(a) **(b)**

Figure 3.13: First self-sufficient multi-family house in Brütten, Switzerland: (a) the PV-façade; (b) installing underground hot water storage. (taken from [Umwelt Arena, 2018])

Energy efficient lighting, household appliances, and an internal heating system that transfer excess heat from the south side of the building to the north side, are additional features. Again, a multitude of storage solutions work in combine to ensure the self-suffiency: electrochemical, chemical and thermal storage technologies designed for a variety of time scales – hours, days and long term.

3.6.2 The Hybrid Urban Energy Storage

Introduced to the DESIRE work in 2014 [Doetsch and Grevé, 2014], the Hybrid Urban Energy Storage (HUES) is a concept where both electricity and heat generation is planned around central, as well as local energy storage technologies. The vision with this concept is to realize a high share of renewable energy by a hybrid integration of generation, and storage technologies, to meet the demands in a city. It is depicted in Figure 3.14.

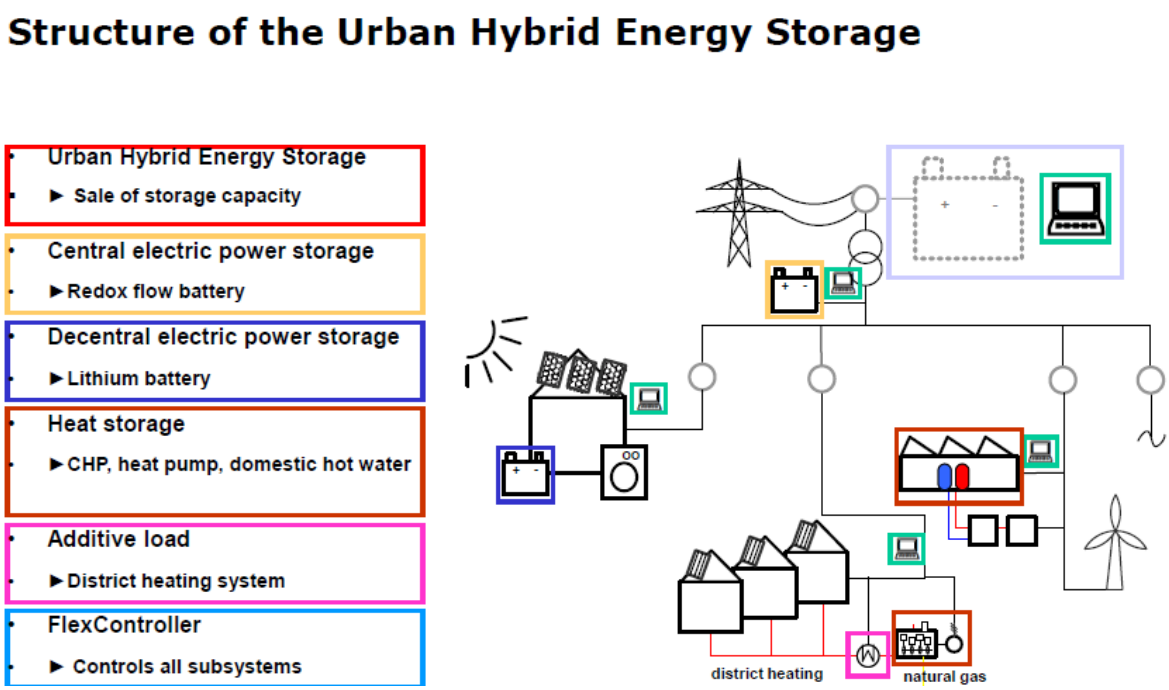


Figure 3.14: The Hybrid Urban Energy Storage Concept (from [Doetsch, 2014])

As shown, central battery solutions (flow batteries envisioned) are combined with DES (lithium ion – household size). Also, the heat flow and networks are interconnected with thermal energy storage integrated.

In addition to “fit-for-purpose” storage, HUES also emphasizes the need for flexible generation and flexible “customers” as well. The concept is additionally described at www.hybrider-stadtspeicher.de.

3.7 On Policy affecting DES Business Opportunities: Regulations and Incentives

DES comes with vast opportunities to bring added value in forming a sustainable energy system. Balancing the grid at large fractions of renewable electricity generation, as well as enabling secure, robust, and cost-effective energy services are traits of integrating DES. Despite the increasing awareness of this potential, there are still factors that hinders implementation of keeping up with storage technology developments: administrative barriers, limited access to grids, and excessive fees and charges [European Commission, 2018]. From a market perspective, DES can be employed to the extent that the new energy system with DES comes with a lower (or equal) cost as compared to the energy system without DES.

In its Energy Storage Roadmap, the International Energy Agency (IEA) [2014] describes policy and economic actions of importance for large scale deployment of energy storage. The roadmap goes over how storage does not fit into existing regulations, often because the technology provides benefits to several parts of the market, like the supply AND demand side, as well as the transmission AND distribution. Of course, there is also an inertia towards change from existing traditional supply technologies and grid management practices. A number of mechanisms and actions are recommended in this roadmap:

- Encourage and support energy storage in off-grid and remote communities
- Real-time pricing
- Pricing by service
- Taxation on final products, rather than energy charge into a storage.

One example of the final point is Germany, where grid fees and taxes must be paid when the electricity is “consumed”, e.g. charged into a storage. This way, the concept of P2H is not so easy to get profitable [Böttger et al, 2014], since taxes on the heat delivered also are due.
In addition to these points, the European Association for Storage of Energy (EASE) encourages market design to allow for specialised storage operators to emerge [Schroeder Pedersen and Durand, 2014]. The European Commission [2017] also high-lights the storage operators and mechanisms supporting their activities. For example, the storage operators are described as independent from the grid operators. As such, storage operators offer multiple services to grid operators, but can at the same time interact with other market actors, e.g. in the demand side. In other words, storage should be cost-effective in its own, with a market value to the flexibility and system benefits through storage.
Related to assuming independent storage operators, the European Network of Transmission System Operators for Electricity (ENTSO-E) wants for the grid operators to have access to storage data, central as well as decentralised, for system security [ENTSO-E, 2016].
In 2014, the stoRE project published their final report [stoRE, 2014], a work that was funded by the Intelligent Energy Europe programme. The overall aim of the project was to improve the regulatory and market framework so as to unblock the path for large scale “electrical” storage facilities. Key elements of the European framework that potential hinders investment in storage were identified, and improvements proposed. For example, stoRE identified that most country policies and directives contained references to “electrical storage”, so its importance for the future is most likely recognize. However, a definition of electrical storage, and a framework for its operation, was missing. Then, electrical storage gets treated as a normal generation unit in many cases. Otherwise, recommendations are in line with the above. However, in addition stoRE suggests that national energy storage targets for grid balancing are put in place by 2025.
Most documented policy strategies are based on a focus on the electrical network, renewables for electricity generation, and balancing the grid when generating capacity becomes more fluctuating with increasing share of solar and wind. However, as described in this chapter, DESIRE-ST2 has brought forward the interconnectivity of energy services. Commercial actions are already in place for working with thermal DES, which also have a balancing effect on the grid. Also, many business cases with hybrid storage solutions (here denoted “fit-for-purpose storage technology”) are being developed presently. Thus, policy, regulation, and market framework must focus on the thermal side, so as not to put in place mechanisms that are biased towards one system solution over another. For example, when it comes to P2H, Schweiger et al [2017] found that

in Sweden waste incineration, and industrial surplus heat (presently available at very low marginal cost, but with low flexibility) reduced the opportunity for balancing the grid with P2H. Then, careful planning of mechanisms, and synergies between them and the sustainability objectives behind, is needed as there are presently strong ambitions to make better use of industrial surplus heat for heating [European Commission, 2016].

Regarding the policy and regulatory framework for DES, it is worth contemplating those examples of government supporting energy storage summarized by the IEA [2014]. These include e.g. subsidies, direct support of demonstration projects, direct mandates to actors to include storage.

California, for example, has mandated solar panels on new single-family homes and apartment buildings built after 1st Jan, 2020 with the goal of increasing renewable energy share on the market [California Energy Commission, 2018]. Adoption of this mandate will help increase the share of clean energy, reduce the electricity load on the grid as well as push forward the implementation of distributed energy storage systems. Such institutionally set regulations may facilitate new business opportunities and can also be considered in EU regulatory framework for certain partner countries.

Additional examples of mechanisms are summarized in Table 3.2.

Table 3.2: Government Actions in Support of Energy Storage (based on [IEA, 2014]).

Country	**Type of Support**	**Overview**
CANADA	Direct mandate Electricity market evolution	Ontario ministry of energy has included energy storage in its energy procurement process, aiming for 50 MW power capacity initially. Also, the procurement process for feed-in-tarriffs (RE projects > 500 kW) has been re-structured to a competitive model where systems integrating RE with storage can be considered.
CHINA	Support of demonstration projects	Financial support from the central government, e.g. for the Zhangbei 36 kWh Li-ion battery project.
EUROPEAN UNION	International collaboration Policy framework development	Co-funding of the stoRE-project [stoRE, 2014].
GERMANY	Support R&D Public information Direct subsidy (2013)	Federal government supports R&D on storage, and finance a website where the public can follow the progress of these projects. Also, a direct subsidy was given to DES combined with distributed PV.
JAPAN	Support of demonstration projects	Projects that demonstrate a time-shift of at least 10% in conjunction with RE electricity. Funds up to 75% of storage cost.
SOUTH KOREA	Support of demonstration projects	MW-scale Li-ion battery demonstrations.
US	Direct mandate, market evolution, price distortion	The California public utilities commission require large utilities to invest in over 1 GW of storage by 2020. Department of energy hosts a global energy storage database. The federal energy regulatory

	reduction, international collaboration.	commission works on opening market to storage, allowing companies other than utilities to sell market assisting equipment.

Real-time pricing is, as mentioned above, a desired mechanism. Here, moving to diverse day and night rates of electricity is at least one step in this direction, and is already proving to enable cost-effectiveness of energy storage installations since it brings a value to the time-shifting of energy. Many commercial installations making use of this, of which ice storage for air-conditioning possibly is the most common.

An incentive measure for encouraging night time electricity use, and the installation of storage, can for example consist of a basic rate related to the maximum power capacity required [kW] ; and a metered rate [kWh] which can vary depending on the time of day, or year [Wang and Kusumoto, 2001], or even follow the real-time pricing.

When it comes to utilising seasonal snow storage for our society's increasing demand for cooling, Nordell [2015] raises some barriers as NOT being the function of the storage, but rather one of the cost of land in densely populated areas as well as permits required. In Sweden, for example, there is a need for building permits for any type of rock-cavern, plus an environmental analysis as to potential negative consequences. This is a lengthy procedure to take into account.

Matrix-Classification C2

Ice storage Alachua County Library

An ice storage cuts day-time energy demand in half, and reduces cost of electricity with over 60%.

Technology Status	Commercial
Storage Capacity	N/A (est 450 kWh)
Power	125 kW

The Alachua County Library Headquarters in Gainesville, Florida, saves on the electricity bill thanks to an ice storage installation which is charged during nighttime, for peak power reduction at night. The installation was done in conjunction with upgrading of the buildings' old HVAC system (from 1992). With the storage, the installed chiller capacity could now be reduced by 20%.

Links

- http://www.calmac.com/energy-storage-installation-alachua-county-library

Based on the above examples, and also the framework mechanisms proposed and reviewed herein, the next step is to carry out an in-depth study of these mechanisms' individual, and combined, effectiveness for supporting DES business development. Such a project must include advanced energy systems modelling, best-practice exchanges among actors involved, and a business development segment. A truly multi-disciplinary endeavour for the benefit of capturing the value of DES.

3.8 Concluding Remarks

DES is a high potential alternative to building large transmission lines over a large regional area, where in the early DESIRE work such transmission lines were discussed to be something to avoid. [Vad Mathiesen, 2012]. Although the author did not high-light DES as an enabling solution, the work in DESIRE-Subtask 2 clearly points to DES allowing excess electricity to be better utilized locally.

For realizing DES business, there is clearly a need for development of new relations (between actors), new actors (e.g. cloud management), and also new business models covering many parts of the market. Also, the regulatory framework and national/regional energy policies must be updated to take a holistic view on energy services – generation, distribution, and demand-side integrated.

The final conclusions from this subtask 2 are:

- There are many business possibilities, although the regulatory framework must be modified to support the large-scale deployment of DES, to harvest its many benefits across market segments.
- Therefore, there is an urgent need for multidisciplinary, and multi-stakeholder R&D concerning the influence non-technical barriers and regulatory framework on the business opportunities of DES.

3.9 References

Andersson, O., and Rydell, L., 2018, The HT-BTES in Emmaboda, Sweden – Lessons learned and further actions, presented at the 14th International Conference on Energy Storage – Enerstock 2018, Adana,Turkey

Bschorer, S., Kuschke, M., and Struntz, K., 2017, Cost ratio analysis evaluating the potential of an ice storage unit in a multi-energy microgrid, in: 2017 IEEE PES Innovative Smart Grid Technologies Conference Europe (ISGT-Europe), https://doi.org/10.1109/ISGTEurope.2017.8260285

Böttger, D., Götz, M., Lehr, N., Kondziella, H., and Bruckner, T., 2014, Potential of the Power-to-Heat Technology in District Heating Grids in Germany, in: Energy Procedia 46, pp. 246-253, https://doi.org/10.1016/j.egypro.2014.01.179

California Energy Commission, 2018, Energy Commission Adopts Standards Requiring Solar Systems for New Homes, First in Nation, http://www.energy.ca.gov/releases/2018_releases/2018-05-09_building_standards_adopted_nr.html (Accessed Aug 2018).

Chiu, J NW; Alfasfos, R; Swedblom, M; Stymne, S; Olivier, JF; Johansson, B, 2018, Cavern Thermal Energy Storage for District Cooling, presented at the 14th International Conference on Energy Storage – Enerstock 2018, Adana,Turkey.

CODES Project, 2018, Control and Optimization of Distributed Energy Storages, http://codesproject.eu/index.php (accessed Aug 2018).

Drake Landing Solar Community, 2018, https://www.dlsc.ca/index.htm (accessed Aug 2018).

Doetsch, C., and Grevé, A., 2014, Hybrid Urban Energy Storage, presentation at the ECES Annex 28 DESIRE , www.eces-desire.org (Member Area).

EIA US Energy Information Administration, Residential Energy Consumption Survey 2015, https://www.eia.gov/consumption/residential/data/2015/index.php?view=consumption#by%20end%20uses (accessed Aug 2018).

ENTSO-E, 2016, Energy Storage and Storage Services --ENTSO-E Position, European Network of Transmission System Operators for Electricity, available at https://www.entsoe.eu/2016/10/21/energy-storage-and-storage-services/ (accessed July 2018).

European Commission, 2018, Energy Storage, https://ec.europa.eu/energy/en/topics/technology-and-innovation/energy-storage (accessed July 2018).

European Commission, 2017, Energy storage – the role of electricity, Commission Staff Working Document, SWD(2017) 61 final, https://ec.europa.eu/energy/sites/ener/files/documents/swd2017_61_document_travail_service_part1_v6.pdf (accessed July 2018)

European Commission, 2016, An EU Strategy on Heating and Cooling, COM(2016) 51 final, https://ec.europa.eu/energy/sites/ener/files/documents/1_EN_ACT_part1_v14.pdf (accessed July 2018).

EWE AG, 2018, Energy Storage in the Cloud, https://www.ewe.com/en/ewe-group/energy-innovations/smart-grid/energy-storage-in-the-cloud (accessed July 2018)

Fleuchaus, P., Godschalk, B., Stober, I. & Blum, P., 2018. Worldwide application of aquifer thermal energy storage – A review. In: Renewable and Sustainable Energy Reviews,94, pp. 861-876, https://doi.org/10.1016/j.rser.2018.06.057

Ghaem Sigarchian, S., 2018, Small-Scale Decentralized Energy Systems -- optimization and performance analysis, PhD Dissertation KTH, ISBN: 978-91-7729-808-3, available online at http://kth.diva-portal.org/smash/get/diva2:1206702/FULLTEXT02.pdf

Government Offices of Sweden, 2016, Multi-party energy agreement (in Swedish, “Ramöverenskommelse mellan Socialdemokraterna, Moderaterna, Miljöpartiet de gröna, Centerpartiet och Kristdemokraterna”), https://www.regeringen.se/ (accessed July 2018).

Hamada, Y., Nagata, T., Kubota, H., Ono, T., and Hashimoto, Y., 2012, Study on a snow storage system in a renovated space, In: Renewable Energy, 41, pp. 401-406, https://doi.org/10.1016/j.renene.2011.11.012

HPTCJ Heat Pump and Thermal Energy Storage Center of Japan, 2018, http://www.hptcj.or.jp/e/ (accessed July 2018).

IEA EBC Annex 17, Newsletter (May 2018), http://www.annex67.org/newsletters/ (accessed July 2018).

IEA, 2014, Technology Road Map – Energy Storage, International Energy Agency, www.iea.org .

Jensen, Søren Ø.; Marszal-Pomianowska, Anna; Lollini, Roberto; Pasut, Wilmer; Knotzer, Armin; Engelmann, Peter; Stafford, Anne; Reynders, Glenn (2017), IEA EBC Annex 67 Energy Flexible Buildings. In: Energy and Buildings 155, pp. 25-34. https://doi.org/10.1016/j.enbuild.2017.08.044 .

Krese, G., Koželj, R., Butala, V. & Stritih, U., 2018. Thermochemical seasonal solar energy storage for heating and cooling of buildings. In: Energy and Buildings, 164, pp. 239-253. https://doi.org/10.1016/j.enbuild.2017.12.057

Liu, J., Zhang, N., Kang, C., Kirschen, D., and Xia, Q., 2017, Cloud Energy Storage for Residential and Small Commercial Consumers: A Business Case Study: in Applied Energy 188, pp. 226-236. https://doi.org/10.1016/j.apenergy.2016.11.120

Martin, R., 2016, Germany Runs Up Against the Limits of Renewables, in: MIT Technology Reviews, https://www.technologyreview.com (accessed July 2018)

Nordell, B., 2015, Using ice and snow in thermal energy storage systems, In: Advances in Thermal Energy Storage Systems -- Methods and Applications, Cabeza, L. F., (editor), Woodhead Publishing, ISBN: 978-1-78242-088-0, https://doi.org/10.1016/C2013-0-16453-7

Nordell, B., and Skogsberg, K., 2005, 21. The Sundsvall Snow Storage — Six Years of Operation, In: Thermal Energy Storage for Sustainable Energy Consumption -- Fundamentals, Case Studies and Design, Paksoy, H. Ö., editor, Springer, Netherlands, ISBN-13 978-1-4020-5290-3 (e-book)

Reuss, M., 2015, The use of borehole thermal energy storage (BTES) systems, In: Advances in Thermal Energy Storage Systems -- Methods and Applications, Cabeza, L. F., (editor), Woodhead Publishing, ISBN: 978-1-78242-088-0, https://doi.org/10.1016/C2013-0-16453-7

Rinne, S., and Syri, S., 2015, The Possibilities of Combined Heat and Power Production Balancing Large Amounts of Wind Power in Finland, in: Energy, 82, pp. 1034-1046, https://doi.org/10.1016/j.energy.2015.02.002 .

Schweiger, G., Rantzer, J., Ericsson, K., and Lauenburg, P., 2017, The potential of power-to-heat in Swedish district heating systems, in: Energy, 137, pp. 661-669, https://doi.org/10.1016/j.energy.2015.02.075 .

Schroeder Pedersen, A., and Durand, J. M., 2014, European Energy StorageTechnology Development Roadmap towards 2030, presentation at the ECES Annex 28 DESIRE , www.eces-desire.org (Member Area).

Sibbitt, B., Mcclenahan, D., Djebbar, R., Thornton, J., Wong, B., Carriere, J., Kokko, J., 2012, The Performance of a High Solar Fraction Seasonal Storage District Heating System – Five Years of Operation, In: Energy Procedia, 30, pp. 856-865, https://doi.org/10.1016/j.egypro.2012.11.097

Sonnen GmbH, 2018, sonnenCommunity – die weltweit größte Plattform für Strom-Sharing, https://sonnen.de/sonnencommunity/ (accessed July 2018)

Statistics Sweden, 2016, Electricity supply, district heating and supply of natural gas 2015, http://www.scb.se/en/finding-statistics/statistics-by-subject-area/energy/energy-supply-and-use/annual-energy-statistics-electricity-gas-and-district-heating/pong/publications/electricity-supply-district-heating-and-supply-of-natural-and-gasworks-gas-2015/ (accessed July 2018).

Stockholm Exdergi, 2018, Underground storage reduces emissions, https://www.stockholmexergi.se/fjarrkyla/underjordiskt-lager-minskar-utslapp/ (accessed Aug 2018, in Swedish).

stoRE project, 2014, stoRE – Final Publishable Report, available at www.store-project.eu (accessed July 2018).

Termoekonomi AB, 2009, Stockholm / Hornsberg project: Energy storage 45,000 m3, http://www.termoekonomi.se/wp-content/uploads/2015/02/6.-Energy-storage-45000-m3-Termoekonomi.pdf (accessed July 2018)

Thomann, R., A current account for renewable energies, MVV Energie AG, https://www.mvv.de/en/mvv_energie_gruppe/nachhaltigkeit_2/nachhaltig_wirtschaften_1/innovationen_1/strombank/strombank_1.jsp (accessed July 2018)

Umwelt Arena Schweiz, 2018, ERSTES ENERGIEAUTARKES MEHRFAMILIENHAUS IN BRÜTTEN, http://www.umweltarena.ch/ueber-uns/energieautarkes-mfh-brutten/ (accessed Aug 2018).

Vad Mathiesen, B., 2012, Smart energy systems and energy storage in the transition to renewable energy systems inD enmark , presentation at the ECES Annex 28 DESIRE , www.eces-desire.org (Member Area).

Wang, M. J., and Kusumoto, N., 2001, “Ice Slurry Based Thermal Storage in Multi-functional Buildings”, in: Heat and Mass Transfer, 37, pp 597-604, https://doi-org.focus.lib.kth.se/10.1007/PL00005891

Werner, S., 2017, District heating and cooling in Sweden, in: Energy, 126, pp 419-429, https://doi.org/10.1016/j.energy.2017.03.052

Weightman, G., 2004, the Frozen Water Trade: a True Story, Hachette Books, ISBN 9780786886401.

Zart, N., 2017, Batteries Keep on Getting Cheaper, https://cleantechnica.com/2017/12/11/batteries-keep-getting-cheaper/ (accessed July 2018)

4 Subtask 3 - Potential of Distributed Storage Solutions for the Integration of Renewable Energies

4.1 Introduction

In subtask 3 of IEA ECES Annex 28, the aim is to identify which distributed energy storage (DES) technologies could be technically and economically beneficial for the integration of fluctuating renewable energy sources (RES) in different types of energy systems. In the subtask, the technical and economic potential for DES solutions is quantified, and it is identified which DES technologies have the largest total (technical and economic) potential. For this, different DES technologies are modelled in the context of a whole energy system on a national scale. For comparison and combination with the DES technologies, energy conversion technologies and other methods for balancing supply and demand in the system are also included in the modelling work. A categorization of the energy supply and demand balancing methods included in this work is shown in Figure 4.1.

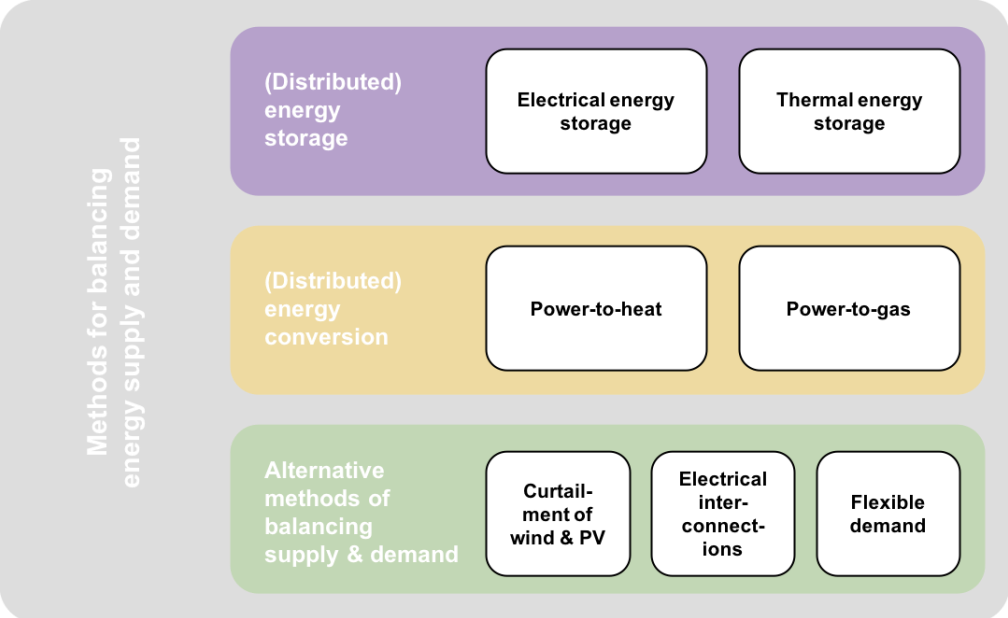


Figure 4.1: A categorization of the technologies for balancing energy supply and demand that are included in the modelling work in subtask 3.

4.2 Methodology

The modelling of the different technologies for energy supply and demand balancing is performed using a scenario-based approach. The scenario structure is illustrated in Figure 4.2. The technologies are modelled one at a time in scenarios 1-15 and as combinations in scenarios 16-19. The technologies are modelled within the settings of five different

energy system typologies (configurations A-E). Each energy system configuration has a baseline scenario (A0-E0), to which the results of the other scenarios within the same configuration are compared. For each of the scenarios fifteen variations are introduced, where the electricity generation from fluctuating RES (wind turbines and PV) is gradually increased with each variation to investigate the performance of the technologies in integrating fluctuating RES. This approach results in 63 scenarios, which each exist in fifteen variations, making a total of 945 model simulations. In addition to this, variations in the energy storage or conversion capacity have been carried out for some scenarios, and a sensitivity analysis has been carried out on some of the model input parameters. The modelling has been performed using the energy system simulation tool *EnergyPLAN*, developed by Aalborg University [EnergyPLAN 2018].

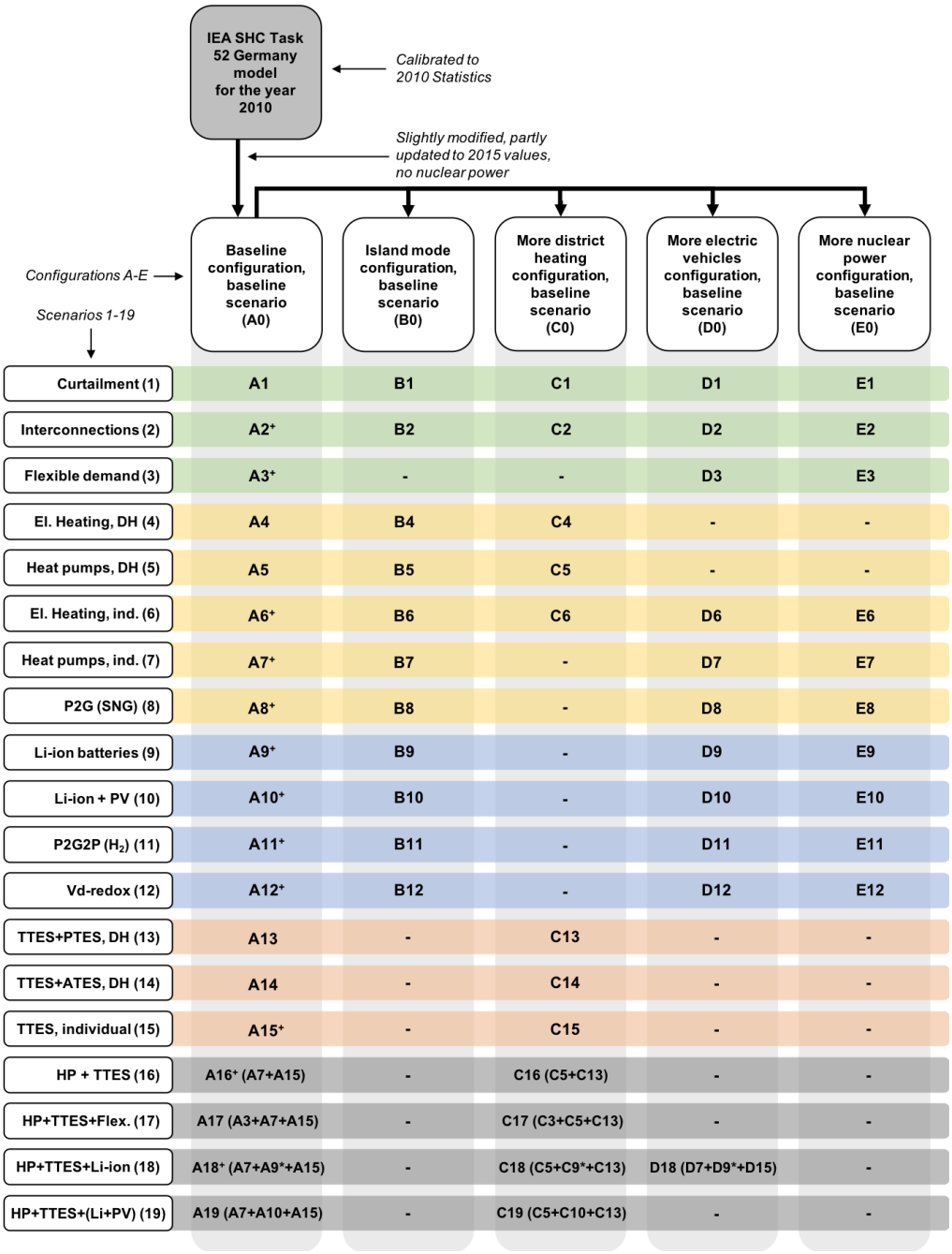


Figure 4.2: A listing of all modelled distributed energy storage or conversion technology scenarios (#1-19), and in which energy system configurations (A-E) they were modelled.

The results of the scenarios have been assessed using the three indicators shown in Figure 4.3. These indicators are used for quantifying the technical and economic impact of and potential for introduction of each technology in the energy system. The indicators are:

- The annually discharged energy. This is a measure of how well the technology facilitates the integration of fluctuating RES by consuming overproduction and “discharging” it (i.e. sends energy back) to the system again in another form or at another time.

- The reduction in the total annual CO_2 emissions arising from the operation of the energy system.
- The total annual socio-economic costs of the energy system (a measure of how much the operation of the energy system costs society as a whole during one year).

The scenarios are considered feasible if the introduction of the technology lowers the CO_2 emissions and total system cost and increases the discharged energy, compared to the baseline scenario of the same energy system configuration. The potential of each technology is assessed based on the combined performance of each technology in the three indicators.

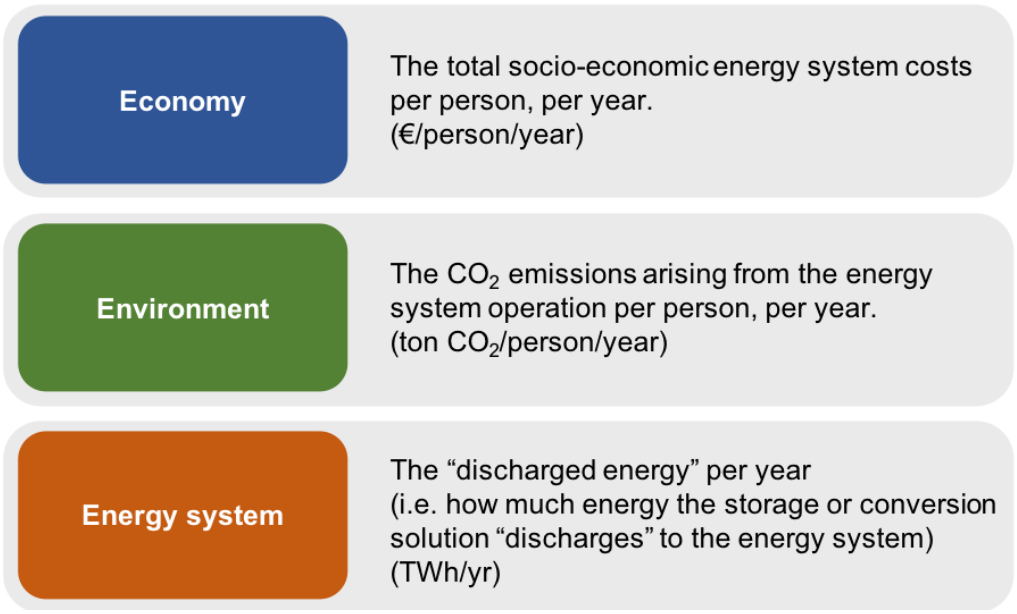


Figure 4.3: A description of the three indicators used for quantifying and comparing the results of the model scenarios.

4.2.1 Main Results

The results of the baseline scenarios of all configurations A0-E0 are shown in Figure 4.4. The results are shown in terms of the economic indicator (total annual socio-economic energy system costs per person), the environmental indicator (total annual CO_2 emissions per person) and in terms of the electricity overproduction in the system on an annual basis (i.e. the amount of electrical energy that cannot be integrated in the energy system). The energy system indicator of "discharged energy" is not applicable for the baseline scenarios, as they contain no DES or other technologies for balancing energy supply and demand in the system.

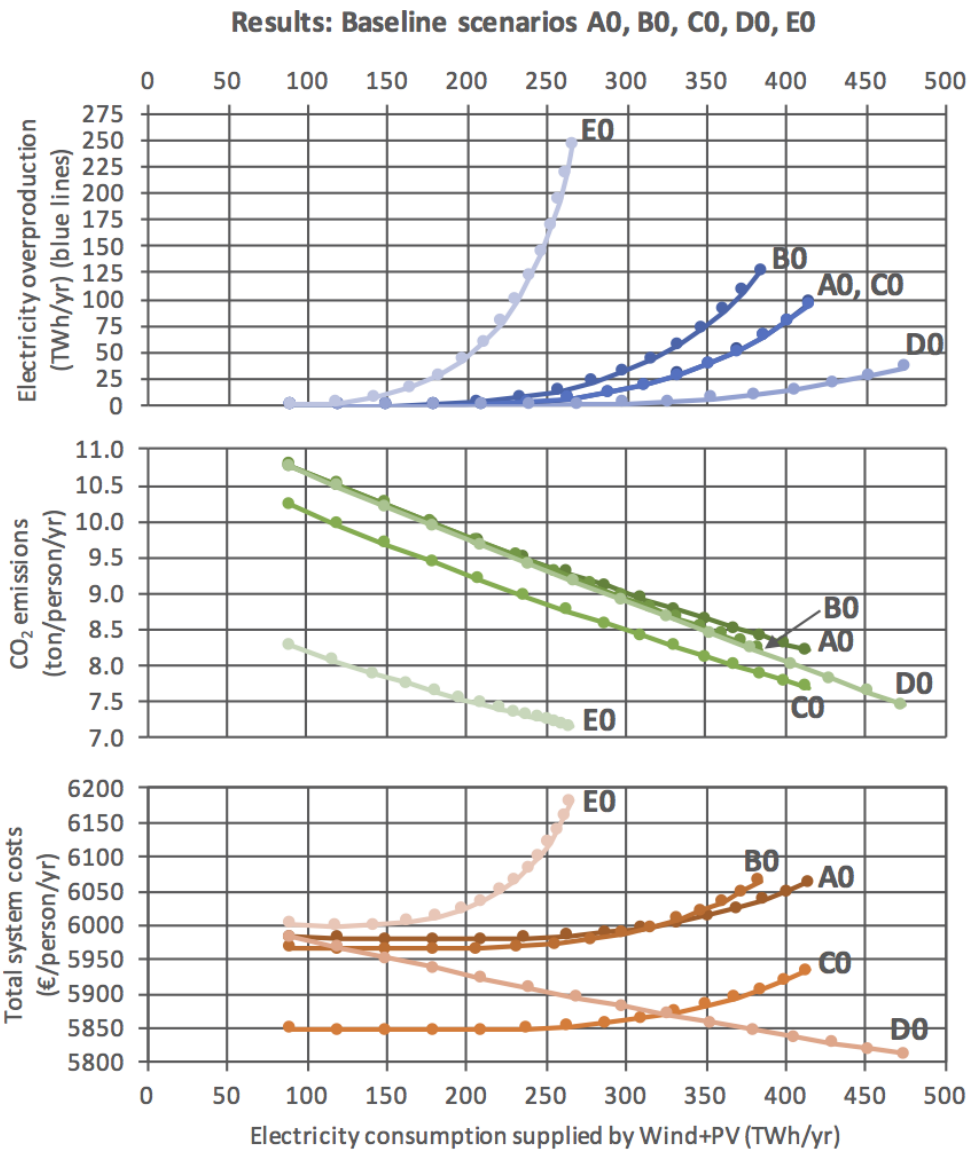


Figure 4.4: The results of the simulations for the baseline scenario for each of the energy system configurations (A0-E0). Note that the secondary axes do not all start at zero.

In the baseline configuration (A0), which resembles Germany's energy system, energy supply and demand balancing measures are needed for wind and PV generation greater than around 300 TWh/yr. The island mode configuration (B0) has total system costs and CO_2 emissions similar to A0, but a greater need for energy supply and demand balancing. The introduction of more district heating (C0) lowers both the total system costs and the CO_2 emissions without introducing more need for energy supply and demand balancing, compared with the baseline configuration (A0). The introduction of electric vehicles (D0) together with more wind and PV generation can yield the largest cost savings and CO_2 reduction, and has the least need for energy system balancing measures out of all the baseline configurations. The nuclear power configuration (E0) has lower CO_2 emissions than the other baseline configurations but is the

most expensive baseline scenario and has the greatest need for supply and demand balancing.

System redesign measures can be a very effective way of cost-effectively integrating large amounts of fluctuating RES and reducing CO_2 emissions. The results show that a transition away from energy system configurations A (based on Germany's energy system), B (island mode) or E (more nuclear power) towards a combination of C (more DH) and D (more EVs) is beneficial on the indicators. The introduction of more DH increases the potential for inexpensive large distributed thermal energy storage and the transition to more EVs leads to the introduction of a large distributed electrical energy storage capacity in the system. This capacity can be utilised as flexibility for the system by ensuring that the EVs are smart charged. Together with such redesign measures, flexibility in the electricity and/or heating sectors should be introduced along with a power-to-gas coupling of these sectors. An example of this is the combination of heat pumps and thermal energy storages in individual heating solutions and flexible electricity demand.

The overall trends in the results of scenarios 2-19, are summarized for each energy system configuration A-E in Table 4.1 through Table 4.5. Electrical energy storages are technically feasible, but not economically feasible due to high investment costs. It may, however, be possible to implement EES in an economically beneficial way in some electricity system configurations by combining them with the above-mentioned flexibility and power-to-heat technologies. The economic feasibility of the energy supply and demand balancing technologies is generally less in the configuration with EVs as the EVs already offer considerable flexibility via smart charging. The feasibility of these technologies in the EV configuration would increase with even more fluctuating renewable electricity generation. The results of the vast majority of scenarios are very robust against changes in fuel costs and CO_2 emission prices, as shown in a sensitivity analysis of the results.

In the tables, the effect of each energy supply and demand balancing technology (or combination of technologies) on the system is categorized for the indicators into "beneficial" (green), "neutral" (yellow) or "not beneficial" (red). The division in these three categories is defined as follows for the three indicators:

- *Total annual socio-economic energy system costs (change in €/person/year, relative to the corresponding baseline scenario):*
  Green: $x < -25$
  Yellow: $-25 \leq x \leq 25$
  Red: $x > 25$

- *Total annual CO_2 emissions from energy system operation (change in ton/person/year, relative to the corresponding baseline scenario):*
  Green: $x < -0.2$
  Yellow: $-0.2 \leq x \leq 0$
  Red: $x > 0$

- *The annual discharged energy (TWh/yr):*

Green: $x > 10$
Yellow: $0 \leq x \leq 10$
Red: $x < 0$

Table 4.1: The result trends for all scenarios in energy system configuration A, divided into the categories “beneficial” (green), “neutral” (yellow) and “not beneficial” (red) for each of the three indicators. Scenarios 16-19 are hybrid scenarios with the following combinations: A16=A7+A15; A17=A3+A7+A15; A18=A7+A9+A15; A19=A7+A10+A15.

Scenarios A	#	Total system cost	CO_2 emis-sions	Fluctuat-ing RES integra-tion
Electric interconnections to abroad	2			
Flexible electricity demand	3			
Electric heating in district heating	4			
Heat pumps in district heating	5			
Electric heating in individual heating	6			
Heat pumps in individual heating	7			
Power-to-gas (biogas methanation)	8			
Li-ion batteries	9			
Li-ion batt. coupled to photovoltaics	10			
Power-to-gas-to-power (hydrogen)	11			
Vanadium-redox flow batteries	12			
Pit & tank TES in district heating	13			
Aquifer & tank TES in district heating	14			
Tank TES in individual heating	15			
Heat pumps + Tank TES	16			
Heat pumps + Tank TES + Flex. dem.	17			
Heat pumps + TTES + Li-ion batteries	18			
Heat pumps + TTES + (Li-ion+PV)	19			

Table 4.2: The result trends for all scenarios in energy system configuration B.

Scenarios B	#	Total system cost	CO_2 emis-sions	Fluctuat-ing RES integra-tion
Flexible electricity demand	3			
Electric heating in district heating	4			
Heat pumps in district heating	5			
Electric heating in individual heating	6			

Heat pumps in individual heating	**7**			
Power-to-gas (biogas methanation)	**8**			
Li-ion batteries	**9**			
Li-ion batt. coupled to photovoltaics	**10**			
Power-to-gas-to-power (hydrogen)	**11**			
Vanadium-redox flow batteries	**12**			

Table 4.3: The result trends for all scenarios in energy system configuration C. Scenarios 16-19 are hybrid scenarios with the following combinations: C16=C5+C13; C17=C3+A5+C15; C18=C5+A9+C13; C19=C5+A10+C13.

Scenarios C	**#**	**Total system cost**	**CO_2 emis-sions**	**Fluctuat-ing RES integra-tion**
Flexible electricity demand	**3**			
Electric heating in district heating	**4**			
Heat pumps in district heating	**5**			
Pit & tank TES in district heating	**13**			
Aquifer & tank TES in district heating	**14**			
Tank TES in individual heating	**15**			
Heat pumps + Tank TES	**16**			
Heat pumps + Tank TES + Flex. dem.	**17**			
Heat pumps + TTES + Li-ion batteries	**18**			
Heat pumps + TTES + (Li-ion+PV)	**19**			

Table 4.4: The result trends for all scenarios in energy system configuration D. Scenario 18 is a hybrid scenario with the combination D7+D9+A15.

Scenarios D	**#**	**Total system cost**	**CO_2 emis-sions**	**Fluctuat-ing RES integra-tion**
Electric interconnections to abroad	**2**			
Flexible electricity demand	**3**			
Electric heating in individual heating	**6**			
Heat pumps in individual heating	**7**			
Power-to-gas (biogas methanation)	**8**			
Li-ion batteries	**9**			
Li-ion batt. coupled to photovoltaics	**10**			
Power-to-gas-to-power (hydrogen)	**11**			
Vanadium-redox flow batteries	**12**			

Heat pumps + TTES + Li-ion batteries	**18**			

The indicator values for the scenario variations with the highest amount of wind power and photovoltaic generation are used as a basis for the categorisation in the tables. Not all technologies were modelled in energy system configurations B-E; the results of the excluded scenarios in configurations B-E were not anticipated to provide substantial additional information compared to the results of these scenarios in configuration A.

Table 4.5: The result trends for all scenarios in energy system configuration E.

Scenarios E	**#**	**Total system cost**	**CO_2 emissions**	**Fluctuating RES integration**
Electric interconnections to abroad	**2**			
Flexible electricity demand	**3**			
Electric heating in individual heating	**6**			
Heat pumps in individual heating	**7**			
Power-to-gas (biogas methanation)	**8**			
Li-ion batteries	**9**			
Li-ion batt. coupled to photovoltaics	**10**			
Power-to-gas-to-power (hydrogen)	**11**			
Vanadium-redox flow batteries	**12**			

None of the individual changes can make up for the gains of an energy system redesign. The results show that individual heat pumps are feasible in all energy system configurations. Flexible electricity demand is potentially feasible in all configurations except the EV configuration (D). With even more RES electricity generation than introduced in the scenarios, it would likely also be feasible in configuration D. TTES are potentially feasible in all investigated configurations, but have a small effect on the integration of RES when implemented alone. A connection with the electricity sector througsh power-to-heat should be looked into when implementing TTES, for pursuing the benefits of this storage technology.

The most feasible technology combinations are those that provide flexibility both in the electricity sector and the heating sector and have a link between the two (power-to-heat). An example of such flexible sector coupling is a combination that includes TTES, heat pumps and if possible also flexible electricity demand.

Electrical energy storages are in general technically feasible, but not economically feasible due to high investment costs. It may, however, be possible to implement EES in an economically beneficial way in some electricity system configurations by combining them with the above-men-

tioned flexibility and power-to-heat technologies. The economic feasibility of the energy supply and demand balancing technologies is generally less in the configuration with EVs as the EVs already offer considerable flexibility via smart charging. The feasibility of these technologies in the EV configuration can be expected increase with even more fluctuating renewable electricity generation. The results of the vast majority of scenarios are very robust against changes in fuel costs and CO_2 emission prices, as shown in a sensitivity analysis.

4.3 Policy Recommendations

Based on the results obtained in this subtask, the following policy recommendations can be given in order to obtain the best integration and the greatest technical and economic benefits of transitioning towards very large capacities of fluctuating renewable energy generation:

4.3.1 Recommendations for energy system redesign

- **District heating, with low-carbon heat generation:** A system redesign towards more district heating would be feasible. A conversion away from individual heating towards district heating with low-CO_2 emitting heat generation should be prioritised. The redesign towards more district heating increases the potential for introducing *low-cost distributed energy storage in the form of large-scale thermal energy storages*.

- **Electric vehicles with smart charging:** A system redesign towards more electric vehicles would be feasible. A massive conversion away from internal combustion engine (ICE) vehicles towards electric vehicles should be prioritised. To maximize the positive effects of introducing electric vehicles, they should be smart charged. The redesign towards more electric vehicles with smart charging introduces a *substantial and cost-effective distributed electrical energy storage capacity in the system in the form of vehicle batteries*.

- **Some level of electrical interconnections to island systems can be beneficial:** Going away from island systems towards interconnected systems would be beneficial on all indicators to some extent. This measure, however, has a limited potential with a high penetration of renewable electricity generation. The feasibility of interconnecting current island energy systems to other energy systems should be investigated carefully where this is geographically and technically possible.

- **Less inflexible nuclear power**: Emphasizing a conversion away from inflexible nuclear power towards other forms of low-CO_2 emitting power generation or towards very flexible nuclear power generation should be prioritised in energy systems with a large nuclear power capacity, that wish to integrate fluctuating RES.

4.3.2 Recommendations for distributed energy storage and conversion technologies

- **Flexible sector coupling:** The most feasible technology combinations are those that provide flexibility both in the electricity sector and the heating sector (district heating), and have a link between the two (power-to-heat). An example of this is a combination of DES and flexible sector coupling; e.g. combinations that include tank thermal energy storage (TTES), heat pumps and flexible electricity demand.

- **Individual heat pumps:** The introduction of heat pumps should be prioritized in order to replace fossil fuelled heat generation in individual heating.

- **Flexible electricity demand:** It should be investigated and tested (e.g. in demonstration projects) to which degree electricity consumers are willing to be flexible and how socio-economically expensive it would be to compensate them for their flexibility.

- **Thermal energy storages:** When thermal energy storages are implemented, connections with the electricity sector through power-to-heat should be looked into for increasing the positive impacts of the TTES. Thermal energy storages in district heating are more economical and can have the potential to provide more flexibility than thermal storages in individual heating.

- **Reduction of electrical energy storage investment costs:** Electrical energy storages, power-to-gas and electrical interconnections are all technically beneficial for the energy system but cause increased total system costs due to high technology investment costs. Research and development should be prioritized with the goal of reducing the price of these solutions. With the price levels used in this model, the implementation of these technologies should only be prioritized in energy systems where very high integration of fluctuating RES and very large reductions in CO_2 emissions are clearly prioritized higher than the minimisation of the total socio-economic energy system costs. The economic feasibility of these solutions may be improved by implementing them in combination with flexible sector coupling to the heating sector.

4.3.3 Other policy recommendations

- **Ensure a positive investment framework for technologies that generate and integrate renewable energy:** Measures should be taken to ensure that energy technologies that generate or integrate renewable energy in the energy system have a positive investment environment compared to energy generation based on fossil fuels. This can be endorsed e.g. by removing subsidies for fossil fuel consumption and/or by introducing economic incentives for renewable energy generation and balancing technologies. Such policies would advance the transition towards a CO_2 neutral energy supply and make the integration of large amounts of fluctuating renewable energy more economically viable. Higher fuel prices make the introduction of DES and other technologies for balancing energy supply and

demand more economically feasible, as shown by the sensitivity analysis of the results.

- **Increase CO_2 emission prices:** Measures should be taken to ensure that for existing polluters, the costs of emitting CO_2 reflect the actual socio-economic costs related to the emissions. This would make the integration of large amounts of fluctuating renewable energy more economically viable and would make the introduction of DES and other technologies for balancing energy supply and demand more economically feasible, as shown by the sensitivity analysis of the result.

5 Subtask 4 - Control Requirements for Distributed Energy Storages

Important for the successful operation of distributed energy storage solutions are intelligent operation and control mechanisms. In Subtask 4, existing Smart Grid technologies and future R&D demand should be identified. Since the collaboration with smart grid related TCPs like the International Smart Grid Action Network (ISGAN) could not be realized in the course of the Annex, the scope of this subtask had to be limited to the first of the following three goals:

- Collecting the state-of-the-art in Smart Grid solutions
- (Developing requirements for an intelligent operation of different energy storage technologies)
- (Identifying future R&D demand for the actual implementation of DES in Smart Grids)

The last two goals might be postponed to future activities.

5.1 Motivation for (DES in) Smart Grids

According to the Electric Power Research Institute “A Smart Grid is one that incorporates information and communications technology into every aspect of electricity generation, delivery and consumption in order to minimize environmental impact, enhance markets, improve reliability and service, and reduce costs and improve efficiency” [EPRI 2017].

There are multiple reasons that motivate the research and development and final roll-out of such smart grids. Within this ECES Annex 28, the focus is set on the integration of renewable energies through distributed energy storages (DES). The increasing distributed generation of electricity leads to increasing distance between consumer load centers and the actual generation of the electricity. Additionally, the increasing volatility of the generation due to increased renewable shares brings stability challenges to the grids. Grid components like substations are often not designed for load flows to higher grid levels occurring during high renewable feed-in. This leads to an increasing need for flexibility measures, which can be optimally implemented in such a “smart grid” [El-hawary 2014]. One solution could be distributed energy storages intelligently operated in a smart grid to facilitate the integration of renewables otherwise curtailed and to help stabilizing the grids. The intelligent operation enables the exploitation of the storages full potential.

5.2 Applications of distributed energy storages in smart grids

This chapter focuses on the collection of examples describing DES in smart grid applications. The collection is based on expert interviews as well as previous work in ISGAN Annex 1 [ISGAN 2013] and the DOE global energy storage database [DOE Global Energy Storage Database

2018]. The aim is to show existing applications where DES are implemented in smart grids and to give an overview on the necessary information flows and technologies needed.

The DOE database counts 1652 energy storage projects (at the time of printing) out of which 128 are described as “smart grid” projects. Out of these 128 projects, 38 could be identified as smart grid related DES projects for the integration of renewable energies. The ISGAN Annex 1 project catalogue counts 98 smart grid projects. Nine DES related projects could be extracted from this collection, of which five projects have a focus on fostering the integration of renewable energies. Together with project examples collected in expert interviews (dropping duplicate projects) a total count of 47 DES smart grid examples was collected (see Table 5.1 for reference).

It is worth mentioning, that the vast majority of the projects implement electro-chemical energy storages (mostly lithium based battery storages). Only few of the projects implement other technologies like redox flow batteries, lead batteries, hydrogen storage with fuel cells, flywheels or thermal storages.

Categorizing the examples shows three main applications for DES in smart grids. Each main application is explained in the following accompanied by one short examplary project description. For a better understanding, a methodology for visualizing the information and electricity flows in a smart DES application was developed based on the definition of DES introduced in the introduction. Depending on the application different stakeholders own and/or operate DES. Benefits can be categorized into systemic benefits, economic benefits and energetic benefits.

Table 5.1: List of Smart Grid projects with implemented DES [ISGAN 2013], [DOE Global Energy Storage Database 2018]

#	Project Name	Technologies
1	Freqcon's Tallaght Smart Grid Testbed, Dublin Ecoult	Hybrid Lead-acid Battery/Electro-chemical Capacitor
2	INGRID Hydrogen Demonstration Project	Hydrogen Storage
3	ACEA Raffineria Substation Smart Grid	Lithium Ion Titanate Battery
4-18	Quick Charging EV's Powered by the Sun (15 project sites)	Lithium Iron Phosphate Battery
19	Santa Rita Jail Smart Grid - Alameda County RDSI CERTS Microgrid Demonstration	Lithium Iron Phosphate Battery
20	Technology Solutions for Wind Integration - Center For Commercialization of Electric Technology (CCET)	Lithium Manganese Oxide Battery
21	Del Lago Academy (IES)	Lithium Polymer Battery
22	Marshall Steam Station Energy Storage Project	Lithium Polymer Battery
23	McAlpine Circuit CES System	Lithium Polymer Battery
24	PDE Smart Microgrid System	Lithium Polymer Battery
25	SCE Irvine Smart Grid Demonstration: CES	Lithium Polymer Battery

26	250 kW / 1 MWh ElChe Wettringen	Lithium-ion Battery
27	7-Eleven Distributed Energy Storage System (DESS) - ConEdison / Green Charge Networks	Lithium-ion Battery
28	Gapado Island, Jeju Smart Grid Project	Lithium-ion Battery
29	Intelligentes Netz Energie Speicher System (INESS)	Lithium-ion Battery
30	La Guardia Airport Avis Car Rental - Green Charge Networks	Lithium-ion Battery
31	NICE GRID project in Carros (Southern France): Low Voltage Grid Batteries (LVGB)	Lithium-ion Battery
32	NICE GRID project in Carros (Southern France): Secondary Substation Battery (SSB)	Lithium-ion Battery
33	NICE GRID project in Carros (Southern France): smart hot water tanks	Thermal energy storage
34	SCE Irvine Smart Grid Demonstration: RESU	Lithium-ion Battery
35	The Zurich Dietikon 1 MW BESS	Lithium-ion Battery
36	University of Hawaii Smart Grid Regional and Energy Storage Demonstration Project (Maui Smart Grid)	Lithium-ion Battery
37	Brooklyn Army Terminal Smart Grid Demonstration Project	Valve Regulated Lead-acid Battery
38	Washington State University 1 MW UET Flow Battery - Avista Utilities	Vanadium Redox Flow Battery
39	Orkney Energy Storage Park	Lithium-ion Battery
40	Smart Grid Showcase Region Salzburg (Leafs Project)	Lithium-ion Battery, Hot water storage
41	VENTEEA	Lithium-ion Battery
42	MILLENER project	Lithium-ion Battery
43	REFLEXE smart grid France	Lithium-ion Battery
44	Caterva SWARM	Lithium-ion Battery
45	AEP Ohio gridSMART Demonstration Project	Lithium-ion Battery
46	SWM/STORNETIC Flywheel storage in virtual power plant	Flywheel
47	Cryogel Ice Storage at Sports Hub, Singapore	Ice storage

5.2.1 DES for limited substation capacity/islanding

The first application of DES in smart grids is the possibility to support substations and T&D equipment and possibly run parts of the grid in island mode. The electricity system has seen rapidly growing shares of renewables within the past years. Especially photovoltaics generators are largely situated on rooftops of residential or commercial buildings within the distribution grids. Coming from a centralized generation of electricity, the distribution grids are designed for load flows from higher grid levels to lower grid levels. Renewable feed in within the distribution grid however might exceed the demand particularily during sunny days with low demand. Not only high feed-in but also increasing demands due

to new consumption models (e.g. electric vehicle charging) can bring the T&D equipment to its limits. Distributed energy storages can – if intelligently operated – relieve this situation and defer a possibly expensive upgrade in T&D equipment.

Islanding is usually a consequence of bigger disruptions in integrated networks, where the network breaks up into smaller islanded grids with asynchronous frequencies. Small parts of a bigger electricity grid however can run autonomously using DES until the integrated system is restored. In case of the island mode operation, the energy storage keeps the islanded part of the grid stable.

Figure 5.1 shows the visualization of energy and information flows for this application. The energy storage can be situated in the distribution grid, owned and operated by the grid operator. The DSO usually processes information centrally. Weather forecasts enable better storage operation planning during peak renewable feed-in. Information collected

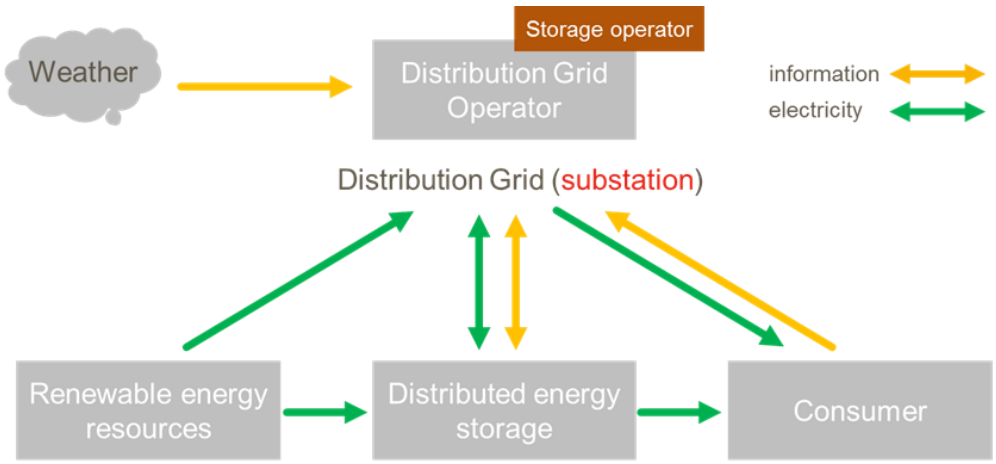


Figure 5.1: Visualization of energy and information flows in the application of DES for limited substation capacity/islanding

at consumer site (e.g. by “smart meters”) enables real time demand estimations especially important during peak times. The automated data processing at the DSO then controls the storage based on this information. The DES can also be situated at consumer sites distributing the needed energy onto multiple storages. The control signals however still coming from the grid operator need to be transmitted to as many storages as needed to cope with the respective grid situation. This increases the ICT effort but works analogously.

The systemic benefits of this application are the stabilization of the grid. Economic benefit is the deferred grid upgrade investment. From an energetic point of view, the increased feed-in of renewables and reduced losses are beneficial.

Matrix-Classification 1-A, Configuration Code HD3

AEP Ohio gridSMART Demonstration Project, USA

T&D investment deferral with Li-Ion Batteries (Community Energy Storage, CES) in the Distribution Grid integrating distributed PV generation

Technology Status	Pilot
Storage Capacity	50 kWh_{el}
Power	25 kW

Li-Ion batteries are installed in the distribution grid to relieve the grid during peak hours of PV feed-in and demand. Substation replacement is deferred.

Links

- www.aepsustainability.com

5.2.2 DES for ancillary services

DES can also be utilized for ancillary services. Frequency control is necessary to keep the frequency of the system constant and to adjust supply and demand to any given time with respect to the active power. With

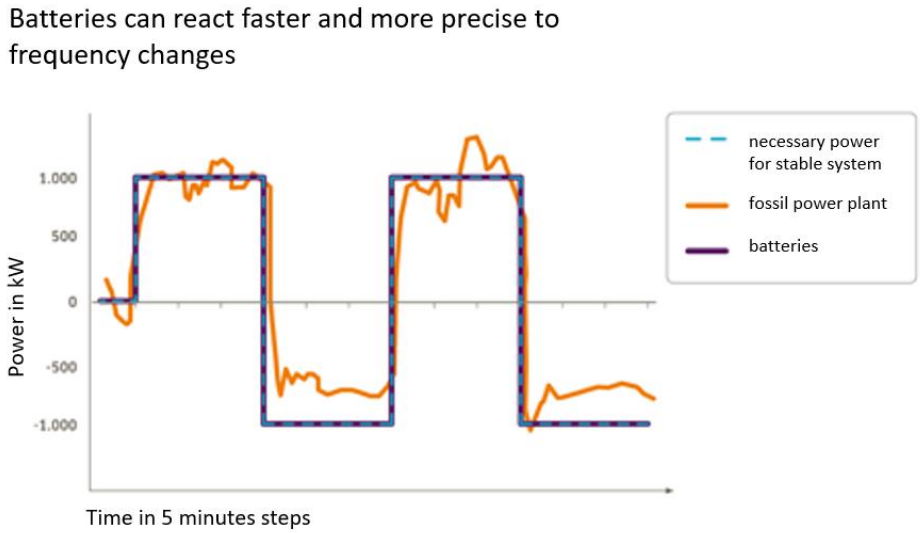


Figure 5.2: fast reaction times of batteries compared to fossil power plants. [Younicos 2018]

increasing production from inverter-based generation units like PV, spinning masses need to be replaced by new technologies. Energy storages can offer this functionality since the inverters can mimic the inertial behavior of electromechanical generators. Storages also offer primary and secondary operating reserve capabilities especially due to their minimal latency in the order of milliseconds Figure 5.2.

Besides frequency control, grid voltage also needs to be controlled within the allowed voltage range. Storages offer reactive power as well as fault power and can control voltage by actively charging and discharging effective power within a grid. This becomes escpecially important with increasing distributed renewable generation levels. Figure 5.3 shows the deviation of the grid voltage over the length of an exemplary low voltage grid with various consumers with installed PV generators. The green area represents the allowed voltage range. Feed-in from PV leads to an increase in grid voltage whereas consumption leads to decreasing voltage levels. The worst case – maximum feed-in from PV and no consumption – is used for dimensioning a low voltage grid. Without energy storages, the voltage surpasses the maximum allowed voltage in close proximity to the substation and makes further feed-in from PV down the line impossible (red line). Storages at the end of the grid line or at each feeder can help improve this situation and keep the voltage level in the allowed range (green and yellow lines). However, it has to be considered, that a poorly dimensioned storage at the wrong position can also have a negative impact on the voltage level (blue line) [Sterner, et al. 2015].

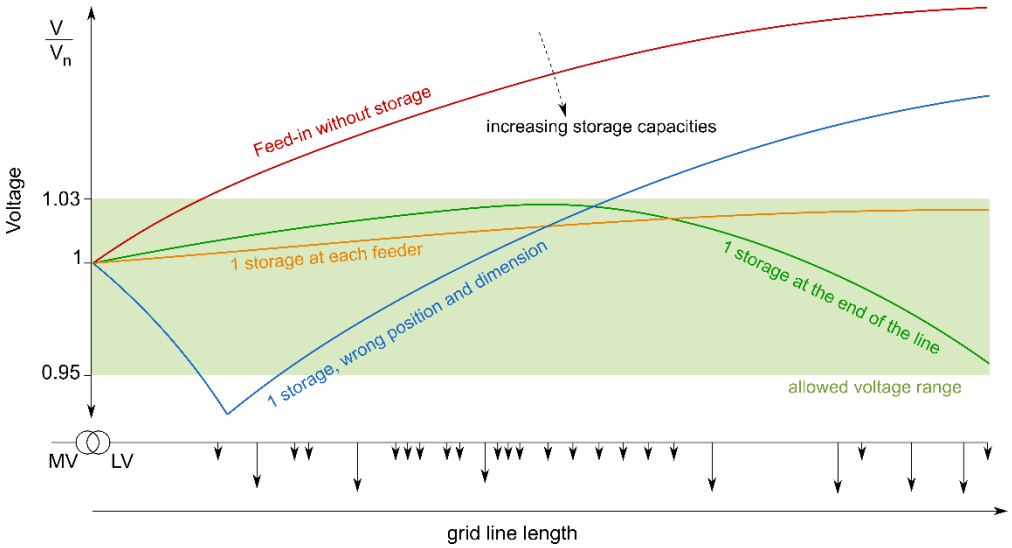


Figure 5.3: Voltage change in DG with and without electrical energy storages at maximum feed-in and zero consumption [Sterner, et al. 2015]

Depending on the regulatory and market frameworks, storages need to fulfill prequalification requirements. In the case of Germany, storages need to have minimum capacities (power and energy) for participating in the operating reserve markets. In the case of distributed energy storages these capacities can only be reached by pooling multiple storages together.

Figure 5.4 shows the visualization of the information and energy flows for DES participating in operating reserve. A trader who aggregates distributed energy storages operates the storages through a platform and participates in the operating reserve market. The energy flow is directed from the storage to the grid in case of positive operating reserve and from the grid to the storage in case of negative operating reserve. Information flows from the DSO to the trader providing the signal for operating reserve as well as from the trader to the storage for the operation. Additional information about weather and consumer behavior as well as market data enables the trader to optimize his storages. The systemic benefit of this application is the stabilization of the grid. Economic benefit is the possible participation and generation of profits in the operating reserve markets.

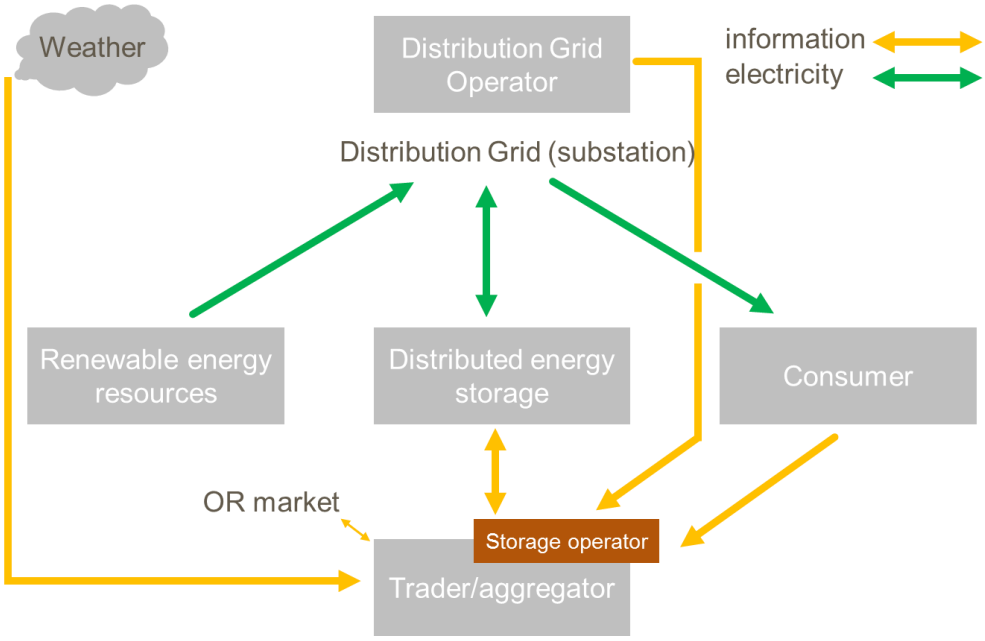


Figure 5.4: Visualization of energy and information flows in the application of DES for ancillary services

Matrix-Classification A-1, Configuration Code BD17

SWM/STORNETIC Flywheel storage in virtual power plant, Germany

Grid connected flywheel storage for ancillary services wthin a virtual power plant

Technology Status	Pilot
Storage Capacity	100 kWh
Power	600 kVA

SWM uses STORNETIC flywheel storages to show the possibilities to provide ancillary services with distributed energy storages within a virtual power plant configuration with multiple different energy carriers including bioenergy, wind, PV, and hydro.

Links

- https://www.swm.de/geschaeftskunden/dienstleistungen/virtuelles-kraftwerk.html

5.2.3 Arbitrage

The economical value of electricity fluctuates strongly with fluctuating supply and demand. Coming from a fossil fuel based electricity generation these fluctuations were usually limited to night-day shifts due to lower demands during night times. Heading towards systems with high shares of volatile renewable generation the price fluctuations can increase. During times of low demand and surplus from renewables like wind and PV,

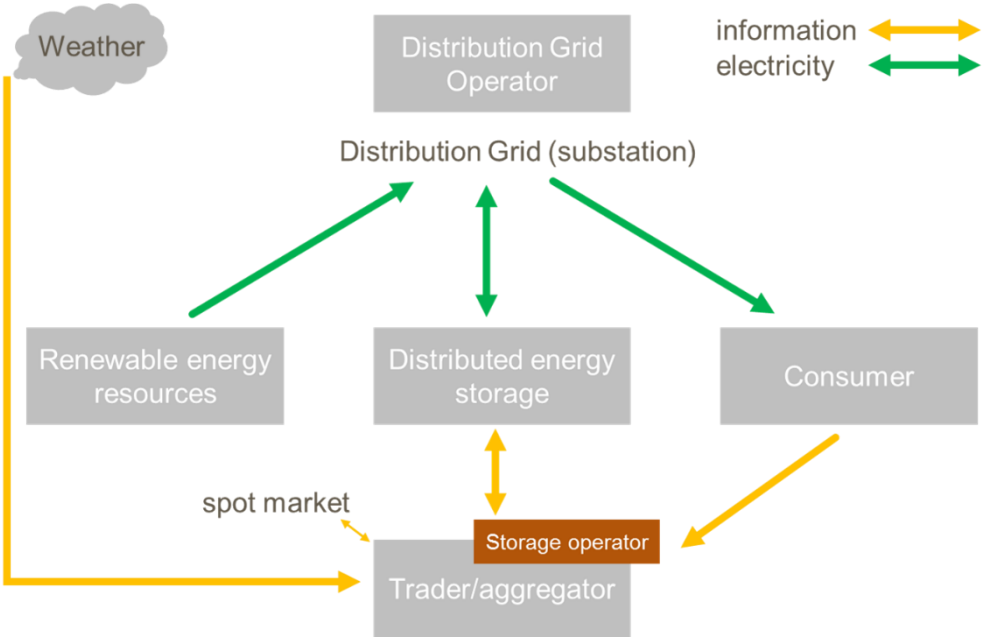


Figure 5.5: Visualization of energy and information flows in the application of DES for arbitrage

prices drop and even negative prices are possible. Whereas during peak demand times and simultaneous low availability of renewables or unscheduled power plant outages. Consequently, it may be profitable to store electricity at times of low prices and use or sell it during times of high prices. In the case of distributed energy storages, the storage operator needs access to the spot market or to price flexible electricity tariffs. In any case, price information needs to be available. Additional information on weather and consumer behavior can improve economics by making market and consumer behavior predictions possible. Energy is exchanged directly with the grid in the case of temporal electricity spot market arbitrage. Another way of arbitrage is the decoupling of obtaining cheap energy (e.g. electricity) and shifting the consumption to times of high prices. For both arbitrage options mentioned, intelligent algorithms processing price/weather and consumer data are needed to beneficially operate the respective energy storage. Better data availability automatically facilitates the optimization of the arbitrage operation and hence yields bigger economical benefits.

Matrix-Classification C-2, Configuration Code B10

Cryogel Ice Storage at Sports Hub, Singapore

An ice storage facility reduces operating costs and increases energy savings

Technology Status	Commercial
Storage Capacity	100 MWh_{th}
Power	36 MW_{th} + 16 MW_{th} "ice spray"

With a total ice storage volume of 2200 m^3 a large sports hub in Singapore is provided with necessary air conditioning. The operational costs of the air conditioning are reduced dramatically by shifting energy needs to times of low energy prices.

Links

- http://www.airclima-research.com/references

5.2.4 Combining applications for benefit stacking

The true potential of DES in a smart grid can be revealed combining multiple applications. The benefits can hence be stacked and the overall effect on the energy system and the integration of renewables, as well as the economics are optimized. With intelligent control mechanisms, DES can be operated to serve multiple purposes like substation support, operating reserve, arbitrage and maximizing the self-consumption of a building with fluctuating renewable generation capacities at the same time.

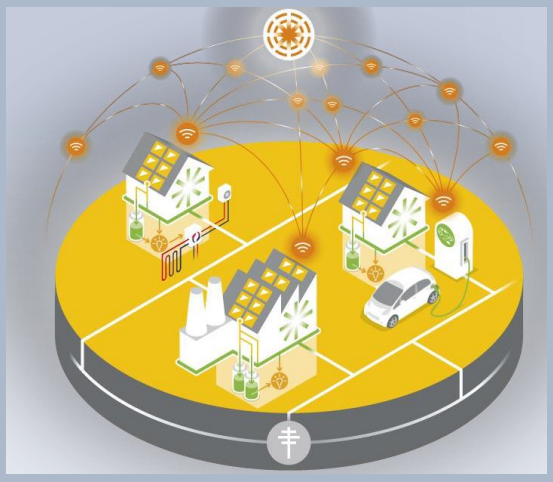
This leads to questions about ownership and operation of the DES and possibly diverging interests of the different stakeholders. A homeowner buying a battery storage to increase his self-consumption has in the first place no interest (and possibility no possibility due to prequalification requirements) in providing ancillary services with his storage capacitiy. A homeowner offered an incentive by a storage distributor/aggregator to provide a small percentage of his storage capacity for ancillary services however can benefit by increased self-consumption and revenues from providing storage capacities to the aggregator. One example for this is shown in the following example box.

Matrix-Classification 1-A, Configuration Code BD3

Caterva SWARM, Germany

Smart connected home battery storages for grid services and maximising self-consumption

Technology Status	Commercial
Storage Capacity	varying
Power	varying



Batteries in residential buildings are interconnected and managed by a central management system. Participation in the primary reserve market is made possible while simultaneously maximizing the self-consumption of PV-home-owners.

Links

- www.caterva.de

5.3 Information and communication infrastructure

The intelligent operation of distributed energy storages requires suitable information and communication technology (ICT) infrastructure. Information transmission between smart grid components and other parts of the energy system and data processing and control is a crucial part of any smart grid application. Figure 5.6 shows the overview of communication grids and routes in an electrical smart grid according to NIST [NIST 2014]. Although the scope of this report only covers distributed energy storages, it can be seen that interactions for the smart operation of such storages go beyond the distribution grid. Storages situated in the distribution grid or at customer site need to interact with distribution operators through appropriate metering and service interfaces over field area networks. The integration in markets also needs a communication channel through either grid operators or third party service providers.

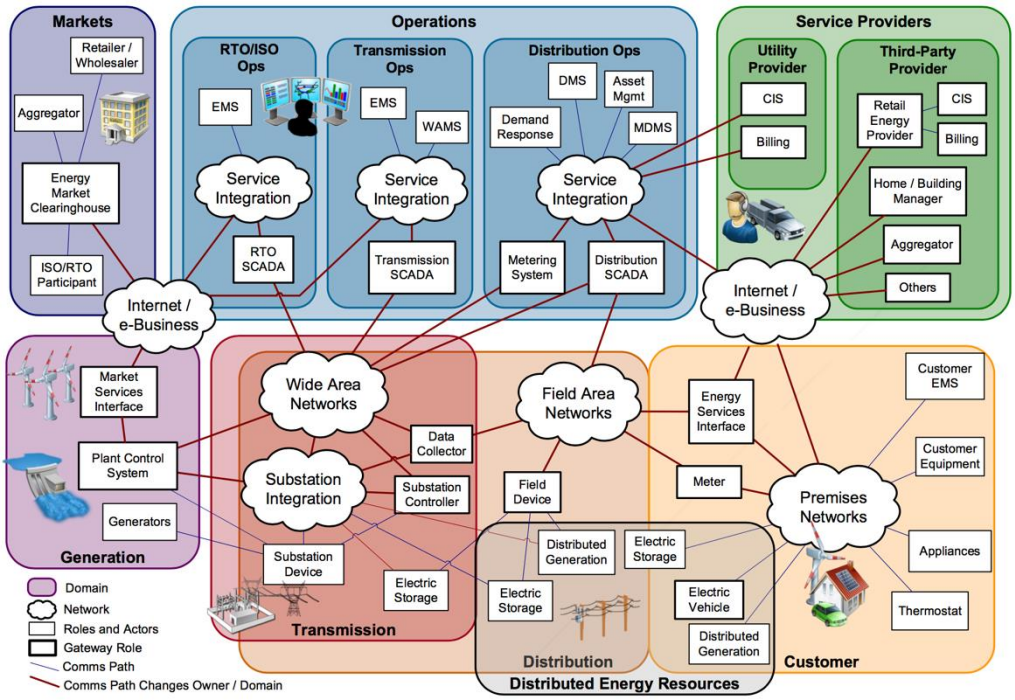


Figure 5.6: Communication infrastructure overview in an electrical smart grid [NIST 2014]

The applicable communication technolopgies and protocols vary for each application. Ethernet, PLC, Zigbee, GPRS, WiMAX, LTE are the communication technologies applied in the Grid4EU projects [Frémont 2012]. A lot of effort has been put in standardizing communication protocols within the last decade. However, there exists a wide variety in protocols. G3 PLC, Meters and More, P1901, PRIME, ISO/IEC 14908-3, IEC 60870-5-104, IEC 61850, IEC 62056, etc. are the protocols applied only in the Grid4EU projects [Frémont 2012]. Besides the communication technologies and protocols, data and information models play also an important role in the smart grid architecture and there again exists a multitude of standards.

Most of the investigated smart grid projects use their own proprietary ICT based on different standards optimized for the respective special application. A universal standard regarding the ICT protocols is desirable but possibly hard to implement due to the diversity of applications and integrated hardware.

Challenges also exists regarding the complexity of the interconnection of high numbers of components. Escpecially since the DES applications in smart grids may also affect private homeowners, security and safety of the systems and data privacy need to have topmost priority. The progressing digitalization might offer solutions to overcome these challenges. The concept of blockchain promises simplifications regarding the autonomous contracting and trading between millions of interconnected devices [BDEW 2017]. Biggest advantage is the dezentralised, direct and autonomous transaction between production, storage and consumption devices. Central intermediaries like metering operators, traders, supply companies and payment providers (e.g. banks) could become obsolete in the future electricity system. The economical and efficient access

to the market would be facilitated for a theoretically infite number of deliberately small devices including distributed energy storages in the electricity grids. [Hasse, et al. 2016].

5.4 References

[BDEW 2017] BDEW. Blockchain in der Energiewirtschaft. Berlin: BDEW Bundesverband der Energie- und Wasserwirtschaft e.V., 2017.

[DOE Global Energy Storage Database 2018] DOE Global Energy Storage Database. Sandia Corporation. 2018. http://www.energystorageexchange.org.

[El-hawary 2014] El-hawary, Mohamed E. „The Smart Grid - State-of-the-art and Future Trends.“ Electric Power Components and Systems, 2014: 239-250.

[EPRI 2017] EPRI. - Electric Power Research Institute. November 22, 2017. http://smartgrid.epri.com/.

[Frémont 2012] Frémont, Jérôme. „Grid4EU - gD4.1 & gD4.2 Guidelines for standards implementation.“ EDF, ENEL, 2012.

[Hasse, et al. 2016] Hasse, Felix, Dr. Axel von Perfall, Thomas Hillebrand, Erwin Smole, Lena Lay, und Maximilian Charlet. Blockchain - Chance für die Energieverbraucher? pwc, 2016.

[ISGAN 2013] ISGAN. Annex 1 Smart Grid Project Catalogue. USA: ISGAN, 2013.

[NIST 2014] NIST. NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 3.0. National Institute of Standards and Technology (NIST), 2014.

[Sterner, et al. 2015] Sterner, Michael, Fabian Eckert, Martin Thema, und Franz Bauer. Der positive Beitrag dezentraler Batteriespeicher für eine stabile Stromversorgung. BEE - Bundesverband Erneuerbare Energie e.V., 2015.

[Younicos 2018] Younicos. 2018. www.younicos.com.