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Economic and Monetary Affairs

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Energy Storage: Which Market Designs and Regulatory Incentives Are Needed?

Study for the ITRE Committee



DIRECTORATE GENERAL FOR INTERNAL POLICIES
POLICY DEPARTMENT A: ECONOMIC AND SCIENTIFIC POLICY

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STUDY

Abstract

This study analyses the current status and potential of energy storage in the European Union. It aims at suggesting what market designs and regulatory changes could foster further cost reduction and further deployment of energy storage technologies to provide services supporting the Energy Union strategy. This study was prepared by Policy Department A at the request of the Committee on Industry, Research and Energy Committee (ITRE).

This document was requested by the European Parliament's Committee on Industry, Research and Energy (ITRE).

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LIST OF ABBREVIATIONS

ACER	Agency for the Cooperation of Energy Regulators
BEV	Battery Electric Vehicles
CAES	Compressed Air Energy Storage
CEER	Council of European Energy Regulators
CHP	Combined Heat and Power
CRM	Capacity Remuneration Mechanism
CSP	Concentrated Solar Power
DLC	Double Layer Capacitor
DSO	Distribution System Operators
EC	European Commission
EED	Energy Efficiency Directive
ENTSO-E	European Network of Transmission System Operators for Electricity
ENTSO-G	European Network of Transmission System Operators for Gas
EPBD	Energy Performance of Buildings Directive
ESS	Energy Storage System
EU	European Union
EU ETS	EU Emissions Trading System
FES	Flywheel Electrical Storage
GHG	Greenhouse gases
GW	gigawatt
GWh	gigawatt hour
h	Hour
H2	Hydrogen Storage

ICT	Information and Communication Technologies
IEA	International Energy Agency
IEC	International Electro-technical Commission
in dev.	in development
IPCC	Intergovernmental Panel on Climate Change
kW	Kilowatt
kWh	kilowatt hour
LA or Pb	Lead Acid (battery)
LCOE	Levelised Cost of Energy Storage
LIB	Lithium-Ion battery
LiS	Lithium Sulfur (battery)
Me-Air	Metal-Air (battery)
Min	Minute
MW	Megawatt
MWh	Megawatt hour
n.a.	not available
NaNiCl	Sodium Nickel Chloride
NaS	Sodium Sulphur Batteries
NiCd	Nickel-Cadmium Battery
NiMH	Nickel-Metal Hydride Battery
PCI	Projects of Common Interest
PCM	Phase Change Materials
PIP	Priority Interconnection Plan
PEV	Plug-in Electric Vehicle

PHS	Pumped Hydro Energy Storage
PHEV	Plug-in Hybrid Electric Vehicle
PV	Photovoltaic
RED	Renewable Energy Directive
REEV	Range-Extended Electric Vehicle
REMIT	Regulation on wholesale energy market integrity and transparency
RES	Renewable Energy Sources
RFB	Redox Flow Batteries
R&D	Research and Development
sec	Second
SMES	Superconducting Magnetic Energy Storage
SNG	Synthetic Natural Gas
SSO	Storage System Operators
TEN-E	Trans-European Energy Networks
TES	Thermal Energy Storage
TSO	Transmission System Operator

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EXECUTIVE SUMMARY

Background

Energy storage may improve the security of energy supply and contribute to balancing the European energy system. Gas storage plays an important role to provide energy security, especially in regions with larger dependency on gas imports. Profitability and utilisation levels of gas storage facilities are barriers to deal with in these regions, especially in supply crisis times. The electricity system will require more flexibility if higher shares of renewable energy are integrated. Energy storage is one of the available flexibility options. Flexibility represents the extent to which an energy system can adapt supply and demand to maintain system stability in a cost-effective manner.

Energy storage can effectively contribute to the objectives of the Energy Union (security of supply, energy efficiency, decarbonisation of the economy, research innovation and competitiveness). However, it is treated very differently in EU regulation. While the European Gas Directive explicitly mentions storage as one core element of the gas distribution system, the Electricity Directive does not mention storage. This lack of clarity has resulted in some Member States applying double grid fees to electricity stored by pumped hydro facilities, for example. On the side of decentralised storage, expected cost reductions for solar panels combined with energy storage can enable self-production of electricity in households and businesses. At present there is no common EU regulatory approach towards this situation. Issues like net metering, feed-in tariffs and self-production and consumption are entirely regulated at Member State level.

To fully unleash the potential of energy storage, technological developments need to be complemented with coherent policies and market design.

Aim

This study aims at suggesting what market designs and regulatory changes could foster further cost reduction and further deployment of energy storage technologies for the provision of services supporting the Energy Union strategy.

Promising fields of further development

A wide range of energy storage technologies exists. Few of them are market mature or nearly mature, others are still too expensive. R&D efforts in technologies like heat pumps and storage heaters could provide a high degree of load shifting flexibility. Energy storage facilitates the deployment of smart grids, integration of renewable generation and electromobility in the networks. It also assists the transition towards an energy system where end-users can provide flexibility to the system, either with stationary batteries coupled with their own self-production generation units, or using vehicle-to-grid as a second application of their vehicle batteries.

Conclusions and policy recommendations

Six policy recommendations, each associated with one conclusion is proposed for implementation in the EU, in case it is concluded that further support for energy storage is desired to help achieving the ambitions of the Energy Union.

1. R&D to achieve competitiveness

Industrial production of novel and improved energy storage technologies is marginal in Europe compared to the activities and rapid developments in the United States and Asia. However, Europe can still play a role in the rapidly expanding markets for tools, products and services for integrating storage into electricity networks and at end-users. If the choice

of energy storage is made, the EU and its Member States should stimulate and invest more in R&D activities and product development of cost competitive storage solutions for those services that are in line with the Energy Union's strategy. These efforts should be accompanied with the development of competitive industrial structures in storage production. The R&D strategy of Europe should also facilitate smart grid and smart city developments, also incorporating smart vehicle charging and vehicle-to-grid technologies (smart mobility).

2. Barriers to gas storage

Present gas storage capacity seems sufficient in most EU Member States. However, Member States with greater dependency on gas imports from outside the EU face security concerns. Profitability of gas storage facilities, actual utilisation and access in times of crises are barriers to address when increasing gas storage capacities in those Member States. Cross-border use of gas storage capacities between Member States should be intensified, especially in emergency supply situations. It is recommended to remove regulation barriers hindering new gas storage capacity, especially in regions vulnerable to lack of supply. Regulation should be made more specific in relation to required strategic stock levels, interconnection capacity and local production.

3. Storage for renewable energy producers

Energy storage associated with centralised renewable energy production could effectively contribute to system adequacy. Recent Member State rules (EC 2014/C 200/01) stipulate that generators receiving state aid should at least adhere to standard balancing requirements. There are several options to provide incentives to larger renewable energy producers to realise a more balanced feed into the grid. For instance, the Europe Infrastructure Package contains an exemption of Pumped Hydro Storage (PHS) from its financing provision, which could be reevaluated. A common approach at EU level for such incentives should be assessed and could be combined with existing grid priority rules. The merit order mechanism could also be reviewed to assess possible modifications to support this direction, for instance by reinforcing price signals through scarcity pricing.

4. Flexibility markets

Energy storage and other flexibility options allow larger shares of intermittent renewables with low marginal costs fed into the system. This potentially leads to lower wholesale prices. However, the current Electricity Directive¹ does not mention storage. Flexibility markets should be designed to be technology neutral. In this way energy storage and other flexibility options would have the chance to compete against flexible fossil-fuel based generation units. It is recommended that the new energy market design announced in the Energy Union Summer package (EC, 2015c) and the upcoming revision of the Electricity Directive (EC, 2015c) acknowledge the multiple services that energy storage can provide.

5. Ownership and control of storage by grid operators

Energy storage is an alternative to provide more stability, reliability and resilience to transmission and distribution grids. The use of storage by grid operators is, however, limited at present because unbundling requirements do not allow transmission and distribution operators to directly own or control energy storage infrastructure. These disadvantages could also hamper the use of electric vehicles as storage for grid services or in combination with smart grids. It is recommended to clarify the position of storage in different steps of the electricity value chain and allow transmission and grid operators

¹ Directive 2009/72/EC concerning common rules for the internal market in electricity.

invest, use and exploit energy storage services for purposes of grid balancing and other ancillary services.

6. Storage and end-users

Energy storage could well become a common household appliance in the future. Batteries and thermal storage options such as power-to-heat and heat pumps in combination with solar power systems are quickly becoming an economically attractive option for households and small businesses. In September 2015, US Company Tesla has started shipping its firsts 7 kWh Lithium-Ion (LIB) home batteries (Powerwall) to fulfil more than 100,000 reservations made by US clients at a retail price of 3,000 USD. Different household and industrial product versions of Tesla's LIB batteries are already sold out through 2016. In Germany, the price of power from a combined solar and storage system is expected to drop below the retail price of grid electricity by 2016. Phase Change Materials (PCM) technologies also show promising developments. These developments may also lead to less desirable effects. Large numbers of end-users turning to self-production and local storage could result in load defection or even grid defection, seriously affecting the revenue models of network operators and traditional power generators. It is recommended that the European Commission gives guidance to Member States on how to adapt support schemes in such a way that energy storage at end-user level is stimulated in a harmonised way across the EU. Policy impact assessments should also be performed to explore the implications of 'grid parity' of combined self-production and storage, the possible modifications to the regulatory and tariff frameworks to anticipate effects of load defection, and the risks of mass grid defection.

1. INTRODUCTION

The energy markets in Europe are not yet fully integrated into a single market. However, all the different energy markets in Europe share some common issues. Among those, strong concern exists for:

- the security of gas supply from abroad; and,
- the suitability of the current design of the EU electricity system and the capacity available to handle the increasing intermittency of renewable energy.

Energy storage in all its forms adds buffers to the gas and electricity systems contributing to energy security, reliability and resilience. Gas storage plays an important role in providing energy security, especially in regions with greater dependency on gas imports. Profitability and utilisation levels of gas storage facilities are barriers to address when increasing gas storage capacities for these regions. The electricity system will require more flexibility if higher shares of renewable energy are integrated. Flexibility basically represents the extent to which an energy system can adjust supply and demand to maintain system stability in a cost-effective manner. Electricity storage, next to demand side management, grid interconnections and new flexible power generation units, are the flexibility options available to the system.

On 25 February 2015, the European Commission published its Communication COM (2015) 80 final on the Energy Union Package (EC, 2015a). The Energy Union aims for a single energy market to ensure affordable, secure, competitive and sustainable energy for Europe and its citizens. The Energy Union strategy has five mutually-reinforcing and closely interrelated dimensions:

1. Energy security, solidarity and trust;
2. A fully integrated European energy market;
3. Energy efficiency contributing to moderation of demand;
4. Decarbonising the economy; and,
5. Research, Innovation and competitiveness.

Energy storage offers valuable services to all these five dimensions. The introduction of energy storage may improve the security of energy supply and may contribute to balancing the energy system. Energy storage, same as other flexibility options, can contribute to deferring infrastructure investments in the gas and electricity systems, and even, in certain cases, eliminate the need of them.

"I believe [if] we find ways of generating and storing power from renewable resources we will make the problem with oil and coal disappear, because economically, we'll wish to use these other methods. If we do that, a huge step will be taken in solving the problems of the Earth." – Naturalist Sir David Attenborough, interviewed by US President Barack Obama in June 2015².

A wide range of energy storage technologies exists; some of which can be implemented to provide multiple services, but no single technology is suitable for all applications. Technologies for energy storage are diverse and range from bulk storage such as gas storage, pumped hydro storage and compressed air storage to short-term storage such as flywheels, many types of batteries and electrochemical capacitors.

A few energy storage technologies are market mature or nearly mature, but others are still too expensive. Most of the energy storage options that are not yet market mature are

² <https://www.youtube.com/watch?v=NZtJ2ZGyvBI>.

already technology mature. In many cases, the competitiveness of energy storage is affected due to lower cost of non-storage technologies. With exception of pumped hydro storage (PHS), energy storage technologies still require additional support to keep reducing their costs until their potential can be fully realised.

Energy storage can be coupled with so-called Capacity Remuneration Mechanisms (CRMs) applied to electricity markets. This option is actively discussed in today's energy markets, driven by the perceived need to support flexibility as well as to secure electricity supply in markets with growing shares of renewables. CRMs provide incentives for new capacity investments and for keeping existing capacity in the electricity markets. Capacity markets are one type of CRM. The right combination of CRMs and flexibility options, like energy storage, could effectively help system stability and long term competitiveness of energy prices.

This study analyses the current status and potential of energy storage in the European Union. It provides suggestions on what market designs and regulatory incentives could foster further cost reductions and further deployment of energy storage technologies for the provision of services supporting the Energy Union strategy.

Chapter 2 gives an overview of the value of energy storage in general and for the EU in particular, a description of services that energy storage can provide together with a description of their associated technologies. Chapter 3 analyses the role of energy storage in the EU in the past, present and future. It discusses how current policies affect the deployment of storage and what barriers currently exist for it. Chapter 4 assesses the potential contribution of energy storage to the objectives of the Energy Union's strategy. Chapter 5 describes the state of play of R&D in the EU and the potential of smart grids and electro-mobility as promising fields for the further development of storage in the EU energy system. Chapter 6 summarises all the key findings of this report in six overall conclusions and relates them to their impacts on the energy value chain and to the five dimensions of the Energy Union strategy. Six policy recommendations associated with these conclusions are proposed for implementation, in case it is concluded that further support for energy storage is desired to help achieve the ambitions of the Energy Union.

2. OVERVIEW

KEY FINDINGS

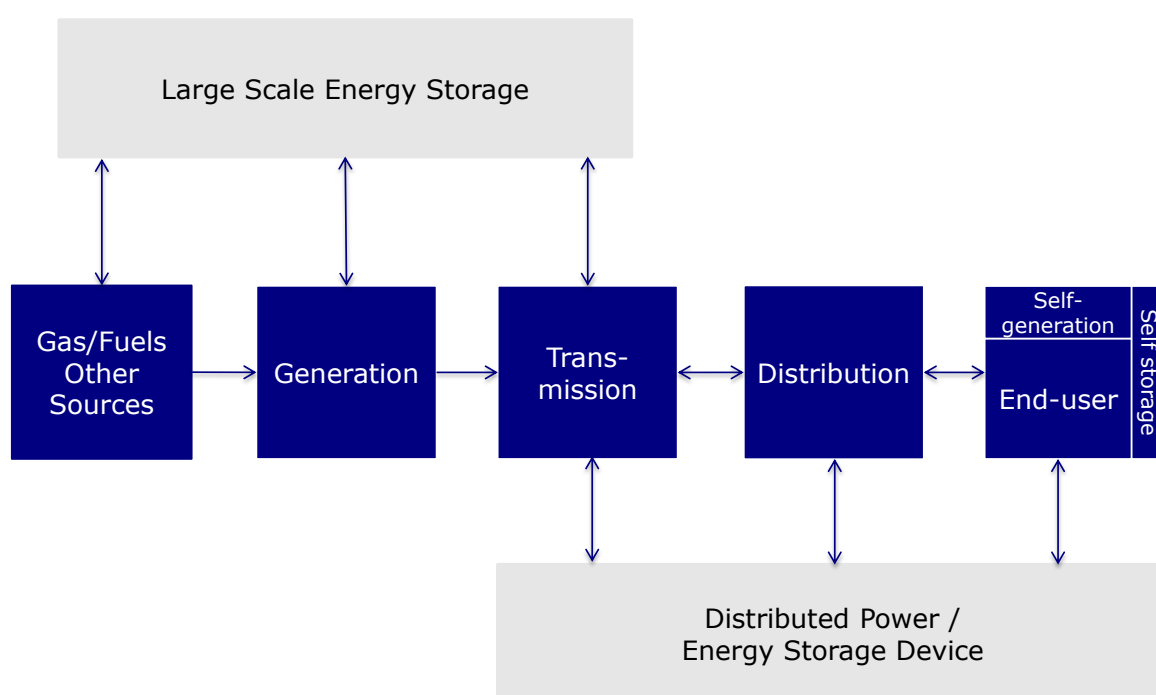
- Energy storage enables better management of intermittent gas or electricity supply and its value lies in the types of services it can provide.
- Energy storage technologies include a large set of centralised and distributed designs of different size ranges that are capable of supplying an array of services to energy systems to increase their flexibility.
- The use of energy storage services can make possible the deferral or reduction of investments in infrastructure for energy supply, production, transmission and distribution. Energy storage also facilitates arbitrage opportunities for gas and electricity.
- Services provided by energy storage can effectively support the five dimensions of the Energy Union strategy.

2.1. The Value of Energy Storage

Q 1: What is energy storage?

Energy can be temporarily stored with help of different technologies before releasing it to supply energy or power services. Depending on the technology used and the desired effect, energy can be stored from fractions of a second to months. Energy storage can be applied to all steps of the energy value chain (see Figure 1). Energy storage allows for decoupling of energy supply and demand, and can be used to bridge temporal and geographical gaps between them. By bridging these gaps, energy storage decisively helps to realise more integrated, optimised and flexible energy systems.

Figure 1: Energy storage in the energy value chain



Source: Adapted from (Makansi, 2008).

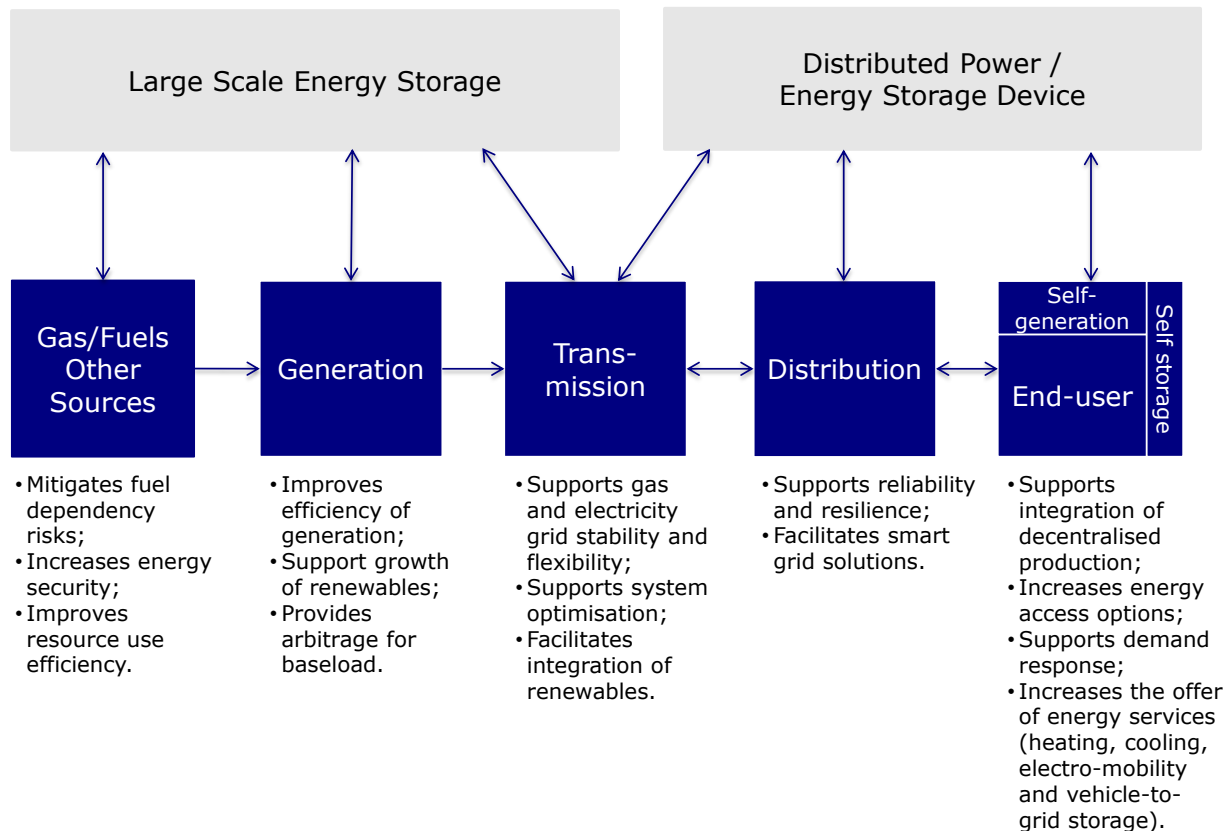
Figure 1 illustrates that large-scale and distributed storage form a new dimension in the energy value chain. The versatility of energy storage becomes clear as it can be used by producers, grid operators and end-users.

Q 2: What is the value of energy storage?

Energy storage enables better management of intermittent gas or electricity supply and its value lies in the types of services it can provide.

Energy storage can add value in each step of the energy value chain as shown in Figure 2.

Figure 2: Value of storage in each step of the energy value chain

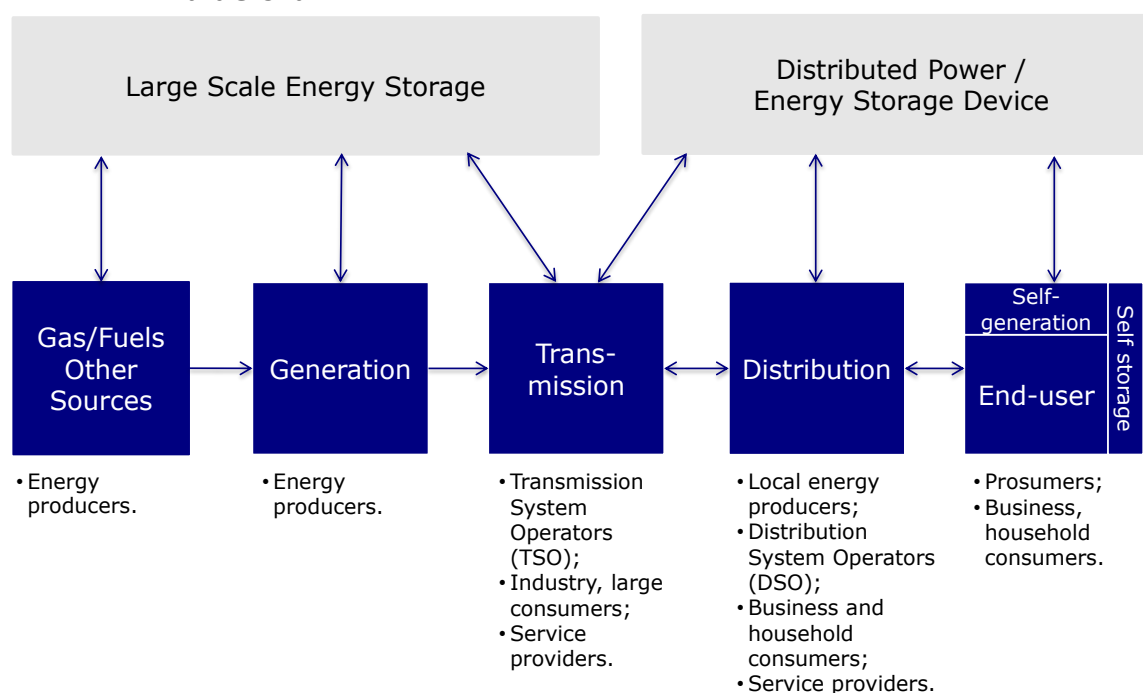


Source: Authors.

The deployment of energy storage can defer (or potentially avoid) investments such as new gas supply routes, new power generation capacity or the upgrade of transmission and distribution electricity grids. Energy storage also facilitates arbitrage opportunities for gas and electricity. Arbitrage refers to energy storage during low demand periods and low prices, so that the stored energy can be sold during high demand periods for a profit.

Different actors, each with different roles, can benefit from the services that energy storage can provide. Figure 3 shows their position in the energy value chain.

Energy storage may add some loss of efficiency to the system compared to direct use of energy. However, if it is deployed, it is because it adds flexibility and improves the reliability of supply. This is specially the case for electricity systems.

Figure 3: Actors that benefit from storage services along the energy value chain

Source: Authors.

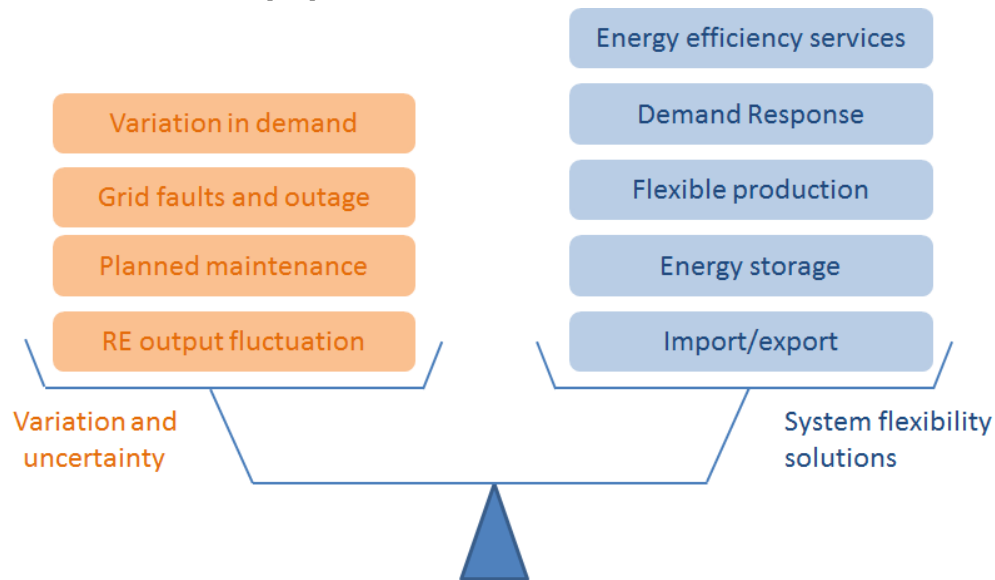
Q 3: How does energy storage add flexibility to the EU electricity system?

Flexibility is the ability to maintain continuous service in the face of rapid and wide swings in supply or demand. Flexibility improves the system adequacy and capacity adequacy of energy systems. System adequacy and capacity adequacy define the strength of an energy system in, respectively, the short term and the longer term. System adequacy refers to the ability of the energy system to meet the aggregate demand of all consumers at virtually all times. Capacity adequacy is the long-term ability of the energy system to match demand and supply. In other words, capacity adequacy is the ability of the system to ensure that sufficient investments are made such that demand and supply can also be balanced in the longer term. In short, flexibility represents the extent to which an energy system can adapt supply and demand as needed to maintain system stability in a cost-effective manner.

The European Union (EU) is transitioning from a centralised, fossil-based energy supply towards a more decentralised system with a higher share of renewable energy. Households and communities are also gaining more relevance as they may self-produce part of their own energy needs. As a result, it is expected that supply and demand balance in the EU electricity system will become increasingly challenging and more flexibility options will be needed.

Figure 4 shows the challenges to system balancing and the flexibility options available to mitigate these challenges.

The value of energy storage as flexibility option in the EU electricity system needs to be assessed under a double uncertainty: uncertainty concerning the direction, cost and timing of innovations in storage technologies, as well as uncertainty concerning the changes in generation, demand and grid flexibility needs. Technology choices and scale for energy storage in Europe will depend on whether the EU moves mainly towards a 'European-wide energy superhighways' system, or if it evolves towards a system of rising local energy autonomy, featured also by widespread demand side management and smart grids. In both system designs, storage can make a contribution to increase the system's flexibility.

Figure 4: Challenges to system balancing and options to increase flexibility in the electricity system

Source: Authors.

Q 4: At what percentage of renewable energy share is energy storage needed in an electricity system?

Energy storage should be considered a facilitator rather than a requisite for renewable energy growth and integration. There is no single and precise answer to the need for storage once a certain share of intermittent renewable energy has been reached in an electricity system. Estimates for the need on energy storage range from 20% to beyond 60% of renewable energy share (DLR, 2012), (BET, 2013), (Borden, 2014), (IRENA, 2015a), (Martinot, 2015a), (Martinot, 2015b), (Martinot, 2015c).

The key issue though, is how to ensure the balancing of the system at all times. The extent to which balancing can be done largely without energy storage depends on the grid design, quality of the grid, size of the system, technologies used in power generation, the capacity of interconnections with other systems, the way markets are operated, the level of demand side management and the international cooperation with neighbouring systems. For an island system, the need of energy storage is more pressing than for a large and well-integrated market (such as the Central Western Europe region, comprising Belgium, France, Germany/Austria and the Netherlands).

Several other flexibility options are in competition with energy storage to provide required balancing services. These other flexibility options are readily available now, and in most cases, at lower cost. When energy storage is also economically viable, it increases its competitiveness. Regulatory incentives and market design can help energy storage technologies to develop further and become more competitive.

Q 5: How can foreign energy policy impact EU decisions on storage?

Political dynamics have a much stronger impact on gas storage than on electricity storage, as there exist import dependencies on gas between states. Russia is the largest supplier of crude oil, natural gas and solid fuels for the EU Member States. Russia's share of EU-28 imports of natural gas has reached a share of 39.3% in 2013 (Eurostat, 2015). Together with Norway, they supply more than two thirds (69.1%) of the gas imports. In general, EU-28 dependency on energy imports rose from less than 40% of gross energy consumption in the 1980s to 53.2% by 2013 (Eurostat, 2015). Countries that depend on imported gas

supply use gas storage to build up stocks and maintain energy security. If gas supply is stopped, gas storage is then a tool for reducing the dependency. However, this purpose of using gas storage is limited because it cannot replace a diversified supply strategy (CEER, 2013).

2.2. Services

Q 6: What services and applications are provided by energy storage?

Energy storage services can broadly be classified into five types: bulk energy, renewables integration, ancillary, transmission and distribution, and customer energy management. All these services, either alone or combined, are design elements for flexibility options that are valuable to the European energy system.

Bulk energy services provide large-scale and, often, long-duration storage. At the bulk scale, energy storage can be seasonal, ranging from days to months. Bulk energy services exist for electricity and gas storage and can be used to increase security of supply in general (gas storage) and overall grid capacity (capacity adequacy). Bulk energy services can also be used for price arbitrage.

Renewables and other integration services can be used in conjunction with intermittent renewable energy sources (like wind or solar) to address and compensate intermittency in their energy or power output (system adequacy). Waste heat utilisation belongs to this type of service as well.

Ancillary services from energy storage can be provided by delivering power for short durations (from a fraction of a second to minutes) relative to bulk services. Some key ancillary services are: frequency regulation, load following, voltage support in the transmission and distribution systems, black start, spinning reserve, and non-spinning reserve.

Transmission and distribution services help defer the need for capital-intensive transmission and distribution upgrades or investments to relieve temporary congestion in the network. This is achieved by temporarily addressing congestion in the network and, in this way, mitigating substation overload.

Customer energy management services may be provided by storage systems of smaller capacity than the ones required for other type of services. These systems are generally located at the end of the distribution network or off-grid. For customers connected to the grid, these services include demand shifting and peak reduction. Electric vehicles are within this service type. These services may indirectly help the integration of more renewable energy as well. For off-grid customers, these services ensure more reliable power supply from locally-available fossil or renewable energy resources.

Applications of energy storage are associated with the services they provide. A clear allocation is not always possible, as storage systems are often used for multiple purposes. A tentative classification of is shown in Table 1 and further explained in Annex 1.

Table 1: Specific applications of energy storage

Service type	Service application	Contribution to Energy Union
Bulk energy storage	<ul style="list-style-type: none"> Central gas storage; Central electricity storage facilities; Seasonal storage for electricity or heat. 	<ul style="list-style-type: none"> Security, solidarity & trust; Market integration.
Renewables and other integration	<ul style="list-style-type: none"> Variable supply resource integration; Waste heat utilisation; Support Combined Heat and Power (CHP) plants; Power-to-Gas and Power-to-Heat; Supply of the transport sector with hydrogen and electricity by renewable energy sources; Charging stations for electric vehicles. 	<ul style="list-style-type: none"> Decarbonisation; Market integration; Energy efficiency; Security, solidarity & trust.
Ancillary	<ul style="list-style-type: none"> Frequency regulation; Load following; Voltage support; Black start; Spinning reserve; Non-spinning reserve. 	<ul style="list-style-type: none"> Decarbonisation; Market integration; Security, solidarity & trust.
Transmission and distribution	<ul style="list-style-type: none"> Transmission and distribution congestion relief; Supporting infrastructure for overhead cable for buses, trains or trams; Uninterruptible power supply. 	<ul style="list-style-type: none"> Market integration; Security, solidarity & trust; Decarbonisation.
Customer energy management	<ul style="list-style-type: none"> Demand response and peak reduction; Integration of electric vehicles in the system; Enabling self-sufficiency of a single building or a small local grid (off-grid); Maximising electricity self-production and consumption. 	<ul style="list-style-type: none"> Decarbonisation; Security, solidarity & trust; Energy efficiency.

Source: Authors.

2.3. Technologies

2.3.1. Classification and Relation to Services

Q 7: How do storage technologies relate to different types of services?

The types of services that storage can provide depend on both the level of application and the characteristics of the storage asset. As shown in Figure 1, storage assets can be deployed at the centralised generation and transmission level (large-scale centralised storage), down to distribution and residential or local level (decentralised, local storage).

The five service types, clustered and defined in section 2.2, require technology solutions that are typically characterised by their ability to store or provide energy (kWh) or to provide power (kW) over a certain time period (h). Table 2 relates services and these regimes to suitable technologies. It is shown that there is not a one-to-one relationship of services to technologies, but technologies mostly compete in certain storage size classes.

Storage technologies are thus categorised by size, starting with large size storage technologies. In Figure 5, storage technologies are compared to each other in more detail with respect to energy content, power and typical charge/discharge times.

Table 2: Service types and relation to technologies

Service type	Characteristics ³
Bulk energy storage	Size: Large scale (>>MW to >GW; 100MWh to 100GWh regimes) Discharge time: days to months Technology: Gas, SNG, Hydrogen, PHS, CAES, Redox Flow Batteries
Renewables and other integration	Size: Mid to large scale (~100kW to ~100MW; 100kWh to 100MWh regime) Discharge time: minutes to several hours or 1 day Technology: Batteries (LIB, Pb Acid, RFB, NaS, NaNiCl), hydrogen, gas, PHS, (CHP)
Ancillary	Size: Small to large scale (>10kW to 100MW; 0,1kWh to >MWh regime) Discharge time: less than seconds to minutes or hours (max 1 day) Technology: DLC, SMES, FES, Batteries (e.g. Lead acid, LIB), hydrogen, gas
Transmission and distribution	Size: Mid to Large scale (MW to ~100MW; >kWh to 100 MWh regime) Discharge time: minutes to hours Technology: Batteries (LIB, RFB), large Flywheel, SMES, small CAES, PHS
Customer energy management	Size: Small or mid-scale and off- or on-grid (kW to MW; kWh to MWh regime) Discharge time: minutes to hours Technology: Batteries (LIB, Pb Acid, RFB, NaS, NaNiCl), gas, hydrogen (μCHP)

Source: Authors.

- **Large-scale** central pumped hydro energy storage (PHS⁴) is traditionally the grid connected storage option that is mostly used. In addition to PHS, compressed air energy storage (CAES⁵) as well as central gas storage (natural gas⁶, synthetic natural gas - SNG⁷), hydrogen⁸ (H₂, chemical storage) or even batteries (e.g. Redox Flow Batteries - RFB) can be suitable solutions for bulk energy storage services depending on the concrete application.

³ For abbreviations, please refer to the list of abbreviations after the table of contents.

⁴ PHS: During periods of low electricity demand and/or prices, water is pumped from a lower level reservoir to an upper reservoir. During periods of high electricity demand and/or prices, the water is released to generate and sell the electricity.

⁵ CAES is another large-scale storage option where, during low price periods, the compressed air is injected into subterranean caverns or porous rock layers and, during high price periods, the air is released to drive a generator to produce electricity.

⁶ Natural Gas (NG) is a hydrocarbon gas mixture consisting primarily of methane and can be stored for an arbitrary long period of time in natural gas storage facilities for later consumption. It can be prepared/converted e.g. as compressed (CNG) or liquefied (LNG) natural gas. This increases the volumetric energy density (up to 600 times) making the transport of gas more economic.

⁷ SNG is a fuel gas which can be produced from fossil fuels (e.g. lignite coal, oil shale), bio-fuels (bio-SNG) or renewable electrical energy (Power-to-Gas).

⁸ Hydrogen generation is done e.g. by steam reforming, landfill gas or electrolysis (Power-to-Gas). Storage mechanisms are e.g. compressing hydrogen, liquefying hydrogen, chemically – e.g. metal hydrates or physically – e.g. cryo-compressed.

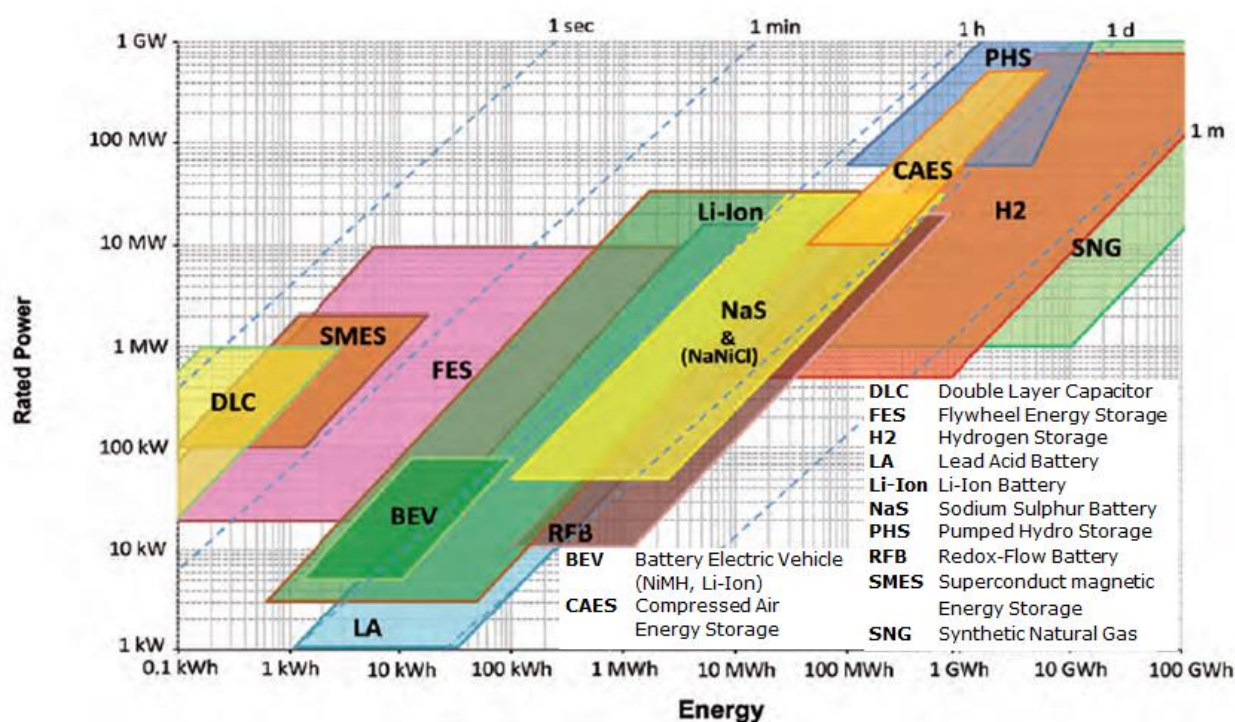
- **Small to large-scale** batteries (electrochemical storage) are currently the next biggest category of storage technologies and can be technologically feasible for all the energy storage service types, depending on the electrochemical system. The broader application portfolio for batteries is expected to unfold beginning on the local level and distribution grid level with decentralised small to mid-scale applications and then expanding to larger scale services (EUROBAT, 2013), (Thielmann et al, 2015). For illustration, the market for PV-battery systems in private households in Germany has been ca. 10.000 in 2013/2014 and it is expected to grow to 40.000 sold systems by 2016. However, bulk storage technologies and flexible generation units are still the most economic solutions for large scale applications and for services related to the transmission grid.

Lithium-Ion Batteries (LIB) are currently considered the most attractive battery system due to their comparably higher energy density, efficiency and lifetime (especially cycle life) together with higher cost reduction potentials. Lead acid batteries (LA or Pb-Batteries) have the advantage of lower investment costs but have higher mass and lower cycle life. They are used alternatively to LIB in PV-batteries for household systems. LIB are expected to be cost competitive as compared to LA by 2020 (Schlick et al, 2012) since their increasing demand for battery electric vehicles (BEV) is triggering mass production and consequent costs reductions. LIB cell manufacturers are mainly in Asia (e.g. Panasonic in Japan or Samsung SDI and LG Chem in South Korea). European providers of stationary storage systems, especially in Germany (partly also from automotive industries – e.g. Daimler/Deutsche Accumotive), are currently positioning themselves in the market of LIB PV-battery household systems.

Sodium sulphur batteries (NaS) as well as Sodium Nickel Chloride (NaNiCl) batteries have the disadvantage of high working temperatures (around 270-350 °C) leading to high thermal management efforts which limits their applicability. Worldwide, the company NGK (Japan) is dominating the market for NaS batteries today. In future, low temperature NaS batteries might be developed but they are still in R&D phase (Wen et al, 2012).

Redox flow batteries (RFB) have the advantage of unlimited longevity due to their attractive refuelling concept, although the long-term stability is still an issue for research. Comparably they have lower energy density than LIB and more complicated electronics. RFB are thus rather suitable for larger scale installations, where the effort for maintenance is better justified. There are only a few companies worldwide offering RFB to the market (active in Europe, e.g. Gildemeister AG in Germany, formerly Cellstrom GmbH in Austria).

- **Small to mid-scale** (energy content) storage: Flywheel electrical storage (FES, mechanical storage), double layer capacitors (DLC electrical storage) or super-capacitors and superconducting magnetic energy storage (SMES, electrical storage) have the advantage of providing high power in very short time. The energy content is comparably low as compared to batteries or the large chemical and mechanical storage technologies. In contrast to low energy content, these technologies have a unique advantage for applications such as uninterruptible power supply or grid stabilisation at the distribution grid and at customer side, whenever power is needed for a short time but with instantaneous, immediate demand.

Figure 5: Comparison of rated power, energy content and charge/discharge time for different storage technologies

Source: (IEC, 2012).

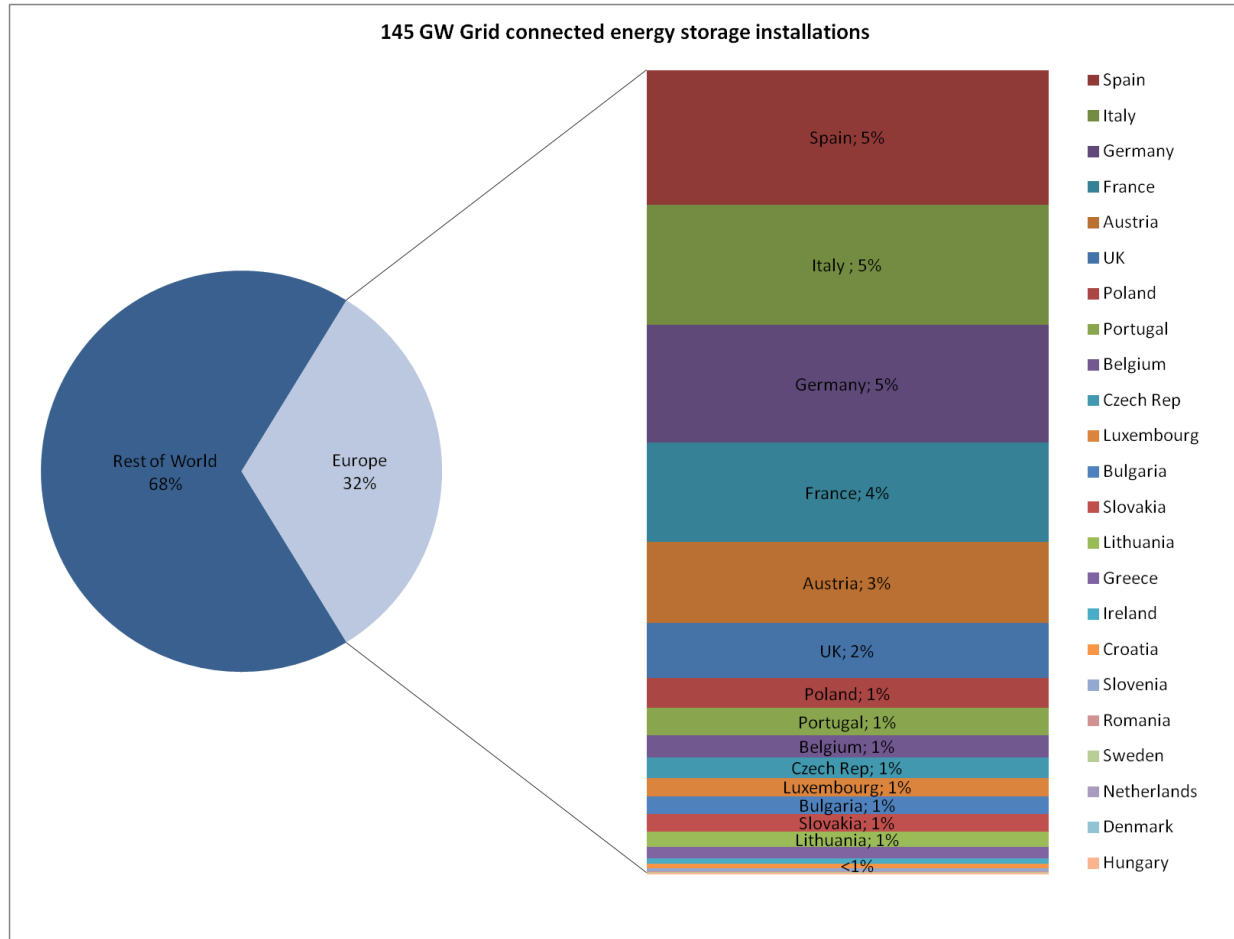
Table 7 in Annex 1 shows core technological parameters of different storage technologies with their status as of today.

2.3.2. Development and Costs in the EU

Q 8: Which technologies are well established and which ones are expected to play a role in future EU energy systems?

At present, the installed energy storage capacity connected to the grid in Europe is higher than 50 GW. Around 95% of this storage capacity is based on PHS installations. Worldwide, the situation is similar with around 98% of the capacity based on PHS. Globally, PHS capacity has grown at a pace of 2.7% in recent years to 145 GW today. The share of energy storage systems other than PHS has grown from below 1% in 2005 to more than 1.5% in 2010 and 2.5% in 2015 (a more than 10% growth rate) (IEA, 2015b), (DOE, 2015).

Figure 6 shows the current share of installed storage capacity in the EU and in individual Member States.

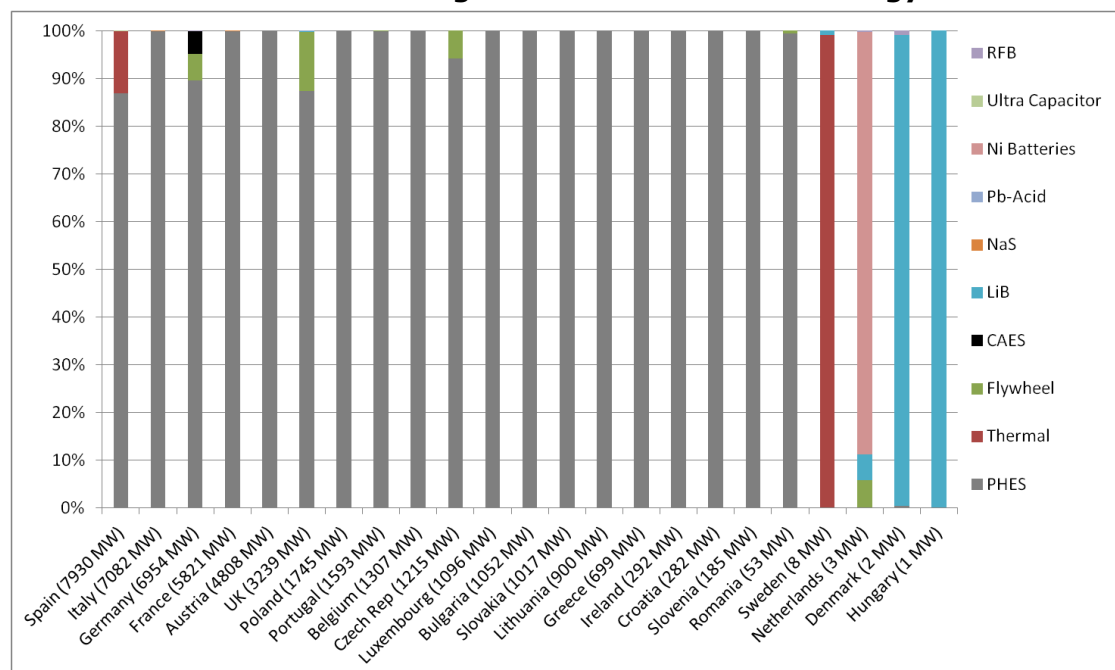
Figure 6: Share of EU and Member States grid connected storage installations.

Source: (DOE, 2015).

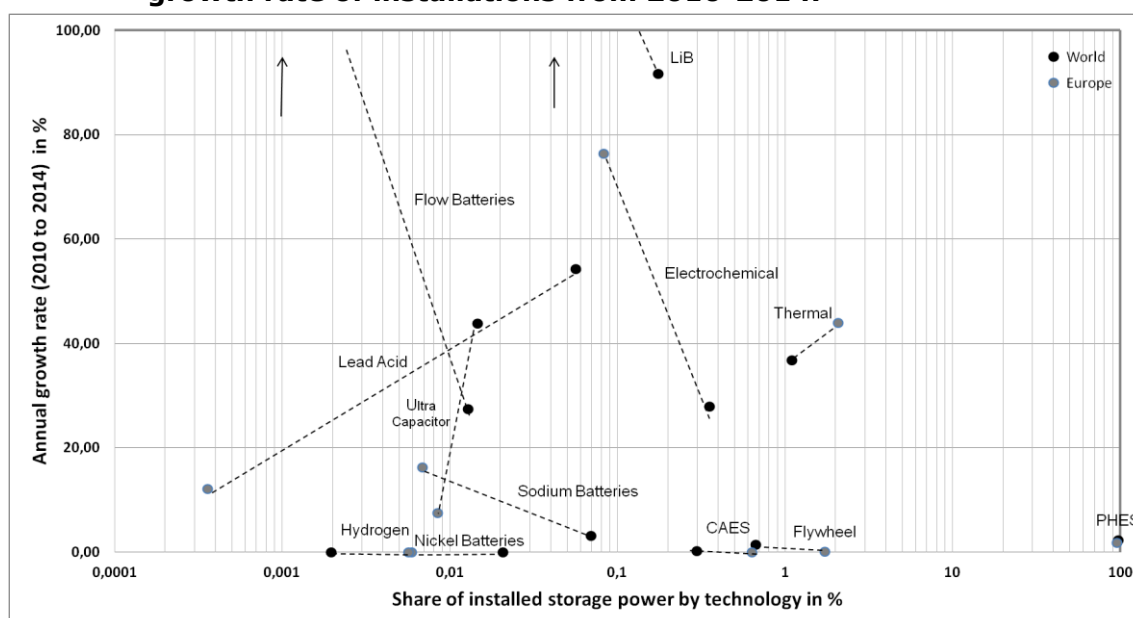
Figure 7 shows the technology portfolio by size and share for different EU Member States. Figure 8 shows the European wide (grey) and worldwide (black) share of installed grid-connected energy storage power by technology vs. the growth rate of new installations in the last 5 years. PHS is dominating but growth rates are higher for other technologies.

In Europe, electrochemical and thermal storage technologies as grid-connected storage technologies are currently growing in importance compared to worldwide developments. The reason for the growth of thermal storage (e.g. molten salts) is the connection to Concentrated Solar Power (CSP) plants, especially in Spain. A reason for the particular growth of LIB and RFB compared to other battery technologies is the very high potential for technology improvement and cost reduction. Other batteries and capacitors show high growth rates, but the share of these technologies in the European energy storage portfolio is lower. Growth rates for CAES and Flywheel storage are low.

Bulk storage like PHS and also natural gas storage can cover the demand for seasonal variations, but are not suitable solutions for the increasing role of fluctuating renewable energies (wind and solar). Certain battery systems could meet some of these needs as soon as technologies get mature and their costs decline sufficiently.

Figure 7: Grid connected storage installations and technology share in the EU.

Source: (DOE, 2015).

Figure 8: Share of installed grid connected energy storage by 2014 vs. annual growth rate of installations from 2010-2014.

Source: (DOE, 2015).

Q 9: What is the cost of energy storage?

Besides the investment cost in terms of power (€/kW) and energy (€/kWh), the use over the lifetime (cycle and calendar lifetime) also has to be taken into account to determine which storage technologies are most suited for each application. The most suitable indicator to compare the different storage technologies is the levelised cost of energy storage⁹ (LCOE in €/kWh) which includes investment and use over full lifetime (e.g. costs for balance of plant, power conversion, operation and maintenance, replacement, recycling,

⁹ For LCOE definitions see e.g. (Fraunhofer ISE, 2013) or (Zakeri et al, 2015).

discharge cycles and lifetime are typical factors to be included). Also, a number of factors considered in LCOE calculations depend on the application and the specific business case.

LCOE assessments¹⁰ show that the most economic storage installations are PHS and large scale CAES. However, they have limited future cost reduction potential since they are mature technologies. Table 3 shows mean values of LCOE calculations for storage technologies relevant for three different kinds of services (bulk service, transmission and distribution support, frequency regulation).

Table 3: LCOE assessment for different services and technologies

EUR/kWh	IRENA, 2012	Zakeri et al, 2015		
Technology	Range	Bulk service	T&D support	Frequency
PHS	0.05-0.15	0.12	--	--
CAES	0.10-0.20	0.13-0.16	0.2	--
Lead Acid	0.25-0.35	0.32	0.29	0.26
NaS	0.05-0.15	0.24	0.25	--
VRFB	0.15-0.25	0.35	0.34	--
Fe-Cr		0.21	0.25	--
NiCd		0.42	0.34	--
ZEBRA		--	0.35	--
LIB	0.30-0.45	--	0.62	0.43
Zn-Br		--	0.21	--
Hydrogen		--	0.42-0.48	--
Flywheel		--	--	0.21

Source: (Zakeri et al, 2015).

The LCOE calculations indicate that PHS and CAES are still most attractive for bulk services. Batteries however are getting more economic for transmission and distribution (T&D) support. It is expected that LIB reduce costs by a factor of two in the 2020-2030 decade (Nykqvist, 2015). Thus, batteries should not be too far from being economically attractive.

¹⁰ There are many independent LCOE calculations and technical, economical changes have to be taken into account carefully. Cost numbers can be from different dates which leads especially to differences for younger technologies with large cost reduction potentials.

3. ROLE OF ENERGY STORAGE IN THE EU

KEY FINDINGS

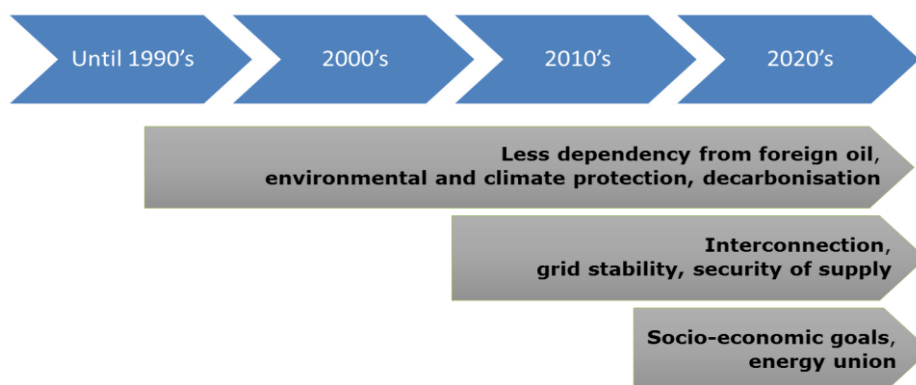
- Most existing electricity storage systems, namely large PHS, were built in Europe traditionally to store base-load overcapacity from nuclear and coal-fired power stations and to supply from storage to accommodate fluctuations in demand.
- The EU energy system is evolving towards a single market-driven system where energy storage and other flexibility options can play a role in accommodating an increasing share of intermittent renewables production. However, the investment climate for flexible mechanisms is not clear, due to uncertainties in the policy framework and their impacts on prices across Europe.
- Internal market regulations for energy treat storage very differently. While the Gas Directive explicitly mentions storage as one core element of the gas distribution system, the Electricity Directive does not mention storage. Lack of clarity in the role and position of electricity storage has resulted in some Member States in situations like applying double grid fees to electricity stored by pumped hydro facilities, for example.
- Expected solar panel cost reductions combined with energy storage can enable a future change of habits for households and businesses, which then produce their own electricity partly or fully. However, there is no common regulatory approach towards this situation across Member States (e.g. net metering, feed in tariffs, self-consumption regulation).

3.1. Evolution of Policy Objectives

Energy policies promoting a single energy market are becoming more and more defined at the EU level. In addition to the geographic challenge, the role of energy storage is also changing. The new challenge is no longer to store base-load overcapacity, but to handle an increasing amount of intermittent renewable generation. Different types of energy storage at different levels in the energy value chain can play a role to accommodate intermittency and to balance supply and demand of electricity. In order for the EU goals to be reached, energy policies and regulations shall allow for the changing roles of storage and incentivise them for being competitive against other available flexibility options.

Figure 9 summarises the evolution of higher-level objectives of the EU electricity system regulations. These objectives have also largely been the drivers for gas regulations.

Figure 9: Evolution of EU regulation's objectives related to electricity storage



Source: Adjusted from (Lapillone, 2012).

3.2. Past Role

Q 10: What used to be the role of storage in national energy policies?

In the 1950's and 1960's, the availability of cheap oil and gas brought about a partial switch from coal-fired electricity plants to oil- and gas-fired power generation. During these decades, the construction of the first nuclear power plants in Europe also occurred. In the 1960's to 1980's, most large PHS units that are still present in Europe were built by national utility companies to store base-load overcapacity from nuclear and coal-fired power stations, and to supply from storage to accommodate fluctuations in demand.

In the 1970's, two 'oil crises' disturbed the power market. In reaction to strong increases in world oil prices, EU Member States started to pay attention to decreasing their dependency on foreign oil. Parallel to that integration and liberalisation process, attention for climate and environmental protection had grown from the end of the 1980's with milestones like the creation of the Intergovernmental Panel on Climate Change (IPCC) in 1988 and the signature of the Kyoto Protocol in 1997. This has led to the setting of goals for energy system decarbonisation, which would later become a main driver for the energy transition and thus for the increasing attention to energy storage as facilitator of intermittent renewables.

Following earlier policy steps¹¹, the Third Energy Legislation Package of 2009 promoted regional national emergency measures including gas storage requirements, to secure the energy supply in the event of severe disruptions of gas supply.

Because the flexibility of fossil power plants increased over time and the penetration of intermittent renewable energy remained low, the capacity of the PHS systems built in the 1970's-1980's sufficed until a few years ago and interest for additional electricity storage capacity remained limited.

3.3. Present Role

3.3.1. Current Policies Affecting Storage

Q 11: What is the role of storage in current energy policies?

Fast-growing shares of intermittent renewable energy sources are being realised as a consequence of the implementation of EU's climate goals and targets set for Member States. This has resulted in increasing concern over the future electricity grid stability.

This has manifested itself in several Member States starting to discuss the need for Capacity Remuneration Mechanisms (CRMs) to increase flexibility in the electricity system. These discussions focus mainly on the availability of flexible gas-fuelled power stations. Pressure to improve and expand the interconnection infrastructures has also increased, as well as a renewed interest for the future role of electricity storage technologies. Until now, however, this renewed interest has not yet led to actual relevant increases in storage capacity. The use pattern of these facilities is shifting from accommodating base-load overcapacity towards balancing short term intermittency.

The main internal market regulations for energy are the Gas Directive (Directive 2009/73/EC concerning common rules for the internal market in natural gas) and the Electricity Directive (Directive 2009/72/EC concerning common rules for the internal market in electricity). These Directives treat storage very differently. In the Electricity Directive storage is not mentioned, in the Gas Directive storage is explicitly mentioned in its scope as one of core elements of the gas distribution system.

¹¹ For instance the 1994 Energy Charter Treaty.

Gas

The internal market for gas is mainly ruled by the Gas Directive and related regulations. The Gas Directive (art 15) considers storage as one of the core elements of the gas distribution system. In this Directive Storage System Operators (SSO) are recognised as relevant market players that should be 'unbundled' from other activities. An SSO has to provide for third party access, either through negotiated or regulated access.

Security of supply issues have been a strong driver, especially related to geopolitical conditions, with obligations for Member States to arrange for storage operators. This is reflected in European Commission Communication COM(2014) 330: European Energy Security Strategy (EC, 2014a).

Because of the defined position of gas storage in the Gas Directive, its position within the EU regulatory framework is not under discussion.

Electricity

The Electricity Directive regulates the unbundling of Transmission System Operators (TSO), Distribution System Operators (DSO) and the functions of electricity generation and supply. As energy storage is not mentioned in the Electricity Directive, the position of energy storage in relation to the unbundling requirements is not clear. As a result, electricity storage is generally regarded as a generation system (WIP et al, 2013). The Directive also specifies that a TSO cannot "directly or indirectly exercise control or exercise any right over any undertaking performing any of the functions of generation or supply" of electricity.

One of the elements of the Electricity Directive is the initiation of ACER (Agency for the Cooperation of Energy Regulators), which has developed the 'Framework guidelines on electricity balancing' (ACER, 2012), directed at the TSOs. These guidelines do not specify any technology for balancing the electricity grid and leave the use of energy storage open. The European Network of Transmission System Operators for Electricity (ENTSO-E) has published a draft network code for electricity balancing (ENTSO-E, 2013), based on ACER's guidelines that includes the possibility for energy storage facilities to become Balancing Service Providers.

ACER also coordinates the implementation of Regulation (EC) No 1227/2011 on wholesale energy market integrity and transparency (REMIT). This Regulation is valid for both electricity and gas and includes energy storage in its monitoring and transparency obligations.

ENTSO-E states in its latest Ten Year Network Development Plan (ENTSO-E, 2014, p 485) that it is an 'open question' which players (private market operators contributing to system optimisation or regulated operators) are allowed to own and manage electricity storage systems.

These statements show that ownership and control of energy storage by regulated entities under the Electricity Directive is a point of discussion. The examples below illustrate that several Member States feel the need to give their TSOs a role in owning, managing or contracting energy storage for electricity.

Some specific national developments on energy storage regulation are:

- Italy has stipulated that the TSO (and DSOs) can build and operate batteries under certain conditions. (Italian decree law 93/11, Art 36, paragraph 4). Italian network regulator (AEEGSI) passed a Decision on Provisions related to the Integration of Energy Storage Systems for Electricity in the National Electricity System (Decision 574/2014/eel of 10 November 2014) defining network access rules for energy storage.(for more information see the case study in Box 4, section 4.2);

- the TSO in Ireland, EirGrid, is developing a program, due to start in 2017, that will allow energy storage companies to provide grid services via a system of competitive bids (Stone, 2015);
- the UK National Grid held in December 2014 a first capacity market auction, which was also open for energy storage facilities.

Q 12: How do energy security policies affect storage?

Gas storage is important for energy security as it provides a buffer to supply interruptions, close to end-use markets.

The EU has developed a common framework for security of supply. An important element of this framework is the minimum limit set for security of gas by Regulation (EU) 2010 No 994 on security of supply. It contains two main elements that aim to define the infrastructure needed in each Member State to provide a minimum level of security of supply: i) the N-1 infrastructure standard, which describes the ability of a country to satisfy total gas demand during a day of extreme high demand, in the event of disruption of the single largest gas infrastructure, and ii) the obligation to install physical reverse flow capabilities at interconnection points. It also contains a 'supply standard' for the vulnerable or protected customers (e.g. households): a country needs to be able to provide its vulnerable customers for at least 30 days of high demand.

The European Energy Security Strategy (EC, 2014a) also addresses gas storage. It considers gas storage to be of strategic importance for supply security and suggests that there are "synergies in further cooperation across borders, by developing a regulatory framework for gas storages that recognises their strategic importance".

Important, also in times of crises, is a well-functioning gas market and clear regulations to access of storage facilities. The Strategy puts a strong emphasis on completing the transposition of internal energy market legislation into national laws by the end of 2014, including unbundling rules, reverse flows capabilities and access to gas storage facilities.

With these policies the EU tries to increase the resilience of the European gas system and gas storage is seen as a strategic element in these policies. The use of storage for energy security depends on several aspects: available storage capacity, actual utilisation of storage and access to storage in terms of crisis.

Europe has developed a common framework for security of supply. An important element of this framework is the minimum limit set for security of gas by Regulation (EU) 2010 No 994 on security of supply. It contains two main elements that aim to define the infrastructure needed in each Member State to provide a minimum level of security of supply: i) the N-1 infrastructure standard, which describes the ability of a country to satisfy total gas demand during a day of extreme high demand, in the event of disruption of the single largest gas infrastructure, and ii) the obligation to install physical reverse flow capabilities at interconnection points. It also contains a 'supply standard' for the vulnerable or protected customers (e.g. households): a country needs to be able to provide its vulnerable customers for at least 30 days of high demand".

Q 13: How does stimulation of electricity production from renewable sources affect storage?

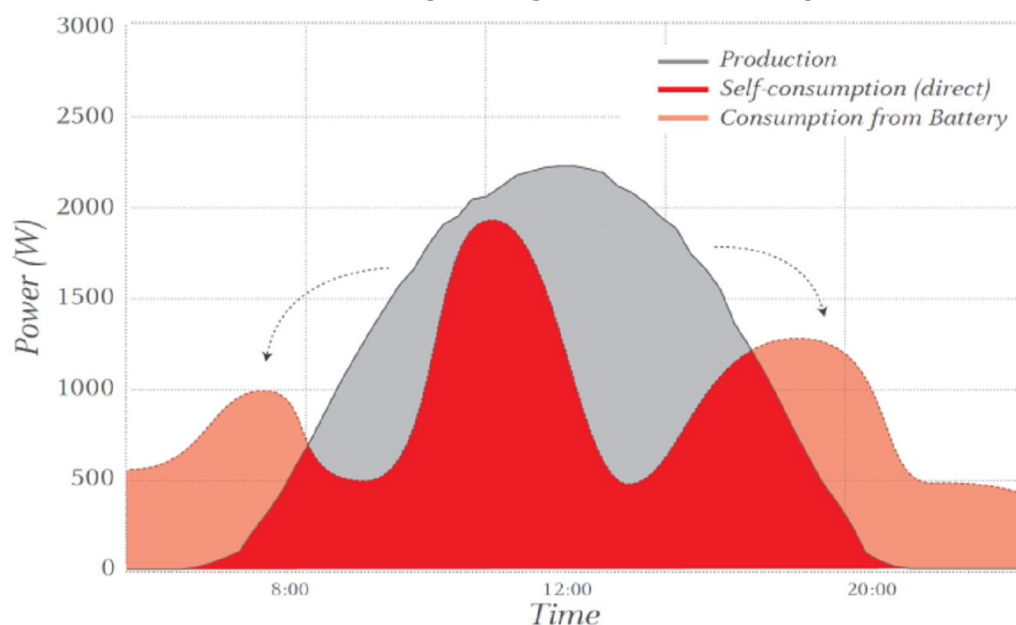
In most EU Member States, production of electricity from renewable sources is stimulated, either through investment subsidies or through direct financial support for production of

electricity. Financial support is primarily based on the actual supply of electricity to the grid, for instance through feed-in tariffs or net-metering¹².

There is no common EU approach for financial support of renewable electricity production; consequently, a wide variety of different approaches has been developed, different in each Member State. Many countries started with investment subsidies, but for small end-users many of them have now moved to feed-in tariffs. Some countries have developed pure net-metering schemes (e.g. Belgium, Denmark and the Netherlands), and some countries (e.g. Germany, Italy) have introduced mechanisms to promote instantaneous consumption of the electricity produced, next to feed-in tariffs. Various intermediate schemes exist between the different approaches.

For prosumers¹³ storage has a value, because it enables the optimisation of production and consumption 'behind-the-meter'. Storage could increase the percentage of self-consumption of locally produced power from some 30% to 65-75% for households (EC SWD (2015) 141 final), see Figure 10. This would lower their electricity bills by avoiding electricity supply, transport fees and taxation for electricity. However, deployment of storage is strongly affected by financial support for renewable electricity production, especially when support is based on the actual supply of electricity to the grid. Depending on the height and conditions of the support, these schemes make use of energy storage 'behind-the-meter' unattractive.

Figure 10: Effect of local electricity storage on self-consumption of a household



Source: Commission Staff Working Document SWD (2015) 141 final, p.4.

Deployment of storage by stand-alone facilities (such as wind farms or solar parks) is not directly influenced by financial support based on actual supply of electricity to the grid, although conditions for financial support have to include normal balancing requirements (EC 2014/C 200/01), which provides an incentive to invest in storage.

¹² Net-metering: Self-produced electricity supplied to the grid is deducted from electricity bought from the grid (the electricity meter 'turns backward').

¹³ Prosumers: businesses or households that both produce and consume electricity.

Q 14: How do policies on decarbonisation affect energy storage?

Decarbonisation of the economy has been translated into long-term targets on emission reductions, energy efficiency and renewable energy. It is also addressed in several European Directives.

In 2009, Europe enacted the "20-20-20" climate and energy targets to be achieved by year 2020: a 20% reduction in EU greenhouse gas emissions from 1990 levels, a 20% share of EU energy consumption produced from renewable resources and a 20% improvement in the EU's energy efficiency. This was followed, in March 2011, by the European Commission Energy Roadmap 2050 (COM(2011) 885 final), which contained indicative shares of greenhouse gas (GHG) emission reductions from the power sector for 2030 and 2050.

The European Commission presented, in January 2014, the 2030 policy framework for climate and energy. The 2030 framework was agreed by the European Council in October 2014, and was integrated in the Energy Union package presented by the European Commission in February 2015. The key targets include:

- a reduction of EU domestic GHG emissions by at least 40% below the 1990 level by 2030. This target is defined to keep the EU on a cost-effective track towards an 80% reduction by 2050. Sub-targets set to achieve this 40% reduction are:
 - a reduction of 43% in emissions from the sectors covered by the EU Emissions Trading System (EU ETS) by 2030, compared to 2005 emission levels;
 - a reduction of 30% of emissions from sectors outside the EU ETS by 2030, compared to 2005 emission levels;
- an increase in the share of renewable energy to at least 27% by 2030;
- an indicative target of at least 27% improvement in energy efficiency by 2030.

It is estimated that the share of electricity produced from renewable sources to meet these targets will grow to 36% by 2030 and 50% in 2050 (EC, 2013a). The substantial share of intermittent renewable energies in the electricity mix results in the increasing need for flexibility options, including energy storage.

There are several EU Directives that directly contribute to the goal of decarbonising the European economy. The most prominent Directives are the Energy Efficiency Directive (EED), the Renewable Energy Directive (RED), the Energy Performance of Buildings Directive (EPBD) and the EU Emission Trading System Directive (EU ETS), of which the latter two only have an indirect effect on energy storage:

- the RED drives the increase of renewable electricity production, resulting in an increased need for flexibility. It also establishes energy storage as one of the elements that can contribute to the security of the electricity system (art. 16-1);
- the RED stipulates priority access (guaranteed access) to the grid for electricity from renewable energy sources (Art.16-2), but it does not give such operators any responsibility to contribute to system's flexibility. However, many investments for renewable energy make use of some form of state support and are, therefore, subject to the state aid guidelines, which, since June 2014, requires that RED beneficiaries have balancing responsibilities. (EC COM 2014/C 200/01));
- the EED sets as a criterion that network regulations or tariffs shall not prevent energy storage (Annex XI of the EED);
- the EU ETS set a carbon pricing mechanism that makes electricity from renewables cheaper;

- The EPBD sets energy performance requirements for buildings that stimulate use of renewables.

With respect to gas storage, the expected effect of these Directives is mixed. Some growth of biogas production is expected, which will also include local gas storage, but biogas only represents a small share of the total gas consumption. Overall gas demand in 2030 is expected to reduce with approximately 25%, compared to gas demand in 2015 (EC, 2015b), due to increased energy efficiency and decarbonisation.

Q 15: How do grid fees affect energy storage?

Grid fees can play an important role in the deployment of energy storage. The applicability of grid fees depends on the way energy storage is viewed by the regulator.

Grid fees are paid for the use of the electricity network to transport electricity. Normally, grid fees are paid by the final consumer and consist of a flat fee per volume of electricity. In some countries the electricity generator also pays grid fees for access to the grid. With storage, the electricity grid is used twice (supplying electricity to the storage and from storage to the final consumer), but the storage facility itself is neither a (first) generator, nor a final consumer. This situation is regulated differently in various countries.

According to EURELECTRIC (EURELECTRIC 2012), in several countries, existing regulation treats pumped storage both as a generation asset (required to pay a grid fee for transmission grid access) and as a final consumer (required to pay the grid access fee a second time). Eight Member States (Czech Republic, Spain, Italy, Lithuania, Poland, Portugal, Slovakia and the United Kingdom) do not impose grid fees to storage plants while three Member States (Austria, Belgium and Greece) and Norway apply fees for both charging and discharging of storage. In 2012, Germany introduced a rule that exempts new PHS or capacity extensions of existing PHS from grid fees for 20 years and 10 years, respectively (Zucker, 2013).

EURELECTRIC makes the case that withdrawing electricity from the grid with the aim of electrical, chemical, mechanical or thermal storage and re-feeding it with a delay into the transmission or distribution systems are not final consumers and should be exempted from the obligation to pay grid charges for final consumers.

The way grid fees are applied is not only relevant for large scale pumped hydro facilities, but also for future developments, such as the use of energy storage for grid optimisation, in smart grids, or the use of electric vehicles for energy storage as a grid service.

Most EU Member States have volumetric grid tariffs (per kWh) for residential consumers, in combination with storage volume based network tariff systems favour the use of storage to minimise consumption from the grid.

Capacity-based tariffs could provide better incentives to provide flexibility. It gives an incentive to end-users for the use of storage to minimise peak demand. The share of self-generated electricity that is stored and self-consumed is expected to grow. Capacity based tariffs can help to make network tariff payments less dependent on the share of self-generation, storage and consumption and have consumers with self-generation contribute more to network cost.

Grid tariff settings could also include incentives for network optimisation, for instance by using a reduced tariff in case the network operator can initiate or delay demand for network optimisation purposes, making system cost reductions possible. For example, a study from TU Delft compares the impact of optimised electric vehicle charging to uncontrolled charging for the cost of network reinforcement and calculates 20% savings for Dutch distribution networks (Verzijlbergh, 2013).

The case study on Germany (Box 1) shows actions taken by the German government to make development of new pumped hydro storage more attractive.

Box 1: Case study: Grid fees in Germany

Germany's discussions to widen exemptions for electricity storage facilities from grid tariffs.

At this moment, the German Federal Energy Industry Act (EnWG) Sec. 118 (6) contains a provision for hydrogen and hydrogen-based gas facilities to be exempted from network access charges. Further, the German Renewable Energy Sources Act (EEG) 2014 Sec. 60 exempts electricity storage facilities from the EEG levy (e.g. pumped storage power plants and battery storage facilities), if the stored electricity is exclusively fed back into the grid from which it is originally drawn.

In May 2015, the German Federal Council (Bundesrat) proposed to extend these exemptions. The proposal is to prolong the exemption in the EnWG so that new electricity storage facilities that are commissioned within a 15-year period, starting (retroactively) on 4 August 2011, will be exempt from grid fees for a period of 40 years (currently EnWG provides for a 20-year exemption). Pumped-storage plants for which pump or turbine capacity increases by at least 7.5% or whose storage capacity increases by at least 5% after 4 August 2011 are proposed to be exempt for 20 years instead of currently 10 years.

The German Association of Energy and Water Industries (BDEW, 2014) has proposed definitions of energy storage to be used in this legislation.

An "energy storage facility" is defined as a "Facility which receives energy with the objective of storing it electrically, chemically, electrochemically, mechanically or thermally and of making it available again for use at a later time."

An "electricity storage facility in the electricity supply system" is proposed to be defined as an "energy storage facility which receives electrical energy from a general supply grid, temporarily stores it and later feeds the released energy back into a general supply grid. Drawing electrical energy for the purpose of temporary storage in an electricity storage facility does not constitute final consumption."

3.3.2. Incentives and Threats to Relevant Actors

Q 16: Which actors can make use of energy storage and what incentives and threats do they face?

Table 4 indicates the different services that energy storage can provide to different actors in the energy value chain.

In the gas system, storage can only be provided by Storage System Operators. These operators need to act independently from other entities in the gas supply chain. They act as service providers to gas suppliers, distribution companies and end-users in the industry and electricity production.

Table 4: Actors that can make use of storage, incentives and threats

Level	Actor	Activity	Services that can provide	Incentives to use storage	Threats for deployment
Generation / suppliers	Energy producers	Gas, coal, nuclear Solar, wind, biomass	Bulk storage, arbitrage. Renewables integration	Price differences between peaks in demand and supply	Possibility of double grid fees
Transmission grid	TSO	Transmission activities	Renewables integration, ancillary and transmission	Costs of contracting flexible capacity for balancing	Unclear whether TSO is allowed to own or control storage
	Industry/ large consumers	Co-generation	Energy management and integration	Price difference between peaks, electricity can follow heat production	
		Energy consumer	Energy management and integration	Price difference between peaks	
	Service company	Service provider	All above	All above	Storage services not mentioned in Electricity Directive. Double grid fees
Distribution grid	Local energy producer	Solar, wind, biomass	Renewables integration and arbitrage	Price difference between peaks in demand and supply	Grid priority and feed in tariffs are no incentives for energy storage. Double grid fees
	DSO	Distribution activities	Renewables integration, ancillary and distribution	Balancing costs	DSO is in most countries not allowed to own or control storage
	Business, industry, household	Energy consumer Cogeneration Prosumer	Energy management and integration	Depends on price settings Low or no remuneration for electricity supplied to grid	Electricity prices may not reflect peak value differences. Feed in tariff, net metering are no incentive for storage
	Service company	Service provider	All above	All above	Unclear business model for grid related services. Double grid fees
Off grid	Business, household	Independent	Energy management	No or low remuneration for supplying the grid	Grid connection obligations

Source: Authors.

In general, both for producers and energy service providers, the main incentive to utilise energy storage within the electricity system currently is the use of storage to enable arbitrage, that is using prices differences in gas and electricity supply and demand to make a profit. This is only economical for very large volumes, and requires direct access to gas and/or electricity trading markets. Energy storage as a service can operate in different parts, and different levels, of the electricity value chain, for which different regulatory frameworks are applicable. These differences are especially relevant for the applicability of grid fees and represent a bottleneck to use a storage facility for different services.

Grid operators at transmission and distribution level can benefit from storage by using it for renewables integration services and other ancillary services for grid planning and operation. However, the value of ancillary services is often difficult to determine and the legal framework for storage as flexibility services in the electricity system for grid balancing is not clear.

3.4. Future Role

Q 17: What role can energy storage play in the Energy Union?

The European Commission envisages a transition from the present electricity system to a more decentralised system where consumers can act as 'prosumers' and also produce energy, and where large wind farms and solar parks provide a substantial, but variable, share of electricity production. Also, as part of this transition, a 'modal shift' is expected: an increase of the relative role of electricity in relation to other energy carriers. The resulting increase in electricity demand may, on the one side, increase the pressure on network stability, but, on the other side, the 'new demand' may also be better suited for demand side management (car battery charging, power-to-heat functions) than the present demand, and therefore may positively influence network stability.

In the future energy system, the challenge will not be base-load overcapacity, but intermittent renewable generation. Different types of storage at different levels in the supply chain can play a role to accommodate intermittency and balance supply and demand of electricity. Storage of energy can augment power quality and grid integrity, thereby protecting customers against fluctuations and high prices. Decentralised storage options can support the decentralisation goals. All these developments will increase the need for regulations to evolve so that they will provide a level playing field for the transition to happen. Energy policies and regulations will have to adapt to enable flexibility options, including the changing role of energy storage. The European Commission has announced in its Energy Union Summer Package of 15 July 2015 that it is working on a new energy market design. This new energy market design will aim at providing an opportunity to reach level playing field for energy storage, clarify the position of energy storage for both regulated and non-regulated entities and acknowledge the multiple services that energy storage can provide. In Box 2, a case study is given on a regulation allowing experiments in the Netherlands to provide insights on how regulations should be adapted.

Box 2: Case study: Policy in the Netherlands – Room for experiments

In February 2015, the Netherlands introduced a temporary regulation that allows 'Electricity Law experiments' combining local production, consumption and electricity storage to facilitate and promote smart grids. This regulation is meant for projects that combine local production of renewable energy and consumption for 'local' (up to 500 end users) or 'regional' scale (up to 10.000 end users). These experiments will allow parties to be responsible for production, net management and delivery of sustainable electricity, without permits otherwise required. Also, experiments with tariff structures are expected.

The goal is to have twenty experiments starting each year for the next four years. The

experiments will run over a period of ten years, with an option for prolongation. The ambition is that experiments will realise a significantly higher utilisation of renewables, a significantly lower peak load in the network or a significantly increased role of consumers. The idea is that successful experiments could lead to structural adaptation of regulations.

3.5. Barriers to Further Development

The main challenge for energy storage is economic. If storage systems are available at low capital costs, it is expected that they will find broad use, as they are suited for a variety of applications, as discussed in section 2.2. However, the present situation discourages potential investors because there is uncertainty with respect to the future development of energy systems and market design in Europe. Definite regulations are needed that specify questions of ownership of storage or levies that have to be paid.

In addition to the technological and economic challenges, other factors could impair the potential of storage technologies and hinder their market development in the European Union. Different barriers are presented in Table 5 divided into the following categories: technology, economics, market & regulation and social acceptance.

Technology and economic barriers can be reduced by supporting research, for example by funding programmes. However a breakthrough in this area is not automatically guaranteed because it is hard to predict. Market & regulation barriers are more predictable as they are the result of policy design and implementation. Social acceptance barriers depend mainly on the parties involved and are hard to influence from the outside. Education strategies and demonstration projects seek to address them.

Table 5: Barriers to the deployment of energy storage

Barrier	Bottleneck	Description
Technology	R&D progress	Improved efficiency and energy densities (especially of batteries) is key factor for market launch.
Regulation	Harmonisation of European Energy Policy	European countries have difficulties to find a common position concerning the future energy mix which has a negative effect on investment planning.
Economics	Specific investment	High costs compared to conventional producers with similar services like flexible gas turbines.
	Commercial scale	Need for large-scale cost-intensive demo projects to alleviate risk from utilities before they decide to invest.
Market	Harmonisation of European markets	Markets and transparent prices for ancillary services are not fully developed in the EU. Appropriate market signals and schemes for storage are missing.
	Investment climate	Investment climate for flexible mechanisms, including storage, is not clear due to uncertainties in the policy framework and their impact on prices.
	Business models	A single service may be insufficient for an economical use: comprehensible business models are needed.
	Ownership	Classification of operation purpose is not always clear or even mixed (support of generation vs. transmission), regulations are needed that clarify who is allowed to be

Barrier	Bottleneck	Description
		storage owner.
	Business culture	Utilities are risk averse and need planning security.
	Price formation	Market pricing systems often do not enable time-of-use tariffs and do not accommodate for variation over time of production costs.
	General regulations for storage	Operation concepts for storage are manifold, so the establishment of general regulations is challenging. It is possible a number of individual regulations will be needed.
	Grid expansion	Additional transmission capacities lower the demand for storage and other flexibility mechanisms.
	Regulatory focus	Often, storage is treated as generation rather than as transmission technology. Incentives, standards and government plans are written for renewable generation only, excluding storage or its effects on grid stabilisation.
Social acceptance	Acceptance of renewables	Citizens may reject the expansion of renewable energy sources which indirectly results in less need for storage.
	Acceptance of storage technologies	Citizens could reject large-scale storage due to environmental impacts or may refuse remote control of small storage in households.

Source: (EC, 2012).

4. CONTRIBUTION TO ENERGY UNION OBJECTIVES

KEY FINDINGS

- Gas storage, combined with interconnection capacity and reverse flow capabilities, can help provide regional resilience to shocks and disruptions in gas supply. This is especially important in regions that depend on one supplier and where market integration and interconnections are insufficient. Stronger regulation is needed for access to stored gas in times of crisis;
- Electricity storage is one of the flexibility options that allows for more integration of renewable energy sources and, therefore, helps to decrease the dependence on imported fossil fuels for the long term;
- Electricity storage can provide simultaneous services to multiple stakeholders. Producers of renewable electricity could help balance the system with centralised storage facilities coupled to their generation plants. However obligations and incentives are needed to promote this;
- Energy storage can also provide balancing services directly to the transmission and distribution grids for peak reduction and overload management. Current interpretation of unbundling requirements prevent TSOs and DSOs from directly owning or controlling energy storage infrastructure;
- While centralised storage is currently more suited to providing ancillary services due to size requirements and current commercial arrangements, distributed storage could also provide similar services through emerging aggregation services;
- Energy storage can contribute to energy efficiency of prosumers as some may limit consumption to what they produce and store. However, net metering or feed in tariffs do not incentivise to optimise their systems;
- One of the most important values of storage lies in avoiding the waste of renewable energy that otherwise will be curtailed;
- Energy storage also contributes to lower wholesale prices and mitigating their volatility, as it helps to integrate more renewable electricity at the most convenient times. It may also play a role in mitigating non-favourable regional price formation due to capacity limitations in the transmission grid;
- R&D efforts on technologies like heat pumps and storage heaters could provide a high degree of load shifting flexibility. European R&D in smart grid developments, incorporating smart vehicle charging, vehicle-to-grid technologies (smart mobility) could also result in many benefits to the EU.

The Energy Union strategy is designed to bring more affordable energy, greater energy security, sustainability and competitiveness. It consists of five interrelated dimensions:

- energy security, solidarity and trust;
- a fully integrated European energy market;
- energy efficiency contributing to moderation of demand;
- decarbonising the economy; and,
- Research, Innovation and Competitiveness.

The potential contribution of energy storage to each of these five dimensions is analysed in the following sections.

4.1. Security of Energy Supply

Q 18: How can energy storage contribute to security of energy supply?

The European Energy Security Strategy (EC COM(2014) 330) defines the focus for energy security as follows:

"resilience to shocks and disruptions to energy supplies in the short term and reduced dependency on particular fuels, energy suppliers and routes in the long-term."

Energy storage can play different roles to enhance energy security within Europe:

- gas storage, combined with interconnection capacity, reverse flow capabilities and close to end-user markets, contribute to regional resilience to shocks and disruptions in gas supply. Six Member States (the Baltic States, Finland, Slovakia and Bulgaria) depend on Russia as the only external supplier (EC COM(2014) 330). Gas storage provides a buffer to them;
- electricity storage can help balance fluctuations due to renewable energy production providing with flexibility to the EU electricity system. Increasing the amount of electricity from renewable sources improves long term security of supply, and makes the EU less dependent on imports of fossil fuels. Other flexibility options include demand side management, interconnection capacity and back up provided by gas power stations. For the latter a secure gas supply is required in which gas storage plays a role (see previous bullet point);
- enabling 'Power to gas' and 'Power to heat' to provide additional flexibility to the energy system and increase security of supply. Excess electricity from renewable sources can be converted into hydrogen or synthetic natural gas (Power to Gas) displacing imported oil and gas. Excess electricity can also be converted to heat or cold (Power to heat), which can be stored locally to increase the uptake of electricity from renewable sources. Possibilities include storage in aquifers (seasonal storage), production of ice as buffer for use as air-conditioning later in the day and for heat accumulation in buildings. Research (ECN, 2014) shows that power to gas will remain a relatively expensive flexibility option.

Q 19: Do we need more gas storage to contribute to security of supply?

Gas storage can help provide regional resilience to shocks and disruptions in gas supply. It is not possible, though, to determine whether a country has sufficient storage capacity without examining other elements that contribute to security of supply: interconnection capacity, possibilities for two way interconnection flow and local gas production.

Europe has developed a common framework for security of supply. An important element of this framework is the minimum limit of 30 days 'supply standard' for the vulnerable and protected customers as explained in section 3.3.1. These standards combined define a minimum level of security of supply for each Member State that is realised through a mix of interconnection capacities, storage and production.

The implementation of the Gas security of supply regulation was tested in a stress test (EC SWD(2014) 325 final). The stress test concluded, that the infrastructure standard by itself can give a false impression of security and needs to be combined with other indicators that give an indication of the flexibility of the gas system, (for instance, daily withdrawal rates from storages under various filling scenarios). The Commission services indicate that the flexibility of the EU gas grid is not fully satisfactory yet. The Gas security of supply

regulation is currently under evaluation. One of the issues to evaluate is whether the standards stimulate storage sufficiently. Some countries have set separate rules on the amount of gas storage required in relation to the volume of gas used.

The European Network of Transmission System Operators for Gas (ENTSO-G) sees a lack of sufficient integration in regions outside of Western Europe (ENTSO-G, 2015). This translates into high supply dependence on Russian gas in the Baltic region, Central-Eastern and South-Eastern Europe and dependence on LNG in Spain, Portugal and South of France. The Baltic region and South-Eastern Europe are still vulnerable to a disruption of the transit of Russian gas through Belarus and/or Ukraine.

Storage alone cannot guarantee security of supply. Availability of storage capacity, use of this capacity and whether stored gas can be accessed in times of crisis should be examined as well.

Availability of storage capacity

Whereas the amount of storage capacity has increased across Europe (+20% in 2009-2015), the overall demand for gas is steadily decreasing and is expected to further decrease (-25% in 2015-2030). (EC, 2015b). The Council of European Energy regulators (CEER), consequently suggests that current storage capacity might already be sufficient (CEER, 2015). At the same time, the economics of operating a storage facility can be quite marginal (EC, 2015b) and combined with the expected decrease in gas demand, could have an impact on available storage capacity in future. ENTSO-G puts little emphasis on storage to increase security of supply and sees the main solutions for improved security of supply in enlarging Europe's supply portfolio and further integrating gas markets around Europe.

Use of storage capacity

Gas storage levels across Europe in winter 2014/2015 were the highest seen in recent years, the average accounted for 51 days (total EU-27 plus Switzerland, Turkey) (EC, 2012). As the storage capacities are currently not fully exploited, they can be regarded as sufficient for the actual regular demand level. CEER stresses that in well-functioning markets as in North West Europe, security of supply is delivered through wholesale market price signals and market participants consider that further intervention to increase security of supply is unnecessary (CEER, 2015). However, in regions where market integration is still lacking, price incentives do not guarantee sufficient gas storage in stock (see Box 3) and interventions should be considered. The Centre for Security Studies (CSS) suggests the introduction of stronger regulation for gas storage to enhance the ability to face a supply disruption (Geden, 2014). Access to gas storage, which has, so far, been neglected at the regulatory level, is becoming more and more important in the context of liberalised markets, as only storage can ensure the necessary degree of flexibility.

Box 3: Case study: Interventions to guarantee sufficient gas storage in stock

Examples of interventions to guarantee sufficient gas storage in stock are:

France and Poland have set storage obligations for the amount of storage that gas suppliers need to provide. For example, in France, suppliers are required to hold at least 80% of their storage capacity rights by November 1, each year. The storage rights are based on their customer portfolio.

Italy has implemented a rule on keeping a strategic stock, aimed at facing potential shortages or reductions in supply or crisis situations in the gas system. The strategic stock is paid for by gas producers and importers, based on a share of their annual produced and/or imported volume.

Access to stored gas in times of crisis

CEER underlines the importance of access to storage in crisis situations (CEER 2015). Access should be non-discriminatory, both within countries and across border. Some countries depend completely, or to a certain degree, on storage in neighbouring countries. This can be more cost effective and should not pose a problem in a well-functioning internal market. The European Energy Security Strategy (EC COM (2014) 330) suggests that there are “synergies in further cooperation across borders, by developing a regulatory framework for gas storages that recognises their strategic importance for supply security”.

More gas storage capacity can always contribute to increased security, but, in general, the EU seems to have sufficient capacity. More important, at the moment, is that market conditions are regulated in such a way that gas storage capacity remains available, that storage is filled when peak demands can be expected and that access to stored gas is guaranteed, also in crisis situations. Capacity and use of that capacity needs to be improved in certain regions as the infrastructure standard is not yet met by all countries and price signals in certain regions do not guarantee sufficient storage.

Q 20: Does the South Stream cancellation change the need for gas storage?

The South Stream pipeline was designed to open a new supply route for Russian gas to enter the European market, which would make the EU more resilient in terms of physical supply routes. The project was cancelled in December 2014. Immediately thereafter, Russia announced plans on the Turkish Stream, transporting Russian gas under the Black Sea to Turkey and then to the Turkish-Greek border. Greece would become the main hub of this stream for EU markets, pumping up to 47 billion cubic meters into EU markets according to Gazprom. The Turkish Stream would be built primarily to transport Russian gas, but could also make gas from other sources accessible in the medium term: Azerbaijan, Middle East (e.g. Iraq, Iran), the Caspian Basin (e.g. Turkmenistan) and the Eastern Mediterranean (e.g. Israel, Cyprus, Lebanon). It would be up to the EU how to store and distribute the gas in Europe. Additional infrastructure would be needed to connect the Turkish Stream to existing infrastructure in Europe.

In this new context, ENTSO-G has opened in April 2015 a new ‘exceptional’ call for projects and Bulgaria has indicated it wants to build a gas storage facility¹⁴. Also, Romania could be a candidate for storage facilities as it has a number of depleted gas fields. The plans for the Turkish Stream are still far from certain, but if this pipeline would indeed be constructed, it could provide a strong incentive to further develop a regional gas infrastructure, which would also need to include gas storage. The EC might play a crucial role as coordinator of this regional infrastructure and facilitate between Member States, gas companies, SSOs, energy regulators and European financial institutions, to support the financing of a regional gas infrastructure system, crucially important for the energy security and economic competitiveness of the overall South-Eastern European region (Hafner, 2015).

4.2. Integration of Energy Markets

Q 21: What is the role of energy storage in facilitating integration into the single energy market?

The integration of the European electricity markets can result in a potential benefit between 12.5 and 40 billion Euros per year, or a medium value of 6.8 €/MWh (Baritaud, 2014). In order to integrate renewable electricity generation, the Energy Union package points out the need for flexibility options on both the supply and demand sides.

¹⁴ <http://www.aa.com.tr/en/economy/541242--bulgaria-proposes-gas-storage-facility-for-turkish-stream>.

Flexibility options, such as energy storage, can positively influence efficiency in the use of resources in the process of integrating European energy markets, as addressed in section 2.1. Figure 4 shows the flexibility options currently available.

Energy storage and other flexibility options can be coupled with CRMs. Capacity markets currently under discussion in the EU are one type of CRM. They have an inherent risk of creating lock-in effects for such capacity when they focus mainly on providing extra funding for flexible fossil fuel units. Power capacity investments that will be made on the basis of this complementary market will become a part of the European energy landscape and would, in normal market circumstances, be operated for decades. It is crucial to ensure that such new investments do not create additional barriers to the goals set by the Energy Union. Energy storage and other flexibility options could be coupled with those capacity markets to reduce this risk and deliver correct price signals to ensure efficient investments.

Energy storage can serve both the supply and demand sides of the electricity system by facilitating a shift in either over time. The types of services that storage can provide (see section 2.2) depends on both the level of application and the characteristics of the storage asset. Storage assets can be deployed at centralised generation and transmission level (large scale centralised storage), down to distribution and residential level (distributed storage). A key distinction between storage technologies is their ability to provide power (kW) and their ability to provide energy (kWh). Their cost, in terms of power (€/kW) and energy (€/kWh) capacity, together with the cycle lifetime, are the most pertinent characteristics determining which applications storage technologies are most suited for. Energy management applications, such as peak shifting, can be provided by both centralised and distributed storage.

Centralised storage is currently more suited to providing ancillary services due to size requirements and current commercial arrangements, but distributed assets could provide similar services through emerging aggregation services. Distributed storage also has the potential to support distribution networks in the integration of embedded intermittent generation through local network peak reduction. It is estimated, though, that with current wholesale prices, most storage options are currently more expensive than additional transmission capacity or gas-fired flexible generation capacity. This may change rapidly as new innovations and lower costs are developed.

The Energy Roadmap 2050 also considers energy storage as a critical element to facilitate the transition towards a sustainable electricity system. The Priority Interconnection Plan (PIP) and the list of Projects of Common Interest (PCIs) include some projects with a storage element, but most of these are PHS storage.

Q 22: What are the main impacts of energy storage as a flexibility option?

Direct impacts

The main direct impacts of energy storage as a flexibility option are:

- **system Adequacy:** Storage has a positive impact on system adequacy as it improves the utilisation of the network, both at the transmission and distribution levels;
- **capacity Adequacy:** Storage has a positive impact on capacity adequacy as it can delay or reduce the need for investment in new production capacity;
- **decarbonisation:** Storage has a positive impact on decarbonisation of the electricity system as it enables better integration and use of renewables;

- Costs: Storage may have a negative impact on utilities suffering of the “missing money problem”¹⁵ as it would be more difficult for them to recover the investments made in (gas-fired or coal based) capacity units that will no longer operate.

Indirect impacts

The main indirect impacts of energy storage as a flexibility option are:

- system Adequacy: Local storage options (batteries or electrical vehicles) enable system balancing at the local level;
- environmental load: The production of storage equipment and the construction of storage facilities at large scales may put more pressure on the materials needed to build them. More pressure on the need for rare earths and chemicals may happen.

In Italy (see Box 4), the national grid operator, Terna, will introduce a capacity market through a system of annual auctions for reserve capacity that can include PHS. The system specifically prices flexibility; and the capacity mechanism is likely to favour technologies such as pumped hydro storage (Patrian, 2015). This is one in a range of actions taken by the Italian government to stimulate energy storage.

Box 4: Case study: Policy in Italy

Italy is experiencing severe balancing problems related to renewable production (mainly in the south) and electricity consumption (mainly in the north) and limited interconnection between regions. Consequently, Italy has taken several steps to address these problems, including increasing energy storage:

1. In 2011, Italy has stipulated that Terna, the national transmission system operator, can build and operate batteries under certain conditions. It establishes that the national transmission system manager “may develop and manage diffused electricity storage systems using batteries” (Italian decree law 93/11, Art 36, paragraph 4).
2. Since 2011, Terna is involved in two research projects developing 75 MW of batteries to store electricity. Batteries will be located in the south of Italy close to wind power generation locations (www.terna.it).
3. In 2013, the Italian government decided to introduce a new capacity market system, which should make additional reserve capacity available, starting from 2017. This system will enable Terna to contract flexible reserve capacity through a system of annual auctions. The system specifically prices flexibility and the capacity mechanism is likely to favour technologies such as pumped hydro storage (Patrian 2015).
4. In November 2014, the Italian network regulator AEEGSI passed a decision (574/2014/eel) defining network access rules for energy storage. It defines energy storage as a power generating system and makes energy storage subject to connection, dispatching and metering obligations. Energy storage facilities are required to pay a connection fee in line with the fee paid by high efficiency combined heat and power generation plants. With respect to dispatching, energy storage systems are treated as programmable (dispatchable) units if considered as single power generation systems, and as programmable or non-programmable units if considered as part of a group of generation systems, depending on the characteristics of the other units in the group (NERA 2014).

¹⁵ Difficulty to recover investments made in fossil fuel capacity units that will no longer operate).

Q 23: Can the Electricity Directive be adapted to better enable energy storage?

The combination of the unbundling rules and the lack of a definition of energy storage in the Electricity Directive makes it difficult for transmission and distribution companies to commit to investments in storage. For grid operators, energy storage can provide several services related to grid balancing and optimisation of the electricity system as a whole, avoiding investments in grid extension or flexible production capacity. However, the control of storage by grid operators is restricted, although some exceptions are made in the case of R&D projects. In most countries, the lack of a definition in the Electricity Directive has led to the interpretation that a storage unit is regarded as an entity that (also) supplies electricity, which is an activity that regulated transmission and distribution entities should refrain from.

This situation is illustrated by the ongoing discussion between EURELECTRIC and ENTSO-E. EURELECTRIC claims that ownership of pumped hydro storage should be a "competitive" business, and not a "regulated" one, and is incompatible with the unbundling provisions of the Third Energy Package" (EURELECTRIC, 2012). ENTSO-E does not share this opinion on ownership. In their Ten Year Network Development Plan 2014 (ENTSO-E, 2014), storage ownership by "private market operators" or "regulated operators" is regarded as an open issue. ENTSO-E proposes large scale demonstrations of storage to validate both "storage benefits" and "potential asset ownership solutions (Zucker et al, 2013).

Also the stoRE project (WIP et al, 2013), sees the position of energy storage in relation to the unbundling principle as a bottleneck for energy storage. StoRE recommended in 2013 that the European Commission: *'officially clarify the applicability of the unbundling principle to electricity storage (Article 9(1) of the Electricity Directive), by including a clear definition of electricity storage in the Directive'*.

The unclear situation for the use of energy storage by grid operators also hinders the development of energy storage as a commercial service because the different values for energy storage, for different entities, could be combined into one storage facility, providing different services simultaneously to different entities.

Position of Energy storage in the electricity value chain

Energy storage as a service can operate in different parts of the electricity value chain, for which different regulatory environments are applicable.

- energy storage 'behind the meter'. Storage within a household or company can be used as means for arbitrage and to optimise self-production and consumption. No use is made of the network so no transport cost or taxes apply;
- energy storage as third party service. Energy storage as a separate facility that is accessed through the grid, as a service to other entities (producers, consumers, TSO, DSO). Grid fees can apply, depending on national regulations, for supply to the storage facility and for supply from the facility to the end-user;
- energy storage used in operating the grid. Storage can be used by grid operators as ancillary service to balance the grid and improve power quality. In principle, no separate transport fees or taxes apply, costs are included in the network fee.

Technically, it is possible to combine the different types of storage in one facility (or for example in an electric vehicle), and use it for multiple purposes simultaneously, creating more value for the storage unit and improving the business case for an investor. However, from regulatory and administrative point of view, this situation is quite complex.

The regulatory situation in Europe for storage can be compared to the US, where a study by MIT on the future of solar (MIT, 2015) concluded on storage:

"At the moment, consistent pricing for storage-related services or market plans for providing grid storage do not exist, and economic uncertainty inhibits investment. A clear revenue generation model for storage operators will help clarify opportunities for profitability, reduce uncertainty, and spur investment."

Defining a clear position for energy storage in the electricity system will help to provide a business case for storage and make investments in storage more viable. The position must address the different services storage can provide and take into account the different regulatory environments in which it can be of value. The new energy market design, as announced in the Energy Union Summer package from 15 July 2015, provides an opportunity to clarify the position of energy storage for both regulated and non-regulated entities.

Elements relevant to clarify the position energy storage in the electricity system:

- Define whether grid operators can have ownership and/or control over energy storage for purpose of grid balancing and other ancillary services.
- Clarify and streamline the position of storage in the different regulatory environments (behind-the-meter, third party service, grid operation) where it can be of value, including applicability of taxation and grid fees.
- Take into account that a specific storage facility can be used simultaneously for multiple purposes, which can improve its specific business case.

It is not yet clear if and when energy storage will become competitive, compared to other flexibility and investment options, but clarifying its position will reduce uncertainty for investments and will provide a basis for energy storage to compete on a more or less equal basis with other techniques and services that can provide similar capabilities.

The California case (see Box 5) illustrates an example that requires grid operators to contract third parties to provide for a certain amount of energy storage at different levels in the electricity network. The California case study is also interesting for the development and use of a model to make calculations on the value storage can provide to different stakeholders. These calculations facilitated the discussions between the different stakeholders on the value of storage and helped to set the level of storage required.

Box 5: Case study: Energy storage mandate in California

Background

California introduced the AB32 legislation in 2006, establishing a 33% target for electricity from renewable sources by 2020 (California, executive order S-14-08). The California Energy Commission (CEC) developed regulations on energy storage, among other actions, to mitigate effects of intermittency of renewable energy production.

Regulation AB 2514

Adopted in 2010, the 'Energy storage systems' regulation (AB 2514) makes a distinction between publicly-owned electric utilities (POUs) and Investor-owned electric utilities (IOUs). The POUs have to purchase a targeted energy storage capacity equivalent to 1% of peak load by 2020. For the IOUs, the act requires the California Public Utilities Commission (CPUC) to set targets for the procurement of 'viable and cost-effective energy storage systems'. The CPUC established an energy storage target of 1,325 megawatts for 3 IOUs to be installed by the end of 2024 (CPUC mandate 2013). The target is divided in sub targets related to storage at the transmission level, distribution

level and at the end-user level, behind the meter. Targets are defined in power capacity (MW) without defining technology, ramp-up time, amount of energy (MWh) or duration. It is left to the market to determine what kind of energy storage is the most cost effective and adds the most value to the electricity system (Newman, 2013). The legislation aims specifically at stimulating new types of energy storage for electricity such as compressed-air energy storage (CAES), battery-based energy storage, thermal energy storage, fuel cells and other technologies. It rules out large pumped hydro storage. The mandate specifies that utilities cannot own more than 50 percent of the storage projects they propose. Intention of the mandate is that utilities collaborate with each other, with dedicated service providers and/or with customers (Newman, 2013). The 2024 target has been set based on an extensive stakeholder consultation process and simulation model that enabled stakeholders to rate the value of energy storage assets and services. The set amount is almost 3% of the average state peak load in 2010 (St. John, 2013).

Current status and expectations

In 2014, the first bi-annual procurement plans from IOUs were approved (CPUC 2014). The California Independent System Operator (CAISO) is dealing with a “large influx” of storage project proposals—more than 2.1 GW, three times as much capacity as is required by the first phase of the mandate.

Experts say that the state will turn into the world’s leading energy storage test bed (Hockenros, 2015). Policy makers see this regulation as a way to open up the market. *“This regulation suggests procurement targets for energy storage with the goal of market transformation. The hoped-for result is that when the energy storage market becomes sustainable, procurement targets for storage will no longer be needed and it will compete to provide services alongside other types of resources.”* (St. John, 2013).

4.3. Energy Efficiency

Q 24: Does energy storage play a role in realising more energy efficiency?

The role of energy storage in relation to energy efficiency is relatively marginal. In principle, storage will result in reduced overall efficiency as in each conversion step energy will be lost. However, energy cannot always be used immediately and the value of storage lies in avoiding wasting it and in balancing supply and demand. If the alternative is to stop renewables production or disrupt gas supplies, some incidental losses when storing energy is not very relevant.

In the case of self-production and consumption by prosumers, storage can have some contribution to increased efficiency. Some prosumers will see a challenge in becoming self-sufficient, limiting their consumption as much as possible to what their own production and storage can provide.

In itself, energy storage can be expected to become an important household appliance, for which the efficiency of the appliance is a relevant aspect. To support this expected market growth at the end-user level and guarantee services and quality offered by energy storage products, they should be included as a product group under the Energy Labelling and Ecodesign Directives. Standards, information and regulation on efficiency, safety, quality, performance, recycling and liability should be developed.

4.4. Climate Objectives, Decarbonisation and Share of Renewables

Q 25: Would energy storage help to decarbonise the electricity sector?

As described in section 3.3.1, Europe's policies for the reduction of greenhouse gas emissions and for the promotion of renewable energy have already resulted in a steep growth in the share of renewable energy sources, especially in electricity. Current electricity networks and markets were not designed for handling a large share of intermittent renewable energy. Energy storage itself does not reduce emissions and in fact, extra CO₂ emissions related to the construction and operation of storage facilities as well as from energy losses in the storage process may occur. But acting as a flexibility option avoids curtailment of renewable electricity production. By helping to control the output of the system, energy storage also helps to reduce the price volatility that may result in high levels of intermittency.

Q 26: How does grid priority for renewable electricity affect developments in energy storage?

Grid priority, or guaranteed access, for renewable energy on the electricity grid is an important aspect of the Renewable Energy Directive and the principle is also underlined in the Electricity Directive. In the evolution of energy policy, grid priority has improved the business case for investments in renewable energy and helping ensure that as much renewable electricity as possible is produced and fed into the system. In a system with a relatively small share of electricity from renewable sources this policy helps to increase its share. In systems with larger shares of renewable energy, grid priority also increases the need for flexibility. The issue is that grid priority rules are not accompanied with obligations or incentives for those generators to provide the system with flexibility as well.

Recently, the EC has limited the priority access for investments that make use of some form of state support and are, therefore, subject to the state aid guidelines. Since June 2014, state aid guidelines require that Renewable Energy Directive beneficiaries have balancing responsibilities (EC COM(2014) 200/01).

There are several options to incentivise generators to realise a more balanced feed in of electricity from renewable sources, even when no state aid is involved. For example, grid priority could be linked to a certain degree of flexibility provided by the generator, and feed-in tariffs or any other compensation could depend on the degree of flexibility offered. Such incentives will lead to generators to investing in flexibility, with energy storage being one of the available flexibility options.

4.5. Research, Innovation and Competitiveness

Q 27: Would energy storage make European energy prices more competitive?

Electricity from renewables (solar, wind) has the lowest marginal production cost and consequently comes first when merit order mechanisms are applied. Energy storage helps to integrate more renewable electricity at the most convenient time. Energy storage also has very low marginal costs and can further strengthen the position of renewables at expense of production capacity with higher marginal costs, such as coal and gas fuelled production units. Therefore energy storage contributes to lower wholesale energy prices and mitigates their volatility. If sufficiently competitive options for storage of electricity were available, these would compete with other flexibility options and with costs of grid strengthening. If competitive enough, energy storage has the potential to lower future electricity prices and make them less variable in time. However, at present, the costs for large-scale electricity storage options are high and its effects on the competitiveness of Europe's electricity prices will remain limited. As in other fields, innovation and

development may lead to the emergence of energy storage products that could increase competitiveness.

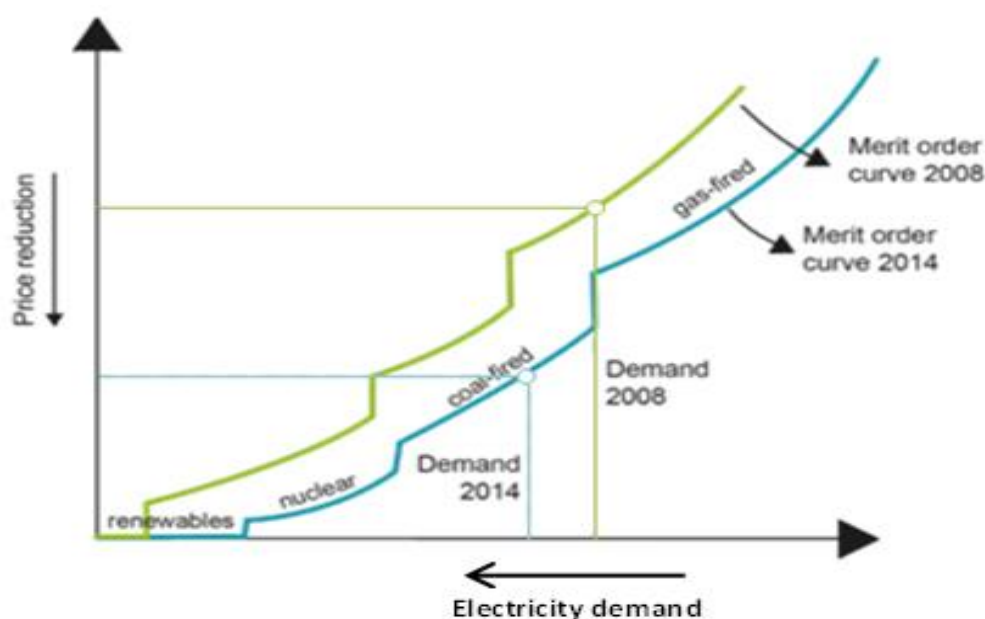
The Institutional Paper 'Investment perspectives in electricity markets' (EC, 2015f) discusses the merit order in view of the decarbonisation of the power system and proposes market arrangements to be explored. One of these arrangements is to reinforce price signals through scarcity pricing: prices should accurately and visibly indicate the needs for proper functioning of the power system in periods of scarcity and thus provide incentives for the use of flexibility measures such as storage and demand response.

Figure 11 shows the effect of increasing share of renewables on the energy price. According to the merit order mechanism, the energy price is settled at the point where the demand line crosses the cost curve. Increasing the share of renewables from 2008 to 2014 had the effect that gas fired power plants have been less used. This effect is more prominent if, in addition, the electricity demand decreases.

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Figure 11: Stylised Merit Orders for the years 2008 and 2014



Source: (De Meulemeester, 2014).

Energy storage may also play a role in relation to regional price formation. For example, in Italy, where 38.6% of the electricity demand is now covered by renewable energy sources,

limitations in transmission grid capacity are leading to regional price differences (D'Antoni, 2015).

These regional price differences will grow with increasing shares of renewable electricity production. These regional price differences can be expected to create a case for strengthening of the transmission grid (EEnergy Informer, 2014), and/or for competitive bulk electricity storage.

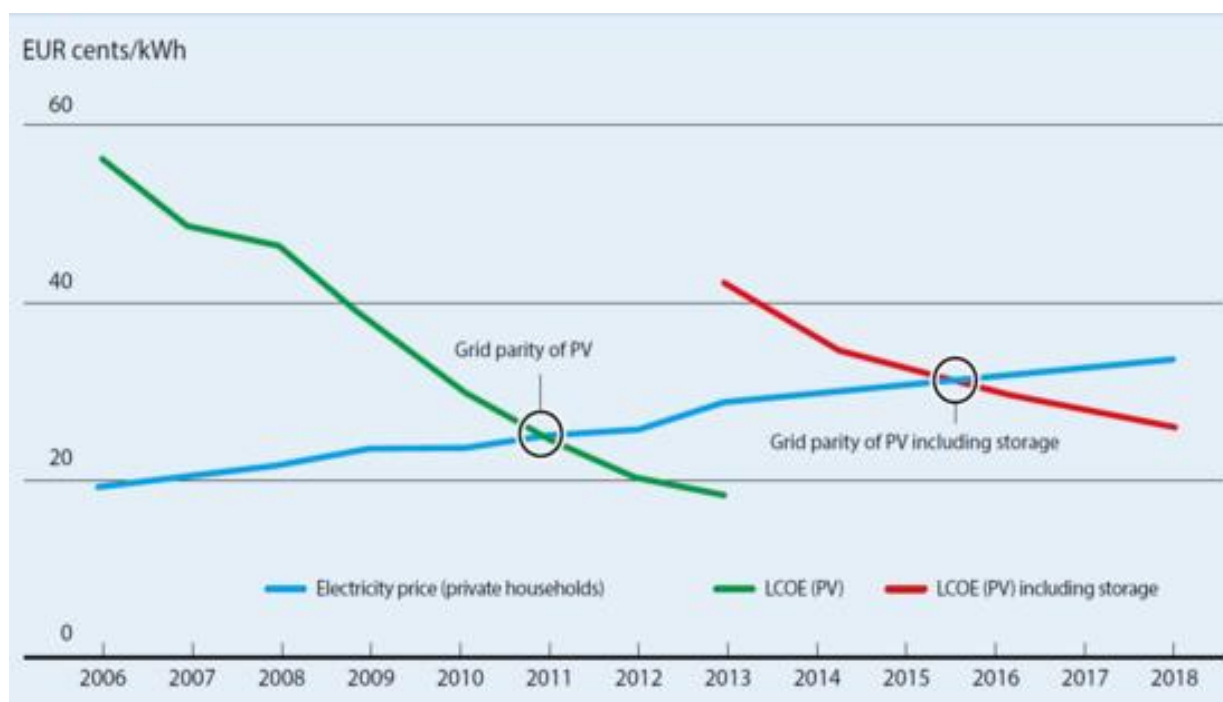
Q 28: How can local electricity storage influence electricity costs for end-users?

Local electricity storage may have larger implications for end-users though, especially the prosumers with 'behind-the-meter' renewable electricity production. The actual influence will be strongly related to the price evolution for solar cells and small scale storage.

Prices for small scale electricity storage and solar cells have been declining steadily and are expected to decline further. In most European countries, especially in South Europe but also in Germany and the Netherlands, decentralised PV has already reached retail 'grid parity': the levelised cost of electricity of PV 'behind the meter' has become lower than the retail price for electricity. This means that PV is economically attractive for the prosumer as long as the electricity produced can be consumed at retail price¹⁶. A household installation consisting of PV plus energy storage will reach retail grid parity in Germany already in 2016 (Roland Berger, 2015), see Figure 12.

The attractiveness of energy storage for prosumers depends strongly on retail electricity prices and on incentives and remuneration for renewable electricity production. If there is a price difference between self-consumed electricity and power purchased from the grid, this is an incentive to optimise self-consumption using local energy storage.

Figure 12: Grid parity of household PV and PV with storage in Germany



Source: (IRENA, 2015b).

¹⁶ As a rule of thumb, a household in Northwest Europe with a PV system would consume about 30-40% of the generated electricity at the moment of generation. The rest is delivered to the grid.

This could have large implications to the system if many end-users, especially in rural areas, switch to solar plus local storage. For distribution and transmission companies this would reduce the electricity volumes delivered, an effect called 'load defection'. End-users in climates with sufficient solar resources in winter might even choose to invest in larger storage units and go 'off-grid' altogether, causing 'grid defection'. As transport costs are primarily based on transported volumes, these companies could then expect their revenues affected.

Analysis by RMI (Rocky Mountain Institute, 2015) shows that grid defection of larger groups of customers would result in an increase of overall electricity system costs, compared to prosumers with solar cells and storage that stay connected to the grid.

Some EU Member States are considering controversial measures to protect revenues of grid operators. The Spanish government is, for example, considering taxation of local energy storage to discourage the use of batteries or other storage systems by people who produce electricity, with solar or photovoltaic panels for instance, and who are connected to the national power grid. Although this can be a short term solution, such a measure would not be in line with the long-term ambitions of the Energy Union concerning decarbonisation, cheaper electricity and security of supply.

Q 29: What research and innovation related to energy storage can help to strengthen EU competitiveness?

The EU and its Member States should stimulate R&D activities focused on cost competitive storage solutions for those services that will be of importance and are in line with the Energy Union's strategy. A high degree of load shifting flexibility can be provided by heat pumps and storage heaters for space heating as they are equipped with a distinct storage unit. These are non-expensive technologies with potentially a large impact as flexibility option. Smart grid developments, such as incorporating smart vehicle charging or vehicle-to-grid technologies (smart mobility) are promising areas for further development as well. These promising areas can create new employment and export opportunities for Europe. Efforts should be accompanied with the development of competitive industrial structures in storage production to ensure that storage will be available when demand increases.

5. THE STATE OF R&D AND PROMISING FIELDS OF FURTHER DEPLOYMENT

KEY FINDINGS

- Energy storage facilitates the deployment of smart grids, integration of renewable generation and electro-mobility in the networks, at the same time improving security of supply and efficiency of the system;
- Energy storage also facilitates the transition towards an energy system where customers can provide flexibility to the energy system, either with stationary batteries coupled with their own self-production generation units, or using vehicle-2-grid as a second application of their vehicle batteries. Regulation could promote smart grids to avoid grid defection;
- The business cases for storage in smart grids and for electro-mobility acting as storage option for the grid are, however, difficult at present due to the lack of tariffs differentiation and regulatory barriers;
- Industrial production of novel and improved energy storage technologies (in particular electrochemical storage) is marginal in Europe. Joint and common efforts of several EU institutions and stakeholders is required to achieve competitiveness in large scale production of storage technologies.

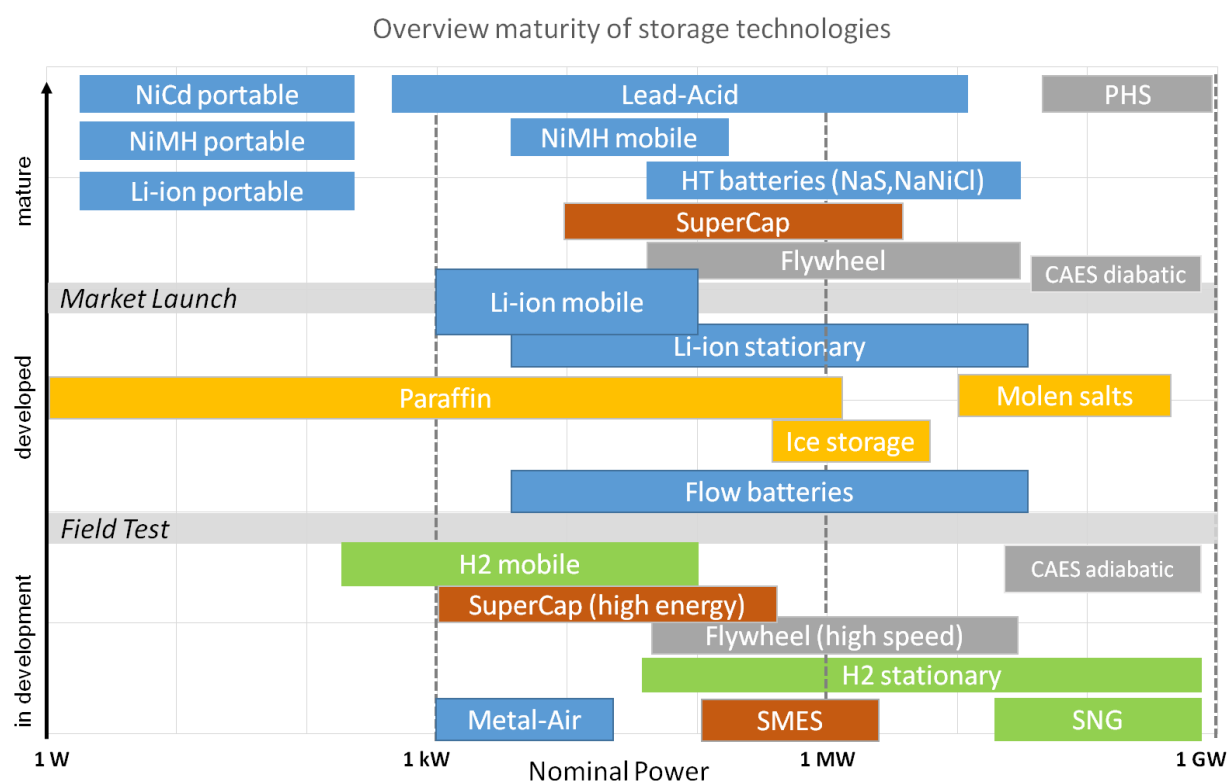
5.1. State of Play of Research & Development

This section gives an overview of research and development activities concerning energy storage. Technologies are presented by degrees of maturity and research activities by storage technology are highlighted. The data shown indicates what kind of technologies are in the focus of present research activities and which technologies could play a role in the future energy system.

Q 30: What is the maturity of different storage technologies and which technologies are in focus of R&D activities?

Figure 13 provides an overview of the maturity of different storage technologies. Some important highlights are:

- nicd, NiMH, Lead Acid and high temperature (NaS, NaNiCl) batteries have still some room for improvements and thus for R&D activities;
- LIB batteries have reached maturity for their use in portable devices and in the last 5-10 years they showed intensive research activity for stationary applications, mainly as large-format batteries for battery electric vehicles (BEV);
- flow batteries (RFB) are already used for large storage installations but have to prove their long-term stability;
- metal-Air (in particular Li-Air) batteries and also Lithium-Sulfur Batteries are still the subject of fundamental research;
- thermo-chemical energy storage technologies are developed and in use but also provide room for improved storage media;
- chemical fuels (hydrogen, SNG) also are still under development. Their use in the context of electric and stationary applications is strongly linked to the construction of a hydrogen infrastructure;
- Supercapacitors need still to be further improved towards high energy applications and SMES have to reduce their costs.

Figure 13: Maturity of different storage technologies

Source: Adapted from (IEC, 2011). Blue: electrochemical, red: electrical, grey: mechanical, green: chemical, yellow: thermal.

R&D activities are visualised in terms of publication and patent activities that respectively illustrate the level of research and of bringing technologies to the market. Figure 14 shows the relative publication intensity¹⁷ for various technologies compared to battery publication, indicating:

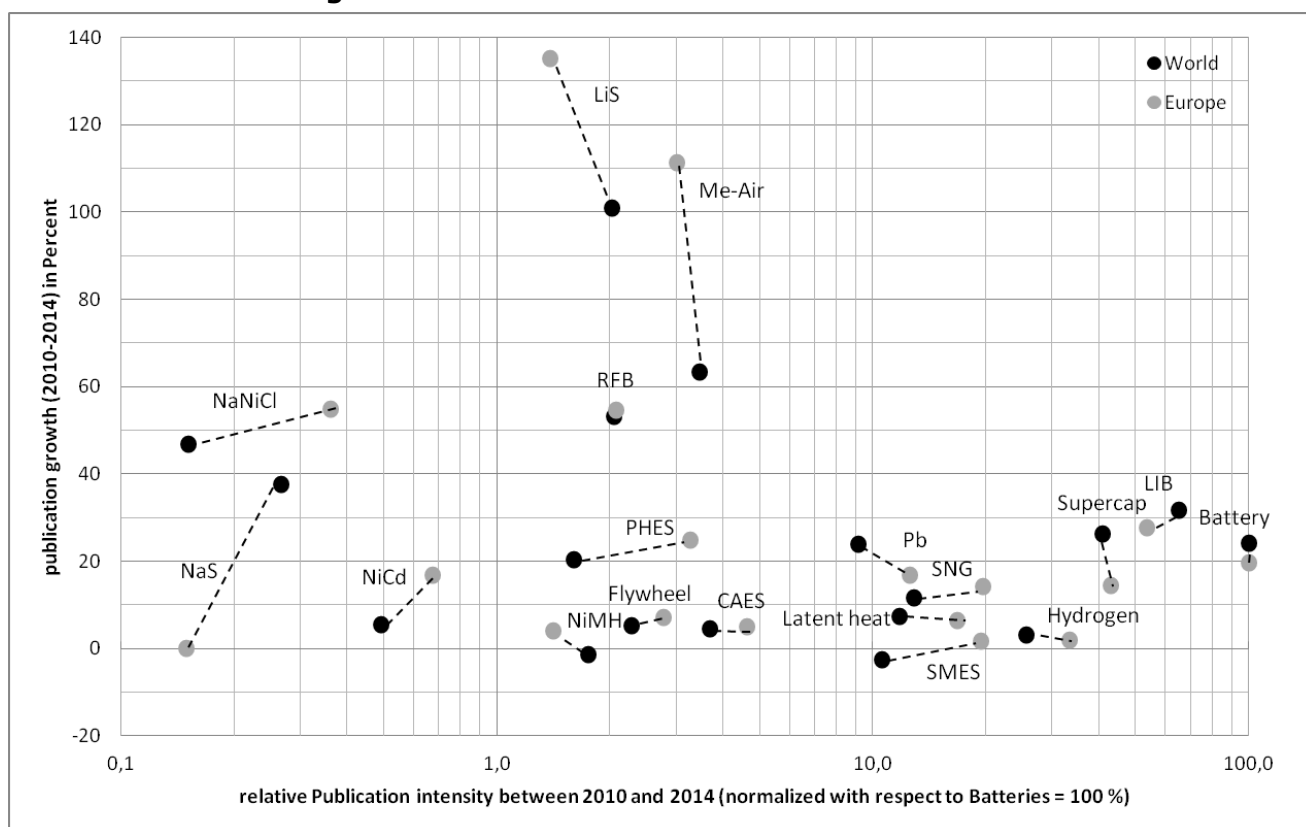
- very high share of publications for LIB batteries, mostly linked to R&D for electric vehicles;
- high research intensity for hydrogen storage and supercapacitors, followed by the other storage technologies;
- low publication intensity, but relatively high growth rate for RFB as well as high-energy next-generation battery technologies - Lithium Sulfur (LiS) or Metal-Air (e.g. Lithium, Zinc, Aluminium, etc. based), which are still in early R&D phases;
- the EU has comparatively a broader portfolio of technology research with some technologies showing a higher growth of publications and patent activities, for example, for flywheels, CAES and LIB.

Combining the information on market maturity (Figure 13) and R&D activities (Figure 14) illustrates which technologies may have a high potential for improvements. Europe's current focus on LiS and Me-Air technologies (relative to other countries, mainly Japan, South Korea, China, USA) can be understood, since Europe might lead in their development

¹⁷ Keyword based and mostly hierarchically organised search strings (e.g. LIB, RFB as sub-searches of batteries) have been formulated for ESS technologies and analysed via the Web of Science (WoS).

in the future technologies. The most active Member States in these R&D activities are Germany, France, Italy, Spain and the UK.

Figure 14 Publication intensity vs. growth in Europe and world for selected technologies



Source: (DOE, 2015).

Q 31: What main sources of funding are available for Energy Storage R&D in the EU?

In the past years, the EU Member States and the EC have been significantly investing in development of energy technologies (EEGI, 2014). The EU funded Grid+ project has identified 331 distinct projects (including in the EU and 14 Member States) with a total value of 2.6 billion EUR, whereof 1.8 billion EUR are devoted specifically to energy storage technologies¹⁸ (EEGI, 2014). Spain, France, Germany, Italy, Austria, Netherlands, the UK, Belgium and Denmark are among the Member States with highest project numbers and budgets.

The EU, and in particular Southern Europe, is heavily focusing on batteries. In addition, investments are also being made in Power-to-gas (e.g. Germany, Spain) and thermal storage. Mechanical storage (CAES, PHS) is well developed in Northern and Central Europe.

Most efforts on storage are research efforts; which is explained by the smaller investment requirements for such activities. Many projects cover the distribution and the end-user levels, whereas large and concentrated investments can be seen rather for transmission and generation-based storage. This illustrates that large and centralised storage technologies have been mature for a longer period of time. For the coming years, demonstration and pilot projects on distribution/local level are expected, in particular on electrochemical, chemical and thermal storage.

¹⁸ This is comparable to the full FP7 energy theme budget (2007-2013, ca. 2.2 billion EUR).

National governments are the main source of funding, although the EC's share is relatively high in comparison to general R&D spending in the EU (e.g. battery technology funding in Germany has only been much higher than on the EU level under FP7). The Grid+ study has found a contrast between EU15 and newer Member States from which no extra activity is reported.

On a global level, Japan (in particular the New Energy and Industrial Technology Development Organisation - NEDO) is the leader in investments in battery, fuel cells and other energy technologies. The USA (e.g. Department of Energy) is funding storage technologies, typically with the goal to get to transformative and particularly cost competitive technologies. Other global players such as China and South Korea invest in storage technologies as well, with the aim to export cost competitive solutions, especially those with potential for mass markets (e.g. batteries).

5.2. Smart Grids

The EU recognises the importance of smart grids in achieving its policy objectives. Within the TEN-E directive (Regulation 347/2013 on guidelines for trans-European energy infrastructure), 'smart grid' is defined as

"an electricity network that can integrate in a cost efficient manner the behaviour and actions of all users connected to it, including generators, consumers and those that both generate and consume, in order to ensure an economically efficient and sustainable power system with low losses and high levels of quality, security of supply and safety"

In principle, smart grids can refer to both transmission and distribution networks. This section deals with the analysis of further deployment of energy storage related to smart distribution networks and microgrids. The microgrid concept refers to electricity distribution systems that contain distributed energy resources, such as generators, storage devices or loads. Those can be operated in a controlled, coordinated way, either while connected to the main power network or while isolated.

Q 32: What is the benefit of storage in smart grids?

Part of the growth in renewable energies takes place at the distribution level. Distribution networks have not been designed for taking up large amounts of electricity, but rather for distributing it to final customers. Hence, if decentralised feed-in by renewable energy sources is large and/or takes place in regions with low demand, the networks reach technical limits more quickly. Moreover, as its production fluctuates, it is likely to provoke imbalances, deviations from voltage limits or violations of the thermal line limits. Expansion, upgrade and/or changes in the operational strategy are needed to cope with situations of local overload and power fluctuation.

Energy storage, both centralised and decentralised, can be one solution for a proper integration and management of renewable generators. A few examples are:

- the case study of the El Hierro island shows (see Box 6), that a PHS system, allows operators to keep the system balanced and stable. This storage system makes possible to deal with the fluctuations from wind turbine generation and provides efficient performance for the system with high level of quality and security of supply. The excess of electricity generation by the wind turbines is used for pumping water to the upper reservoir instead of curtailment. If there is a lack of generation, the water in the upper reservoir is used for generating electricity. PHS is also required because diesel engines as backup have a slower response than PHS;

- in the Bronsbergen holiday resort in Zutphen, Netherlands, the grid operator tests at present a smart microgrid. The system uses batteries to store unused electricity from PV panels and is operated in a way to minimise grid losses (IA Network, 2013);
- Germany deploys battery storage, Spain batteries and capacitors, and Slovenia uses capacitors in primary substations to optimise operation of distribution systems (Ref-e, 2015);
- other flexibility options can also be used to optimise the operation of distribution systems. In about half of the EU, DSOs use smart grid technology and/or flexibility options (i.e. interruptible loads) though mostly in demonstration projects. In France, ripple control of electric water heaters is used. In the Netherlands, flexibility is provided by demand side resources and decentralised generation. Also in other Member States, smart grid demonstration projects are realised such as in the UK, Italy, Austria (Ref-e, 2015).

However, conventional grid expansion in transmission and distribution networks is typically less costly than storage for Germany (Agora Energiewende, 2014 and Leuthold, 2015). Costs are driven by the necessary storage capacity that increases with the need to store peaks of feed-in in particular, even though these occur only very rarely. Storage becomes comparatively more attractive in situations with long distances to be newly built and high network expansion cost. Network expansion is sometimes difficult because of other problems, such as when lacking public acceptance and facing long realisation times. Also, if future development of load and generation is uncertain, network expansion may not be the optimal solution. Storage can be a (temporary) solution in those cases. It can alleviate network congestion and thereby provide the distribution network operator with time to consult on and develop a long term network expansion solution (Leuthold, 2015).

Box 6: Case study: Grid integration on El Hierro island, Spain

Security of power systems on islands is a key issue. System balancing requires short-response time generation technologies that can quickly respond to demand variations, due to their small size when compared to a continental power system. A shift from fossil-fuelled generation to renewable supply can require storage as a supply security measure.

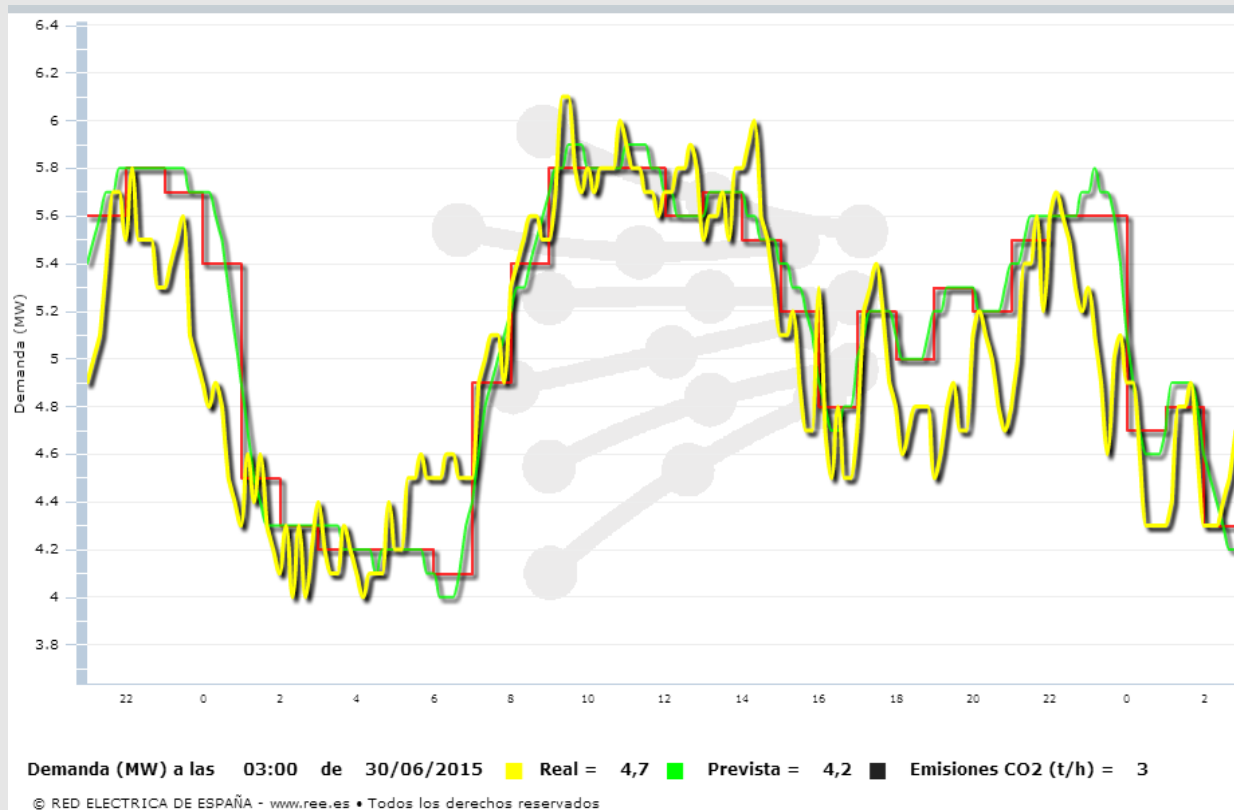
This is the case of El Hierro island, at the Canary Islands (Spain), with a total consumption of 42 GWh, with a peak demand nearly of 7.5 MW and valley demand of almost 2.6 MW. Demand traditionally has been met by the Llanos Blancos 13 MW fuel engine based power plant. With the aim of evolving to a 100% renewable power supply, 5 wind turbines of 2.3 MW each have been installed (11.5 MW in total) and a pump hydro storage (PHS) system has being built (6 MW of pumping power; 11.3 MW of generation power). This renewable system was designed to meet a demand of 48 GWh.

The wind turbines supply all electricity to the grid. The PHS system is used for balancing the power system. The engines are kept as a backup for a lack of wind resource or water stored in the upper reservoir. Current performance of such system during one day can be seen in

Figure 15 and Figure 16, which shows how the demand varies and how the generation system covers such demand, illustrating that the PHS system has to fill the gap between demand and generation.

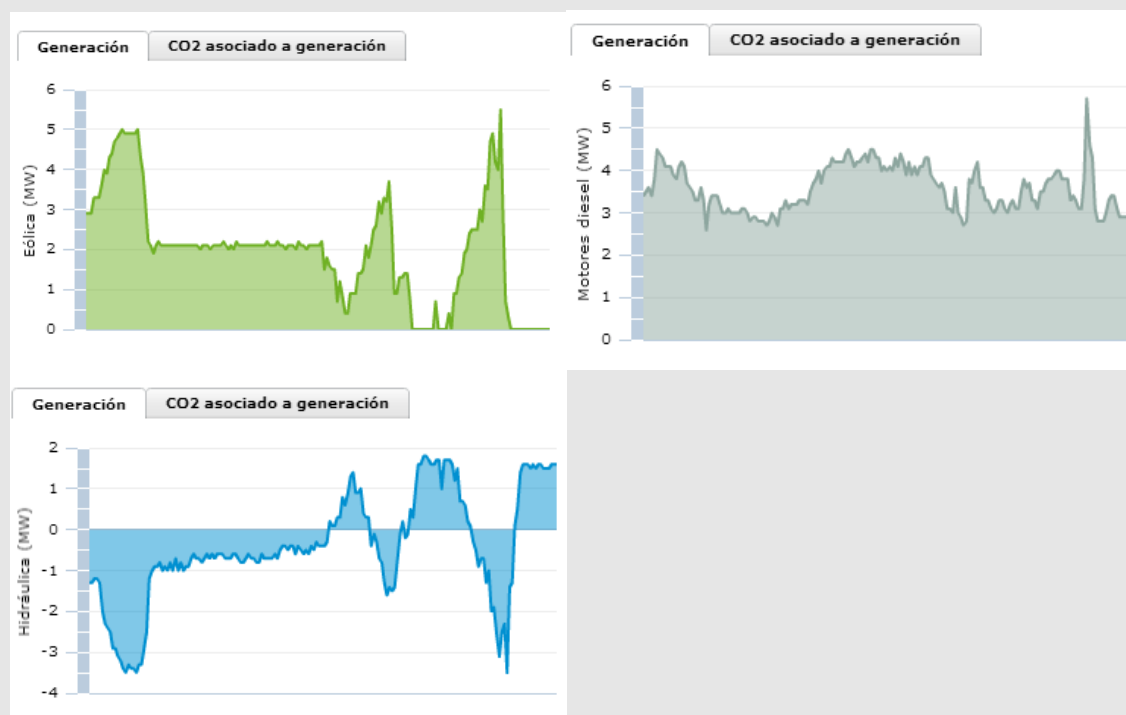
The promotion of this system has taken 10 years and its construction 4 years. It was inaugurated in June, 2014. In its first phase, it expects to achieve 80% renewable generation, to save 1.8 M€ annually and to avoid the emission of 18.7 tn CO₂, 100 tn SO₂ and 400 tn NO_x.

Figure 15 Real demand curve (yellow), forecasted demand (green) and generation scheduled (red) on 29th June 2015 at El Hierro Island.



Source: Red Eléctrica de España <https://demanda.ree.es/visionaCan/VisionaHierro.html#>.

Figure 16 Real Wind turbines generation (left), diesel engines generation (centre) and pumped hydro system (right) on 29th June 2015 at El Hierro Island



Source: Red Eléctrica de España <https://demanda.ree.es/visionaCan/VisionaHierro.html#>.

Storage can provide grid services such as voltage control, power flow control and balancing (see section 2.2). It can reduce peak feed-in e.g. from PV installations or wind power but also increase feed-in in times of undersupply. This can be highly beneficial when feeders would otherwise experience voltage problems requiring a grid upgrade. The benefits are highly case-specific, however. If the feeder is not experiencing these problems, the benefits of local storage are small (Willard, 2014). Storage can also contribute to power quality and continuity of supply, thereby reducing customer outage costs. These benefits, however, are difficult to quantify.

Storage can also mitigate future peak demand increases that may occur, due to diffusion of electric vehicles and heat pumps, by shifting part of that demand. The use of storage for the network purposes described above requires a “network oriented” operation of storage. Benefits of storage technologies are achieved if they are deployed together with Information and Communication Technologies (ICTs) in order to allow proper grid operation and management.

Q 33: How is the potential use of smart grid storage different for end users and network operators?

Storage can also be installed by private actors in commercial areas, homes and buildings, either as single installations or within microgrids. End users will typically operate storage to their private benefit, e.g. for local energy management to optimise own-consumption and in combination with external power procurement. For private consumers, this often implies maximising on-site consumption since power prices and network tariffs are often based on the kWh.

In some countries network tariffs are capacity based (per kW). In those cases, storage can be used to minimise peak demand and thereby optimise network connection costs. Also, commercial or industrial users could use storage for peak shaving to reduce capacity-based payments for network utilisation. Another application is the realisation of arbitrage in the power market. In this case, their operation is based on price signals, i.e. typically the spot price or the retail tariff “market oriented”. Other benefits are autonomy and the possibility to disconnect from the main grid.

Microgrids are designed to be able to operate in island mode, i.e. without connection to the main network, to protect users from grid instability or disasters. In this mode, storage provides the flexibility to balance local supply and demand, absorbing all remaining deviations, as can be seen in

Figure 16 (right side) of the El Hierro Case Study. In grid-connection mode, microgrids can support the distribution network via local flexibility reserves from controllable loads and storage. Also storage installed for private purposes such as procurement optimisation can provide network services as a secondary use case. Since they are mainly refinanced via their first activity, they could likely offer network services at very competitive cost (Agora Energiewende, 2014).

Q 34: How does the operational strategy influence the potential benefits of storage for smart grids?

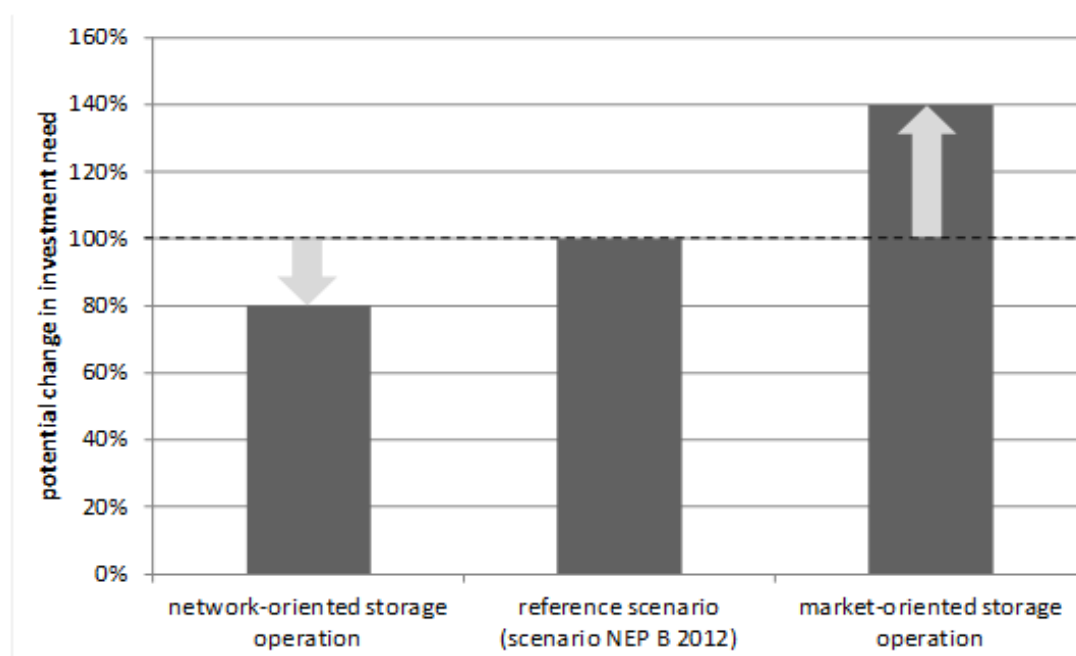
The contribution that storage can make to smart grids will heavily depend on the operational strategy. The two contrasting operational strategies at present are market-oriented and network-oriented operation.

Market prices at the distribution level in EU Member States are not differentiated by location, hence, they do not include network conditions. As a consequence, market-based operations can cause congestion in the network and lead to suboptimal results at the system level. For the case of Germany, Dena estimates that, while a network-oriented operation of energy storage can reduce the expansion needs for the system by 20%, a

market-based operation could increase it by roughly 40% (Dena, 2012) (see Figure 17). A study from TU Delft compares the impact of optimised electric vehicle charging to uncontrolled charging for the cost of network reinforcement and calculates 20% savings for Dutch distribution networks (Verzijlbergh, 2013). A combination of both strategies is possible in the form, that market-oriented operation is limited in critical network situations.

A special form of market-oriented operation is the use of storage to maximise own consumption. This model will likely increase as PV-installations increasingly reach grid parity. But, even though self-consumption reduces grid use, it does not necessarily contribute to smart grids. Also, peak demand may be unaffected and network may be even strained with uncoordinated self-generation/ consumption (EDSO, 2015).

Figure 17: Potential impact on network investment from storage operation for German distribution networks until 2030



Source: (Dena, 2012).

The operation of a storage installation will be dependent on the incentives and benefits of storage for the different users. These, in turn, are influenced by regulation and market design, which currently do not particularly favour network-oriented storage utilisation. The main factors influencing decentralised storage in smart grids are:

- lacking price differentiation: The market prices important for storage operation are rarely differentiated to reflect the network conditions. This implies that they currently do not incentivise storage operation to provide network benefits;
- few rewards for provision of system benefits: there is no consistent framework for rewarding potential contributions from storage to system stability, as these services have been present without further intervention because of the technical characteristics of conventional generating capacity;
- unbundling requirements: Storage deployment may suffer from uncertainties about unbundling requirements. These uncertainties may differ depending on the purpose of the storage (Beck et al., 2013), and may prevent the use of network storage for market benefits, or vice versa. The operation of storage by third-party service companies can be a solution;

- energy-based network tariff systems: Most EU Member States have volumetric grid tariffs (per kWh) for residential consumers. Such network tariffs favour the use of storage to minimise consumption from the grid rather than providing flexibility. Recently, there seems to be increasing interest in implementing a capacity-based component in the network tariff. In Italy, consumers pay for the size of their connection (by default, 3kW¹⁹). Additionally, network tariffs on self-generation installations are levied depending on the capacity (COM, 2015). The Netherlands introduced capacity-based network charging in 2009 (Kieft et al., 2009). In Spain, tariffs already comprise a capacity-based component in addition to a volumetric charge, but an increase of the capacity-based part is being discussed (CNMC, 2014). Capacity-based tariffs could provide better incentives to provide flexibility or use storage to minimise peak demand²⁰. Also, network tariff schemes for commercial users may contain barriers for the flexible use of storage for system benefit;
- standardised load profiling: Households and smaller commercial users are often billed based on standardised load profiles. Hence, real changes in consumption behaviour do not lead to monetary gains (or losses) either for consumers or for suppliers;
- barriers for DSOs: Last but not least, there are legal and/or regulatory barriers for network operators to deploy flexibility-based solutions (SGTF-EG3, 2015). Distribution network operators may be reluctant to deploy innovative solutions, including storage, if they fear that the costs are not recognised in the fees that they are allowed to charge.

Q 35: What is the relationship between energy storage and smart grid policies?

Römer et al. (2012) find that decentralised energy storage is socially desirable, but the benefits are split among many different actors. In the near future, storage is unlikely to generally be an economically viable alternative to network expansion both for transmission and distribution networks. It seems to only be beneficial in specific cases. However, significant amounts of storage are expected within the distribution networks, motivated by other uses such as electric mobility or household storage systems (Agora Energiewende, 2014). These installations could theoretically provide network services as secondary activity if they have incentives to do so, which is currently usually not the case.

Römer et al. (2012) conclude that underinvestment in socially-desirable decentralised storage is “a likely threat”, as, in many cases, private benefits do not outweigh private costs. In the major smart grid projects that started in 2012 and 2013, the “use of storage as additional source of grid flexibility is one of the key themes” (JRC, 2014)²¹. Budget allocated to storage in smart grids also increased in the R&D roadmap 2014-2016 for the European Electricity Grid Initiative (EEGI - one of the European Industrial Initiatives under the Strategic Energy Technologies Plan (SET-Plan)). They foresee 100 M Euro (around 10% of the total budget) for storage integration into network management. This is 60% above the originally-planned budget, even though the total budget declined (EEGI, 2014).

¹⁹ http://www.autorita.energia.it/atlane/it/elettricit/capitolo_2/paragrafo_1/domanda_6e.htm. Last accessed 22.07.2015.

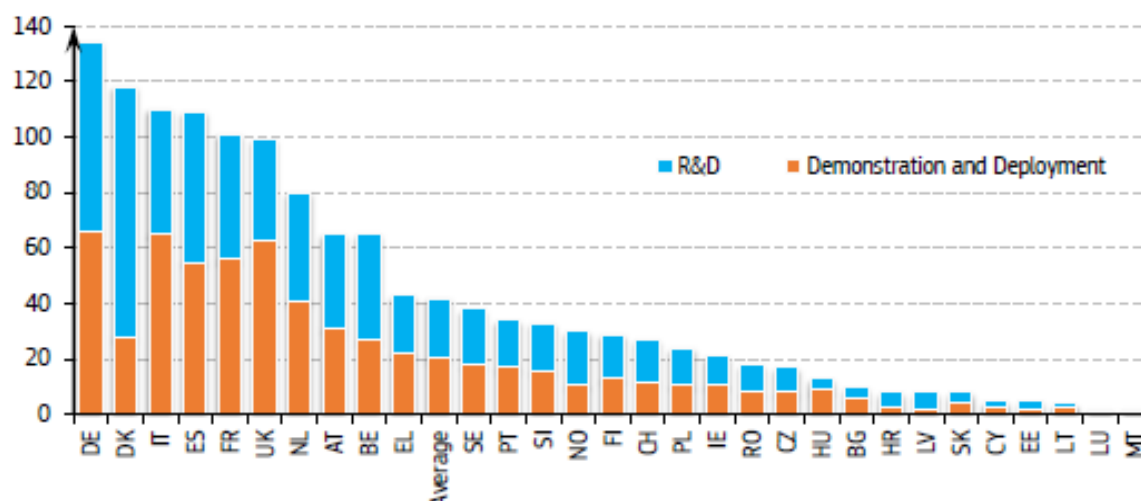
²⁰ They are also a way to make network tariff payments less dependent on the share of self-generation and have consumers with self-generation contribute more to network cost.

²¹ The European Smart Grid Technology Platform installed a working group on energy storage and grid integration, which aims to provide a vision on the integration of storage into the grid while respecting cost and benefits. <http://www.smartgrids.eu/node/146>.

Most smart grid projects are realised in Western European countries and almost equally include a mix of R&D and demonstration and deployment projects. Support programmes play an important role in driving these activities: 90% received some form of public funding (JRC, 2014). Projects in Eastern Europe also mainly receive public funding.

The list of Projects of Common Interest features two projects in the area of smart grids: North Atlantic Green Zone Project (Ireland, UK) and Green.Me (France, Italy). Also, a new project SINCRO.Grid (Slovenia, Croatia) has been submitted. All three projects include the use of storage (Zucker, 2013).²²

Figure 18: Number of smart grid projects per stage of development and country



Source: (JRC, 2014).

Market design and provision of incentives

The issue of storage in smart grids should not be addressed in isolation, but jointly with other flexibility resources such as demand side response, flexible generation or sector coupling. Within smart grid activities, a further differentiation of tariffs is often discussed (SGTF-EG3, 2015). This would make diverse flexibility options more attractive and would also benefit storage. The differentiation could be temporal, but also spatial and, hence, include network characteristics. Such developments address the problem of flexibility, e.g. from storage, but also other from other flexibility options that can be traded to access the value they can bring to the system. For small resources, it is essential to remove barriers for aggregators (ENTSO-E, 2015).

5.3. Electro-mobility

Q 36: What is the potential role of electro-mobility as storage option for the EU energy system?

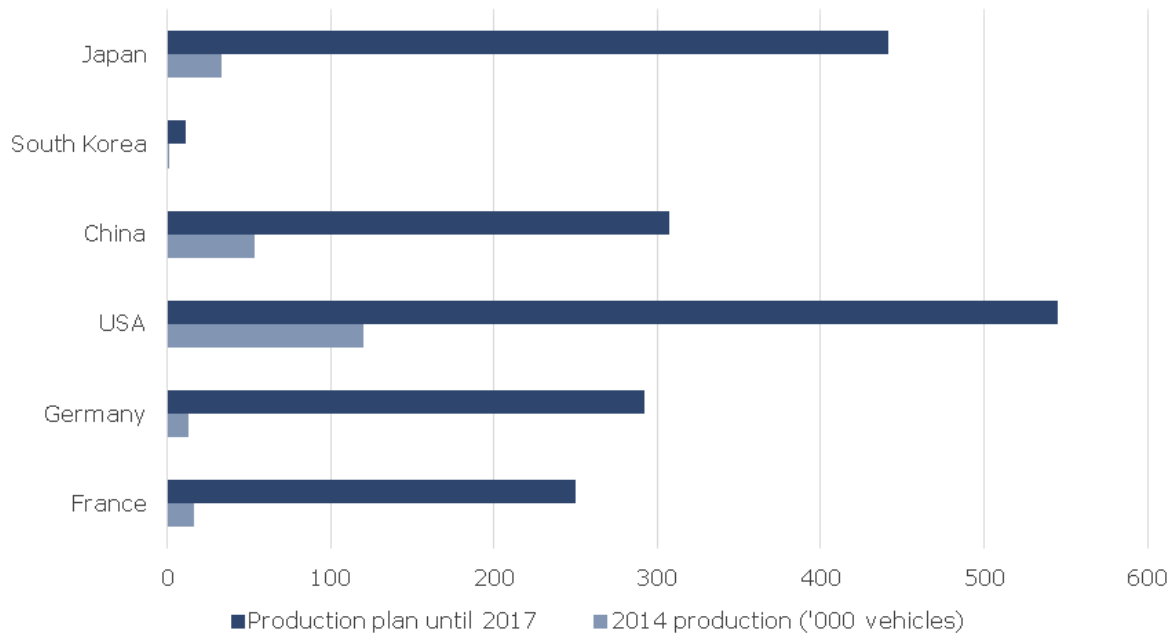
Electro-mobility represents the concept of using plug-in electric vehicles (PEV) in combination with charging stations, electricity production infrastructure and information and communication technologies. PEV includes battery vehicles (BEV) and plug-in hybrid electric vehicles (PHEV) as well as range-extended electric vehicles (REEV). All PEV can be driven with electricity alone and charged at the power mains.

Global PEV stock has surged, rising from 180,000 PEV on the road in late 2012 to 665,000 at the end of 2014. Figure 19 shows the 2014 production of PEVs in major producer countries. The three countries with the highest percentage of global EV stock include the

²² <http://www.eles.si/en/sincrogrid.aspx>, last accessed: 22.07.2015.

United States (39%), Japan (16%), and China (12%). Sales of PEV in Europe have risen rapidly too. Figure 20 shows the market share of PEV sales in leading European countries in comparison with the three largest global players. Sales figures are strongly linked to support schemes in the countries (IEA, 2015b).

Figure 19: Production of PEVs in major countries



Source: Data from (Bernhart, 2015).

Vehicle electrification has also gone multi-modal, with 46,000 electric buses and 235 million electric two-wheelers deployed in the world by the end of 2014. (IEA, 2015b).

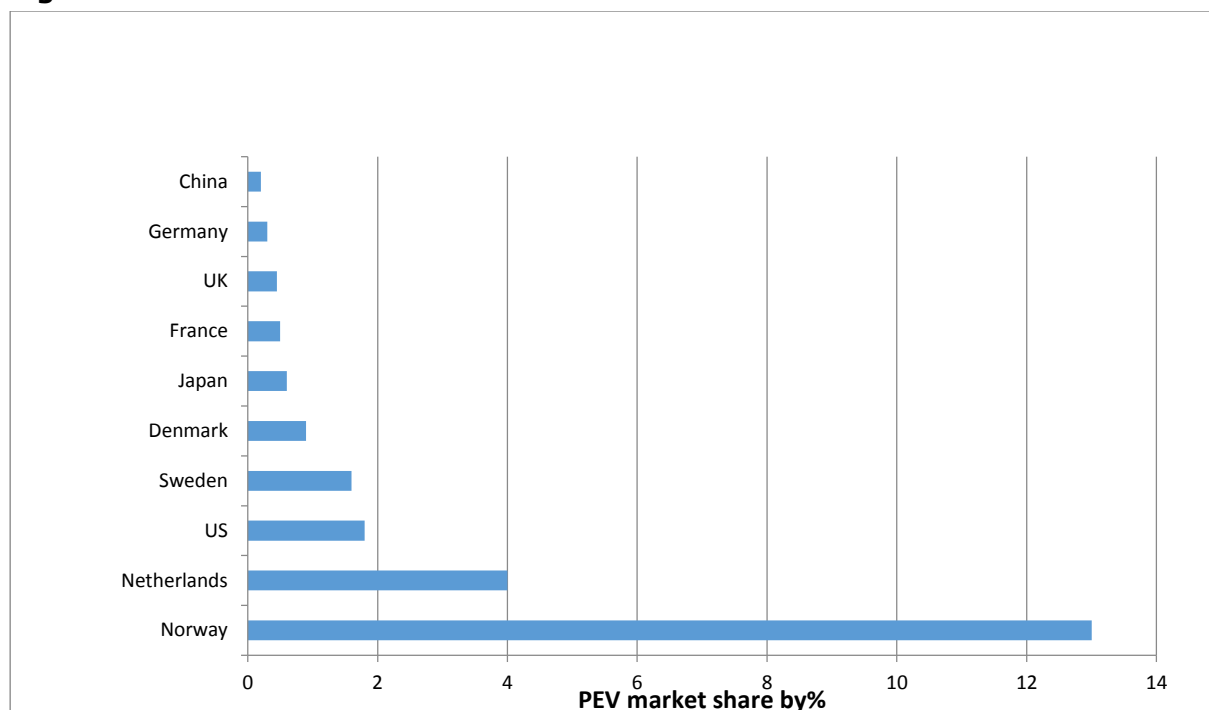
At present, PEV represents only 0.03% of the total passenger car stock in the world. Its rapid growth in the past three years makes PEV a promising global market, however. France and Germany, for example, have a strong commitment to support the development and market penetration of PEV. Germany's target is to have one million PEV operating on German roads by 2020. By 2020, the French government aims for two million. All EU countries together have a target of around eight million PEV by 2020 (EC, 2013b). Technological improvements, like energy densities and falling prices for LIB batteries, are expected to make PEVs technically and economically competitive to conventional fuel vehicles in the near future.

Three fourths of all vehicle sales in the world by 2050 would need to be PEV to meet the 21% share of CO₂ emissions reduction allocated to the transport sector to limit the average global temperature increase to 2°C by 2050 (IEA, 2014a). The EU has set the goal for a reduction of 60% of all GHG emissions from the transport sector compared to 1990 by 2050. This implies a reduction of vehicle emissions to 20 g CO₂/km in 2050. Alternative fuel vehicles in general, but in particular PEV or fuel cell electric vehicles, are needed to reach this target.

The promising outlook for PEV makes them interesting as energy storage option for the EU energy system. Vehicles of European private car owners are parked 95% of the time. Therefore, the batteries of PEVs can be used as flexible storage option. The use of PEV as energy storage option offers a second application field, which could be attractive from an economic viewpoint.

In addition to the reduction of oil imports and usage, demand of electricity would increase significantly, by around 10% in the EU if PEV becomes dominant in the transport sector. This will allow for larger integration of electricity produced from renewable energy sources. These will benefit job creation and welfare growth in the EU. The GHG emissions will also decrease significantly, if the electricity comes from renewable or other sources with low GHG-emissions. Further, the growth of PEV has the potential to unlock innovation and create new advanced industries with job growth and enhance economic prosperity.

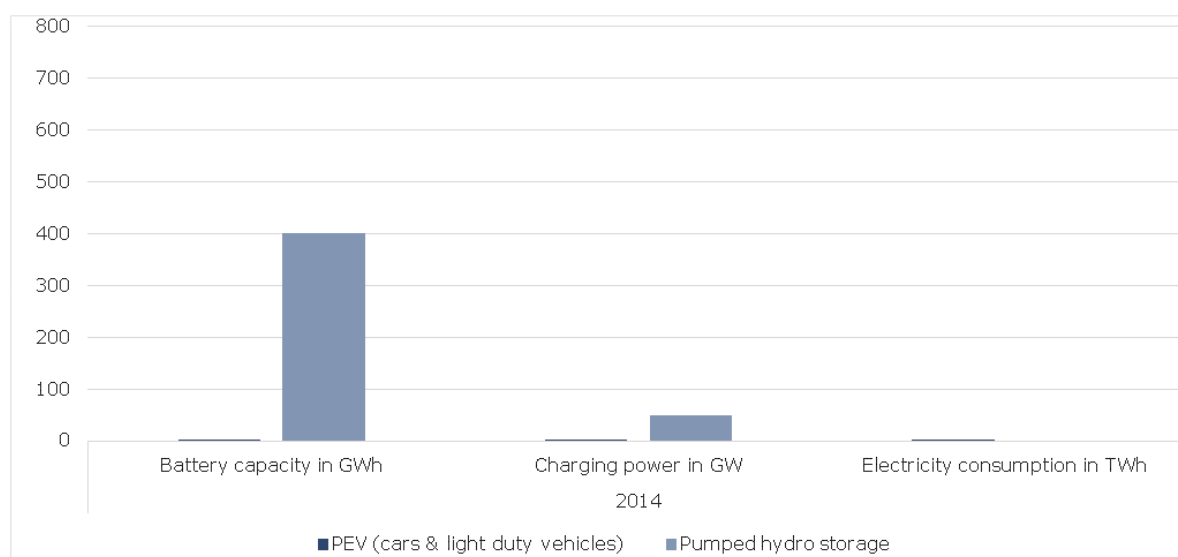
Figure 20: PEV market sales shares of different countries in 2014

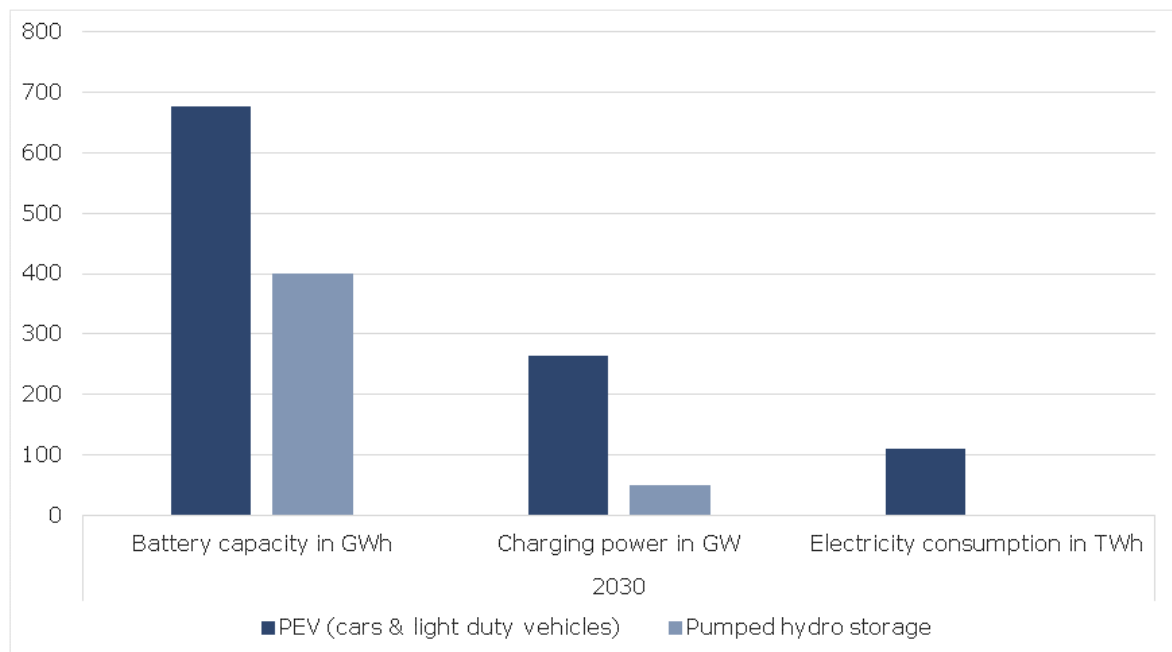


Source: Data from (IEA, 2015b).

Figure 21 shows the storage potential from PEV compared to PHS assuming an optimistic market penetration of PEVs by 2030. Whereas, currently, the storage potential from PEV doesn't play any role, PEV can be of higher importance compared to PHS in 2030.

Figure 21: Capacity and power comparison between storage from PEV and PHS in the EU for 2014 and 2030



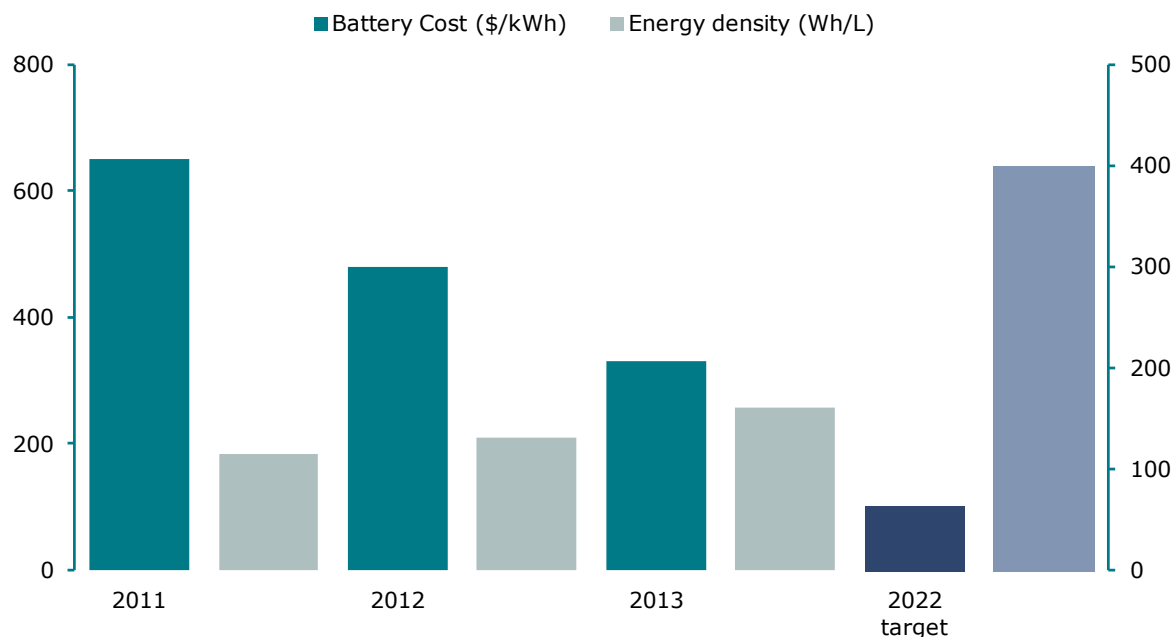


Source: Authors. Own calculation, assumption: 14% PEV market penetration.

Q 37: What are the perspectives for automotive battery development and production in the EU?

The most relevant challenges for the future development of PEV are the cost and energy density of traction batteries. One third of the retail price of PEVs is accounted for by the battery price. Most consumers find the 80 to 150 km driving autonomy offered by most PEV producers a major purchase barrier. Cost and energy density of batteries for PEV have been steadily improving and it is expected that this trend will continue (see Figure 22).

Figure 22: Cost and energy density of PEV batteries

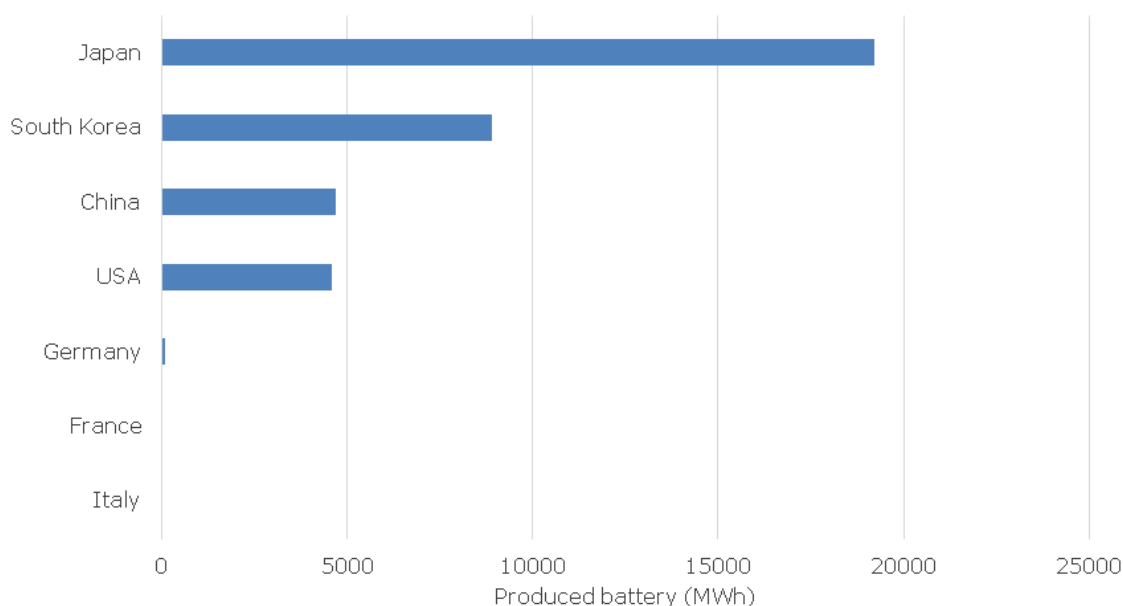


Source: (IEA, 2015b).

These improvements will have relevant spill over effects for other markets, such as for PV-batteries. Some of the automotive battery manufactures, like Tesla/Panasonic or Daimler/Deutsche Accumotive, have announced their entrance to the stationary batteries

market. Mass production of LIB batteries at competitive costs will lead to benefits for stationary storage applications at the end-user level.

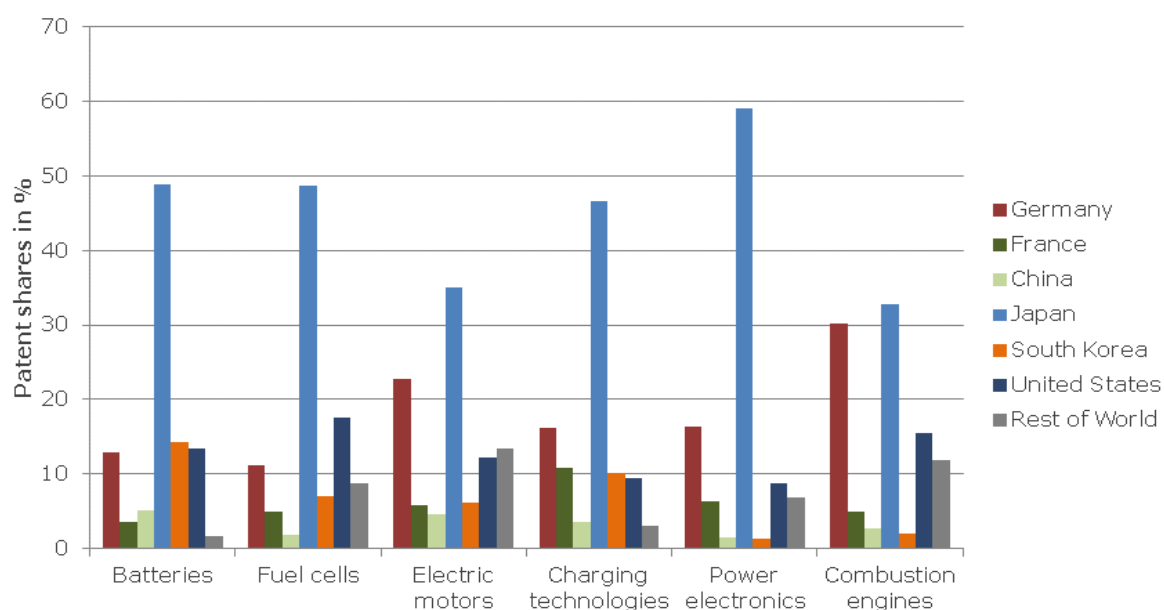
Figure 23: Production of batteries for PEVs and hybrid vehicles 2013



Source: Data from (Bernhart, 2015).

Germany and France are the most prominent EU Member States in the production of PEV (see Figure 19), however their production of batteries for PEV is insignificant (see Figure 23). R&D activities in both countries rank at the level of largest producer countries (see Figure 24). Being competitive at large-scale production of batteries for PEV and for stationary applications will require a joint and common effort of several EU institutions and stakeholders.

Figure 24: Patent shares of electro-mobility technologies for major countries



Source: (Fraunhofer ISI, 2014).

Box 7: Case study: Vehicle to Grid in Germany

Vehicle-to-grid (V2G) describes a system in which plug-in electric vehicles communicate with the power grid to sell demand response services by either delivering electricity into the grid or by throttling their charging rate. Since most vehicles are parked an average of 95% of the time, their batteries could be used to let electricity flow from the car to the power lines and back.

In a case study for Germany, the capability of PEVs was investigated to balance intermittent renewable energy sources (RES) (Dallinger, Wietschel, 2012).

One conclusion is that PEVs provide a very high power/energy ratio. Compared with other storage devices, PEVs are able to offer a high total connection power. A fleet of 12 million PEVs can provide power totalling 54.12 GW (2030 scenario) with a relatively low usable amount of battery storage of 123.95 GWh (ratio 0.44). However the driving behaviour restricts the use of mobile storage. This situation will improve in the future due to better batteries as well as more PHEVs in comparison to BEVs, which is an emerging market trend.

The main purpose of PEVs is to fulfil mobility needs at equivalent costs to those of conventional vehicles. A cost-sensitive consumer will maximise the distance driven electrically in order to recoup the higher initial investment of PEV compared to conventional vehicles (whereas the fuel cost of PEVs are lower). This implies high utilisation of the battery and therefore reduces the time period available for load shifting and/or vehicle-to-grid services. PEVs are therefore utilisable as a short time storage option (1–2 days) with limitations (e.g. infrastructure or consumer needs) in the load management time during the day.

The introduction of control mechanism is necessary to realise demand shifting; but the consumer reaction to price signals is unclear, because economic incentives from electricity markets are low. The current base peak spread at the European Energy Exchange (EEX) is only about 3 ct./kWh.

The case study shows that PEVs can contribute to balancing intermittent renewable energy sources in Germany. The number of hours with a surplus of electricity, which means that the generation of intermittent photovoltaic and wind power plants is higher than the assumed demand, could be reduced significantly. Nearly 3 TWh, or around 50%, of the negative residual load (so called surplus electricity, which cannot be used for other purposes) can be consumed using load shifting of PEV due to the higher utilisation of power from German wind parks during night-time hours.

6. CONCLUSIONS AND POLICY RECOMMENDATIONS

The Energy Union strategy has five closely interrelated dimensions that aim at bringing affordable energy, greater energy security, sustainability and competitiveness to households and businesses in Europe:

- energy security, solidarity and trust;
- a fully integrated European energy market;
- energy efficiency contributing to moderation of demand;
- decarbonising the economy;
- research, innovation and competitiveness.

Energy storage has the potential to play a role in achieving each of these dimensions. In the short term, the need for additional storage capacity is limited and the economic situation is, in general, not very favourable for new installations. However, in the longer term, more flexibility will be needed if higher shares of renewable energy are integrated. Energy storage, next to demand side management, grid interconnections and new flexible power generation units, are the available flexibility options to the system.

To fully unleash the potential of energy storage, technological developments need to be complemented with coherent policies that recognise the value of services offered by energy storage and, in particular, the flexibility services. Adaption of existing policies and new regulations for flexibility options are needed to ensure free and non-discriminatory market access for all flexibility options, including energy storage, on a basis ensuring fair competition. Such a framework should differentiate between different steps in the energy value chain (i.e. energy sources, generation, transmission, distribution, and end-user), as the requirements differ between them. Within this framework, it will become clearer to what degree and in which circumstances cost and technical development of storage can prevail against competing technologies.

Table 6: Policy recommendations for energy storage in the EU

Step in chain	Energy/ fuel source	Generation	Transmission	Distribution	End-user
Contributes to					
Research and innovation	(1) Invest in R&D to achieve competitiveness				
Market integration	(2) Remove barriers to gas storage	(3) Incentivise competitive storage	(4) Provide equal access to flexibility markets	(5) Allow ownership and control of storage	(6) Stimulate storage
Security, solidarity, trust					
Decarbonisation					
Energy efficiency					

Source: Authors.

In this chapter key findings of the study have been summarised in six overall conclusions. These conclusions are related to their impacts to the energy value chain and to the five dimensions of the Energy Union strategy.

Six policy recommendations associated with these overall conclusions are proposed in the following sections, in case it is concluded that further support to energy storage is desired to help achieving the ambitions of the Energy Union (see Table 6).

6.1. R&D to Achieve Competitiveness

Industrial production of novel and improved energy storage technologies (in particular electrochemical storage) is marginal in Europe compared to the activities and rapid developments in the United States or in Asia, and in particular in Japan, South Korea and China. Europe is increasingly investing in research and development of several storage technologies, including Lithium-Ion batteries, Redox flow batteries, thermal storage technologies, hydrogen storage and power-to-gas technologies. An increasing number of projects leading to scientific publications and patent activities and thus knowledge in these fields are receiving public and private financial support.

Europe can play a role in the rapidly expanding market, both in developing technology and in developing tools, products and services for integrating storage into electricity networks and at end-users. However, several bottlenecks, from institutional to financial, still hinder the further R&D, especially the high initial investments for large-scale demonstration projects. EU's preparedness to face the upcoming demand in technologies for small- to large-scale storage services primarily depends on the competitiveness that it can achieve in the related technologies.

Recommendation 1

If the choice to support energy storage is made, the EU and its Member States should stimulate and invest more in R&D activities and product development into promising directions to become competitive in storage technologies. Such innovations can create new employment and export opportunities for Europe. These efforts should be accompanied by the development of competitive industrial structures in storage production to ensure that storage will be available in the future, when the demand for these technologies will increase. Focus should be put on cost competitive storage solutions for those services that will be of importance and are in line with the Energy Union's strategy. This requires increasing value-chain thinking and a systemic view to select the most promising development pathways.

A high degree of load shifting flexibility can be provided by heat pumps and storage heaters for space heating, as they are equipped with a distinct storage unit. These are inexpensive technologies with, potentially, a substantial impact as a flexibility option and they should be developed further. The R&D strategy of Europe should also promote smart grid developments, incorporating smart vehicle charging and vehicle-to-grid technologies (smart mobility), but also recognise and realise chances of future smart cities. A regular exchange of experiences from past projects and activities, including stakeholders along the energy value chain and across storage technologies, could help sharpening such a strategy. The EC has suitable instruments to promote R&D on all different storage technologies. These instruments include the Horizon 2020 Program, the NER 300 Program, the European Economic Recovery Program and the Strategic Energy Technology Plan (SET-Plan).

These policy actions would contribute to the dimension of research, innovation and competitiveness of the Energy Union strategy.

6.2. Barriers to Gas Storage

Energy storage in all its forms adds buffers to the electricity and gas systems, contributing to resilience and to energy security. Gas storage plays an important role in providing energy security, but a significant increase in gas storage capacity across all Europe does not seem to be necessary, as the present storage capacity is, in most places, sufficient and demand of gas is expected to decrease until 2030.

However, regions with greater dependency on gas imports from outside the EU face security concerns. The profitability of existing gas storage facilities, actual utilisation levels of storage and access in times of crises are all barriers to address when increasing gas storage capacities for these regions.

Recommendation 2

Improve regulations by removing possible barriers that may hinder new gas storage capacity, especially in regions vulnerable to lack of supply. It is recommended that regulations addressing the security of gas supply be made more specific on required strategic stock levels, relative also to interconnection capacity and to local production. Cross-border use of gas storage capacities between Member States should be intensified in order to strengthen energy security, especially in emergency supply situations. Implementing these actions would not only contribute to energy security, but also to the integration of the European energy market.

6.3. Storage for Renewable Energy Producers

The Renewable Energy Directive (RED) stipulates priority access to the grid for electricity produced from renewable energy sources, but it does not give such operators any responsibility of contributing to system balancing.

Large-scale storage associated to centralised renewable energy production could effectively contribute to system adequacy. Large pumped hydro storage is cost competitive and already plays an important role in providing flexibility to the energy system. In the short term, there are no other storage technologies foreseen that can compete as well, but in the longer term, some other options could improve their business cases and become competitive. The profitability of large storage facilities has diminished in recent years due to the also decreasing spread of peak/base day-ahead prices.

Recommendation 3

Conditions could be improved for energy storage to be associated with centralised renewable energy projects. Recent Member State rules (EC 2014/C 200/01) stipulate that generators receiving state aid should at least adhere to standard balancing requirements. There are several options to provide incentives to larger renewable energy producers to realise a more balanced feed in to the grid.

It is recommended to investigate what the most effective options are. For instance, the EC Infrastructure Package exempts PHS from its financing provision, which could be reevaluated.

A common approach at the EU level for such incentives should be assessed and could be combined with existing grid priority rules. The merit order mechanism could also be reviewed to assess possible adaptations to support this direction, for instance by reinforcing price signals through scarcity pricing. Implementing these recommendations could effectively contribute to decarbonising the economy, to the integration of energy markets and to energy security.

6.4. Flexibility Markets

The Energy Union Package contains ambitious targets to increase the share of renewable energy and reduce greenhouse gas emissions. Energy storage, demand side management, improved and new interconnections and flexible generation units can all act as flexibility options. Flexibility options allow larger shares of intermittent renewables with low marginal costs to be absorbed into the system. This potentially has the direct consequence of decreasing wholesale prices and deferring and/or lowering future investments in capacity adequacy and in transmission infrastructure.

However, the current Electricity Directive²³ does not mention storage. Moreover, most of the current capacity market discussions in Europe focus on creating reserve capacity markets provided by flexible fossil-fuelled units, rather than including all flexibility options including storage on an equal basis. They are also oriented towards their national market rather than offering a more integrated approach with other Member States markets.

Recommendation 4

Energy storage should receive equal access to markets for flexibility. Flexibility markets, such as the markets for ancillary services or future capacity markets, should be designed to be technology neutral. In this way, energy storage and other flexibility options would have the chance to compete against flexible fossil-fuel based generation units. The design of capacity markets should be harmonised at the EU level with clear guidelines to ensure neutrality in relation to technology choices for flexibility options and following an integrated energy market approach.

In order for storage to broaden the range of available solutions, it is recommended that the new energy market design announced in the Energy Union Summer package (EC, 2015c) and the upcoming revision of the Electricity Directive (EC, 2015c) acknowledge the multiple services that energy storage can provide. Implementing these recommendations could effectively contribute to decarbonising the economy, to the integration of energy markets and to energy security.

6.5. Ownership and Control of Storage by Grid Operators

Problems associated with limitations in transmission and distribution grid capacities are expected to grow as the share of renewables in the system rises. Energy storage supporting the transmission and distribution grids could provide more stability, reliability and resilience to them. In this way, energy storage can help to defer, reduce or even avoid investments in transmission and distribution infrastructure when it is a more economic option.

The use of storage by grid operators is, however, very limited at present, as unbundling requirements do not allow transmission and distribution operators to directly own or control energy storage infrastructure. These restrictions have led to situations like double grid fees being applied to electricity stored by pumped hydro facilities. Similar economic disadvantages could hamper the use of electric vehicles as storage for grid services or in combination with future smart grids.

Recommendation 5

It is recommended to allow transmission and grid operators to invest, use and exploit energy storage services to strengthen flexibility, reliability and resilience of the grids. The development of a harmonised EU approach towards unbundling vis-à-vis extended ownership and control options for storage should address the following relevant issues:

²³ Directive 2009/72/EC concerning common rules for the internal market in electricity.

- allowing network operators' ownership and/or control over energy storage for purposes of grid balancing and other ancillary services, in isolation or in cooperation with other regulated and non-regulated entities, so that a specific storage facility can deliver multiple services simultaneously to different parties;
- clarifying and streamlining the position of storage in different regulatory environments (behind-the-meter, third party service, grid operation), including harmonising the application of taxation and grid fees. A benchmark for grid fees for energy storage across Europe could prove useful;
- assessing the consequences and opportunities of different regulatory options concerning smart grids and proposing a harmonised approach.

This recommendation contributes to energy security, decarbonising the economy and to the integration of energy markets.

6.6. Storage and End-users

Changes may occur faster at the end-user level and energy storage could well become a common household appliance in the future. While utilities are dealing with their "missing money problem" (difficulty to recover investments made in fossil fuel capacity units that will no longer operate), batteries and thermal storage options such as power-to-heat and heat pumps in combination with new solar power systems are quickly becoming an economically attractive option for households and small businesses. In September 2015, US Company Tesla has started shipping its firsts 7 kWh Lithium-Ion (LIB) home batteries (Powerwall) to fulfil more than 100,000 reservations made by US clients at a retail price of 3,000 USD. Different household and industrial product versions of Tesla's LIB batteries are already sold out through 2016. In Germany, the price of power from a combined solar and storage system is expected to drop below the retail price of grid electricity by 2016. Phase Change Materials (PCM) technologies show also promising developments. The resulting expected 'market boom' of local storage units will require adequate product information and certification.

These developments may also lead to less desirable effects. Large numbers of end-users turning to self-production and local storage could result in load defection: significant decrease of electricity demand. Mass load defection would negatively impact the revenue models for network operators and traditional power generators, because more than 90% of grid costs are fixed. While this would contribute to energy security and modernisation of demand targets, it would also undermine solidarity. Mass load defection would negatively impact the revenue models for network operators and traditional power generators. If these parties would react by increasing their fees, solar plus storage would become even more attractive and end users might choose also for grid defection: going off-grid altogether. This could ultimately result in a sharp drop of demand and revenues for network operators and power generators.

Recommendation 6

Energy storage at the end-user level contributes to grid balance. It is recommended that the European Commission provide guidance to Member States on how to adapt support schemes for renewables in such a way that energy storage at the end-user level is stimulated in a harmonised way across the EU. Best practices could include:

- Avoiding restrictions of any kind to renewable energy self-production and consumption with or without decentralised storage, and establishing simplified authorisation procedures for small-scale renewable energy projects with or without storage components;

- Promoting distributed energy storage acceptance and demand side flexibility, including demand response and energy efficiency measures through price signals like dynamic pricing, grid fee structures or variable tariffs and other incentives.

To support the expected market growth of energy storage at the end-user level and guarantee services and quality offered by energy storage products, they should be included as a product group under the Energy Labelling²⁴ and Ecodesign²⁵ Directives. Standards, information and regulation on efficiency, safety, quality, performance, recycling and liability should be developed.

Policy impact assessments should be performed to explore scenarios that combine the right of citizens to produce and store their own energy with maintaining a reliable, affordable and economically sustainable grid. Such impact assessments should analyse:

- the implications for the system of the upcoming 'grid parity' of combined self-production and storage;
- possible modifications to the regulatory framework, especially concerning tariffs and grid fees, in order to absorb the effects of large groups of end-users optimising their own energy production and consumption, and using the grid mainly for back up and sales of excess of own production;
- the need for adaptation of grid fee structures to keep the grid well-functioning and affordable;
- the risk and possible consequences of mass grid defection.

These policy actions would contribute to decarbonising the economy, energy security, solidarity and trust, and energy efficiency contributing to moderation of demand.

²⁴ Directive 2010/30/EC on the indication by labelling and standard product information of the consumption of energy and other resources by energy-related products.

²⁵ Directive 2009/125/EC establishing a framework for the setting of ecodesign requirements for energy-related products.

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ANNEX: DETAILED DESCRIPTION OF STORAGE SERVICES AND ASSOCIATED TECHNOLOGIES

Bulk energy storage services

- **Central gas storage** is used to balance long-term differences in supply and demand. Central gas storage is used for multiple purposes such as:
 - Adjustment of supply and demand: Gas demand is characterised by seasonal fluctuations (high in winter, low in summer) while gas supply is steady. Storage helps to balance supply and demand as storage facilities are replenished in summer and emptied in winter.
 - Short-term flexibility: Gas storage is needed to react in time to changes in demand and supply. Gas demand depends e.g. on temperature that can vary significantly during the week. Fluctuations in gas demand occur as well during the day and shows peaks in the morning and evening.
 - Arbitrage activity: Gas storage is suited for portfolio optimisation and as a financial instrument. It allows arbitrage due to short and long term differences between gas prices on different market segments.
 - Flexibility for gas grid: For transmission operators, gas storage offers flexibility and helps to maintain grid stability.
- **Large central electricity storage** facilities, like pumped hydro energy storage, can be used to provide price arbitrage services. In general, they are connected to high voltage levels. Their operation is oriented on taking advantage of price spreads at the electricity exchange, but they are partially used for offering balancing energy as well (Weber et al, 2014). Therefore, they stabilise the electricity grid and help to maintain supply security as well. Bulk electricity storage allows base load plants (like nuclear power or coal plants) to run almost continuously because energy is stored when demand decreases.

Arbitrage transactions may occur within the same electricity market or between two interconnected markets. In Europe, pumped hydro energy storage currently represents 45 of about 51 GW installed storage capacity. Northern European countries with higher potential for pump storage (like Norway) could offer storage services to other countries if the number and capacity of interconnectors in Europe would be increased.

- **Seasonal storage for electricity or heat** is also used to balance long-term differences in supply and demand. It enables temporal shifts for weeks or even months. In the electricity sector, seasonal differences in the fluctuating renewable feed-in from wind and solar could be compensated by the use of hydrogen storage. In the heat sector, thermal energy storage allows shifting heat supply from summer to winter. This promotes a more efficient use of electricity and supports the decarbonisation goals.

Renewables and other integration services

- **Variable supply resource integration** is realised by smoothing the feed-in of the fluctuating electricity production from renewable energy sources. This can be done with small-scale battery storage on decentralised level, e.g. in combination with solar parks or wind farms. The trade of stored electricity provides an incentive to use storage for adjusting the feed-in to the actual price level. But additional revenues must exceed the storage investment which is at present still challenging.

- Heat storage offers potentials for energy efficiency. **Waste heat utilisation** means the use of heat from industry or from production processes (e.g. biogas) that generate heat as by-product. Heat storage absorbs heat when supply exceeds demand and emits when demand increases. This concept ensures that heat from processes is actually used instead of releasing it into the environment.
- Storage can support **Combined Heat and Power (CHP) plants** for decoupling heat and electricity production. Heat storage allows flexible operation of a plant that is adjusted to price signals for electricity. The operation mode is less dependent on the heat demand and harmonised with the electricity demand. Besides this, efficient use of energy is increased.
- In the heat and electricity sector, concepts like **Power-to-Gas or Power-to-Heat** were developed for integrating electricity from renewables that temporarily exceed the demand. During these periods, electricity is converted into hydrogen or methane, or heat respectively. In case of Power-to-Gas, the produced gas can be fed into the gas grid, used as fuel for the transport sector; or, in case of hydrogen it can be sold to the chemical industry.

As required investments are high for these applications and utilisation rate is low, their market launch depends on future developments. The same applies to Power-to-Heat, which includes technologies like heat pumps or direct electric heating. But Power-to-Heat could make sense for using surplus electricity instead of curtailing wind or photovoltaic plants. In general, both concepts could be deployed only when high shares of renewable energy sources (about 80% of electricity production) are available (Agora Energiewende, 2014). Technical and economic development of technologies will determine if these concepts will get economically viable.

- **Supplying the transport sector with hydrogen and renewable electricity** could increase if manufacturers offer more vehicles with alternative drives and hydrogen or charging infrastructure is constructed. Mobile storage batteries could be used then for ancillary services. While market penetration of this application is still very low, this could change in the next ten years, if the sale of electric vehicles increases and related charging infrastructure is promoted.

Ancillary services

The **provision of ancillary services** includes measures for frequency and voltage control, re-establishment of power supply after blackouts and the management of grid and system operation. They are very important for ensuring supply security. These services require fast response times but have to be maintained only for a short time period. They comprise the following key ancillary services:

- **Frequency regulation** is needed for balancing differences between electricity supply and demand.
- **Load following** is similar to frequency regulation, but covers a longer period of time, e.g. 15 minutes to 24 hours.
- **Voltage support** ensures voltage levels in transmission and distribution grids.
- **Black start capability** is needed to re-start power stations after a system collapse.
- **Spinning reserve** is on line and ready for use in less than ten minutes for compensating unforeseen fluctuations in demand or supply.
- **Non spinning reserve** is another form of reserve capacity that is off line but can be activated quickly and maintained for hours.

Transmission and distribution services

- Electricity storage can compensate overload situations in substations for a period of time. It can also relieve **transmission and distribution congestion** when grid capacity is not sufficient. This eventually results in transmission or distribution investment deferral. Grid expansion is, in general, less expensive than electricity storage and it avoids efficiency losses. However, storage could be an option if the storage services are used by multiple parties and when there are other reasons different than only economics (for example lack of public acceptance).
- The electrification of the transport sector comprises the concept of **overhead cable for buses, trains or trams**. Mobile batteries are needed in this case, but also stationary storage could be used for power control and electricity supply along the railway. These concepts have been tested in pilot projects, but are not yet established in the market.
- Storage systems plays an important role as backup solution in processes that need **uninterruptible power supply** (e.g. in hospitals or data centres).

Customer energy management services

- Consumers could use storage for **demand shifting and peak reduction**. If widely used, this could result in a reduced need for central generation capacity. This application is not yet widespread in Europe, but is part of the debate on security of supply and demand side management.
- Electric mobility offers potentials for the **integration of electric vehicles in the electricity system** if the charging process can be used for electricity production peak reductions. If mobile storage in vehicles is used for feeding back the electricity into the grid, price arbitrage for consumers and benefits for the system are possible. In this case, electric mobility could not only promote the decarbonisation of the transport sector, but offer ancillary services as well.
- Off-grid storage systems are intended to enable the **autarchy of a single building or a small local grid** that is not connected to a larger electricity grid (so-called grid independent island systems). The combination of storage and renewable energy can be used in off-grid systems that lack a well-developed electricity infrastructure.
- Storage systems can be used for **maximising self-production and self-consumption of electricity**. This may become a preferred option of many customers when the costs of self-production plus storage of electricity are below the costs of electricity from the grid. Complete autarchy is usually not attained and a grid connection is still needed for covering the remaining electricity demand. The concept of maximising self-production and consumption is applicable to micro-grids as well. These are defined as networks of local industries or private consumers with access to decentralised generation production that try to be as independent as possible from central power suppliers.

Associated technologies

Table 7 shows core technological parameters of storage technologies associated to services described and with their status as of August 2015. Besides the storage size (energy, power) and discharge times, the typical response or start-up time, energy densities (gravimetric Wh/kg, volumetric Wh/l), power density (Wh/l), efficiencies and lifetimes (years and cycles) are also shown. Also, their feasibility for reserve capacity provision and availability of raw materials or geological conditions are assessed.

Table 7: Comparison of core technical parameters of different electric and thermal storage technologies at present.

Technology	MW	MWh	Response Time	Wh/kg	Wh/l	W/l	Dis-charge Time	Efficiency [%]	Life-time [a]	Cycles	Feasibility for reserve capacity provision	Availability of raw materials or geological conditions	Technological Maturity	Typical applications
PHS	100 MW - 1 GW	100 MWh - 1 GWh	min	0.2 - 2	0.2 - 2	0.1 - 2	Hours	70 - 80	> 50	> 15 000	Yes	limited number of suited places	mature	Time shifting, Power Quality, Emergency supply
CAES	10 MW - 100 MW	100 MWh - 1 GWh	min	-	2 - 6	0.2 - 0.6	Hours	41 - 75	> 25	> 10 000	Yes	lim. number of suited places	developed	Time Shifting
Flywheel	20 kW - 10 MW	0.1 kWh - 1 MWh	< sec	5 - 30	20 - 80	5000	Seconds	80 - 90	15 - 20	20000 - 10Mio	No	unproblematic	mature	Power Quality
Lead Acid	1 kW - 10 MW	1 kWh - 1 MWh	< sec	30 - 45	50 - 80	90 - 700	Hours	75 - 90	3 - 15	250 - 1500	No	unproblematic	mature	Off-Grid, Emergency Supply, Time Shifting, Power Quality
NiCd	1 kW - 100 kW		< sec	15 - 45	15 - 110	75 - 700	Hours	60-80	5 - 20	500 - 3000	No	unproblematic	mature	Off-Grid, Emergency Supply, Time Shifting, Power Quality
NiMH	1 kW - 1 MW		< sec	40 - 80	80 - 200	500 - 3000	Hours	65 - 75	5 - 10	600 - 1200	No	unproblematic	mature	Electric Vehicles
LIB	1 kW - 10 MW	1 kWh - 10 MWh	< sec	60 - 200	200 - 400	1300 - 10 000	Hours	85 - 98	5 - 15	500- 10 000	No	unproblematic	developed - mature	Power Quality, Network Efficiency, Off-Grid, Time Shifting, Electric Vehicles, Off-Grid, Electric Vehicles.
Zinc air	50 kW - 20 MW		< sec	130 - 200	130 - 200	50 - 100	Hours	50 - 70	> 1	> 1000	No	unproblematic	in dev.	Off-Grid, Electric Vehicles.
NaS	30 kW - 10 MW	100 kWh - 100 MWh	< sec	100 - 250	150 - 300	120 - 160	Hours	70 - 85	10 - 15	2500 - 4500	No	unproblematic	mature	Time Shifting, Network Efficiency, Off-Grid
NaNiCl	100 kW - 10 MW		< sec	100 - 200	150 - 200	250 - 270	Hours	80 - 90	10 - 15	1000	No	unproblematic	mature	Time Shifting, Electric Vehicles
VRFB	50 kW - 20 MW		sec	15 - 50	20 - 70	0.5 - 2	Hours	60 - 75	5 - 20	>10 000	-	-	in dev.- developed	Time Shifting, Network Efficiency, Off-Grid
Hybrid Flow Bat.	50 kW - 20 MW		sec	75 - 85	65	1 - 25	Hours	65 - 75	5 - 10	1000 - 3650	No	unproblematic	in dev.	Time Shifting, Network Efficiency, Off-Grid
Hydrogen central/ desentral	1 MW - GW	10 MWh - 100 GWh	sec - min	33.330	600 (200 bar)	0.2 - 2 2.0 - 20	0	34 - 44	10 - 30	1000- 10000	Yes	unproblematic	in dev.	Time Shifting
SNG	1 MW - GW	10 MWh - 100 GWh	min	10 000	1800 (200 bar)	0.2 - 2	hours - weeks	30 - 38	10 - 30	1000- 10000	-	-	in dev.	Time Shifting
DLC	20 kW - 1 MW	0.1 kWh - 5 kWh	< sec	1 - 15	10 - 20	40000 - 120000	Seconds	85 - 98	4 - 12	10000 - 100000	no	unproblematic	mature	Power Quality
SMES	100 kW - 2 MW	0.1 kWh - 10 kWh	< sec	1-10	6	2600	Seconds	75 - 80	n.a.	n.a.	no		in dev.	Time Shifting, Power Quality
Molten Salt	30 - 300		n.a.	85 - 280	n.a.	n.a.	Hours	40-93	n.a.	n.a.	no	unproblematic	in dev.	utility-scale wind and solar integration
Ice Storage	<5 MW	<50 MWh	n.a.			n.a.	Hours	75-90	n.a.	n.a.	no	unproblematic	in dev.	cooling applications such as office buildings, schools, hospitals, retail stores, etc.

Source: (IEC, 2012), (IRENA, 2013) and authors

NOTES

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