Sensible – DELIVERABLE

Energy storage domain roles & classification

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Author(s): Andrea Michiorri, ARMINES
Maria Garcia Pelaez, Arno Dentel, Julian Buderus, THN
Ricardo Bessa, INESC TEC
Clara Gouveia, INESC TEC
Luis Casla Urteaga, INDRA
Tuukka Rautiainen, EMPOWER

Reviewer(s): Jose Manuel Damasio, SIEMENS SA

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Executive Summary

This deliverable presents the experience and the findings of the partners concerning several topics related to the application of electric and thermal storage in power systems, with special attention paid to the SENSIBLE project. The topics considered are: 1) Storage applications, 2) Storage technologies and state of the art of demonstration projects, 3) Regulatory Framework and 4) Key Performance Indicators for High-level projects.

Several classification methods for storage applications have been proposed. With respect to the SENSIBLE project (noting its scope, use cases and the characteristics of the three demonstrator sites), five application areas have been identified which are summarised in Table 1.

Table 1: Domains and applications

<table>
<thead>
<tr>
<th>Domain</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distribution grid</td>
<td>Capacity support</td>
</tr>
<tr>
<td></td>
<td>Dynamic support for local voltage</td>
</tr>
<tr>
<td></td>
<td>Power quality, intentional islanding</td>
</tr>
<tr>
<td>Customer service</td>
<td>Load shifting / Peak shaving</td>
</tr>
<tr>
<td></td>
<td>Maximise self-consumption</td>
</tr>
</tbody>
</table>

An analysis of the state of the art and of current storage technologies has highlighted the following main points:

- Households are responsible for 40% of Europe’s electricity consumption;
- Thermal energy storage and electrical storage must be differentiated;
- Outside Europe, the technology leaders are USA and Japan;
- There have been at least 21 demonstration projects concerning energy storage in Europe in recent years.

The regulations concerning storage technologies in the countries taking part in the SENSIBLE project have been investigated (DE, ES, FI, FR, PT, UK), with particular attention paid to electrical storage. It was found that:

- Existing storage-specific regulations are often limited to the safety aspects of the electrical storage installation;
- Only in Germany is an investment support scheme in place for domestic energy storage;
- Several compensation methods have been identified in energy marketplaces;

High-level project Key Performance Indicators (KPI) have been defined taking into account the suggestions of the European Electricity Grid Initiative, whilst detailed KPIs will be defined for each demonstrator at a later date. The nine KPIs defined range from “Increased RES and DER hosting capacity” to “Loss minimization” and methodologies for their calculation have been proposed.
1 Introduction

1.1 Purpose and Scope of the Deliverable

The objective of this document is to inform the partners of the state of the art and the current situation regarding the business case, the technology and the regulatory framework concerning energy storage, and to provide a summary of the high level KPIs used in the project. With a particular focus on the SENSIBLE project it presents:

- The role of storage in grid applications;
- The storage technologies;
- The state of the art of the technology;
- The regulatory frameworks;
- The links with project KPIs.

This will help to inform the other tasks of WP1 of the existing possibilities and barriers to be taken into account in the definition of the project’s use cases. This deliverable does not present a comprehensive introduction to the topic, but it is focused on the demonstrator sites to be developed during the project, taking into account the storage technologies used and the regulatory framework of the countries concerned.

The document is structured as follows: the role of Distributed Energy Storage Systems (DESS) in a distribution system is described in Section 2, taking into account possible sources of remuneration for storage. Storage technologies are described in Section 3, with a division between thermal storage, electro-chemical storage and electro-mechanical storage technologies. The state of the art concerning DESS grid application is also presented in Section 3, with particular attention given to existing applications and projects on this topic in both the EU and the rest of the world. The regulatory framework is analysed in Section 4, with special attention given to the countries where the demonstrations will be housed, and the evolution of the regulatory framework at European level. Finally a high level description of the KPIs of the project is presented in Section 5, taking into account the EEGI framework. The KPIs described will be adapted to each demonstrator, with the aim that they are coherent between all the demonstrators in this project and other similar projects.

1.2 Applications and classification

An overview of the possible applications and classification methodologies for Electrical Energy Storage Systems (EESS) is presented in this section, whilst a more detailed analysis will be presented in Section 2 and Section 3.

The application of EESS depends mainly on the user, which can be a network operator, a producer or a consumer of electric energy. They can originate from the wish of the user to reduce its operational cost using the possibilities offered by the EESS (such as reducing its energy purchase price) or from the possibility of using EESS as a cheaper or more
effective solution to an existing problem for example the provision of ancillary services. A summary of possible EESS applications is presented in Table 2 for three types of actor, namely the Network Operator, the Electricity Producer and the Electricity Consumer. Each application is characterised by different speeds of response and duration of discharge; these determine which specific EESS technology should be used. Table 2 is based on the framework of the current electric system, where each actor would use an individual storage unit for its own benefit. It is possible that in the future, a new actor can emerge as a storage service provider, able to offer all or part of the suit of energy storage services to other different actors in the network. As well as the three actors mentioned in Table 2, it is possible to imagine other potential users such as retailers or flexibility aggregators, but their action would depend largely on a regulatory framework which at present does not exist.

Table 2: EESS applications by customer/actor

<table>
<thead>
<tr>
<th>Network Operator</th>
<th>Electricity producer</th>
<th>Electricity consumer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time shifting</td>
<td>Time shifting</td>
<td>Time shifting</td>
</tr>
<tr>
<td>Power quality (voltage)</td>
<td>Primary frequency control</td>
<td>Emergency power supply</td>
</tr>
<tr>
<td>Power quality (frequency)</td>
<td>Secondary frequency control</td>
<td></td>
</tr>
<tr>
<td>Reactive power compensa-</td>
<td>Tertiary frequency control</td>
<td></td>
</tr>
<tr>
<td>tion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fluctuation suppression</td>
<td>Voltage control</td>
<td></td>
</tr>
<tr>
<td>Grid voltage stability</td>
<td>Black start capability</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Renewables forecast hedging</td>
<td></td>
</tr>
</tbody>
</table>

EESS can be categorised using several different approaches, with the form of energy storage and the time of discharge being the most common. Details on each technology will be provided in Section 3 with special attention paid to the ones used in the demonstrators of SENSIBLE: here an overview of the different technologies is presented.

In Table 3 EESS are classified according to their form of energy stored, whilst in Figure 1 the classification is reported on the basis of the size and depth of the discharge, from [1].

The other two important parameters that contribute to defining EESS are the cycle efficiency and the auto discharge. The cycle efficiency measures the ratio of the energy discharged by the battery to the energy absorbed, and is a measure of the losses. The auto discharge measures the loss of charge when an EESS is left charged without cycling. Not all EESS reacts in the same way and for some technologies these two sources of losses are more important than in others [1]. EESS can be classified on the basis of their applications or by their suitability to such applications. Studies on this topic exist, but in the case of SENSIBLE, a dedicated mapping of each technology used for the applications in this project will be proposed in this report.
### Table 3: EESS classification

<table>
<thead>
<tr>
<th>Mechanical</th>
<th>Thermal</th>
<th>Chemical</th>
<th>Electrical</th>
<th>Electro-chemical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pumped hydro</td>
<td>Sensible heat</td>
<td>Hydrogen (electrolyser/fuel cell)</td>
<td>Capacitor</td>
<td>Secondary batteries (lead-acid, NiCd, NiMh, Li-ion, NaS)</td>
</tr>
<tr>
<td>Compressed air</td>
<td>Latent heat</td>
<td>Synthetic natural gas</td>
<td>Superconducting magnetic coils</td>
<td>Flow batteries (redox flow, hybrid flow)</td>
</tr>
<tr>
<td>Flywheel</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 1: EESS classification for discharge power and duration [1]
INTRODUCTION

1.3 References

1.3.1 External documents


INTRODUCTION


[53] California Public Utilities Commission, .10-12-007, “CPUC Energy Storage Use Case Analysis”
1.4 Acronyms

ATES Aquifer thermal energy storage
BAU Business as usual
BEMS Building energy management system
BTES borehole thermal energy storage
CAES compressed air energy storage
CCS carbon capture and storage
CHP Combined heat and Power
COP Coefficient of Performance
CSP Concentrated solar power
DER Distributed energy resources
DESS Distributed energy storage system
DSO Distribution system operator
DSUF Distribution System Utilization Factor
EEGI European Electricity Grid Initiative
EESS electrical energy storage system
ESS Energy storage systems
FCR Frequency containment reserve
GEOTABS Geothermal activated building systems
HEMS Home energy management system
HP Heat Pump
HVAC Heating, Ventilation and Air-Conditioning
LV Low voltage
M2M Machine to machine
MAIFI Momentary Average Interruption Frequency Index
MV Medium voltage
PCM phase change materials
PEM Polymer electrolyte membrane
PHS Pumped Hydro Storage
PV Photo voltaic
QoS Quality of Service
RES Renewable Energy Sources
SAIDI System Average Interruption Duration Index
SAIFI System Average Interruption Frequency Index
SLI Starting, lighting, ignition
SMES Superconducting magnetic energy storage
TABS Thermal activated building system
TES Thermal storage systems
TSO Transmission system operators
UTES underground thermal energy storage
VUF Voltage Unbalance Factor
2 Applications

The technical characteristics of each energy storage technology are key to understanding their applicability and their compatibility with the energy supply structures. There are a wide variety of storage technologies with a variety of different technical characteristics (especially in terms of power and capacity). This, together with the fact that many of their potential benefits (both economic and technical) are currently under research means that the analysis of their applications becomes a complicated and wide-ranging task.

Two prominent reports, from SNL [2] and EPRI [3] were published in 2010 in an effort to address this challenge. These reports have become the most widely cited references in the literature.

SNL’s report considers 17 applications divided into 5 categories [2] as given in Table 4.

**Table 4: Five categories of energy storage applications [2]**

<table>
<thead>
<tr>
<th>Category 1 — Electric Supply</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Electric Energy Time-shift</td>
</tr>
<tr>
<td>2. Electric Supply Capacity</td>
</tr>
<tr>
<td><strong>Category 2 — Ancillary Services</strong></td>
</tr>
<tr>
<td>3. Load Following</td>
</tr>
<tr>
<td>4. Area Regulation</td>
</tr>
<tr>
<td>5. Electric Supply Reserve Capacity</td>
</tr>
<tr>
<td>6. Voltage Support</td>
</tr>
<tr>
<td><strong>Category 3 — Grid System</strong></td>
</tr>
<tr>
<td>7. Transmission Support</td>
</tr>
<tr>
<td>8. Transmission Congestion Relief</td>
</tr>
<tr>
<td>9. Transmission &amp; Distribution (T&amp;D) Upgrade Deferral</td>
</tr>
<tr>
<td>10. Substation On-site Power</td>
</tr>
<tr>
<td><strong>Category 4 — End User/Utility Customer</strong></td>
</tr>
<tr>
<td>12. Demand Charge Management</td>
</tr>
<tr>
<td>13. Electric Service Reliability</td>
</tr>
<tr>
<td>14. Electric Service Power Quality</td>
</tr>
<tr>
<td><strong>Category 5 — Renewables Integration</strong></td>
</tr>
<tr>
<td>15. Renewables Energy Time-shift</td>
</tr>
<tr>
<td>16. Renewables Capacity Firming</td>
</tr>
<tr>
<td>17. Wind Generation Grid Integration</td>
</tr>
</tbody>
</table>

EPRI’s report uses SNL’s report as a baseline (since it was published some months later) but in terms of applications takes a different approach by just focusing on the 10 considered most relevant in terms of benefits for owners and operators [3] as described in Table 5.
The key step forward provided by EPRI’s report is the mapping between applications/benefits and the technical and energy storage performance requirements for each application [3] as shown in Table 6.
This approach presents an organisational principle to determine the applicability of the different storage technologies to applications in the electricity supply chain [3], as shown in Figure 2.

<table>
<thead>
<tr>
<th>Application</th>
<th>Description</th>
<th>Size</th>
<th>Duration</th>
<th>Cycles</th>
<th>Desired Lifetime</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wholesale Energy Services</td>
<td>Wind integration: ramp &amp; voltage support</td>
<td>1-10 MW</td>
<td>15 min</td>
<td>5000 yr</td>
<td>20 yr</td>
</tr>
<tr>
<td></td>
<td>Wind integration: off-peak storage</td>
<td>100-400 MW</td>
<td>5-10 hr</td>
<td>300-600 yr</td>
<td>20 yr</td>
</tr>
<tr>
<td></td>
<td>Photovoltaic Integration: time shift, voltage sag, rapid demand support</td>
<td>1-2 MW</td>
<td>15 min-4 hr</td>
<td>&gt;4000 yr</td>
<td>15 yr</td>
</tr>
<tr>
<td>Renewable Energies Integration</td>
<td>Urban and rural T&amp;D deferral, Also ISO congestion mgmt</td>
<td>10-100 MW</td>
<td>2-6 hr</td>
<td>300-4500 yr</td>
<td>15-20 yr</td>
</tr>
<tr>
<td>Transportable T&amp;D Support</td>
<td>Urban and rural T&amp;D deferral, Also ISO congestion mgmt</td>
<td>1-10 MW</td>
<td>2-6 hr</td>
<td>300-500 yr</td>
<td>15-20 yr</td>
</tr>
<tr>
<td>Distributed Energy Storage Systems</td>
<td>Utility-sponsored; on utility side of meter, feeder line, substation, 75-85% ac-ac efficient</td>
<td>25-200 kW 1-phase</td>
<td>2.4 hr</td>
<td>100-150 yr</td>
<td>10-15 yr</td>
</tr>
<tr>
<td>(DESS)</td>
<td></td>
<td>25-75 kW 3-phase</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C&amp;I Power Quality</td>
<td>Provide solutions to avoid voltage sags and momentary outages.</td>
<td>50-500 kW</td>
<td>&lt;15 min</td>
<td>&lt;50 yr</td>
<td>10 yr</td>
</tr>
<tr>
<td>C&amp;I Power Reliability</td>
<td>Provide UPS bridge to backup power, outage ride-through.</td>
<td>1000 kW</td>
<td>&gt;15 min</td>
<td>&gt;15 yr</td>
<td></td>
</tr>
<tr>
<td>C&amp;I Energy Management</td>
<td>Reduce energy costs, increase reliability. Size varies by market segment.</td>
<td>50-1000 kW</td>
<td>4-10 hr</td>
<td>&lt;50 yr</td>
<td>10 yr</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 MW</td>
<td>3-4 hr</td>
<td>400-1500 yr</td>
<td>15 yr</td>
</tr>
<tr>
<td>Home Energy Management</td>
<td>Efficiency, cost-savings</td>
<td>2-5 kW</td>
<td>2-4 hr</td>
<td>150-400 yr</td>
<td>10-15 yr</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Small footprint</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Home Backup</td>
<td>Reliability</td>
<td>2-5 kW</td>
<td>2-4 hr</td>
<td>150-400 yr</td>
<td>10-15 yr</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Small footprint</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. Size, duration, and cycle assumptions are based on EPRI’s generalized performance specifications and requirements for each application, and are for the purpose of broad comparison only. Data may vary greatly based on specific situations, applications, site selection, business environment, etc.
2. Ancillary services encompass many market functions, such as black start capability and ramping services, that have a wide range of characteristics and requirements.
Another prominent report [5] deserves special attention as it provides estimates of the evolution in time of the cost of each storage technology and the recommended steps to take for each specific application in the context of the European goals for 2020 and 2050.

2.1 Selection

In this section a review is made of the most suitable applications considering the project scope and the storage technologies available.

The wide variety of storage technologies and applications (presented in previous section) can be significantly reduced when considering the scope and objectives of the project. As a reminder the basis of the LCE8 call focuses on the benefits of small-scale energy storage at two different levels:

- The distribution grid;
- The building/house level.

in a context where distributed renewable generation together with a more intelligent management of the energy flows (smart grids, local/prosumer energy management systems and advanced ICT technologies) are increasingly prevalent in these domains.

From EPRI's report categorization the applications which gather benefits with highest value that best fit the project scope are:

From the Supply Utility perspective:
APPLICATIONS

- Commercial and Industrial Power Quality and Reliability (avoiding voltage sags, avoiding outages, UPS bridge to backup power, outage ride-through)
- Stationary Storage for Grid Support and T&D deferral (urban and rural T&D deferral, congestion management)
- Distributed Energy Storage Systems (utility sponsor)

From the customer’s perspective:
- Home Energy Management (efficiency, cost savings, reliability)
- Commercial and Industrial Energy Management (reduce energy costs, increase reliability)

EASE’s report [5] highlights a detailed categorization of applications better fitting the European context at the specific levels addressed by this project:

Distribution
- Capacity support: a storage unit is used to shift load from peak to base load periods to reduce peak currents flowing through constrained grid assets.
- Dynamic, local voltage control: DESS may help to maintain the voltage profile within admissible contractual/regulatory limits. In distribution grids, voltage support can rely both on reactive power (made possible for DESS by power electronics) and active power control. The main benefit derives from the deferral of distribution upgrades that would otherwise be necessary to meet the voltage level requirements.
- Contingency grid support: performing capacity/voltage support to reduce the impacts of the loss of a major grid component. They might also be useful in emergency situations, for example after the loss of a major component of the distribution grid.
- Intentional islanding: this consists of using DESS to energise a non-loopable feeder during an outage - improving system reliability by energising a feeder during an outage (DESS used as a voltage source).
- Reactive power compensation: improved distribution system power quality is made possible by power electronics but appears to be a niche application – one application is reducing the amount of reactive energy drawn from the transmission system and charged by the TSO to the DSO.
- Distribution power quality: with storage, the DSO can maintain the voltage profile within acceptable limits, which increases the quality of supply (lower probability of black out or interruptions).
- Limitation of upstream disturbances: DSOs have a network access contract with one or more TSO(s), and must therefore limit the disturbances they cause (eg harmonics) on upstream HV grids to within agreed contractual values. If these limits are exceeded, some types of advanced storage systems can help DSOs to comply with these commitments by performing harmonic reduction.

Customer Services
- End-user peak shaving: energy storage can be used by customers such as industrial sites for peak shaving in order to minimise the part of their invoice that varies according to their highest power demand. Such a service might be profitable if the peaks are sufficiently predictable and relatively short duration.
- Time-of-use energy cost management: a DESS can be charged when the tariff is low and then discharged during peak periods, with the aim of reducing the cost of electricity for the end-users. A consumer with an energy storage unit could also be able to contract an Active Demand (AD) service with the DSO or a supplier.
- Continuity of energy supply: a storage device is able to substitute for the network and maintain local supply in the case of grid interruption; this service reduces the damage to industrial and residential customers in the event of a blackout.
- Limitation of upstream disturbances: the customer’s contract with a given DSO may require them to limit disturbances; energy storage can help them to comply with their commitments.
- Compensation of reactive power: the power electronics converter of a DESS provides the functionality to locally compensate for reactive power loads if required.
- Heat storage: Heat storing devices – e.g. electrical storage heaters – are able to reduce customer cost and assist in load levelling.

2.2 In depth analysis
In this section an in depth analysis of the applications more closely related with the project is presented.

2.2.1 Distribution

Capacity support:
This is an appropriate application, which supports power in distribution grid operation. The CPUC’s report defines this as “Economic value associated with deferring circuit upgrades by discharging a battery during peak load hours, thereby keeping circuit load within the feeder rating [53].

Since this application is related to power capacity and optimization of current flows in feeders, it is more relevant to the MV part of distribution grids where DSOs have growing control in the context of smart-grid development and a more realistic operation visibility than at the LV part. Use cases (and KPIs) proposed in the project are focused on assessing the storage contribution as a component providing flexibility within the available DER which the DSO can operate, in a context where a growing share of RES generation assets is assumed.

The main benefits of this application (specifically for distribution grid operators), are the improvement of the Distribution System Utilization Factor (DSUF) and that it presents an approach which can defer investment in lines and equipment [3].
The management of storage assets to improve DSUF (and in turn deferral of grid investments) is specifically based on **reducing losses by levelling loads in time (from peak to off-peak periods) and also in space by means of load balancing between feeders.** Some authors have analysed the economic value of this drop in distribution losses highlighting the potential to mitigate the energy storage investments. [7] highlights important conclusions when quantifying such economic value:

- Savings in T&D losses increase (i.e. losses decrease) with increasing storage size up to a maximum value beyond which the losses increase again (this maximum would be in the range 25 to 40% of the ratio Storage Size/Peak Load)
- Savings in the T&D losses increase with the ratio of the off-peak to peak loads

From these conclusions, the authors highlight the use of multiple small storage devices at separate sites as the most efficient layout rather than having a single large load shift at one site.

Since many storage technologies are basically suitable for providing this capacity their appropriateness will depend on their technical characteristics (mainly discharge power and energy capacity) and the distribution grid conditions. In line with Nourai’s article [7], EPRI’s report suggests a power rating of hundreds of kWs as the size with the highest economic value [3]

This levelling of load requires a more active optimisation of grid operation by means of new ICT tools, to maintain operation within technical limits. This infrastructure allows the implementation of new optimization power flow algorithms for improvement of operating factors focused on the minimization of technical losses and maximization of load balance between feeders.

**Dynamic, local voltage control**

Several of the energy storage technology applications on the distribution side listed in the previous section can be grouped together if voltage control is considered.

Voltage profile control is becoming a key concern for DSO’s because small-scale RES generation (intermittent in nature) is increasing as a proportion of the DERs connected to the distribution grid. Solutions which can **avoid voltage sags and momentary outages** typically caused by RES by using energy storage are therefore of great interest to DSO’s since they are responsible for the stability and quality of service (QoS) of the distribution grid. The main benefit derives from the deferral of upgrades to the distribution grid infrastructure that would otherwise be necessary to meet the voltage control requirements [5].

Control at MV level to **maintain the predefined DSO voltage profiles** to within admissible contractual/regulatory limits by means of MV grid embedded storage resources is now becoming appropriate with the development of smart-grid technologies and bulk energy storage systems. However, the growing number of RES generation assets connected at LV level makes the use of LV grid embedded storage appropriate for **local**
**APPLICATIONS**

**Voltage Control.** For the LV case embedded control solutions with a capability to operate autonomously and even in off-grid (islanding) mode should be considered in line with the smart-grid paradigm. Use cases (and KPIs) proposed in the project will be focused on the analysis of these two complementary (MV and LV) approaches.

The report by EASE [5] states that distribution grid voltage support can be achieved by both reactive power and active power injection. **Compensation of the reactive power** by storage technologies is made possible via their grid connect converters: the power electronic requirements will also be derived from specific use cases in the project.

**Distribution grid power quality and intentional islanding:**

Another set of applications of storage with respect to the distribution grid are related to the improvement in power quality and reliability: these require the monitoring of performance metrics concerning resilience, continuity of supply and power quality.

The first storage applications were focused on providing a Uninterruptible Power Supply (UPS) as a backup power to prevent short duration (momentary) outages normally for commercial and industrial (C&I) customers requiring the highest reliability standards. [5] calls this application **intentional islanding** making explicit that outages can happen either under planned or unplanned conditions. IEEE-1366 defines the limit between short (momentary) and long (sustained) duration outages as 5 minutes, but most European countries fixe it as 3 minutes [8]. The average number and duration of interruptions define the following set of performance indicators:

- **MAIFI** – Momentary Average Interruption Frequency Index;
- **CAIDI/CAIFI** - Customer Average Interruption Duration/Frequency Index (sustained interruptions);
- **SAIDI/SAIFI** - System Average Interruption Duration/Frequency Index (sustained interruptions);

According to [8] most regulators evaluate only SAIDI and SAIFI, due to the difficulty in measuring MAIFI. The authors point out that current smart meters in the scope of smart grids monitoring tools should enable the measurement of MAIFI and many authors recommend that SAIFI, SAIDI and MAIFI should be evaluated together since some current solutions (such as automated re-closers) that reduce SAIFI and SAIDI may cause an increase of momentary interruptions. The application of storage technologies with their flexible configurations is definitely the most appropriate solution to respond to both momentary and long duration outages.

The use of storage to maintain a DSO’s predefined voltage profiles increases power quality whose assessment is now achievable with smart-grid technologies, which allow Real Time monitoring and control of grid-embedded storage resources to maintain line voltage profiles in order to fulfil nominal grid voltage requirements.

Super-capacitors, flywheels and most electrochemical storage technologies are suitable for providing this capacity characterised mainly by high power discharge rates and short
times of response, together with relatively smaller capacities from seconds to minutes [3].

2.2.2 Customer Services:

Load shifting / Time shift / Peak shaving:

This set of applications at the customer side, (as listed in section 2.1), use specific storage capacity to move consumption or generation in time.

The main benefits of load shifting at the customer side come from the flexibility in consumption that local storage provides, making it adaptable to flexible contractual solutions with retailers (dual tariffs, flexible demand contracts).

The use of heat storage in combination with dual tariffs has been the most widely used application in recent decades. It was particularly popular in the UK during the 1970’s because it represented a tailored solution to optimise supply in the traditional centralised electricity supply chain infrastructure (based on large thermal power plants), which was not able to power down at night. The fact that this application has required no infrastructure refurbishment has made it very attractive, and in modern scenarios in Europe, where large thermal power plants are being dismantled, new use cases for this application that address cheap infrastructure upgrades are being re-assessed. Some of them in the scope of the SENSIBLE project will explore how dual tariffs can be adapted to new generation patterns or work in combination with local RES generation.

More advanced upgrades are required for implementing flexible demand solutions where retailers make use of more modern smart-grid technologies and new smart-meters to “buy” flexibility from customers. The main idea behind this application is to put part of a customer’s load under the retailers control so that supply adjustments (both reductions and increases) can be adapted to market energy prices – Demand Side management (DSM). Local storage devices may be part of this flexible equipment, together with home appliances, PVs, etc., whose status is notified to retailers by monitoring signals and whose control will be by activation/deactivation set-points.

Maximise self-consumption, local RES, security of supply

A second set of storage applications at the customer side comprises the solutions with the capacity to manage local storage and RES generation resources in response to local load by maximising the value of self-consumption i.e. exploiting the “microgrid” concept. This is probably the most powerful application of storage at least when considering its wide range of possibilities (home, building, districts) and also when considering it may represent an easily scalable solution in developing countries which lack large centralised infrastructures.

The use of electrochemical and thermal storage are definitely the most appropriate storage technologies in both residential and commerce and industrial (C&I) areas. Project use cases will analyse both residential and C&I storage managed by Home and
Building energy management systems (HEMS and BEMS) in smart-grid scenarios. The HEMS, comprising electrochemical and thermal storage and PV generation will maximise the flexibility offered to retailers while optimising self-consumption. The BEMS use case is mainly focused on optimising the use of heat storage in combination with a CHP generation unit in a scenario where large customers may have a more direct access to energy markets. In both cases the benefits in terms of efficiency, cost savings and reliability will be explored.

District storage is another level of self-consumption under consideration in the project that contemplates future scenarios where cooperative economies might develop. This application considers the possibility of centralising the location of storage at larger scales in communities while sharing its ownership. The benefit will come from a higher local RES penetration by combining complementary energy consumption patterns (residential, schools, commercial buildings).

The capacity of these solutions to operate off-grid will lead to an improvement in the security of supply impacting the security indicators being considered in the project. More specifically a reduction in the SAIDI and CAIDI performance indicators previously mentioned will effectively take place every time these systems operate in islanding mode due to grid supply interruptions.
3 State of the art

This chapter presents an overview of the different energy storage technologies: thermal storage, electrochemical storage and electro-mechanical storage. The current R&D scenario and the main roadmaps for future energy efficient buildings will put the SENSIBLE project into context as part of an international commitment for the development of a low-carbon future.

3.1 Thermal storage systems

Buildings are responsible for about 40% of the total energy consumption in the European Union. Space heating and hot water take significant portions of this consumption. Therefore thermal energy storage systems (TES) are key to a successful demand response energy market [9].

At the moment thermal storage systems are used to avoid frequent switching of generation units and to guarantee a minimum run time required by generation units. It is also possible that storage systems could store thermal power when electricity is cheap, making it available for later use in other applications such as space cooling and heating or hot water production [10].

Common thermal storage systems include “sensible” and “latent” storage systems. For building technologies, building inertia plays an important role in thermal energy demand.

3.1.1 Sensible Heat Storage Systems

In sensible heat storage systems no phase change occurs during the loading or unloading process. The maximum amount of stored heat depends on the density and the specific heat capacity of the storage material. A typical material is water as it is cheap, it is not contaminated and it has a high specific heat capacity. Other materials such as thermal oil, concrete or special ceramics are used for high temperature performance (over 100°C). The most common sensible TES in buildings are described below. [11]

- *Thermally stratified tanks*. These systems use water as the storage medium. The different temperature volumes stratify so that the hot water flows to the top, cold water remains at the bottom and the thermocline region is in the middle. The heat transfer between the different temperature volumes should be minimal. [9]

- *Concrete TES*. Concrete is a material with good mechanical properties, resistance to thermal loading, high specific heat, low cost and high availability. These properties make it a good thermal storage material to store energy within the building inertia [9]. A typical application in the building sector is for thermal activated building systems (TABS).

- *Rock and water-rock TES*. Rock has a lower volumetric thermal capacity than water but it can work at temperatures over 100 °C. It is widely used in home air-conditioning systems (e.g. Harry Thomason’s technique) and in domestic water production coupled with solar collectors. [9]
Concerning long-term storage (i.e. seasonal storage), underground thermal energy storage (UTES) seems to be a more economically suitable technology. Aquifer thermal energy storage (ATES) uses groundwater directly. If the ground is used as the storage medium with a heat exchanger, it is called borehole thermal energy storage (BTES) and is often a combined with a heat pump [10]

3.1.2 Latent Heat Storage Systems

Latent heat storage systems use phase change materials (PCM) as storage media. The advantage of this method is its higher storage density. During the phase change no temperature increase occurs, providing a temperature restriction during the process. [11]

PCMs can be solid-solid PCMs, solid-liquid PCMs or liquid-gas PCMs. The most commonly PCM used for thermal storage is the solid-liquid phase change. The application determines the operating temperature and therefore the most suitable storage media (Figure 3). PCMs can be classified into organic materials (e.g. paraffins, water) and inorganic materials (e.g. salt hydrates). Different combinations of materials can offer better solutions for special operating points. [9][10][11].

![Figure 3: Material classes investigated and used as PCM. [11]](image)

Water with a melting point of 0°C and an enthalpy of fusion of 334 kJ/kg, is a typical latent storage material in HVAC systems, but it requires large storage volumes. A typical application is an ice storage system in combination with a chiller. The advantages of salt hydrates are their high storage density and thermal conductivity. Paraffins are typically used, due to their chemical inertness and easy handling, although salt hydrates now prevail because of their higher volumetric storage density [11].

PCMs are usually enveloped in the building structure. The PCMs store the heat gained from the room in the wall itself (made from materials with PCM). Later, during the night,
or in colder periods, the PCM in the wall construction will discharge through the air and there is heat transfer to the room. [11]

### 3.1.3 Building inertia

The thermal inertia of a building is the property of the building to store thermal energy in response to temperature fluctuations. Considering for example a cold spell, a temperature change will occur in the building. The rate at which this cooling takes place is determined by a time constant that depends on the heat transfer coefficient $K(W/K)$ and the heat capacity of the building $C(J/K)$ [12].

TABS integrate the building into the energy management and help to reduce peak loads. The building mass is activated with tube heat exchangers that cool or heat the building structure. Water is the heat carrier that flows through the tube system transferring heating capacity to the concrete slabs [13].

TABS provide cooling and heating thanks to a heat pump. The ground can be used as a seasonal UTES, which serves as the heat source for heating during the winter and as heat sink for heat removal from the building during the summer. The underground heat exchanger is connected with a reversible heat pump that provides this double functionality. These technologies through which geothermal heat pumps are integrated into TABS are called “Geothermal activated building systems” (GEOTABS).

Figure 4 shows the diagram of the system used in the Nuremberg demonstrator for the study of building mass and thermal comfort. [14]
3.2 Electrochemical storage systems

Electrochemical energy storage systems store electrical energy in a chemical process or reaction. This reaction takes place inside the storage cell and cells combine to form a battery. These are often optimized in one of two ways. On the one hand they are made as energy storage systems with a long charge / discharge time, low power and higher energy density. These can store kWh to MWh for a time from minutes to days. On the other hand they can be made as higher power systems, which can satisfy higher power demands but at the cost of a lower energy density; they can provide or accept power with a reaction time of milliseconds (mostly dependent on the power converters used). This makes them especially suitable when electrical power is needed as the main output.

Lead acid batteries have the image of being an old technology. Compared to lithium ion batteries the energy density is low, but the power density as well as low temperature performance is quite good. Thus they are still very widely used – and have been for the
last 100 years - in stationary and transport applications. They are the most common battery system however considering the available literature on these devices there appears to be still much to be learned. Work is still required to overcome some of the drawbacks such as low cycle life and poor partial charge storage capability. Large and smaller companies manufacture lead acid batteries throughout the world and the industry has a long history. Higher quality systems exist for stationary and traction applications. Low cost products exist as SLI batteries for the car industry.

Lithium ion batteries are another class of battery types. The common point is that lithium ions are present as the active species. Different active materials exist for both electrodes. The various combinations of materials determines the properties of the cell and the battery. It is the battery system with the highest energy density and a good to very good power capability. Applications range from consumer devices through to power tools, stationary and mobile battery packs. Systems range from a few Wh through to kWh and even MWh. It is the most researched system at present. However a formal battery model does not exist as yet. Many very large manufacturers of lithium ion batteries exist, most of them based in Asia (Japan, Korea and China).

Redox flow batteries are also a class of batteries, based on different chemical redox couples for the storage process. They are often more of a small chemical installation than a traditional battery. Their setup often consists of two tanks storing the redox couples in solution. The tank size determines the storage capacity of the system. The reactor, somewhat similar to a fuel cell stack, determines the power capability of the system. These systems are normally good for energy storage over hours and days. They have characteristic charge and discharge times from one to 6 or 8 hours. Their most common use is as stationary systems. Cycle life and low cost per kWh storage capacity are key parameters for this type of system. A variety of systems exist. Mostly small companies are developing and marketing one specific system with specific redox couples and system setup.

3.3 Electro-mechanical storage systems

A Flywheel energy storage system is a system that stores electrical energy as mechanical (rotational) energy. The main application for flywheel energy storage systems is to provide and accept high power electrical power with duration of up to a few minutes.

Core competences needed to develop these systems are in the area of electric motors and inverters, rotating masses, vacuum technology and bearings as well as system control. These systems need to be robust and have a long lifetime. They are available today from many smaller companies.
3.4 Demonstration Projects

Energy storage can be located at various points of the energy infrastructure. Both energy storage systems at the electric power plants and at the end user location are technologies that can be used by a suitable energy management device and can provide a more efficient energy system. In recent years these technologies have become the focus of many research projects mainly encouraged by government funded programs.

Figure 5 shows the development situation of the different energy storage technologies: mechanical, electro-chemical, thermal, electrical and chemical. Note that the pumped hydro storage (PHS) technological is the only one considered mature. 99% of current operational energy storage locations are PHS installations. [15][16]

![Figure 5: Maturity of energy storage technologies.][10]

Current R&D projects, such as SCADA focus on battery development, and are mainly funded by national R&D budgets in countries outside the EU (Japan, US). Thermal storage systems are considered to be a good solution for space heating and cooling, and water heating and cooling in residential and service sectors. [16]

A summary of energy storage research projects within Europe and leading countries worldwide is presented. The focus of the review is energy storage projects for buildings and communities, as they are more relevant for SENSIBLE project stakeholders. This section does not pretend to be a detailed index of all R&D projects, but does present global trends within energy storage system development.
3.4.1 EU – Projects

The energy storage research in Europe is clearly distributed responding to regional specialisations. Southern Europe specializes in batteries and Northern Europe in mechanical storage. In Western Europe, Power to Gas and chemical storage cover the biggest number of projects. [17]

Through Power to Gas technology, hydrogen is converted into methane, and then easily distributed via the natural gas network. The challenge, however, is investigating an efficient and economically viable decomposition of water into storable hydrogen and oxygen by electrolysis. The following projects serve as examples of the power-to-gas research in Germany, and illustrate the strength in Western European energy storage research. [18]

The project **EKOLYSER** involving the research institutions of the Research Centre Jülich and the Fritz Haber Institute of the Max Planck Society and the industry partners Solvicro, Gräbener Maschinentechnik and FuMA-Tech develops improved components for flexible PEM electrolysis. The goals are to improve the service life of membranes, develop metallic bipolar plates for the demanding operation in electrolyses and reduce the loading of expensive catalysts. [18]

The project **MAPEL** from the Research Centre Jülich and FUMA-Tech GmbH tries to combine the advantages of alkaline electrolysis with PEM-electrolysis, inserting anion exchanger membranes. [18]

In Spain most of the projects deal with chemical and electrochemical storage and electrical storage technologies, and with energy policies. Creating the right policy and market conditions will also contribute to an appropriate energy storage infrastructure. [17] This is the purpose of the projects mentioned below.

The **LIFE ZAESS** project is coordinated by the Proprietary Technology Division of Técnicas Reunidas with the collaboration of the Grid Integration Department of CENER (National Renewable Energy Centre in Spain). The main aim of the project will be validating the techno-economic viability of the Zinc-Air technology developed by Técnicas Reunidas. A demonstrative pilot plant will be constructed and will operate over 12 months allowing the recording of necessary data for later statistical analysis. [19]

The **stoRE** project came to an end on 30 April 2014. It demonstrated the technical and economical viability of Lithium batteries, super-condensators and flywheel storage technologies in large-scale storage systems for isolated areas such as insular communities. Furthermore, it built consensus about the necessary actions for a real integration of the European Energy Framework. [20]

Research in mechanical storage is active in Europe in particular in Germany and the Netherlands. Compressed air energy storage (CAES) has a very low self-discharge rate. Therefore, it is the only technology that can compete with the mature pumped hydro technology in long-term and large-scale applications. [16]
A Norwegian company, Subhydro AS, with funds from the ENERGIX (Large Scale Programme for Energy Research) is working on the development and commercialization of a **subsea pumped hydroelectric plant.** The system consists of a subsea turbine at a water depth of 400-800 meters below an offshore wind turbine. The water passing the turbine goes into large storage tanks, connected to the sea surface by pipelines. The excess energy at peak loads is used to pump water out of the tanks and to charge the system. When wind subsides, the stored water is released through turbines producing electric power [21].

The Danish project **Energy Membrane** (2011-2013) worked on a new form of pumped hydroelectric storage system (PHES) in which the storage reservoir is enclosed in a membrane. On top of the membrane is a weight of soil that creates the necessary pressure to run a turbine. The soil layer sinks or rises, depending on the water volume. The weight of the soil corresponds to the pressure created by the level difference between the two reservoirs in a conventional PHES system. This system is called underground pumped hydro storage (EM-UPH). [16]

Thermal energy storage (TES) is a technology with a wide range of applications. R&D projects for TES have received comparatively limited support from the EU and national budgets up to now. Low Temperature Thermal Energy Storage (LTTES) has been widely investigated, especially for their integration into buildings. Current studies mainly focus on long-term and high-density energy storage to provide seasonal heat storage. [16]

The project **MESSIB** (Multi-source Energy Storage System Integrated in Buildings 2009-2013) integrated 4 different storage systems into a building (2 electrical and 2 thermal). One of the most relevant innovative elements was introducing new phase change materials for improved active components, allowing energy transportation within the building. The development of a conductive fluid material injected in the soil around a heat exchanger served to improve the thermal conductivity of the ground. [22]

The project **EINSTEIN** (Effective integration of seasonal thermal energy storage systems in existing buildings) pretends to develop, evaluate and demonstrate a low energy heating system for existing buildings based on renewable energy. The system consists on Seasonal thermal energy storage combined with heat pumps integrated with the built environment. To validate the suitability of the development 2 demonstrators have been built in Poland and Spain. [23]

A transition to a smart energy network is also occurring. The Smart Grid concept describes an intelligent integration of demand and response of all connected electric power users. Some European projects aim to achieve this with the optimization of energy management systems for communities. [24]

**Nice Grid** is a demonstration centred on distributed energy storage and flexible demand in the urban area of Nice, France. The objective is the development of a local market for flexible resources able to 1) solve voltage issues on low voltage feeders, 2) offer flexibility to the transmission network and 3) test the intentional islanding of a portion of the network. The market sees the participation of the DSO and TSO as customers of flexibility.
and of aggregators as suppliers of flexibility. Three aggregators are present in this project: a residential electric storage operator, a business customer flexibility operator and a grid-level electric storage aggregator. Li-ion batteries have been installed (about 2 MW) and the total flexibility controlled is about 8 MW. [25]

The PREMIO project, with a total budget of 7.5 M€, led by CAPERGERIES pole (EDF, CEA, CORSE) and other partners (ADEME, ARMINES, ERDF) is localized in the area of Lambesc in PACA and is focused on the use of energy storage (thermal and electrical) and demand side management. The project objective is to demonstrate an innovative, open, and repeatable architecture to optimize the integration of distributed renewable generation, storage, demand response and energy efficiency measures in order to provide load relief, local network support and reduce CO2 emissions in the PACA region. [26]

The AMBASSADOR project (Flexible buildings to make eco-friendly districts) will introduce a district wide holistic energy optimisation system. This will enable the shared usage of local energy production and storage in the district as well as provide manage energy flows, predicting and mastering energy consumption and production. [23]

The RESILIENT project (Coupling renewable, storage and ICTs for low carbon intelligent energy management at district level) will describe, develop and install a new concept of interconnectivity between buildings, distributed energy resources and grids. This project will facilitate the implementation of distributed and renewable resources at the building and district level, through integrating micro grid and energy hub concepts. [23]

The project Az. En. Prato allo Stelvio (Italy), funded for a total of 2.9 M€ involves the use of pumping and flywheel storage and of local generation control for accommodating additional distributed generation in a mountain area characterized by remote distributed energy sources. [27]

The objective of MILLENER project (France) is to guarantee, in real time, the supply-demand balance of island territories’ Grid in order to optimize electricity production to reduce greenhouse gas emissions and reinforce energetic independence of isolated territories. Specifically, the project is structured around two main targets: 1) Sensitize consumers to energy efficiency so that they can reduce their energy consumption during peak hours and 2) Harmoniously integrate intermittent renewable energies into the grid. In order to sensitize the customers, 1000 households are equipped with communicating devices favouring energy savings thanks to remote load shedding. [28]

The Shetland Northern Isles New Energy Solutions (NINES) project also presents characteristics relevant for the Grid4EU and NICEGRID projects. NINES is based in the Shetland Isles, an archipelago in the North Sea characterized by a limited load, and a considerable potential for renewable resources limited by stability issues. The project will explore the possibility of using demand side management of local electric heaters and of future wind farms in order to increase the penetration of renewable energy. [29]

IRENE (Integration Regenerativer Energien und Elektromobilität) Siemens AG and the utility company Allgäuer Überlandwerk (AÜW) in the city of Kempten, Germany, together
with the RWTH University in Aachen and Kempten College, have tested a smart distribution grid with high share of distributed energy resources. The project includes expansion of a charging infrastructure for electric vehicles that can use the electricity generated in an eco-friendly manner (for example, from photovoltaic systems). In addition, there are numerous measurements sensors, variable network components, and a large battery storage unit for buffering electricity. The storage unit was designed for a 300-kilowatt output with a capacity of 138 kilowatt hours, based on the electrical output of the photovoltaic plants and the loads in the region being studied. The main result concerning battery storage systems is that they provide several new opportunities for grid operation, whereas, to date, they do not provide a viable economic approach for voltage or power issues without including additional use cases. [30]

The presented projects support the commitment that Europe has taken to achieve the proposed goals of cutting greenhouse gas emissions by 80-95% by 2050.

3.4.2 International Projects

The International energy Agency (IEA) works to ensure reliable, affordable and clean energy for its 29 members. According to its database, the national R&D spending on energy storage in 2011 was led by Japan with a budget of 72 million EUR, followed by the US (37 Million) and Korea (19 Million). [16]

Japan has been traditionally a leading country in battery R&D due to its mature ICT industry. After the Great East Japan Earthquake in March 2011, Japan’s energy policy has been drastically redesigned towards a more nuclear independent system. [31]

One of the key topics is the development of innovative storage batteries beyond the further development of the conventional ones. This will enable a more autonomous electric vehicle with a range equivalent to gasoline-fuels vehicles. [31]

Introducing large storage batteries to power substations is the aim of some demonstration projects commenced in the fiscal year 2013. At the Minamihayakita Substation, in Hokkaido, a 60,000 kWh-level storage battery (redox-flow battery) will be installed. A 20,000 kWh-level storage battery (lithium-ion battery) will also be working in the Tohoku region, at the Nishisendai Substation. [31]

The project “SCADA” develops technologies to control dispersed batteries. The distributed batteries can be assembled and managed as a virtual large capacity battery. A demonstrator was installed in 2012 in the city of Yokohama with various Li-ion batteries on the grid and consumers side that are controlled by battery SCADA. Figure 6 shows an schematic diagram of this technology. [15]
In the US the Federal Energy Regulatory Commission (FERC) Orders 755 (2011) and 784 (2013) recognized the added value of fast-response energy storage. These orders have promoted the activity of many national energy suppliers and organizations in the integration of storage systems. As a result, the research projects of energy storage systems have been pushed [16].

In August 2013 the Advances Research Projects Agency-Energy (ARPA-E) announced 22 projects that were selected to receive 36$ million through RANGE (Robust Affordable Next Generation Energy Storage Systems). This program seeks to accelerate the development of electrochemical storage technologies for a faster integration of electrical vehicles. [24]

An example is the project “Multifunctional Battery Systems for Electric Vehicles” – San Diego, CA, that will develop a new battery that can be built into a vehicle frame. The project Solid Power – “All Solid-State Lithium-Ion Battery” – Louisville will develop lithium-ion batteries more cost efficient and with better energy density compared with standard lithium-ion batteries. [32]

The penetration of renewable energy sources onto the grid is also a big challenge for the USA. Different projects have been working recently on PHS and CAES, as well as in the integration of thermal storage for CSP. An example is the research on the use of CO\textsubscript{2} as a “cushion gas” in CAES. This technology has two advantages: this gas is more compressible than air, allowing higher energy density storage, and the cavern space could be shared with carbon capture and storage (CCS). [16]

In South Korea the new Basic Energy Plan 2013-2035 aims for the change to a demand instead of supply energy management. The adaptation of the demand at energy consumers in industry, households and commercial building, together with the adaptation of ESS will contribute to the reduction of peak loads. [33]
However, the main technology is electrical energy storage with the lead Korean companies in this sector being LG, Samsung and SK. Some economic incentives are also being offered to encourage the use of these systems. Research and development focus on thermal energy storage and networking, and on flow battery. In addition, other management tools are being applied. For instance, an energy-saving worksheet is to be completed by the building property owners to obtain a building permit. [33]

3.5 Roadmaps

The number of households is expected to rise 70% by 2050, from 1.9 billion in 2010 to 3.2 billion in 2050. Furthermore, if no action is taken the energy demand will rise by 50% by 2050. [26] The occupant does not always have an influence on the design of the building and inherits the consequences of developers, municipality or government decisions and policies. The definition of roadmaps to develop an energy efficient building scenario is essential for a low-carbon future. [24]

The building itself cannot be seen as an isolated system but as part of a whole and complex structure. According to the International Energy Agency (IEA) following areas should receive policy support in coming years: [35]

- More demonstration projects with special focus on reducing costs and improving the efficiency and integration of components. [35]
- More information for the consumers. The consumption of electricity by lighting and appliances is increasing. These appliances also provide heat gains to building interiors that are critical for the energy management. By informing the consumers, they will become conscious of the consequences of an improper use of the available technologies. [35]
- Governments should implement systems to collect data of energy consumption by end use in the building sector. This would help improve policy development to an energy demand adapted system. [35]
- More international R&D collaboration, transfer of information and knowledge between the countries and regions involved. Markets and governments should work together on an international level to achieve lower costs and accelerate the technology deployment. [35]

The building as the final energy consumer constitutes a complex structure where heating and cooling represents a 45% of the energy demand [36]. The following technologies contribute to the building’s thermal comfort: [35]

Active solar thermal

Solar thermal technologies are already mature. The following actions should be undertaken for the development of new products and applications, and the reduction of the costs of the system:

- Integration of solar collectors in buildings. The envelopes become solar collectors themselves.
- Research of alternative materials for collector (polymers or plastics)
- Integration of intelligent control systems that communicate with building system management

*Combined heat and power*

This includes fuel cells, micro-turbines and Stirling engines. The main goal in this research area is the optimization of the components and lowering cost through more R&D and more high-volume production.

*Heat pumps*

The priorities for heat pumps are improving the components and the systems of existing technologies for maximizing COPs. Trend technologies are hybrid systems (e.g. heat pump/solar thermal systems) with very high COPs and integrated heat pump systems that interface with smart grid management systems.

*Thermal energy storage systems*

Thermodynamics and material development should collaborate together in the research for sensible storage, systems integration and building applications. Research for thermal storage should focus on reducing cost and improving the ability to shift energy demand. Both, central and decentralized energy storage systems will play an important role.

The high cost is an important barrier to be overcome for bringing them to the market. The promising areas of R&D are PCMs and thermo-chemical stores with hybrid systems that combine PCMs with sensible heat systems.

The main incentives for increasing the use of energy storage systems will be: [36]

- Increasing use of variable renewable resources
- Rising self-consumption and self-production of energy
- Growing emphasis on electricity grid stability, reliability and resilience
- Increasing end use sector electrification e.g. Electrification of transport sector.

The location of the energy storage systems will depend on the services that this technology supplies. It will enable communities to be energy independent. The districts of the future will be more competitive and energy efficient, and will be easily sold or rented when energy prices rise. The change to an electric smart grid will suppose a change in the energy sector structure as it is known nowadays. [24]-[36]

Figure 7 shows the transition to a future smart grid electric distribution. Smart grids enable the integration of other low-carbon energy technologies, such as electric cars, demand response and renewable energy sources. The smart grid increases the interconnection between the energy producer and consumer. This can be on site or nearby. In the following years more pilots should be developed to improve an automated demand response for service and residential sectors. It is also important to incentivize the consumers to respond to changes in energy markets and regulations. [24]-[37]
However, to achieving that, all the parties including government, private sector, and end user public, should be involved. Important obstacles to face are current regulatory and market systems. This revolution supposes high costs that should be studied, making regulatory changes that ensure the share of the costs and the benefits by all the parties involved. Security policies that control and regulate the privacy with customer’s usage behaviour are also needed. [24]-[37]

3.6 Conclusions

The use of renewable energies for energy production will encourage the integration of energy storage systems into the electric grid. Through integrating communication technologies that study and administrate the energy consumption and production needs of the end-user, the electric grid will undergo a revolution. The customer will be an energy consumer and producer at the same time, evolving to a cooperative and integrated smart grid energy system.

This revolution is not possible without energy storage systems, because of the fluctuating feed of renewable energy generation. Therefore storage systems could be used for load shifting during the day and store the energy for later use.

Households account for 40% of the total energy consumption in the European Union. To achieve an efficient energy system, it will be essential to develop the technologies, management systems and policies that provide both household comfort and efficient energy consumption at the same time.

Thermal energy and electrical energy are to be distinguished. Electrical energy storage can be mechanical, electrochemical, chemical, electrical or thermal, the latter according to the temperature of the heat stored. For building technology the main applications are electrochemical storage, mechanical storage as well as thermal energy storage. Table 7 shows the different energy storage technologies that present suitable conditions for being integrated into energy efficient building.
Table 7: Energy storage systems for building technology

<table>
<thead>
<tr>
<th>Form of the energy stored</th>
<th>Type</th>
<th>Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal energy storage</td>
<td>Sensible storage</td>
<td>Short terms (e.g. Thermal stratified thanks, concrete storage)</td>
</tr>
<tr>
<td></td>
<td>Latent storage</td>
<td>Long term (UTES)</td>
</tr>
<tr>
<td></td>
<td>Building mass</td>
<td>PCM (HVAC, Enveloped in the building)</td>
</tr>
<tr>
<td>Electrical energy storage</td>
<td>Mechanical storage</td>
<td>TABS combined with heat pumps</td>
</tr>
<tr>
<td></td>
<td>Electrochemical</td>
<td>Flywheel</td>
</tr>
<tr>
<td></td>
<td>storage</td>
<td>Li-ion, Lead acid, REDOX</td>
</tr>
</tbody>
</table>

A study of the situation in Europe showed that there is a regional specialization. Northern countries specialize in mechanical energy storage, southern European countries in batteries and east countries in electrochemical energy storage technologies.

Outside the EU, it was evidenced how the R&D leader countries are Japan and USA. The researches focus on batteries, smart grid energy systems for communities and further development of batteries for electrical mobility.

PHS is the most mature technology and represents a 99% of the installed storage capacity. Other technologies are still in research phase and a mature market is not available yet. Referring to efficient building technology, TES presents a high maturity for long term storage and seems to be a good option for the implementation of solar district heating. Combined with storage systems, heat pumps and CHP units can provide a load management and support the integration of renewable energies in the building.

Further research and development for higher efficiencies and lower installation costs, as well as improved legal frameworks will be essential for the adaptation of energy storage systems into the future energy system.
4 Regulation

Regulation plays an essential part when it comes to new energy market services and applications since it has always been part of each step of the energy supply chain illustrated in Figure 8. Even though we are seeing some functions, such as electricity retail, being de-regulated, a large proportion of the market still faces strict rules and barriers for open competition. In this chapter the regulatory environment is analysed, especially with regard to the demonstration countries. Finally, amendments to the existing regulations will be suggested.

Figure 8 Electric energy supply chain

4.1 Existing regulation

4.1.1 Regulatory bodies

The impact of regulatory bodies on markets, services, technology and stakeholders varies considerably between countries. In Europe, and particularly in this project’s demonstration countries, the European Union has a significant regulatory role. All the demonstration countries are members of the EU (UK, Germany and Portugal).

In addition to the EU, many other authorities have an impact on the regulation of energy markets. Standards organizations naturally affect which kind of technology is being utilized. Some of the bodies, agencies and organizations relevant to the scope of this project are listed in Table 8.
### Table 8 Regulatory and standards organizations

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>EU</td>
<td>European Union</td>
<td>Coordinates common legislation at European level through the energy policy.</td>
</tr>
<tr>
<td>National energy authorities</td>
<td>-</td>
<td>Monitor compliance with the national energy market legislation.</td>
</tr>
<tr>
<td>ACER</td>
<td>The European Agency for the Cooperation of Energy Regulators</td>
<td>An agency of the European Union which complements and coordinates the work of national regulatory authorities.</td>
</tr>
<tr>
<td>CEER</td>
<td>The Council of European Energy Regulators</td>
<td>A non-for-profit association where the national regulators cooperate and exchange best practice.</td>
</tr>
<tr>
<td>ISO</td>
<td>The International Organization for Standardization</td>
<td>An international standard-setting body composed of representatives from various national standards organizations.</td>
</tr>
<tr>
<td>IEC</td>
<td>The International Electrotechnical Commission</td>
<td>A non-profit, non-governmental international standards organization that prepares and publishes international standards for electrotechnology.</td>
</tr>
<tr>
<td>CEN</td>
<td>The European Committee for Standardization</td>
<td>Develops European standards and other technical specifications</td>
</tr>
<tr>
<td>CENELEC</td>
<td>The European Committee for Electro-technical Standardization</td>
<td>Develops European standards and other technical specifications</td>
</tr>
<tr>
<td>ETSI</td>
<td>The European Telecommunications Standards Institute</td>
<td>Develops European standards and other technical specifications</td>
</tr>
<tr>
<td>National standards organizations</td>
<td>-</td>
<td>Develops, approves and publishes national standards.</td>
</tr>
</tbody>
</table>

#### 4.1.2 Key research areas

Several studies have already been undertaken concerning energy storage solutions and the associated market regulation. Numerous barriers to the large scale deployment of energy storage solutions have been identified. Regulation concerning the openness of competition between different technologies has been identified as a one of the most critical barriers.

In this study, we have decided to select a few key topics which address the regulatory environment for the applications being demonstrated. With these key topics and the extensive background information provided by earlier studies, we can identify the most significant barriers associated with entering the energy storage market. This approach was selected since the regulations are extensive and a comprehensive analysis is not within the scope of this project.
Table 9 List of the regulatory topics for further analysis

<table>
<thead>
<tr>
<th>Topic</th>
<th>Connection with the project’s scope</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Regulatory compensation methods</strong></td>
<td></td>
</tr>
<tr>
<td>Energy tariff structures</td>
<td>Several identified energy storage business cases include the shift of consumption from a time to another. Energy tariffs have an important role in this business case and therefore they should support the developed solutions. Also grid tariffs affect for example how peak load management actions could be executed.</td>
</tr>
<tr>
<td>Investment support schemes for energy storage</td>
<td>Obviously investment support schemes affect how willing consumers, companies and the industry are to invest in new energy storage technology and services. The penetration of new technology opens up opportunities for utilities, service providers etc. to develop new solutions for the customers.</td>
</tr>
<tr>
<td>Revenue compensation mechanisms for energy storage</td>
<td>Energy storage can also be compensated in other ways than just supporting investments. Feed-in-tariffs are a good example of this which has tremendously increased the amount of distributed renewable energy in some countries.</td>
</tr>
<tr>
<td><strong>Regulatory for marketplaces</strong></td>
<td></td>
</tr>
<tr>
<td>Wholesale market structures</td>
<td>The marketplaces for storage solutions should support new innovative services and applications. Many of the developed business cases for example utilize the electricity day-ahead and intraday markets which therefore can’t segregate new technology and solutions.</td>
</tr>
<tr>
<td>Ancillary markets and products for energy storage</td>
<td>The development of energy storage solutions may also need totally new markets or market structures. We already have several marketplaces for ancillary services like the ones mentioned below but the problem can also be that the markets between different countries don’t support each other.</td>
</tr>
<tr>
<td>Example of ancillary markets:</td>
<td></td>
</tr>
<tr>
<td>- Frequency regulation</td>
<td></td>
</tr>
<tr>
<td>- Synchronous reserve</td>
<td></td>
</tr>
<tr>
<td>- Nonsynchronous reserve</td>
<td></td>
</tr>
<tr>
<td>- Voltage support (reactive power)</td>
<td></td>
</tr>
<tr>
<td>- Blackstart</td>
<td></td>
</tr>
<tr>
<td>- Balancing power</td>
<td></td>
</tr>
<tr>
<td><strong>Regulation for technology</strong></td>
<td></td>
</tr>
<tr>
<td>Standardization and technical requirements for storage</td>
<td>Standardization affects which kind of technology can be utilized and also how open the competition between different technologies can be. Common legislation like in EU naturally helps the penetration of new technology.</td>
</tr>
<tr>
<td>Grid connection legislation for energy storage</td>
<td>Regulation regarding technology is only one part of the equation. How the technology can be utilized should also be evaluated. This is where topics like grid connection comes to play. In this project various types of technology will be demonstrated and therefore this is especially important.</td>
</tr>
<tr>
<td>Smart metering</td>
<td>Smart metering can also affect the utilization of storage resources. Compensation mechanism can for example require a smart meter to enable net metering. Smart meters can also stimulate energy efficiency actions and pave the way for new innovative solutions.</td>
</tr>
</tbody>
</table>

Table 9 describes the different key topics. The topics have been divided into three categories which correspond to the areas where most of the immediate market barriers exist. The barriers are described in more detail in the Chapter 4.2.
4.1.3 Existing regulation in selected countries

The demonstration countries considered in this project were selected for the analysis of existing regulation. This is because it’s most convenient to analyse the regulation through the applications and use cases, as defined for the demonstrations. A range of use cases are considered, from building level to energy communities and finally grid level storage solutions.

Table 10 Existing regulation in Germany with reference to the outlined key topics

<table>
<thead>
<tr>
<th>Regulatory compensation methods</th>
<th>Different grid tariffs in use</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- Energy consumer with a demand below 100,000 kWh/a have a basic constant tariff.</td>
</tr>
<tr>
<td></td>
<td>- Energy consumers above 100,000 kWh/a must have a ¼-hour power measurement. The grid tariff is calculated by using the highest power value of a ¼-hour during the billing period.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Regulatory compensation methods</th>
<th>Different supply tariffs in use</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- Basic constant tariff</td>
</tr>
<tr>
<td></td>
<td>- SPOT-market</td>
</tr>
<tr>
<td></td>
<td>- Energy suppliers are obligated to provide a flexible tariff (since 2011) regulated by the German Energy Act (EnWG), if it is economically and technically acceptable.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Regulatory compensation methods</th>
<th>Investment support schemes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- Investment support for electro-chemical storage systems in combination with photovoltaic systems (Peak = 30 kWp) for private households, companies, etc.</td>
</tr>
<tr>
<td></td>
<td>- Support for renewable energy systems regulated by the German Renewable Energy Act (EEG)</td>
</tr>
<tr>
<td></td>
<td>- Support for efficient CHP-Units regulated by the Cogeneration Act (KWK-Gesetz)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Regulatory compensation methods</th>
<th>Revenue compensation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- No compensation mechanisms specifically for storage solutions.</td>
</tr>
<tr>
<td></td>
<td>- Storage systems could act on the Day-ahead, Intraday and as tertiary control power like other energy consumers or generation units</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Regulation for market places</th>
<th>Whole-sale market structures</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- Storage resources are managed at the wholesale markets either as a production or consumption units.</td>
</tr>
<tr>
<td></td>
<td>- Common market for day-ahead is EPEX with a minimal trading unit of 0,1 MWh.</td>
</tr>
<tr>
<td></td>
<td>- Common market for intraday is EPEX SPOT with a minimal trading unit of 0,1 MWh.</td>
</tr>
<tr>
<td></td>
<td>- Trading at the EPEX is only possible as an authorized trader.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Regulation for market places</th>
<th>Ancillary markets and products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary reserves</td>
<td>- Primary control for stabilizing the grid frequency (PRL). Has to be available after 30 seconds and for a time period of 15 minutes.</td>
</tr>
<tr>
<td>Secondary reserves</td>
<td>- Secondary control for stabilizing the grid frequency (SRL). SRL is used for the energetic balance in the single control area. Has to be available after 5 minutes.</td>
</tr>
<tr>
<td>Tertiary reserves</td>
<td>- Tertiary control for stabilizing the grid frequency (MRL). Has to be available after maximum 15 minutes and for a time period of 4 hours.</td>
</tr>
<tr>
<td>Balancing power</td>
<td>- Balancing power market</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Regulation for technology</th>
<th>Standardization and technical requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standardization follows standards from VDE-AR-E 2510-50 for electrochemical storages in private households.</td>
<td></td>
</tr>
<tr>
<td>-Industrial applications are standardized according IEC 62619</td>
<td></td>
</tr>
</tbody>
</table>
Grid connection legislation
- The German Energy Act (EnWG) regulates the grid connection for production, consumption and storage units.
- The connection is managed by the DSO.
- The DSO is obligated to connect all systems, if the DSO rejects a connection to the grid a economical or technical reason has to be presented.

Smart metering
- The metering point operation is regulated in the German Energy Act (EnWG). The operation is the duty of the grid operator.
- The rollout of smart meter is planned to be driven by the market with some exceptions (new buildings, consumers with a demand above 6000 kWh/a, operator of CHP and renewable energy units).
- At the moment about 7% of the residential customers are equipped with a smart meter.
- Storage resources are not mentioned separately.

In addition to the demonstration countries, a few additional countries were also selected to give the analysis more depth. In total six countries are considered: the UK, Germany, Portugal, Spain, France and Finland.

The results from the analysis of the regulatory environment in Germany can be found in Table 10. The final results covering all the countries are exhibited in Annex A.

4.2 Barriers and proposed amendment for the project

The barriers prohibiting market entry for energy storage systems can be divided into three categories, covering the main factors limiting mainstream acceptance of energy storage solutions. The first category includes market barriers, which place limitations on energy storage usage and the associated energy trading. The second category consists of technological barriers, which may limit widespread access to energy storage solutions. The last category consists of legislative barriers, which are controlled by the current political climate in each target country.

4.2.1 Market barriers

To enable and sustain the growth of energy storage solutions on the open market, there needs to be a suitable energy trading framework in place. This includes management of energy supply and demand.

This chapter tries to recognize some of the known market barriers that may prevent energy storage solutions becoming more common at all levels of the energy market. In this document the energy market barriers are studied by observing the Nordic electricity market, as the Nord Pool Spot is the leading energy market in Europe. Nord Pool Spot connects the Nordic and Baltic countries as one energy market and offers connections to other European countries such as Germany, The Netherlands and The United Kingdom via its intraday market Elbas. [40]

Nord Pool Spot is divided into two different markets, the Elspot and the Elbas. The Elspot market is the day-ahead market in use in the Nordic countries and the Baltics, whereas
the Elbas is the intraday market used in the same regions. This market structure is also quite common in other countries as well, for example, the French energy market, EPEX FR, follows a similar model, with two different markets, one for day-ahead trading and another for intraday trading. The day-ahead and intraday markets are usually supplemented in each country by ancillary electricity markets provided by the Transmission System Operator (TSO) in that country. For example, in Finland, the Finnish TSO provides 6 different ancillary markets for transmission network reliability purposes.

The markets described above form the basis for electricity exchange in the Nordic countries and due to amount of electricity trading taking place on each day, the markets have few strict rules for participating resources. The rules concerning energy resources can be generalized into 4 different categories: minimum quantity of energy delivered to the market, minimum run time, maximum start-up time and the amount of activations/calls the resource is expected to deliver to the market. In addition to these rules, each of the markets has a different pricing mechanism, varying depending on the market type. In Table 11, all the electricity markets accepting demand response in Finland (Nord Pool Spot markets and the Ancillary markets of Fingrid) are listed with the main rules and pricing mechanisms to provide an overview of the markets in question. This list does not include TSO markets, which require spinning reserve for market entry, and thus is applicable to the case of energy storage systems.

As can be seen in Table 11, the rules vary widely, from market entry capacity to the market pricing, across different market levels. It should be noted that this is within only one market area. The above table lists 9 different markets from 3 different parties. This in itself can present a challenge for a new market player who is trying to gather knowledge of the energy markets available in a given area. The market rules do not explicitly state which types of technical solutions are allowed for each of the markets. This in itself can be seen as a limiting factor as it creates uncertainty as to which technologies are allowed.

From Table 11, it is clear that aside from market regulations there are also numerous technical requirements for energy market access from an energy storage point of view. Depending on the application of the energy storage solution it may be difficult to access certain markets because of the technical restrictions. For example the minimum requirement for energy resource capacity in any of the market places is 0,1MW and depending on the market can go as high as 10MW. The capacity required for market access are usually too large for smaller energy market participants to fulfil and usually leads to the need of resource aggregation. This raises further regulatory questions, as it isn’t always clear if the markets in question allow resource aggregation. In addition to capacity requirements the markets also present requirements for ramp-up times and run-times for the energy resources which must be met.

It should also be noted that some of the markets prohibit offering the same resource to multiple markets at the same time. [38][39].

### Table 11: List of market and market attributes for demand response accepting markets in Finland [38]

<table>
<thead>
<tr>
<th>Market place</th>
<th>Type of contract</th>
<th>Minimum size</th>
<th>Minimum time</th>
<th>Activation time</th>
<th>How many times activated</th>
<th>Price level 2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency controlled normal operation reserve</td>
<td>Yearly and hourly markets</td>
<td>0,1 MW</td>
<td>Not defined</td>
<td>3 minutes</td>
<td>Constantly</td>
<td>15,8€ / MW, h (yearly market) + price of electricity</td>
</tr>
<tr>
<td>Frequency controlled disturbance reserve</td>
<td>Yearly and hourly markets</td>
<td>1 MW</td>
<td>Not defined</td>
<td>5 s / 50% , 30 s / 100%, Immediately when: f &lt; 49,9Hz for 30 s, f &lt; 49,7Hz for 5 s, f &lt; 49,5Hz</td>
<td>Several time per day</td>
<td>4,03€ / MW, h (yearly market)</td>
</tr>
<tr>
<td>Frequency controlled disturbance reserve ON/OFF model</td>
<td>Long term contract</td>
<td>10 MW</td>
<td>Not defined</td>
<td>Instantly when f &lt; 49,5Hz</td>
<td>About once a year</td>
<td>~0,5€ / MW, h + 580€ / MWh + activation fee 580€ / MW</td>
</tr>
<tr>
<td>Automatic frequency restoration reserve - FRR-A</td>
<td>Hourly market</td>
<td>5 MW</td>
<td>Not defined</td>
<td>Must begin within 30 s of the signal’s reception, must be fully activated within 2 minutes</td>
<td>Several times a day</td>
<td>Hourly market + energy price</td>
</tr>
<tr>
<td>Balancing power market</td>
<td>Hourly market</td>
<td>10 MW</td>
<td>Not defined</td>
<td>15 minutes</td>
<td>According to the bids, several times per day</td>
<td>Market price</td>
</tr>
<tr>
<td>Fast disturbance reserve</td>
<td>Long term contract</td>
<td>10 MW</td>
<td>Not defined</td>
<td>15 minutes</td>
<td>About once a year</td>
<td>~0,5€ / MW, h + 580€ / MWh</td>
</tr>
<tr>
<td>Elspot</td>
<td>Hourly market</td>
<td>0,1 MW</td>
<td>1h</td>
<td>12h</td>
<td>-</td>
<td>Market price</td>
</tr>
<tr>
<td>Elbas</td>
<td>Hourly market</td>
<td>0,1 MW</td>
<td>1h</td>
<td>1h</td>
<td>-</td>
<td>Market price</td>
</tr>
<tr>
<td>Strategic reserves</td>
<td>Long term contract</td>
<td>10 MW</td>
<td>Not defined</td>
<td>15 minutes</td>
<td>Rarely</td>
<td>-</td>
</tr>
</tbody>
</table>

Note: The table includes details on the market participants, minimum size, minimum time, activation time, how many times activated, and price level for various categories of markets and reserves in Finland.
Another limiting factor is the minimum run time regulations for the resources. For example, in the Elspot and Elbas markets the minimum run time is 1 hour, which means that the minimum capacity for an energy storage solution is 0,1MWh or 100kWh.

It is clear that even on the national level there is a need to simplify and harmonize the market rules and designs. The need for harmonized market rules becomes even clearer when observing, for example, European wide market access. EASE, a European association for Storage of Energy recommends the following:

_EASE recommends that technical rules and potential market designs regarding ancillary services (including FCR) should be shaped in such way that, without discrimination, every energy storage technology meeting the actual requirements must be eligible to participate_ (http://www.ease-storage.eu/position-papers.html).

In more detailed list EASE also calls for the following principles in shaping up the future retail energy markets.

**Table 12 Energy market shaping actions [41]**

<table>
<thead>
<tr>
<th>List of retail energy market shaping actions by EASE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goals of increased empowerment of the consumer in a competitive, sustainable and secure energy system should be primarily attained through instruments designed in a market oriented, non-discriminating and technology-neutral manner; In particular:</td>
</tr>
<tr>
<td>− Energy storage constitutes a special and important asset of the complete energy value chain. Therefore the current and future levy structure should not hinder the integration of energy storage;</td>
</tr>
<tr>
<td>− The use of energy storage must be technologically neutral: each case must adopt the most suitable technological and economic solution. Therefore any wording in this regards must be open and not technically discriminatory;</td>
</tr>
<tr>
<td>− The main challenge is related to the value of energy storage, being it monetary or socio-economic, as it can deliver a number of strategic service both to the regulated and to the de-regulated parts of the power industry. Therefore the operator of such devices may differ;</td>
</tr>
<tr>
<td>− Energy storage will play an important role in new market designs, especially regards to flexibility markets;</td>
</tr>
<tr>
<td>− Specific storage regulation and market mechanisms for flexibility in combination with a new market design will help to create energy storage markets and will contribute to the development of a competitive energy storage industry in Europe.</td>
</tr>
<tr>
<td>EASE therefore calls for:</td>
</tr>
<tr>
<td>− A non-discriminatory consideration of and a fair treatment for energy storage alongside other measures, such as demand side management and the increase of inter-connection capacity, when considering possible solutions for enhanced grid flexibility, stability and quality;</td>
</tr>
<tr>
<td>− A market design that allows specialized energy storage operators to emerge, as long as this does not trigger market distortion.</td>
</tr>
</tbody>
</table>

The comments from EASE found in Table 12 signal that there is a need for clearer, more uniform and harmonized market rules. The current model, where each of the nationalities has their own markets and market rules, is a clear barrier for market players wanting
access to different markets in order to fully utilize the energy storage resources to their maximum capacity.

### 4.2.2 Technology barriers

When it comes to energy storage services, technology plays a crucial part. A wide variety of possible storage technologies exist and therefore various regulatory issues and standards need to be taken into account. In this chapter the main regulatory barriers associated with storage technologies will be analysed. Amendments for regulation to enhance the penetration of storage enabled energy market services will also be proposed.

It is still widely recognized that the biggest barrier slowing down the utilization of energy storage solutions is high life cycle costs [39]. This is not a regulatory issue but can be affected, for example, through standardization. When talking about standardization one should not forget system, interface and integration aspects. It is not only about how storage resources are built and connected to the grid but also about how they can be utilized by external management systems and M2M based dynamic microgrids. In this sense open interfaces and information models like Modbus and CIM are important and should be supported and endorsed by regulation.

Another regulatory barrier is associated with the dual role of storage solutions. Energy storage operators may be treated as a producer or consumer at any given time. This sets challenges on how the resources are to be treated by the market. Usually the resources have an individual ID and an energy balance is calculated based on their attributes. If the resources have a dual role then additional information may be required to manage the resources.

The same problem arises if local storage resources are moved from one location to another, or they are being utilized by different stakeholders with different energy suppliers. This creates a balance management challenge which can be overcome by common information models and energy market structures which support the dynamic nature of storage solutions. For example, in Finland it has been recognized that the full utilization of distributed energy resources at common energy markets requires a flexible operator and flexible trading model. A flexible operator ensures that the information being exchanged at the markets support the technology and the regulatory frameworks and vice versa.

### 4.2.3 Legislative barriers

This section identifies barriers related to the legislation and standardization of electricity markets and related technologies. Legislation and standardization are discussed together because they are often closely linked. For example, the two areas usually give direct or indirect input to each other and therefore current standards may influence future legislation, or vice versa.
However, they remain distinct, as legislation is set and maintained by governments while standards are issued by standardization bodies. Furthermore, there are both “official” and “unofficial” standardization bodies. This forms a multidimensional and quite complex field, which requires careful consideration when developing new applications and business cases for energy storage solutions. Table 13 demonstrates the division of standards into two different categories and sub-categories.

Table 13 Division of standards into official and unofficial standardization bodies.

<table>
<thead>
<tr>
<th>Standards</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>International standardization bodies</td>
<td></td>
</tr>
<tr>
<td>IEC</td>
<td></td>
</tr>
<tr>
<td>ISO</td>
<td></td>
</tr>
<tr>
<td>European Union level standardization bodies</td>
<td></td>
</tr>
<tr>
<td>ACER</td>
<td></td>
</tr>
<tr>
<td>CEER</td>
<td></td>
</tr>
<tr>
<td>CEN</td>
<td></td>
</tr>
<tr>
<td>CENELEC</td>
<td></td>
</tr>
<tr>
<td>ETSI</td>
<td></td>
</tr>
<tr>
<td>National level standardization bodies</td>
<td></td>
</tr>
<tr>
<td>SFS</td>
<td></td>
</tr>
<tr>
<td>DIN</td>
<td></td>
</tr>
</tbody>
</table>

As can be seen from Table 13, there are two different categories of standards, which have often been described as either official or unofficial. The official standardization bodies are often governed and steered by governmental organizations, for example in the case of International Standardization Organization (ISO) and International Electrotechnical Commission (IEC), they are governed by the United Nations (UN). The unofficial standardization bodies are typically consortiums comprising of companies driven by similar goals. An example of one such consortium is the European Association for Storage of Energy (EASE), which drives for the standardization of energy storage solutions in Europe.

Another matter considering standards, as well as legislation, can be seen in the left column of the Table 13. The standards and legislation operate at several different levels, varying from national to international.

While usually the “upper level” standardization and especially legislative bodies have a trickle-down effect on the “lower level” legislative and standardization bodies, it is not uncommon to find some differences between the levels and between different standardization and legislative bodies on the same level. For example, legislation differs between all the European Union (EU) countries, although the legislation in individual member
states is steered by the EU to some degree. This shows that even when the organizations are at the same level and are under the steering of same upper level there are still differences in legislation. This causes problems for the businesses, because legislation varies from country to country, and while there are some cases of shared legislation, for example in the Nordic countries, where the TSOs are all governed by the same legislation, it is very difficult to identify when this is the case.

Another barrier to market entry is that the legislation is written to be as general as possible and ideally applicable to all kinds of technical solutions. However, it is identified that this may delay the deployment of energy storage solutions. While from the legislative viewpoint, this generality can be seen as an action which moves the responsibility of defining best practice from the legislators to the industry, from the viewpoint of investors and developers, the lack of specific legislation means there may be little or no guidance as to what should be regarded as practice. [39]

The main barriers identified in the legislative domain were the complexity of the domain itself and the indecisiveness of the legislation. While it is understandable that there are needs for legislation on different levels and the legislation has to be broad in scope so that it is not overly prohibiting or limiting to new technological or business opportunities, there is a need for clearer and more specific guidance with regards to energy storage. This section discusses and proposes different solutions to overcome the barriers presented in the previous section.

The first barrier -- the complexity of the legislative domain -- should be tackled with clear and definitive actions the aim of simplifying and harmonizing existing legislation. Within the European Union this would mean Union-wide and cross-border collaboration. A few examples can be seen in the Nordic countries, and between Germany and Austria, but more is needed to simplify and harmonize the relevant legislation governing the markets. [42]. The second barrier, discussed in the previous section, is that the legislation lags behind the development of new technologies, such as energy storage. While the current legislation tries to circumvent this problem by defining the law as broadly as possible, from the technological and business case viewpoint, this can limit access to the market, since the various energy storage solutions are fundamentally very different to technologies already participating in the energy market.

A possible solution would be to begin discussions with the regulatory bodies during the research and development phase in order to share knowledge about the new solutions and to accelerate the development of laws and standards. This would allow legislation to be up to date when new technologies and solutions hit the market. This presents new challenges for legislators, as the EC points out in its working paper on energy storage solutions:

*The framework should be technology neutral, ensuring fair competition between different technological solutions (not picking a winner).*

(EC 2013)
It should ensure fair and equal access to electricity storage independent of the size and location of the storage in the supply chain. (EC 2013)

The regulatory framework needs to provide clear rules and responsibilities concerning the technical modalities and the financial conditions of energy storage. (EC 2013)

The points presented in this document concentrate mainly on the upper level of the regulatory framework. The regulatory framework governing energy markets and technologies is far deeper than what is presented here, but it is believed that these are key challenges which should be addressed in order to provide a more suitable legislative framework.
5 Project KPI Definition

*Key Performance Indicators* (KPI) are the primary means by which the project progress and impact is assessed. The SENSIBLE KPI are used to define and measure progress towards the integration of local/small-scale storage in electrical distribution networks and prosumer communities and provide the methodology for assessing project goals and objectives.

In this project, the KPI defined by the European Electricity Grid Initiative (EEGI) Research and Innovation Roadmap 2013-2022 [43] was used. The KPI and associated methodology are briefly described in Section 5.1.

5.1 EEGI KPI Framework

The objective of the GRID+ FP7 EU Project ([www.gridplus.eu](http://www.gridplus.eu)) was to support management and planning of the “European Electricity Grid Initiative” (EEGI) in from 2012 until 2014. EEGI is one of the European Industrial Initiatives proposing a nine year R&D program concerned with the modernisation and development of future electricity networks in Europe.

The Grid+ project defined a set of KPI with the aim of quantifying the contribution of R&I activities to the overall objectives the EEGI R&I roadmap. The KPI are intended to quantify the enabling role of network operators in reaching European energy goals in the coming decades. Particular emphasis was given to how a “low-carbon economy” could become an affordable reality by 2050. Two groups of KPI were established [43]:

- **Implementation effectiveness KPI**, which are intended to measure the progress of R&I activities. Partial completion of functional objectives is reported as a percentage of the total workload associated with the objective in question. This may be extended to sets of functional objectives, taken from the clusters defined in the EEGI Roadmap.

- **Expected impact KPI** attempt to estimate the potential contribution of new research. New results and research activities are assessed against the requirements set out in the EEGI Roadmap.

The Implementation effectiveness KPI are considered to be outside of the scope of the SENSIBLE project.

Figure 5.1 depicts the EEGI KPI framework, which comprises three different levels of KPI [43]:

- **Overarching KPI** consist of a limited set of networks and system performance indicators, but are able to clearly show the contributions made by EEGI activities. Performance is assessed in terms of progress towards the high level aims stated in the EEGI roadmap. These KPI are intended to provide a broad overview of the
benefits that may be achieved through European R&I projects and are to be evaluated at a system level.

- **Specific KPI** are used to assess the impact of clusters of projects against the functional objectives set out by the EEGI Roadmap.
- **Project KPI** are proposed by each R&I project of the EEGI Roadmap and are used to assess the impact of individual projects within the wider EEGI programme. Aggregated results from the Project KPIs are to be used to evaluate performance of the Overarching and Specific KPIs.

**Figure 9: EEGI KPI framework**

Within the scope of the SENSIBLE project, some of the most representative “Specific KPIs” will be considered. In addition, other KPI, that seek to contribute to an impact assessment of small-scale storage at each of the demonstrator sites, are defined in the project’s goals. A similar approach has been followed by other projects, such as FP7 SuSTAINALE, evolvDSO, iGreenGrid, and IDE4L [45].

### 5.2 SENSIBLE KPI List and Definitions

Each of the SENSIBLE KPI must meet the following criteria:

- **Relevant to** and **consistent** with the specific project’s goals and objectives;
- **Representative of** and appropriate to the three demonstration sites (Évora, Nottingham, Nuremberg);
- **Attainable** – this requires targets to be set. Targets must be observable, achievable, reasonable and credible under expected conditions of the demonstrators taking into account the required functions, available components and available data;
- **Specific** – clear and focused to avoid misinterpretation or ambiguity;
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- **Measurable** – ideally, it should be possible for the KPI to be quantified and measured, although they may be either quantitatively or qualitatively assessed as required;
- **Timely** – achievable within the given project timeframe;
- **Understandable** – KPI should be clear and unambiguous. Individuals and stakeholder groups should know the meaning of the stated KPI and be able to contribute to the wider project goals as a result.

Table 14 presents the list of SENSIBLE KPI. Note that four KPI were selected from the EEGI Roadmap, and five additional KPI were considered in order to assess project goals and measure the impact of energy storage technology on consumers and prosumers. The KPI mentioned in a report produced by the Energy Research Knowledge Centre (ERKC) as part of the Information System for the Strategic Energy Technology Plan (SETIS) [43] were also considered.

A subset of these KPI will be selected for each demonstrator in the framework of Task 1.4.

### Table 14: SENSIBLE high-level KPI list

<table>
<thead>
<tr>
<th>ID</th>
<th>SENSIBLE KPI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>EEGI Specific KPI</strong></td>
</tr>
<tr>
<td>1</td>
<td>Increased RES and DER hosting capacity</td>
</tr>
<tr>
<td>2</td>
<td>Reduced energy curtailment of RES and DER</td>
</tr>
<tr>
<td>3</td>
<td>Power quality and quality of supply</td>
</tr>
<tr>
<td>4</td>
<td>Increased flexibility from energy players</td>
</tr>
<tr>
<td>5</td>
<td>Investment deferral (MV network)</td>
</tr>
<tr>
<td>6</td>
<td>Increased percentage of self-consumption</td>
</tr>
<tr>
<td>7</td>
<td>Increased economic welfare</td>
</tr>
<tr>
<td>8</td>
<td>Consumer awareness and engagement</td>
</tr>
<tr>
<td>9</td>
<td>Losses minimization (network, inverters)</td>
</tr>
</tbody>
</table>

Table 14 presents a set of high-level KPI. As part of WP2-4, the low-level KPI used to assess the SENSIBLE KPI will be provided. For instance, the successful operation of an LV network in islanding mode provides a low-level KPI that can be used as part of the assessment of the impact of SENSIBLE solutions on the quality of supply (high-level KPI number 3). Annex B provides a template (based on [45]) for describing the individual low-level KPI at one of the three demonstration sites.

The remainder of this Chapter describes the high-level KPI associated with this project.

**Increased RES and DER hosting capacity**

In order to fulfil the requirements of low carbon energy policies, distribution systems must ensure sufficient capacity and flexibility to allow for the connection of RES and DER while simultaneously maintaining reliability and security at acceptable levels.
The objective of this KPI is to increase distribution networks hosting capacity (expressed in kW or MW) for RES and DER integration, by promoting investment in small-scale and local energy storage solutions and by taking advantage of advanced power electronic solutions to help improve distribution system performance.

The RES/DER hosting capacity is defined in [43] as the total installed capacity of RES/DER that can be connected without compromising either system stability or reliability. Large scale generation from wind or photovoltaic (PV) sources is not within the scope of this project. Therefore, the definition of DER used here is the same as that found in [43], and refers to small and medium-scale wind and PV generation or other small-scale distribution generation (DG) resources connected to the grid at the distribution level.

In the SENSIBLE project, this KPI is expected to be calculated with an ex-ante methodology based on simulation studies such as those used for network planning purposes. The measurements and results collected from the demonstration phase (WP4) of this project will be used to provide additional data for these simulations.

The KPI is assessed by calculating the percentage of additional RES/DER that can be connected to the grid above the Business As Usual (BAU) scenario:

\[
EHC_\% = \frac{HC_{SENSIBLE} - HC_{BAU}}{HC_{BAU}} \cdot 100\%
\]  

Where:
- \(EHC_\%\): the enhanced hosting capacity of RES/DER when SENSIBLE solutions are applied with respect to the BAU scenario
- \(HC_{SENSIBLE}\): the additional hosting capacity of RES/DER when SENSIBLE solutions are applied, with respect to the currently connected generation (kW or MW)
- \(HC_{BAU}\): the additional hosting capacity of RES/DER then the BAU scenario is applied, with respect to the currently connected generation (kW or MW).

The BAU scenario reflects the normal evolution that the network would experience with only conventional solutions (e.g., no storage in the LV network). For the BAU scenario, it is necessary to estimate the maximum possible connected generation, considering the currently connected generation for a specific network. A methodology for calculating the maximum generation values for both the BAU and SENSIBLE scenarios is presented in [47] and [48].

**Reduced energy curtailment of RES and DER**

Various scenarios may result in curtailment of the output power supplied by RES and DER. These include:
- Over-voltage in the transmission or distribution system as a consequence of surplus RES/DER generation;
Voltage dips or system stability problems as a result of routine or emergency maintenance, system failure or power system faults;

- Power quality issues, such as voltage unbalance on three phase systems.

The objective of this KPI is to minimize curtailment of the energy (expressed in kWh or MWh) supplied by RES/DER generation due to technical and operational problems and to identify how storage devices, as well as corresponding management tools, can contribute to a reduction in RES/DER output curtailment.

The use of storage devices, potentially combined with demand-side management, can enhance the integration of RES/DER by storing this surplus energy when demand is low. Furthermore, power electronic devices associated with storage devices can potentially provide additional grid support functionalities such as voltage control and voltage sag mitigation and this could contribute to further reductions in RES/DER output curtailment.

This KPI, which may be found in the EEGI framework, is calculated as follows:

$$ E_{\text{not-injected}} = \frac{E_{\text{baseline}} - E_{\text{measured}}}{E_{\text{baseline}}} \cdot 100\% $$

Where

- $E_{\text{not-injected}}$: the percentage reduction in energy not injected into the network due to LV network conditions [kWh or MWh].
- $E_{\text{baseline}}$: Total energy not injected into the network due to LV network conditions when the initial network configuration is considered [kWh or MWh].
- $E_{\text{measured}}$: Total energy not injected into the network due to LV network conditions the new network configuration is considered [kWh or MWh].

It may not be possible to directly compare the two test cases for demonstration projects such as this one. An alternative method of assessing the KPI should therefore be considered. In this case, an ex-post methodology with field measurements should be used to evaluate the instances of curtailment or disconnection experienced by a PV installation connected to the LV grid. This data may then be used to perform an estimation of the total energy lost to curtailment. For instance, the PV generation stored in a battery to avoid over-voltage problems can be measured and compared with the estimated energy that would be curtailed in a baseline scenario (i.e., no storage). This data can be extrapolated to annual average values if the number of disconnection events for one year at a given RES/DER site is available. A detailed calculation methodology for this KPI is presented in [43]

**Power quality and quality of supply**

This KPI is concerned with power quality problems and interruption of the supply. The large scale integration of RES/DER may introduce several challenges with regards to
voltage quality, particularly for LV systems. However, the use of storage devices, together with the deployment of local and high-level control and network management strategies can contribute to mitigate such problems.

At the same time, flexible control of storage devices can contribute to improvements to the continuity of supply, by providing backup power during supply interruptions occurring in the MV and LV networks. When the MV network becomes unavailable, energy storage can enable the LV network to continue operating as an autonomous microgrid, isolated from the rest of the grid.

The EEGI framework proposes three indicators of power and supply quality for distribution grids: (a) SAIDI (System Average Interruption Duration Index) and SAIFI (System Average Interruption Frequency Index) indicators; (b) measurement of deviation the of line voltage profiles from the nominal values and limits found in EN 50160; (c) average time required to respond to grid faults.

The SENSIBLE project is developing tools for (a) the effective operation of LV networks as an island in both planned and unplanned scenarios; (b) optimized LV network operation under normal, steady-state operating conditions. The first tool will be assessed by considering the SAIDI, since it should result in a reduction in the number of interruptions of the supply to consumers connected to the LV network. The improvement in SAIDI can be calculated as follows:

\[
\Delta \text{SAIDI}_\% = \frac{\text{SAIDI}_{\text{SENSIBLE}} - \text{SAIDI}_{\text{baseline}}}{\text{SAIDI}_{\text{baseline}}} \cdot 100\%
\]

In this case, the improvement in SAIDI will correspond to the time that the LV network is capable of operating in an islanded mode without interruption of service. The SAIDI can also be compared with historical values (e.g., months from previous years).

The second tool is to be assessed by considering improvements to the line voltage profiles and can be quantified as follows:

\[
V_\% = \frac{V_{\text{baseline}} - V_{\text{SENSIBLE}}}{V_{\text{baseline}}} \cdot 100\%
\]

Where:

- \(V_\%\): overall improvement of the voltage profiles;
- \(V_{\text{SENSIBLE}}\): voltage profiles with the SENSIBLE solution;
- \(V_{\text{baseline}}\): voltage profiles of the baseline scenario (i.e., no storage in the LV network).

The baseline scenario can be estimated with a power flow algorithm using real measurements taken from historical data, i.e. without any voltage control actions performed by the storage devices. Several possibilities exist for the measurement methodology. The GRID4EU project proposes one methodology to calculate this indicator [48]. This criterion can also be measured during islanding operation.
As referred previously, storage may also be used to aid in reducing voltage unbalance occurring in LV networks due to the connection of a large number of single-phase devices. In this case, specific KPI are defined to assess the reduction in voltage unbalance.

European Standard EN50160 defines Voltage Unbalance Factor (VUF) as the ratio of negative sequence voltage to positive sequence voltage. The VUF may be determined as follows.

\[
VUF_{\text{neg}} = \frac{V^-}{V^+} \cdot 100\%
\]  

(5)

Where
- \( VUF_{\text{neg}} \) - Negative voltage unbalance factor (%)
- \( V^- \) - Magnitude of negative sequence voltage component (V)
- \( V^+ \) - Magnitude of positive sequence voltage component (V)

The voltage should be measured at customers’ point of connection to the distribution network. EN50160 defines a statistical approach for the evaluation of voltage unbalance. The magnitude of the negative sequence voltage component is determined by the average value over a fixed 10 minute interval. In order to comply with the standard, the VUF should be less than 2%, for greater than 95% of the time over a one week observation period. Unbalance due to zero sequence voltages is not considered in EN50160.

The KPI related to voltage unbalance improvement can be quantified as follows:

\[
VUF_{\%} = \frac{VUF_{\text{baseline}} - VUF_{\text{SENSIBLE}}}{VUF_{\text{baseline}}}
\]  

(6)

Where
- \( VUF_{\%} \): improvement to the voltage unbalance factor (%)
- \( VUF_{\text{SENSIBLE}} \): voltage unbalance factor with the SENSIBLE solution (%);
- \( VUF_{\text{baseline}} \): voltage unbalance factor for the baseline scenario (i.e., no storage in the LV network) (%).

This KPI can be measured through simulation using real measurements from historical data and experimentally in a laboratory environment as well as at the SENSIBLE LV pilot sites. For SENSIBLE demonstrators, adequate power quality analyser equipment need to be installed in order to measure the effect of grid support strategies in reducing voltage unbalance.

Another power quality problem of interest is the occurrence of voltage sags, which are usually associated with power system faults. Voltage sag is defined as a sudden reduc-
tion of the supply voltage to a value between 90% and 1% of the nominal voltage, followed by a voltage recovery after a short period of time, typically between 10 ms and 1 minute.

Energy storage can be installed, either at a customer’s point of connection or as part of the DSO network infrastructure (e.g. at MV/LV substations), in order to mitigate voltage sag occurrence. Voltage sags are characterized by the minimum voltage detected and the duration of the occurrence. The contribution of storage may be assessed by comparing the minimum voltage during a voltage sag, both with and without storage. Therefore the contribution of storage can be quantified as follows:

\[
\Delta V_{\%} = \frac{\Delta V_{\text{baseline}} - \Delta V_{\text{SENSIBLE}}}{\Delta V_{\text{baseline}}} \tag{7}
\]

Where

- \(\Delta V_{\%}\): Voltage sag magnitude in relation to nominal voltage (% of nominal value);
- \(V_{\text{SENSIBLE}}\): Voltage sag magnitude with the SENSIBLE solution (% of nominal value);
- \(V_{\text{baseline}}\): Voltage sag magnitude of the baseline scenario (simulation with measured data) when storage is not considered (expressed as a % of nominal value).

To avoid a reduction in the quality of power delivered to customers, measurements associated with this KPI should be performed in a controlled, laboratory environment.

Finally, it is worth considering associating a KPI with the MAIFI (Momentary Average Interruption Frequency Index) [49]. This is only practical if the smart meters installed at the demonstration sites are able to measure and quantify momentary interruptions to the supply.

**Increased flexibility from energy players**

In [49], flexibility is defined as: “On an individual level, flexibility is the modification of generation injection and/or consumption patterns in reaction to an external signal (price signal or activation) in order to provide a service within the energy system. The parameters used to characterize flexibility in electricity include: the amount of power modulation, the duration, the rate of change, the response time, the location, etc.”

Controllable resources, such as loads participating in demand-side management schemes and dispatchable micro-generation units can provide the flexibility required for participation in the wholesale market. Flexibility may be further increased by the introduction of energy storage solutions into a market player’s resource portfolio. Market players can use energy storage for price arbitrage and provision of ancillary services (e.g., restoration of supply, replacement reserve and voltage control) in order to maximize their profit and increase competitiveness.
This improvement in flexibility is also of value to the rest of the power system, since it increases the reserve and ramping capacity without requiring additional investment or incentives for conventional power plants. Furthermore, it also increases the flexibility of available sources at the distribution level and provides the DSO with resources that can be contracted to solve local problems in the distribution network. This KPI is intended to assess an energy market player’s flexibility in this context, with emphasis on the use of energy storage for improving flexibility.

The SENSIBLE project is also addressing the DSO perspective and the possibility of using storage flexibility for network management tasks, such as voltage control, congestion management and loss reduction. Therefore, the increased flexibility from the perspective of the DSO is also measured in this KPI.

Flexible services can be provided either individually by each resource or aggregated, with improvements resulting from the coordination of the different resources. For example, storage installed at the residential level can be coordinated with available RES and controllable loads in order to provide greater flexibility than any of the individual resources is able to provide alone.

For the energy player perspective, increased flexibility would be a measure of additional storage participation in ancillary services and can be defined as:

$$A_S = \frac{C_{SENSIBLE} - C_{BAU}}{C_{BAU}} \cdot 100\%$$  \hspace{1cm} (8)

Where

- $C_{SENSIBLE}$: represents the amount of flexible capacity participating in ancillary services, including small-scale/local storage under the SENSIBLE scenario and the developed optimization tools.
- $C_{BAU}$: represents the amount of flexible capacity participating in ancillary services, including only other resources providing flexibility, such as controllable loads or other DER (controllable small-scale generation) under BAU scenario.

Note that BAU flexibility is only considered when there are other resources capable of providing flexibility (e.g., controllable loads). Otherwise, the flexibility is calculated as the ratio between storage capacity used by market players or by the DSO, and the total storage capacity in the portfolio.

From the perspective of the DSO, the KPI can be quantified as in Eq. 8, but with reference to the use of energy storage in its management tasks (e.g. voltage control, congestion management, losses reduction) rather than in energy trading.

The quantification of the system flexibility will require monitoring equipment for each type of flexible resource (loads, controllable generation and storage) and can be differentiated according to the different applications of the installed energy storage units (residential, community/microgrid and grid support).
**Investment deferral (MV network)**

In order to meet increasing electrical energy demands, an expansion of distribution-level energy sources is required in order to avoid violating operating limits of the existing infrastructure (e.g., overloaded transformers and lines). Network planning, with consideration of the connection of DER can defer investments in additional or upgraded distribution assets, as a significant proportion of demand can be sourced locally.

The present value (PV), with continuous compounding of deferred investment, is given in [50]:

\[
PV(\tau) = \frac{IC}{e^{p\tau}}
\]  

(9)

Where
- \( IC \): investment cost,
- \( \tau \): deferral time
- \( p \): interest rate.

The network planning KPI, named as Deferred Distribution Capacity Investment – DDCI, can be calculated as follows [50]:

\[
DDCI = \frac{NRC_{BAU} - NRC_{SENSIBLE}}{NRC_{BAU}}
\]  

(10)

Where:
- \( NRC_{BAU} \): net present value of the network reinforcement cost for the BAU scenario,
- \( NRC_{SENSIBLE} \): net present value of the network reinforcement cost for the SENSIBLE scenario.

The BAU value is based on the distribution network at the reference year, taking into account planned investments in distributed generation, their location and their size. The SENSIBLE scenario considers the installation the total planned DER capacity (mostly PV) and of storage devices at the minimum possible cost.

**Increased percentage of self-consumption**

At the building/residential level, the main drivers to increase self-consumption of renewable generation (mainly PV) are demand-side management and storage. The main objective is to minimize the energy consumed from the grid and maximize the use of renewable generation.

Self-consumption can be defined as all the electrical energy produced and immediately used to power residential/building loads and includes energy which is stored for later consumption. Storage in charging mode will be considered as a load and contributes to an increase in self-consumption. Depending on the level of sub-metering, there are dif-
Different methodologies to calculate the percentage of self-consumption. Assuming separate metering is available for generation and storage, self-consumption may be defined as:

\[
SC\% = \left(1 - \frac{L_{net}}{L_{total}}\right) \times 100\%
\]

(11)

Where
- \(L_{total}\): total load (in kWh);
- \(L_{net}\): net load (in kWh).

The total load is calculated from the separate meter readings for storage and micro-generation as follows: \(L_{total} = L_{net} + E_{DER} \pm E_{storage}\), where \(E_{DER}\) is the energy produced by the micro-generator and \(E_{storage}\) is the energy injected or absorbed by the storage unit.

The KPI is given by:

\[
\Delta SC\% = \frac{SC_{SENSIBLE} - SC_{BAU}}{SC_{BAU}}
\]

(12)

The BAU scenario is calculated using demand and micro-generation without storage or demand-side management.

**Increased economic welfare**

Storage located at the building and community levels has a potential social impact and financial benefit for the consumers. The main objective is to reduce electrical energy costs for the participants of the pilot tests and provide recommendations in order to influence consumer behaviours and energy trading policies.

The KPI associated with socio-economic welfare is assessed by calculating the reduction in the consumers electricity bill, given by:

\[
\Delta MB\% = \frac{MB_{BAU} - MB_{SENSIBLE}}{MB_{BAU}}
\]

(13)

Where
- \(MB_{BAU}\): monthly electricity bill in the BAU scenario (in €);
- \(MB_{SENSIBLE}\): monthly electricity bill in the SENSIBLE scenario (in €).

Different methods can be considered to calculate the monthly electricity in the BAU scenario: (a) use statistical techniques to estimate the baseline load (i.e., without control actions) of the building or home [51]; (b) install sub-metering in order to measure different circuits (e.g., storage device, PV production) and calculate the baseline load; (c) compare with past bills for the same month; (d) use the load profile of a building or home with similar characteristics (e.g., total load capacity, number of habitants, type of building, load profile etc.).
The method used to calculate the BAU will be defined during the demonstration site setup.

**Consumer awareness and engagement**

The engagement of consumers in smart grid functions at the residential level, such as local energy storage and demand-side management actions, is an important indicator to measure if consumers are likely to have an interest in being involved in test-pilots. The main objective of this KPI is to measure acceptance and engagement of consumers having storage at the residential level (i.e., behind the meter). The KPI can be defined as follows [48]:

\[ num\_accept\% = \frac{n_{accept}}{n_{total}} \cdot 100\% \]  

(14)

where

- \( n_{accept} \): percentage of consumers who agree to be part of the test-pilot;
- \( n_{reject} \): number of consumers involved in the test-pilot;
- \( n_{total} \): total number of consumers contacted to be part of the test-pilot.

Some additional potential impacts could be measured in this KPI, such as the deployment of education policies in schools/universities and impact to consumers of cooperative energy trading.

**Losses minimization (network, inverters)**

The integration of energy storage devices in the LV and MV networks can potentially reduce losses by means of local balancing of energy production and consumption (e.g., avoid inversion of power flows related to increased RES generation), as well as through load shifting, resulting in a reduction in power flow. Another source of potential reduction of losses is the increase of power electronic converter efficiency. This KPI covers the planning and operational requirements of the power system.

At a given time for a given network, the network losses (in kWh or MWh) can be measured as the sum of all the real power being consumed by the network loads subtracted from the sum of all real power being generated by network sources or supplied from the substation. Mathematically it is given by:

\[ P_{loss} = P_T + \sum_{i} P_{prod,i} - \sum_{i} P_{load,i} \]  

(15)

Where

- \( P_T \): active power going through the transformer;
- \( P_{prod,i} \): active power of production unit \( i \)
- \( P_{load,i} \): active power consumed by the load \( i \).
The KPI is calculated as follows:

$$\Delta P_{loss} = \frac{P_{loss(BAU)} - P_{loss(SENSIBLE)}}{P_{loss(BAU)}} \cdot 100\%$$  \hspace{1cm} (16)

The BAU scenario is calculated using a power flow algorithm to estimate, a posteriori, the active power losses without storage control actions.
6 Conclusion

This deliverable has presented the experience and the findings of the partners on the main interest areas concerning the application of electric storage in power systems. The objective of this document is to inform the partners of the state of the art and the current situation regarding business, technology and regulatory frameworks associated with energy storage and to provide a summary of the high level KPIs to be used in the project. Because of the considerable size of this problem, attention has been focused on the characteristics and objectives of the SENSIBLE project. The topics approached are: 1) Storage applications, 2) Storage technologies and state of the art of demonstration projects, 3) Regulatory framework and 4) High level project’s KPI.

Firstly a series of categorisation methods for energy storage devices have been analysed, with a total of 15 possible applications and 11 storage types found. These categories are presented in Table 2 and Table 3 respectively.

The possible applications have been reduced to a maximum of five, taking into account that the basis of the LCE8 call is focusing on the benefits of small scale storage at two different levels: 1) Distribution grid and 2) Building/house level. The five applications selected are:

- Capacity support: to support power flow in distribution grid operation by generating an economic value (associated with deferring circuit upgrades) by discharging the battery during peak load hours, thereby keeping circuit load within feeder ratings;
- Dynamic local voltage support: discharging storage in particular conditions to avoid voltage sags and momentary outages which can be caused by RES;
- Power quality, intentional islanding: the improvement in power reliability that requires the monitoring of performance metrics concerning resilience, continuity of supply and power quality;
- Load shifting / Peak shaving: the main benefits of load shifting at the customer side result from the flexibility in consumption that local storage provides, making it adaptable to flexible contractual solutions with retailers such as dual tariffs or flexible demand contracts;
- Maximise self-consumption: to manage local storage and RES generation resources in response to local load by maximising the value of self-consumption exploiting the microgrid concept

The first three applications are related to the distribution grid whilst the last two are related to the building or community.

Regarding storage technologies, only three types will be used in SENSIBLE, at both the distribution grid and at the building level:

- Secondary batteries: Electrochemical energy storage systems store electrical energy in a chemical process or reaction and are usually optimised to provide large
CONCLUSION

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discharge of energy or short but high power discharge. The three main types are: lead acid, lithium-ion and redox flow batteries;
- Flywheel: is a system that stores electrical energy as mechanical (rotational) energy. The main application for flywheel energy storage systems is to provide and accept high rates of electrical power with a duration of up to a few minutes.
- Thermal energy storage: divided into sensible heat and latent heat, these are key to a successful demand response energy market, considering that buildings are responsible for up to 40% of the total energy consumption in the European Union and that space heating and hot water take a significant portion of this consumption.

A summary of the optimal storage technologies for each application in the SENSIBLE project is reported in Table 15.

Table 15: Storage technology and application summary table

<table>
<thead>
<tr>
<th>Domain</th>
<th>Application</th>
<th>Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distribution grid</td>
<td>Capacity support</td>
<td>Secondary batteries</td>
</tr>
<tr>
<td></td>
<td>Dynamic local voltage support</td>
<td>Secondary batteries</td>
</tr>
<tr>
<td></td>
<td>Power quality, intentional islanding</td>
<td>Flywheel, Secondary batteries</td>
</tr>
<tr>
<td>Customer service</td>
<td>Load shifting / Peak shaving</td>
<td>Sensible heat, Latent heat, Secondary batteries</td>
</tr>
<tr>
<td></td>
<td>Maximise self-consumption</td>
<td>Sensible heat, Latent heat, Secondary batteries</td>
</tr>
</tbody>
</table>

The regulatory framework in the six countries involved in this project has been analysed according to three topics, which can be summarised as: 1) regulatory compensation methods, 2) regulation for marketplaces and 3) regulation for technology. It emerged that:

- Existing specific regulation is often limited to safety aspects of electric storage installation;
- Only in Germany is an investment support scheme in place for domestic storage;
- Several compensation methods have been identified in various marketplaces;

Market barriers are studied by observing the Nordic electricity market as the Nord Pool Spot is the leading energy market in the Europe. A summary of the market barriers identified is reported below:

- Market rules vary widely from market entry capacity to market pricing when observing different market levels;
- In addition to these rules, each of the markets have a different pricing mechanism;
- Aside from market rule regulations there is also set of technical requirements for energy market access from the energy storage point of view;
The capacity amounts needed for market access are usually too large for smaller energy market participants to fulfil and usually leads to the need for resource aggregation;

- Some of the markets prohibit offering the same resource to multiple markets at the same time.

The last part of the document is concerned with a definition of the high level KPIs of the project. After a selection process, four KPIs from the European Electricity Grid Initiative (EEGI) have been selected. These KPIs will help with the comparison of the results of the project with similar demonstration projects in Europe. Following this, five KPIs specific to SENSIBLE have been defined. A list of the nine KPIs defined is given below.

- Increased RES and DER hosting capacity
- Reduced energy curtailment of RES and DER
- Power quality and quality of supply
- Increased flexibility from energy players
- Investment deferral (MV network)
- Increased percentage of self-consumption
- Increased economic welfare
- Consumer awareness and engagement
- Losses minimization (network, inverters)

In each case, the KPIs are relevant to the SENSIBLE project goals, appropriate to the three demonstrators, achievable under reasonable conditions, are non-ambiguous, are measurable and are understood by the partners.
## Annex A Regulation summary by country

<table>
<thead>
<tr>
<th>Energy tariff structures</th>
<th>UK</th>
</tr>
</thead>
<tbody>
<tr>
<td>- The individual approach of each energy company to tariff structure and provision means that a perfect definition cannot be applied to all tariffs within a given type. Broadly speaking the following tariffs exist:</td>
<td></td>
</tr>
<tr>
<td><strong>Standard:</strong> The basic variable tariff offered by a company.</td>
<td></td>
</tr>
<tr>
<td><strong>Fixed:</strong> A tariff offering prices that remain constant at the initially offered level until a pre-defined expiry date, regardless of any price changes announced by the company.</td>
<td></td>
</tr>
<tr>
<td><strong>Economy 7 Electricity:</strong> Offers a day price and a reduced night price for electricity consumed within a given 7 hours each night.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Investment support schemes</th>
<th>UK</th>
</tr>
</thead>
<tbody>
<tr>
<td>- There are no incentives for domestic electric energy storage.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Revenue compensation</th>
<th>UK</th>
</tr>
</thead>
<tbody>
<tr>
<td>- There are no specific compensation mechanisms for electric energy storage. It is considered to be either a production or consumption unit (which are considered mutually exclusive) and should be connected with two separate contracts and meters to the network.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Wholesale market structures</th>
<th>UK</th>
</tr>
</thead>
<tbody>
<tr>
<td>- National Grid Electricity Transmission (NGET) has overall responsibility as ‘residual balancer’ of the electricity system, and takes actions to ensure that electricity supply and demand match on a second-by-second basis. NGET has a number of tools that it can use to do this, including the Balancing Mechanism. The Balancing Mechanism allows NGET to accept offers of electricity (generation increases and demand reductions) and bids for electricity (generation reductions and demand increases) at very short notice. If a market participant generates or consumes more or less electricity than they have contracted for, they are exposed to the imbalance price, or ‘cash-out’, for the difference. The cash-out price is the incentive on market participants to ensure electricity consumers’ demand is met, and the ‘residual balancing role’ of NGET is minimised. The cash-out price is based on NGET’s costs of balancing the system.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ancillary markets and products for energy storage</th>
<th>UK</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Standardization and technical requirements for storage</th>
<th>UK</th>
</tr>
</thead>
<tbody>
<tr>
<td>- The legislation for grid connection only covers production and consumption units (which are considered mutually exclusive). Storage is not specifically mentioned.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Grid connection legislation for energy storage</th>
<th>UK</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Most households will have smart meters installed by their energy company between 2015 and 2020. The first phase was managed by the Office of Gas and Electricity Markets (OFGEM) by March 2011. Since April 2011, the Department for Energy and Climate Change (DECC) has been directly responsible for managing the implementation of the smart meter programme.</td>
<td></td>
</tr>
<tr>
<td>- The Data and Communications Company (DCC) is responsible for linking smart meters in homes and small businesses with the systems of energy suppliers, network operators and energy service companies. DCC will develop and deliver the data and communications service through external providers.</td>
<td></td>
</tr>
<tr>
<td>- When DECC granted the DCC licence, stage 1 of the Smart Energy Code (SEC) also came into force. The SEC is a new industry code and sets out the terms for the provision of the DCC’s services and specifies other provisions to govern the end-to-end management of smart metering.</td>
<td></td>
</tr>
</tbody>
</table>
### Energy tariff structures
- Different grid tariffs in use:
  - Energy consumer with a demand below 100,000 kWh/a have a basic constant tariff.
  - Energy consumers above 100,000 kWh/a must have a quarter-hour power measurement. The grid tariff is calculated by using the highest power value of a quarter-hour during the billing period.
- Different supply tariffs in use:
  - Basic constant tariff
  - SPOT-market
  - Energy suppliers are obligated to provide a flexible tariff (since 2011) regulated by the German Energy Act (EnWG), if it is economically and technically acceptable.

### Investment support schemes
- Investment support for electro-chemical storage systems in combination with photovoltaic systems (Peak = 30 kWp) for private households, companies, etc.
- Support for renewable energy systems regulated by the German Renewable Energy Act (EEG)
- Support for efficient CHP-Units regulated by the Cogeneration Act (KWK-Gesetz)

### Revenue compensation
- No compensation mechanisms specifically for storage solutions.
- Storage systems could act on the Day-ahead, Intraday and as tertiary control power like other energy consumers or generation units

### Wholesale market structures
- Storage resources are managed at the wholesale markets either as a production or consumption units.
- Common market for day-ahead is EPEX with a minimal trading unit of 0.1 MWh.
- Common market for intraday is EPEX SPOT with a minimal trading unit of 0.1 MWh.
- Trading at the EPEX is only possible as an authorized trader.

### Ancillary markets and products for energy storage
- **Primary reserves**: Primary control for stabilizing the grid frequency (PRL). Has to be available after 30 seconds and for a time period of 15 minutes.
- **Secondary reserves**: Secondary control for stabilizing the grid frequency (SRL). SRL is used for the energetic balance in the single control area. Has to be available after 5 minutes.
- **Tertiary reserves**: Tertiary control for stabilizing the grid frequency (MRL). Has to be available after maximum 15 minutes and for a time period of 4 hours.
- **Balancing power**: Balancing power market

### Standardization and technical requirements for storage
- Standardization follows standards from VDE-AR-E 2510-50 for electrochemical storages.
- Further regulation norms for electrochemical storage need to be elaborated.
- Standardization for thermal storage systems is in process, but no regulations are still available.

### Grid connection legislation for energy storage
- The German Energy Act (EnWG) regulates the grid connection for production, consumption and storage units.
- The connection is managed by the DSO.
- The DSO is obligated to connect all systems, if the DSO rejects a connection to the grid a economical or technical reason has to be presented.

### Smart metering (enabling net metering)
- The metering point operation is regulated in the German Energy Act (EnWG). The operation is the duty of the grid operator.
- The rollout of smart meter is planned to be driven by the market with some exceptions (new buildings, consumers with a demand above 6000 kWh/a, operator of CHP and renewable energy units).
- At the moment about 7% of the residential customers are equipped with a smart meter.
- Storage resources are not mentioned separately.
### ANNEX A

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<table>
<thead>
<tr>
<th>Energy tariff structures</th>
<th>1. Energy Supply Tariffs (market regime; includes retailing costs - contracting, metering, invoicing and billing - and energy production costs):</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- &gt;41kVA: prices are defined by contracted power, peak average power, active energy and reactive energy. Prices vary according to time of day (3-4 periods) and season (summer/winter)</td>
</tr>
<tr>
<td></td>
<td>- &lt;41kVA: prices are defined by contracted power, and active energy. Prices vary according to time of day (2-3 periods) and season (summer/winter). Constant prices are also available</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Investment support schemes</th>
<th>2. Grid Access Tariffs (regulated; includes transmission, distribution and global use of the system):</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- Prices are defined by contracted power, peak average power, active energy and reactive energy if &gt;41kVA</td>
</tr>
<tr>
<td></td>
<td>- Prices vary according to time of day (4 periods), season (summer/winter) and voltage supply</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Wholesale market structures</th>
<th>- MIBEL day-ahead market includes:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- Electrical energy market (covers Portugal and Spain) (frequency containment is mandatory for &gt;10MVA)</td>
</tr>
<tr>
<td></td>
<td>- Secondary (or frequency restoration) reserve - energy and capacity price</td>
</tr>
<tr>
<td></td>
<td>- Tertiary reserve market (offers can be changed one hour before physical delivery)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ancillary markets and products for energy storage</th>
<th>- MIBEL intraday market includes:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- 6 sessions for electrical energy (covers Portugal and Spain)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Standardization and technical requirements for storage</th>
<th>- Standardization follows common European and international requirements set by different organizations.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grid connection legislation for energy storage</td>
<td>- The legislation for grid connection only covers production and consumption units. Storage is not specifically mentioned.</td>
</tr>
<tr>
<td>Smart metering (enabling net metering)</td>
<td>- Technical and functional requirements have been approved in Portugal for the installation of smart meters. However, their installation is pending on positive economic assessment.</td>
</tr>
</tbody>
</table>

- Still, the DSO has developed ambitious smart-grids pilot project which has culminated with a deployment of in excess of 50.000 smart meters and all ancillary infrastructures.
### Energy tariff structures
- Tariffs depend on the contracted power supply:
  - $P \leq 10$ KW, small consumers are allowed to stay under the Voluntary Prices for the Small Consumer scheme (VPSC)( Royal Decree 485/2009). The invoice paid by consumers includes the access tariff (for using the distributing company’s electrical network) and the price for the energy consumed (calculated in accordance with a method established by the Administration that depends on tariff periods).
  - $P > 10$ kW, the price to be paid by these consumers includes a regulated price corresponding to the access tariff, a free price for the cost of the energy and a free price corresponding to the retailer’s margin.

### Investment support schemes
- There are no support schemes for energy storage in current Spanish regulatory policies except for the pump hydro and heat storage associated with solar thermal power plants. The rest of the storage technologies are not covered by the current legislation to the point of not being supported by current legal frameworks.

### Revenue compensation
- In the Royal Decree 661/2007 there is an article related to Fuel Cells which received a regulated tariff of 12.04 c€/kWh. Nevertheless the Royal Decree 1/2012 January 27th abolished the bonus for renewable energies and cogeneration including Fuel Cells.

### Wholesale market structures
- Common wholesale marketplace with Portugal.

### Ancillary markets and products for energy storage
- The framework for the ancillary markets is the same as in Portugal. However there’s a lack of definition of capacities and services that energy storage can provide. Many of the services that some storage systems can provide, given the size, would take place in the distribution network which is a regulated market. The current regulation does not allow DSOs to own these plants and provide these services. And sometimes storage systems such as batteries of the order of MW connected to a substation for example, may carry out arbitrage services as part of the free market and therefore are also prohibited for DSOs.

### Standardization and technical requirements for storage
- Although there is no regulation it should follow the standardization of European organisms such as CEN, CENELEC, ETSI and internationals as ISO and IEC whose transition into Spanish regulation corresponds to AENOR.

### Grid connection legislation for energy storage
- No specific regulation concerning electricity storage connection to the grid exists.

### Smart metering (enabling net metering)
- This topic is under the European Regulation Directive 2009/72/EC and Spanish regulations R.D. 1110/2007, ITC/3860/2007 and ITC/3022/2007 that requires the roll-out of Smart meters in all the Spanish geography before end 2018. There is no explicit mention regarding storage and its measurement.
### Finland

| Energy tariff structures | - Storage resources are affected by different tariff structures.  
Different grid tariffs in use: 1) Basic constant tariff, 2) Day/night time tariff, 3) Winter/summer time tariff  
Different supply tariffs in use: 1) Basic constant tariff, 2) SPOT-market based tariff  
Planned tariffs: - Power band based tariff |
|------------------------|-------------------------------------------------------------------|
| Investment support schemes | - In the investment support schemes are specifically mentioned things like solar and ground heating solutions and different energy production units but not energy/electricity storage solutions.  
- Companies, municipalities, communities and consumers are entitled to subsidies which enhance the use of renewable energy sources, increase energy efficiency or lower the stress caused by energy production to the environment in general.  
- Investments which include new technology are entitled to 40% subsidies, investments with basic technology to 30% subsidies and investments made by individual consumers to 25% subsidies. |
| Revenue compensation | - No compensation mechanisms specifically for storage solutions.  
- Feed-in-tariffs for renewable energy (wind power, biogas and wood based plants).  
- Target price for wind power 105,3 €/MWh and for others 83,5 €/MWh. The difference between the target and wholesale market price is paid as a subsidy. The maximum time for production subsidies is 12 years.  
- No feed-in-tariffs for prosumers. Few energy companies have agreed to procure the excess production. |
| Wholesale market structures | - Storage resources are managed at the wholesale markets either as a production or consumption units. Smallest unit for trading is 0,1 MWh which sets it’s own limits.  
- Common Nordic/Baltic wholesale markets covering Finland, Sweden, Norway, Denmark, Estonia, Latvia and Lithuania (Nord Pool Spot).  
- The trading on Nord Pool Spot is governed and regulated through a detailed rulebook. The rulebook is a set of private law agreements applying to all parties involved in trading and related activities. No special rules or reliefs for storage resources. |
| Ancillary markets and products for energy storage | - Storage resources can be utilized at various different market levels. There’s no special regulation for storage but the same market rules imply for them also. The resources can be utilized to avoid deviations in energy balance but also in ancillary markets.  
Primary reserves  
- Frequency Containment Reserve for Normal operation (FCR-N)  
- Frequency Containment Reserve for Disturbances (FCR-D)  
Secondary reserves  
- Automatic Frequency Restoration Reserve (FRR-A)  
- Manual Frequency Restoration Reserve (FRR-M)  
Tertiary reserves  
- Replacement reserve  
Balancing power  
- Balancing power market |
| Standardization and technical requirements for storage | - Standardization follows IEC, CEN, CENELEC, ETSI, ENTSO-E etc. requirements, codes and standards.  
- Nationally standards are coordinated by SESKO ry which translates European or international standards to Finnish SFS-standards if required. SESKO also represents Finnish companies at the international level and enables the participation to development of standards.  
- Energy storage solutions have been identified as a vital part of the future energy systems but at this point SESKO doesn’t have a special position on the subject. |
| Grid connection legislation for energy storage | - The legislation for grid connection only covers production and consumption units. Storage is not specifically mentioned.  
- The connection is managed by the DSOs and a common legislation is defined in the “Law for electricity markets”. |
| Smart metering (enabling net metering) | - A legislation required that every consumption site had to be equipped with a smart meter by the end of 2013.  
- At the moment there is 2,5 million metering points in hourly measurement. All values are gathered in 24 hours and all supplier balances are calculated with real information within 24 hours.  
- Production and consumption at the sites have to be measured separately if the production is transmitted to the grid.  
- Storage resources are not mentioned separately. |
<table>
<thead>
<tr>
<th><strong>Regulatory compensation methods</strong></th>
</tr>
</thead>
</table>
| **Energy tariff structures** | - Tariffs depend on electricity supplier and are based on the power:  
P<36kW, Blue tariff, peak/off peak hours  
P<250kW, Yellow tariff, Summer/winter peak/off peak hours  
P>250kW, Green tariff, A, B, C according if connected to DSO or TSO. Higher flexibility, and remuneration of disconnection  
| **Investment support schemes** | - There are no incentives for domestic electric energy storages. Incentives are given in the form of tax cuts for improved energy efficiency; New solar power and wind power plants are the object of tenders by the energy regulation authority.  
| **Revenue compensation** | - There is no specific compensation mechanism for electric energy storage. As for prosumers, storages should be connected with two separate contracts and meters to the network.  
| - Possible revenues in the actual situations may come from the optimisation of the purchase price of electricity or from the supply of backup power.  
| **Wholesale market structures** | - Storage resources are managed at the wholesale markets either as a production or consumption units. Smallest unit for trading is 0,1 MWh.  
- The electricity market is managed by EPEX SPOT in Paris, the futures by EPEX SPOT in Leipzig  
- The wholesale day ahead and intraday market covers the following countries: France, Germany/Austria and Switzerland  
- Frequency containment (primary) and restoration (secondary) reserves are mandatory for producers larger than 20MW and are remunerated on call.  
| **Ancillary markets and products for energy storage** | - See above the primary and secondary markets.  
| **Standardization and technical requirements for storage** | - Standardization follows IEC, CEN, CENELEC, ETSI, ENTSO-E etc. requirements, codes and standards  
- French standardization is coordinated by Association Française de Normalisation (AFNOR).  
- Guidelines concerning stationary batteries are provided, especially regarding safety of installation and operation. NF EN 50272-2 Décembre 2005  
| **Grid connection legislation for energy storage** | - The legislation for grid connection only covers production and consumption units. Storage is not specifically mentioned.  
| **Smart metering (enabling net metering)** | - A program to install smart meters to the 90% of customers by 2020 is ongoing.  
- With the current systems metering will be done with a resolution of 30 minutes and update every day.  
- With the current regulation a separate meter for consumption and production is necessary.  
- Storages are not considered separately.  
|
## Annex B  KPI basic information

<table>
<thead>
<tr>
<th>KPI Name</th>
<th>Demo Site</th>
<th>KPI ID</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Évora, PT</td>
<td>#1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Nuremberg, DE</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Nottingham, UK</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Main Objective &amp; Domain</th>
<th>Description</th>
<th>Formula to compute the KPI value</th>
<th>Reporting Period</th>
<th>Relevant Standards</th>
<th>Explanation of the Link with High-level KPI</th>
<th>Reporting Audience and Access Rights</th>
</tr>
</thead>
<tbody>
<tr>
<td>[Main objective related of the storage demonstration function &amp; domain of storage application]</td>
<td>[Brief description of the KPI]</td>
<td>[Formula to compute the KPI value]</td>
<td>[Describe here the reporting period of the KPI, e.g. daily, monthly]</td>
<td>[Describe how this KPI measures directly or indirectly the high-level KPI defined in the SENSIBLE project]</td>
<td>[Options: Public, SENSIBLE Partners, EC, Regulators, Other (please specify)]</td>
<td></td>
</tr>
</tbody>
</table>

### KPI CALCULATION METHODOLOGY

<table>
<thead>
<tr>
<th>KPI Step #</th>
<th>Step description (max 50 words)</th>
<th>Responsible</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>...</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## KPI Data Collection

<table>
<thead>
<tr>
<th>Data ID</th>
<th>Type of data</th>
<th>Source/Tools/Devices for Data collection</th>
<th>Frequency of Data Collection</th>
<th>Location of Data Collection</th>
<th>Data collection responsible</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1 [Description/Name]</td>
<td>[Identify the device, database or source for data collection]</td>
<td>Indicate how often, when and for how long data is collected</td>
<td>Where is data measured / located?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>…</td>
<td>…</td>
<td>…</td>
<td>…</td>
<td>…</td>
<td></td>
</tr>
</tbody>
</table>

## KPI Business As Usual (BAU) Scenario

<table>
<thead>
<tr>
<th>Source of BAU or Baseline Values</th>
<th>Simulated Values</th>
<th>Literature Values</th>
<th>Historical Data</th>
<th>Data collected During Demonstration</th>
</tr>
</thead>
<tbody>
<tr>
<td>[Describe how the BAU is calculated or estimated]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Details of BAU or Baseline Calculation</th>
<th></th>
</tr>
</thead>
</table>

| Responsible for Baseline | [Name, Company] |

## General Comments