Energy Local Storage Advanced system

D5.4 Second study of the economic impact in the local and national grid related to all demo sites

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Executive Summary

Introduction

Electricity storage systems are a cornerstone within the European Union's energy policies to "ensure secure, affordable and climate-friendly energy for EU citizens and businesses". (European Commission, 2016) They will play a key role in enabling Europe to reach its objectives in the energy sector.

Electricity storage systems (ESS) represent a flexible element within the electricity system alongside demand response, flexible generation and grid connections and has bearings on other stakeholders such as operators of generation units, grid operators and consumers. All electricity supply systems require flexibility, but predominantly renewable electricity supplied systems need more than others. Hence, there is a need for additional flexibility in most cases when an electricity supply system is transformed to a mainly renewables-based one.

This study deals with the need for and technical potential of storage and the economic impact of energy storage system (ESS) operation on other electricity system stakeholders. It represents a further development and completion of the ELSA deliverable D5.1 published in July 2016.

Impacts of ESS on other parts of the electricity system and its stakeholders

On an operation level, battery storage systems can be used to provide operating reserve and can ensure that the grid is balanced for several hours when it comes to intra-day deviations from forecasted (renewable) generation or demand. Further, they can be used as an alternative to redispatch of power plants or even assisting black start of power plants. In the medium and long term, battery storage systems can change the need for investment in back-up generation plants and grid lines.

For consumers / prosumer, battery storage systems can generate a monetary benefit by flattening the electricity consumption load curve, reduce the operational risk of power interruptions, and increase the quote of self-consumption and autarky in combination with, for example, a photovoltaic system. These operations might have a more or less positive or sometimes even negative impact on other stakeholders and the overall electricity system.

The need for storage

The need for storage or other flexibility options in a given area is dependent on the topology and grid within this area and on the capacity of the power connections crossing the area's boundary. If the latter are strong enough, there might be very little need for flexibility within the area itself, because the balance between generation and consumption can be achieved by simply adapting power imports and exports accordingly. This is even possible if the share of fluctuating renewable power generation is very high.

A number of model calculations exist which determine the need for storage for different shares of renewable power for various European regions or wider areas of Europe and neighbouring countries. Several of them investigate the extreme case of 100 % supply by a mix of PV and wind power and calculate for which mix the need for storage takes a minimum. As PV and wind power are both fluctuating sources, this is an extreme case and the minimum amount of storage obtained for this case is presumably higher than for any other generation mix. Nevertheless, the need for storage found for such scenarios is small compared to the annual energy demand in the investigated area. Most of the required storage in terms of energy is long-term storage and only a modest short-term energy storage need is found which can be met with battery systems. In contrast to the small amount of short-term storage capacity in terms of energy, a high share of fluctuating renewables in the generation mix implies a high need for storage in terms of power. This is because in case of zero PV and zero wind power, the peak power demand in the region must be met by a combination of short-term and long-term storage units for some time. Demand control can reduce the peak demand, but basically the storage units must be able to provide the peak power.

A common finding of these model calculations with regard to long-term storage is that it increases very modestly for renewable shares up to 80 % and very steeply between 80 % and 100 %. This fits with what can be observed in areas which have a high share of renewables already today. In Germany for instance, the annual average share of renewables was 32.6 % in 2015 out of which 21.1 % were PV and wind energy, but the contribution of PV and wind power is very close to 100 % in some hours. Negative prices on the electricity market indicate a clear lack of flexibility in these moments, while the existing flexibility of the system, basically ensured by generation control of thermal power plants and pumped hydro energy storage, is sufficient during most of the year.

However, a crucial point is that these model calculations systematically underestimate the need for short-term flexibility because imbalances are time-scales smaller than the time-step are blurred out. Furthermore, imbalances over distances smaller than the spatial cell diameter are blurred out, because the models do generally not map the real electric network operating resources. If the latter are taken into account, a higher need for short-term storage becomes apparent and battery storage systems are the most suitable option to meet this because they can deal with a broad range of required services better and more cost-effectively than other flexibility options. In quite a number of cases, batteries are also more cost-effective already today than reinforcement of electric network operating resources, at least until the next regular replacement of existing equipment.

The technical potential for ELSA-type ESS

There is a perfect synergy between vehicle stock electrification and the energy transition towards predominantly renewable generation if vehicle batteries get a 2nd life in stationary grid-connected applications. Even at a modest vehicle stock electrification rate of a few percent and a medium battery reuse rate of 50 % the potential of ELSA-type ESS is higher than the present pumped hydro storage potential, notably in terms of power. ELSA-type ESS can provide a significant contribution to the short-term storage needed in electricity systems with a high rate of fluctuating renewable power generation – up to 50 % of the battery storage which will be needed for an optimised 100 % renewable electricity supply of the EU + Norway + Island + Switzerland + Balkan Countries + Ukraine + Turkey according to a recent model calculation.

The economic impact of ELSA-type ESS

In the transition towards a predominantly renewable electricity system, ELSA-type ESS can generate significant value to the overall electricity system, i.e. lower the overall costs of electricity supply. In the case of the UK, considering that the carbon target for 2030 is to be achieved mainly by renewable electricity generation, the value of ELSA-type ESS is more than twice the costs of ELSA-type ESS. Notably, operation cost of conventional back-up power plants can be reduced thanks to ESLA-type ESS avoiding curtailment of renewable electricity generation. Further, investments in conventional back-up units and the distribution grid can be avoided if ELSA-type ESS are installed. It can be assumed that these results are in principle transferable from the UK to other large economies in the EU.

The value of an ESS for the system depends on the operation pattern. Operation patterns contributing to balance the residual demand, i.e. the difference between the demand and (fluctuating) renewable electricity generation, thus smoothing the required residual fossil and nuclear generation, create the highest value, notably by avoiding conventional back-up power plant operation and by reducing the required back-up capacity. This implies that ESS reduce business opportunities for operators of conventional back-up power plants in the short term. However, most of these plants are fired with natural gas and will be needed in the long term for combustion of synthetic natural gas produced from surplus electricity and CO_2. These gas-powered back-up power plants have a strategic importance for a transition towards a highly renewable electricity generation with a share of 80 % and beyond.

Further, operation patterns leading to a more constant power flow in grid lines create value by referring or avoiding grid reinforcements. Here, the impact of ESS is directly beneficial to grid operators: a more constant power flow leads to a better use of grid infrastructure and a better return on investment.

Altogether, a mix of quite diverse operation patterns of individual ESS located at different sites in the electric grid is needed to generate the highest system value.

The main competitor to ELSA-type ESS with similar value for the overall electricity system is demand response. In some cases, provision of demand response is supported by battery storage systems and simply represents a specific case of their application. In other cases, demand response uses inherent thermal energy storage capacity or flexibility of industrial production and might be much cheaper than battery storage.

Existing regulatory framework

In Germany, the existing regulations are not a comprehensive regulatory framework. Different interpretations cause legal uncertainties in the field of storage systems. The legislator bodies recognized this problem and the framework will be expanded and refined within the next years.

Since the electricity is considered in France as basic necessity, the main concern of the French government still focuses on the security of electricity supply and the accessibility of electricity. Thus the electricity tariff, the obligation of purchasing PV electricity, and the electricity market are still highly regulated in France. This regulatory framework seems unhelpful and hindering to the development and implementation of ELSA services offer on the French market.

In Italy, the exploitation of electricity storage is still in an early stage with limited possibilities of usage. However, the country is involved in a deep reformation of the market regulation framework that is planned to switch in its operational phase at the beginning of next year.

Recommendations

Stationary ESS can have a significant value for the overall electricity system and can provide a significant contribution to ensure cost-effective electricity supply notably in systems with a higher rate of fluctuating renewable electricity generation. For this reason, a regulatory and market framework should be created which allows for profitable operation of ESS, whenever the operation pattern creates a system value which is higher than the ESS costs.

ESS with 2^{nd}-life batteries can provide this system value at lower costs than ESS with new batteries, provided the costs for dismantling the batteries from the vehicles and installing them in a 2^{nd}-life ESS, and the costs of maintenance and repair do not overcompensate the savings achieved by using 2^{nd}-life batteries. However, 2^{nd}-life ESS have a positive environmental impact compared to new ESS thanks to a longer total lifetime of vehicle batteries and thus more efficient use of final resources (lithium and others) and grey energy (energy used for manufacturing the batteries) (see ELSA D5.3 and D5.6). If the resulting annual costs of

2nd-life ESS will turn out to be finally even a bit higher than those of new ESS, this positive environmental impact might be reflected by the regulatory and market framework.

The operation pattern of ESS has an impact on the exact value that is created for the overall electricity system. Hence, the regulatory and market framework should reward operation patterns with a higher system value more than those with a low one. In first instance, the following is recommended:

- ESS should be given free access to the market and new market mechanisms should be developed in order to allow deploying the maximum benefit for the overall electricity system. This includes notably markets for smaller amounts of electric energy and power and trade at shorter time-scale. Aggregation and regional market places should be permitted as much as possible.
- ESS should be promoted by removing fees on electricity charged or discharged. The exemption from paying fees could be made dependent on the value of the ESS operation for the overall electricity system:
    - Charging might be exempted if it helps avoiding renewable energy curtailment.
    - Discharging might be exempted if it helps avoiding generation at high cost.
    - Charging and discharging might be exempted if it reduces ramp rates and related inefficient operation and stress on material of conventional thermal power plants.

ESS will most directly impact on the operation of mostly natural gas-fired peak and back-up power plants and might squeeze them out of the market. However, these power plants will be needed again when larger amounts of synthetic natural gas from renewable sources will be available, that is when the share of RES in the electricity generation mix approaches 80 %. They will then be a cornerstone of the presently only available long-term storage technology for the electricity sector, namely power-to-gas. Hence, a strategy is also needed for natural gas-powered plants to bridge the gap between a lower need for them in the short term as a consequence of a strong deployment of battery storage systems, and a high need for them in forthcoming predominantly renewable energy systems. An element of such a strategy could be to rule out lignite and coal power plants, thus increasing the need for gas power plants in the short and medium term.

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AbLaV	Verordnung über Vereinbarung zu abschaltbaren Lasten
AC	Alternating current
AEEGSI	Authority for Electricity, gas and water system
CAPEX	Capital expenditures
CCS	Carbon Capture and Storage
CECRE	Control Centre of Renewable Energies
CEGB	Central Electricity Generating Board
CHP	Combined heat and power
CRE	Energy Regulatory Commission
CSPE	Contribution to Publics Services
CTS	UK Carbon Trust Study
DC	Direct current
DCI	Demand control imminent
DECC	UK's Department of Energy and Climate Change
DER	Distributed energy resources
DNO	Distribution network operators
DR	Demand response
DSIM	Dynamic System Investment Model
DSO	Distribution system operator
DSR	Demand-Side Response
EEG	Erneuerbare-Energien-Gesetz
EFR	Enhanced Frequency Response
ELSA	Energy Local Storage Advanced system
ELSA-DT5-ESS	ELSA-type Energy Storage System (ESS with similar technical characteristics than the last version of the ELSA ESS which was developed in the ELSA project
ELSA-type ESS	Energy Storage Systems with technical characteristics close to the ELSA-DT5-ESS (considered for assessing the technical and economic potential independently from concrete manufacturers)
ENTSO-E	European network of transmission system operators for electricity
EnWG	Energiewirtschaftsgesetz

ESS	Energy Storage System
ETS	Emission trading scheme
ETYS	Electricity Ten Year Statement
EV	Electric vehicle
FES	Future Energy Scenarios
H2	Hydrogen
HRDR	High risk of demand reduction
HV	High voltage
HVDC	High voltage direct current
ICT	Information and communication technology
ITC	Inter Transmission System Operator Compensation for transits
KCE	Kokam Contrainerized Energy Storages System
LCOE	Levelised cost of electricity
LV	Low voltage
MV	Medium voltage
MSG	Minimum Stable Generation
NISM	Notice of insufficient system margin
NTC	Net transfer capacity
OEM	Original equipment manufacturers
PH	Pumped hydropower
PV	Photovoltaic
OCGT	Open Circuit Gas Turbines
OPEX	Operational expenditures
Q	Quarter
R&D	Research & development
RE	Renewable Energies
SCADA	Supervisory Control and Data Acquisition
StromStG	Stromsteuergesetz
StromStv	Stromsteuerverordnung
TSO	Transmission system operator

UCTE	Union for the Co-ordination of Transmission of Electricity
UPS	Uninterruptable power supply
UStG	Umsatzsteuergesetz
VAT	Value added tax
WP	Work package

1 Preface

The integration of electricity storage systems in the power supply system is an important element of the European Union's strategy for the transition towards a low carbon economy. EU targets and activities in the field of renewable energies including energy storage are laid out in more detail in the EU's 2020 Energy Strategy. The latter defines three quantitative targets for the energy sector for the period from2010 to 2020. The first one is to reduce greenhouse gas emissions by at least 20 % compared to the reference year (1990). The second one is to increase the share of renewable energy in the consumption to 20 %, and the third priority to improve the energy efficiency by at least 20 %.

Electricity storage can provide additional flexibility to ensure generation/demand matching and grid balancing for even larger shares of renewable power generation, thus ensuring power supply security, and facilitating climate change abatement, environmental protection, and independency from fuel imports. At local level, storage can improve the management of distribution grids and the efficient use of operating resources, thus reducing costs. In this context, the ELSA project goes even one step further by demonstrating that 2nd life batteries from electric vehides combined with an innovative energy management systems are a cost-effective and sustainable option of such storage systems.

In general, stores are elements of energy supply chains, which provide a buffer between two stages of the energy supply chain (Stöhr, et al., 2014). In conventional energy systems, storage happens essentially at the beginning of the supply chain in form of fossil fuel stores. In a renewable energy system, energy is mainly provided in the form of electricity and storage systems are needed along the entire supply chain. Batteries are one of several storage technologies where energy is put in and out in form of electricity. In the past, battery storage systems were very expensive and, except in some cases, could not be applied cost-effectively. Driven by the activities and developments in the field of electro-mobility, prices for battery storage systems (esp. lithium-ion-systems) have fallen significantly in the last years. At present, the prices of stationary lithium-ion battery systems decrease by 20 % per year. [1] If this trend continues as experts forecast, system prices in 2020 will be one third of those in 2015.[2] Against this background, it can be assumed that the attractiveness of battery applications at different stages of the energy supply chain will increase.

[1] See e.g. Kai Philipp Kairies, RWTH Aachen, in an interview published on 14 July 2016, http://www.pv-magazine.de/nachrichten/details/beitrag/rwth-aachen--rasant-sinkende-kosten-treiben-speichermarkt-auch-in-zukunft-weiter-an_100023775/ [retrieved on 27 July 2016]

[2] (1-20%)^5 = 32.8%

Actual model calculations of the storage need mapping the case of 100 % renewable power supply at the scale of European countries or regions come out with a rather modest energy storage capacity need compared to the annual electricity demand, in particular for short-term storage, but a rather high need for storage power compared to the peak power demand. However, these model calculations tend to underestimate inherently the need for short-term storage inasmuch as they generally do not map the real electric network operating resources. If the latter are taken into account, a clear need for storage becomes apparent and battery storage systems are the most suitable option to meet this because they can deal with a broad range of required services better and more cost-effectively than other flexibility options. In quite a number of cases, batteries are also more cost-effective already today than reinforcement of electric network operating resources, at least until the next regular replacement of existing equipment. Unfortunately, the need for storage complementing cost-efficiently network operating resources cannot be quantified yet.

This study (D5.4) is the second out of two within the ELSA project dealing with the estimation of the efficiency increase and the associated cost reductions achieved by the use of the ELSA-storage systems in local grids related to all demonstration sites. It is an up-date of the first one (D5.1) and adds notably an investigation of the technical potential of 2nd-life batteries (chapter 3.4) and on the economic impact of ELSA battery systems on the electricity system as a whole, notably on back-up generation capacity and the electric grid (chapter 6.2).

Decentralized power generation with a large share of direct local distribution to consumers leads to other grid topologies than central power generation, transmission and distribution. For this reason, local grid services become more important as the share of decentralised generation increases. In order to reflect this paradigm change more clearly and to stretch the focus of this study, the economic impact on the grid operation, the different possible applications of battery storage systems are classified by the grid level at which they are applied.

2 Background

2.1 The ELSA project

Decentralised small and medium-size energy storage systems (ESS) combined to decentralised generation plants can provide a much greater operating flexibility than today's large, centralized energy generation and distribution systems. They can ensure a reliable energy supply of buildings and districts and can enable the integration of a high share of intermittent renewable energy sources. Yet, few such storage solutions are technically mature and economically viable at this stage. Wide-spread application is hindered by the EU's and member states' existing legal and regulatory framework.

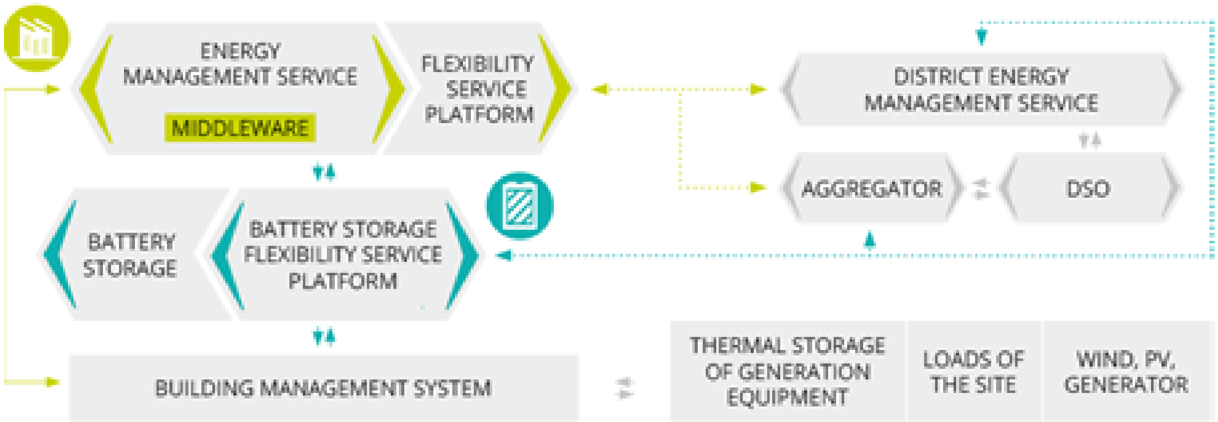

Figure 1: ELSA architecture, Source: (ELSA consortium, 2015)

Objectives

The project Energy Local Storage Advanced system (ELSA) brings distributed storage solutions to maturity. Its objective is to enable their integration into the energy system and their commercial use. ELSA is addressing existing energy storage development needs by combining 2nd life batteries with an innovative local ICT-based energy management system in order to develop a low-cost, scalable and easy-to-deploy battery ESS. These storage solutions are deployed as energy services. Existing legal and regulatory barriers are analysed and international standards are pushed forward. At the same time, ELSA is developing innovative service-oriented business models. Sustainability and social acceptance are taken into account through comprehensive life-cycle and socio-economic impact assessments as well as the involvement of citizens and stakeholder groups.

Planned activities

ELSA's mission is to further develop technology that is already close to maturity. ELSA storage systems will be applied in six demonstration sites representing several application contexts, covering services such as grid congestion relief, local grid balancing, peak shaving, voltage support and regulation. Several feedback loops and the constant involvement of relevant stakeholders will guarantee the optimal implementation at all pilot sites. An evaluation will ensure scalability and proof of feasibility beyond the project.

Demonstration Sites

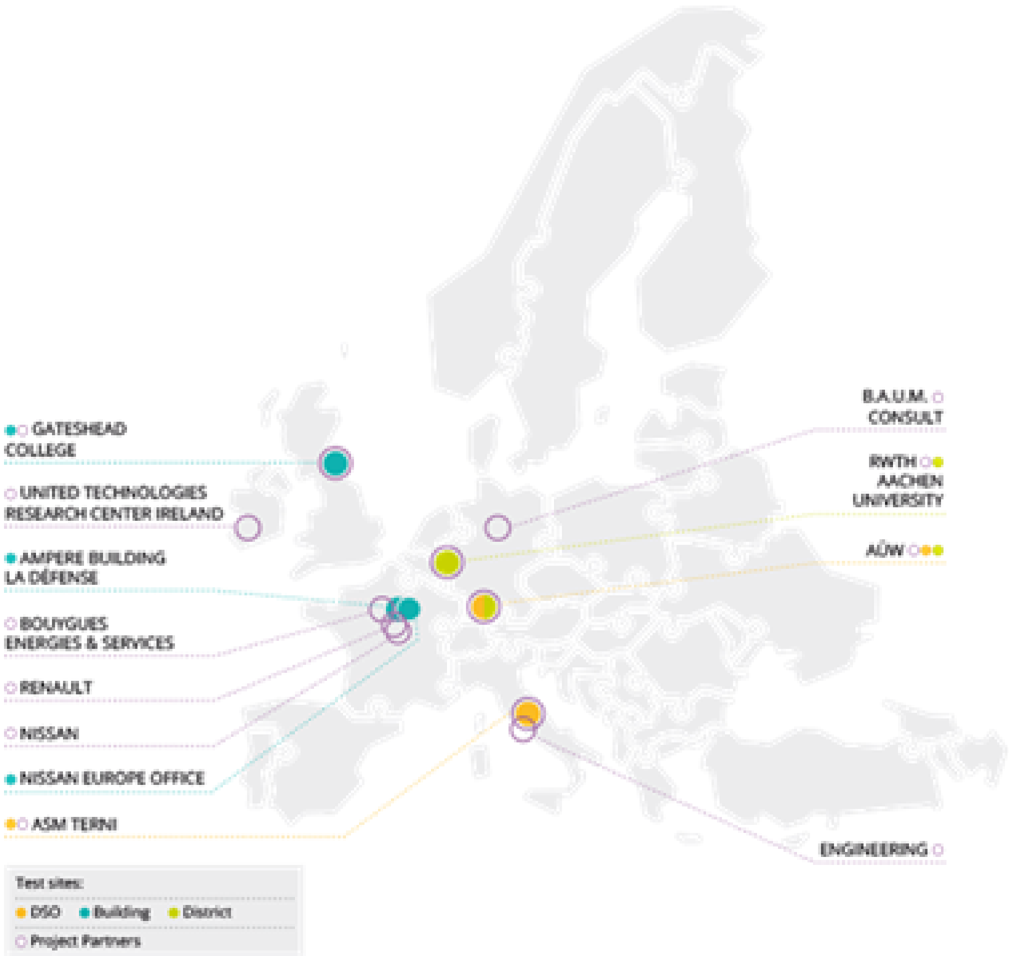

Figure 2: ELSA demonstration sites, Source: (ELSA consortium, 2018)

The demonstration sites include buildings, districts and grids: the Skills Academy for Manufacturing and Innovation facility at Gateshead College (building), United Kingdom, the Ampere Building (offices) at La Défense, France, the NISSAN EUROPE OFFICE at Paris (offices), France, the E.ON Energy Research Centre at RWTH Aachen University (R&D district), Germany, the City of Terni (grid), Italy, and a residential district in the city of Kempten, Germany.

The ELSA consortium

This multi-disciplinary consortium brings together industry players with extensive experience in Electric Vehicle battery storage systems, (Renault and Nissan), as well as in sustainable development, digital and energy networks infrastructure, and building and district management (Bouygues).

Research institutes specialising in the design and manufacturing of components and systems for buildings and industrial applications (United Technologies Research Center Ireland), in the energy sector including ICT for energy (RWTH Aachen) and in the area of smart homes and energy management options (Gateshead College) are also involved as are companies with experience and knowledge in IT solutions for Energy and Utilities (ENGINEERING), in consultancy and training on sustainable development (BAUM), and in the management of electrical distribution systems (ASM and AÜW).

2.2 Goals of Work Package 5

The goals of work package 5 (WP5) are to perform an assessment of the economic and environmental impact of the electric storage systems taking into account the full integration into the local electricity grid, the distributed generation and the further deployment of renewable energy sources.

Further, key business success factors related to system costs, direct value generation, integration in virtual power plant schemes and services provided to grid stakeholders will be identified in WP5. (ELSA Consortium, 2015)

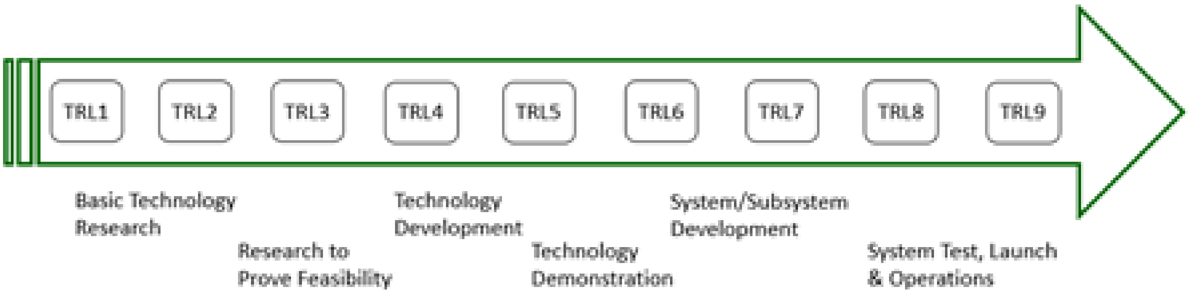

Figure 3: Technology Readiness Levels, Source: (Nasa Technology Readiness Levels, 2015)

A central part of WP5 is to provide elements of an answer to the question how an economic activity exploiting stationary battery storage systems can be sustainable, that is notably how it can create new jobs and reduce the overall environmental impact. (ELSA Consortium, 2015)

2.3 Goals of Task 5.2

The goals of Task 5.2 within WP5 are to estimate the efficiency increase and the associated cost reductions achieved by the use of the ELSA storage systems in electric grids.

Electricity storage will play a key role in enabling Europe to reach its objectives in the energy sector as storage supplies more flexibility in ensuring the generation/demand matching, grid balancing, energy security and optimization of the use of renewable generation assets. Storage can also locally improve the management of distribution networks, reduce costs and improve efficiency.

All economic benefits that (large-scale) storage can provide to different stakeholders can be translated into cost savings all over the supply chain. These will be explored in this task. Eventually, the mentioned efficiency improvements can result in lower electricity prices and more generally, financial benefits for different players. The value generation of storage is a key element for the success of business models for the electrical and thermal systems incorporating storage units. (ELSA Consortium, 2015)

3 The need for and potential of storage

3.1 Progress of the renewable energies expansion

3.1.1 Germany

Responsible Partner: B.A.U.M. Consult

Renewable electricity generation capacity

Figure 4 shows the development of the installed capacity of different types of electricity generation plant types in Germany from 2002 to 2015, and Figure 5 shows the corresponding annual changes in this period.

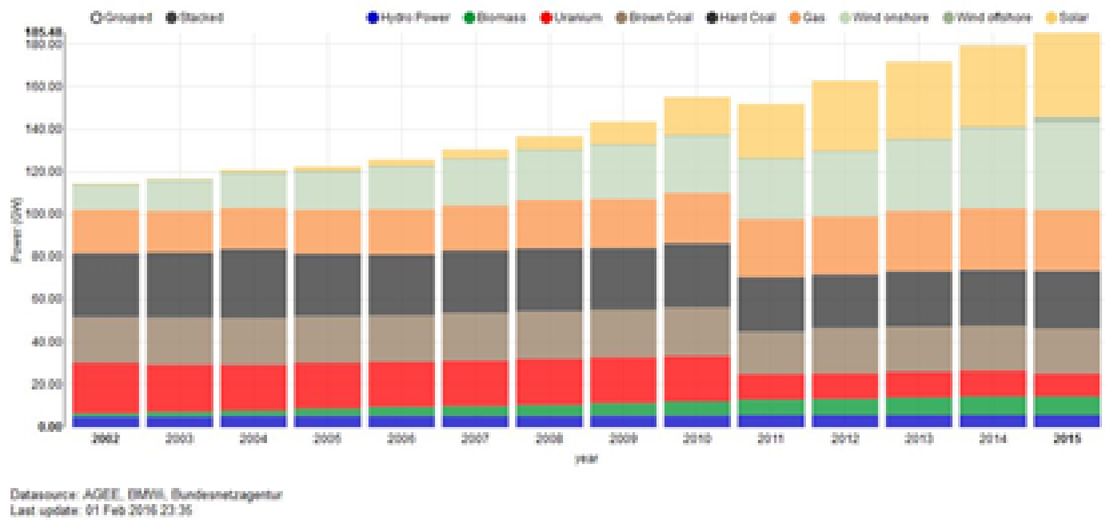

Figure 4: Installed German electricity generation capacity 2002 – 2015, Source: (Fraunhofer ISE, 2016)

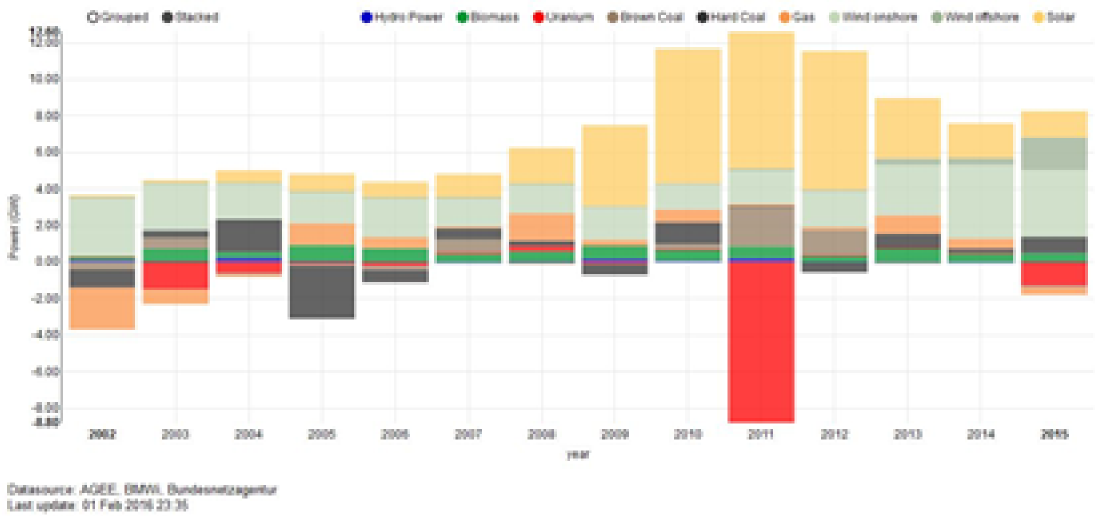

Figure 5: Annual change of installed electricity generation capacity, Source: (Fraunhofer ISE, 2016)

For more than a decade, renewable power stations have dominated new installations in Germany, and by the end of 2015 they accounted for 97.92 GW (52.3 %) out of the total installed power capacity of 185.48 GW. PV power plants accounted for 39.7 GW (21.4 %) and wind power plants for 43.78 GW (23.6 %). The ratio of installed PV and wind power was 48:52, not very far away from the optimum mix of 40:60 for which the need of flexibility in the German electricity system achieves a minimum if PV and wind power are the only sources of electricity and imports and exports of electricity are zero (see subchapter 3.3). Taking into account that (1) PV and wind are not the only sources of electricity, (2) imports and exports of electricity take place, (3) wind power plants are predominantly installed in the north of Germany and (4) PV plants in the south, and (5) the mentioned optimum is very broad, that means deviations from it do not change the overall system cost very much, the mix of PV and wind power plants at national level is close to its economic optimum with regard to storage and equivalent flexibility needs at present.

Apart from renewable power plants, hard coal power plants were newly installed, in particular at the seaside close to harbours for imported hard coal. The lignite electricity generation capacity increased, too, while nuclear started being phased out after the threefold maximum credible nuclear accident in Fukushima in 2011.

The installed power capacity reflects the theoretical maximum electric power that German power plants can provide. However, this maximum power depends on meteorological conditions in the case of PV, wind and hydropower plants and is never reached. Nevertheless, the power provided by German plants is increasingly above the respective instantaneous national consumption and electricity exports are strongly increasing accordingly. Further, the contribution provided by renewable power generation comes often close to the instantaneous consumption thus challenging the flexibility of the conventional power plants to the very end.

Renewable electric energy generation

Renewable energies (RE) accounted for 30.0 % of the German electricity generation of 651.6 TWh and covered 32.6 % of the electricity consumption of 600.0 TWh in 2015. The latter includes grid losses and own consumption within power plants. The lowest hourly contribution of RE was 7.3 GWh, covering 9.9 % of the consumption on November 3 between 4 and 5 p.m., the highest was 50.1 GWh, covering 83.2 % of the consumption on August 23 between 1 and 2 p.m.

Electricity from PV plants covered 6.4 % and wind power plants 14.7 % of the electricity consumption, i.e. 21.1 % was met by quickly and strongly fluctuating power generation (see Figure 6). Slowly varying run-of-the-river hydropower plants contributed the major part of the hydropower generation of 19.3 TWh (3.2 % of the consumption). This number indudes also a minor contribution from storage hydropower generation. Electricity generation from bio-mass contributed 44.2 TWh (7.4 % of the consumption), generation from waste further 5.8 TWh (1 % of consumption). The sum of the percentage values for the contributions of the various energy sources referred to the electricity consumption amounts to 108.6 %. This is due to the fact that 51.6 TWh, that is 7.9 % of the German electricity generation or 8.6 % of the consumption, were physically exported in 2015.

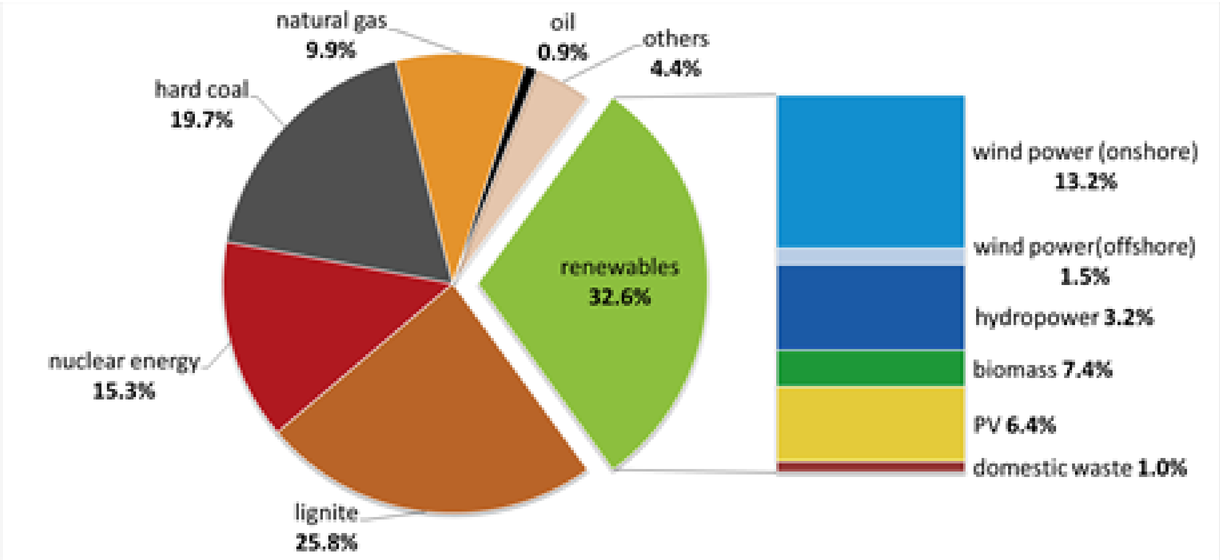

Figure 6: Electricity generation by energy source in Germany in 2015, Source: (AG Energiebilanzen, 2015)

Variation of different contributions to electricity generation

Figure 7 shows the variation of the electricity consumption and the contributions of different renewable electricity sources and conventional power generation during 2015. The generation from biomass remained more or less constant at about 5 GW throughout the year, the generation from run-of-the-river hydropower varied weakly between 1 and 2.5 GW most of the time. Thus, biomass and run-of-the-river hydropower together ensured a reliable minimum renewable power generation of about 10 % of the average power demand of 68.5 GW. PV and wind power generation varied strongly and their sum came close to zero at some moments. However, PV and wind power generation were very complementary and their joint contribution was rarely below their average power of 14.4 GW for more than a couple of days. This is not a proof, but a hint that a mix of PV and wind power generation limits the need for long-term and seasonal storage.

Conclusion 1: There is little to no need for seasonal electricity storage in Germany even if RE meet 100 % of the domestic electricity consumption

This allows drawing a preliminary conclusion concerning the need for storage in Germany: If the renewable power generation had been up-scaled by a factor 3 without changing the relative contributions of the different RE sources, Germany had been being fully supplied with renewable electricity in 2015 without requiring seasonal electricity storage. However, storage for up to several weeks or equivalent flexibility would have been required to bridge periods of low combined PV and wind power generation in January/February and October, and to make use of very high combined PV and wind power generation in March, the summer months and November.

This finding does nevertheless not allow concluding that seasonal energy storage is not required at all even if the German electricity generation is 100 % renewable. First of all, the little varying German hydropower generation cannot be increased by a factor 3 anymore. The same applies for electricity generation from biomass which is more or less constant at present. However, the latter could easily be rendered much more flexible, thus providing generation flexibility and reducing the need for storage. A detailed investigation of the need of storage at different time-scales requires considering different meteorological years. This is presented in subchapter 3.3.

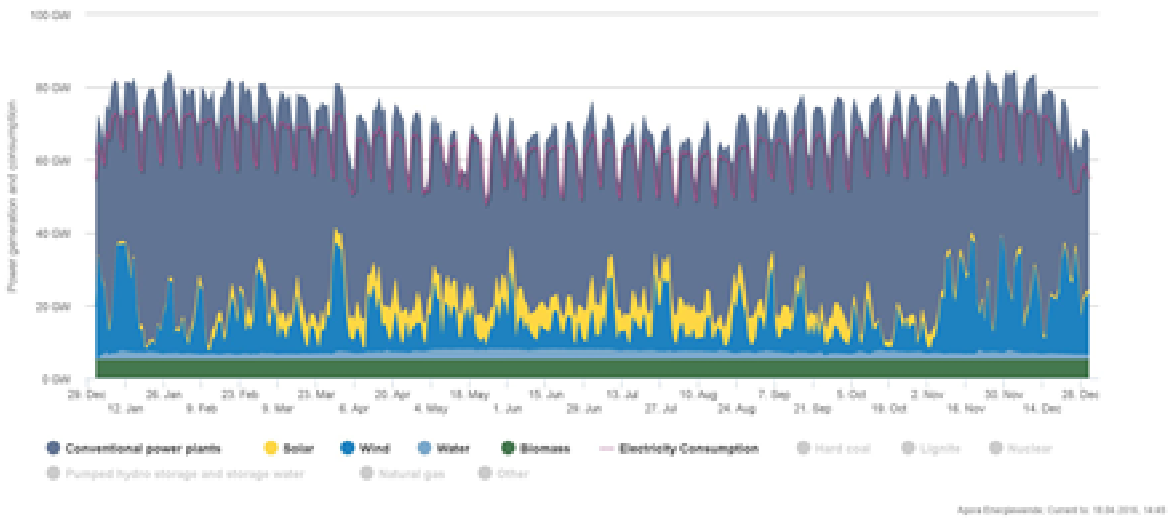

Figure 7: Time-structure of electricity generation in Germany in 2015, Source: (Agora Energiewende, 2016)

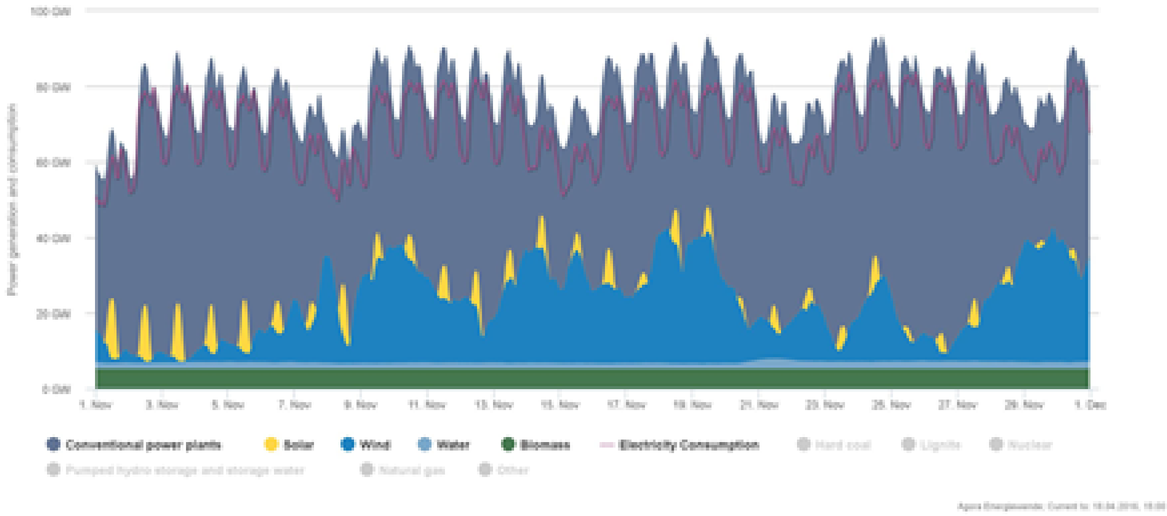

Figure 8: Time-structure of electricity generation in November 2015, Source: (Agora Energiewende, 2016)

At shorter time-scales, a typical daily variation of the combined PV and wind power generation is visible even during winter months as a result of the typical daily variation of PV electricity generation. It is basically synchronous to the daily variation of the consumption (see Figure 8), but in most months, the daily variation of PV power generation is stronger than the variation of the consumption. Hence, the residual load, that is the difference between the consumption and the renewable power generation, shows no longer a maximum at noon, but a dip at noon on most days and two maxima, one in the morning and one in the late afternoon and early evening.

Flexibility provided by imports/ exports, hard coal and pumped storage hydropower plants

Apart from a few hours per year, electricity generation in Germany is always higher than the consumption. Physical net exports amounted to about 7.9 % of the German electricity generation in 2015. The countries to which most electricity exports went were Austria, The Netherlands and France.

Variations of the electricity exports are one means for balancing the gap between generation and consumption in Germany. The most important flexibility however is provided by hard coal power plants which are typically ramped up and down twice per day, and by (pumped) storage hydropower plants. Lignite and nuclear power plants are usually run with a constant output.

Natural gas power plants have high ramp rates and are most suitable to respond quickly to electricity demand variations, but were very little used to that end. Their contribution to the total electricity consumption was only 9.9 %, most of it in combined heat and power plants which are mainly heat demand-led and cannot follow the electricity consumption. The flexibility of gas-fuelled combined heat and power plants with regard to electricity demand fluctuations could be improved at low cost by enlarging the heat storage of such plants, but this does not yet happen at significant scale. Once it will happen, it will reduce the need for other forms of short-term flexibility such as battery storage.

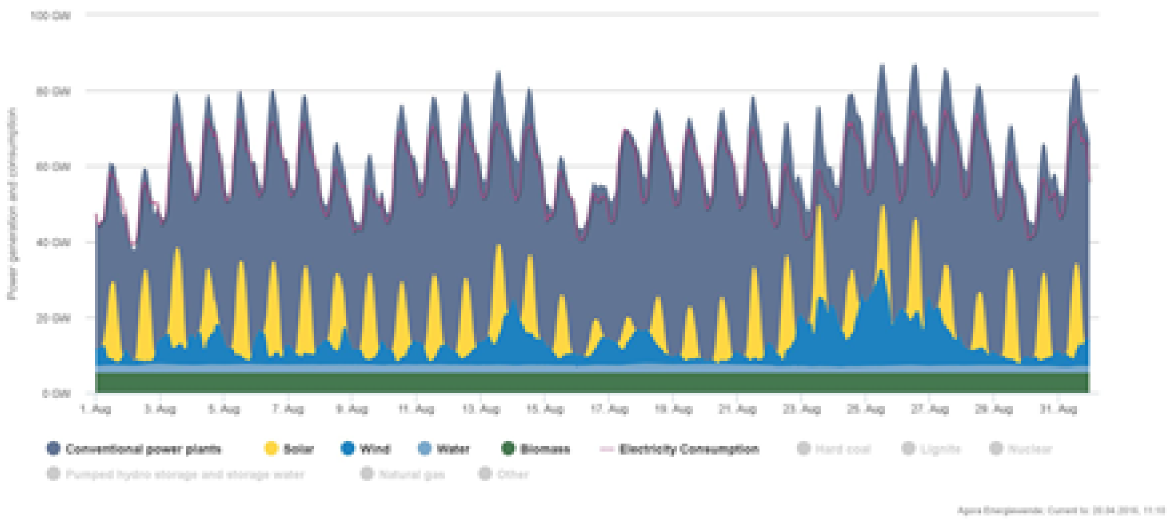

Figure 9: Time-structure of electricity generation in August 2015, Source: (Agora Energiewende, 2016)

Figure 9 and Figure 10 show how the gap between electricity generation and consumption was filled in August 2015. The daily PV generation peaks were synchronous with the midday consumption peak, but much larger. Hence, there was a surplus of electricity generation in the mid of each day. Most of this midday surplus was exported as Figure 9 shows. Conventional generation was reduced at night to deal with the lower demand, and at midday to deal with the high PV generation: hard coal power plants display a larger generation dip each night and a small generation dip every day around noon. Lignite power plants provide a tiny contribution to the daily generation management (see Figure 10).

When the renewable electricity generation came close to the consumption, as on August 23, only the hard coal power generation was reduced almost to zero. Nuclear power generation remained almost constant and lignite power plant generation was reduced only partially, though the spot market electricity price dropped to about 5 €/MWh, thus displaying the inflexibility of these power plant types to respond to variations of the power demand.

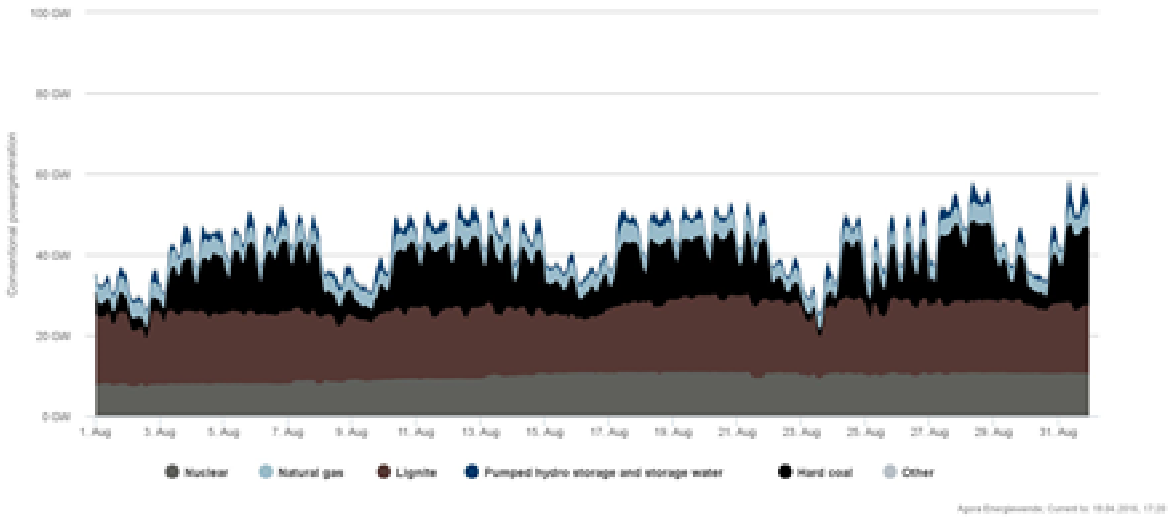

Figure 10: Conventional electricity generation in August 2015, Source: (Agora Energiewende, 2016)

The strongest challenge for flexibility: solar eclipse on 20 March 2015

The ability of the German electricity system to respond to very quick changes of power generation was challenged on 20 March 2015 during the solar eclipse.

Figure 11 shows the generation of PV and wind power in week 20 of 2015 for the different transition grid operation zones. During the solar eclipse on March 20, PV power generation in Germany dropped from 12.9 GW at 9:30 h to 5.45 GW at 10:30 h and then rose to 16.75 GW at 11:30 h (15-minute average values). The variation with a ramp rate of about 8 GW per hour could be predicted very precisely and the drop in PV power generation was balanced by other electricity sources.

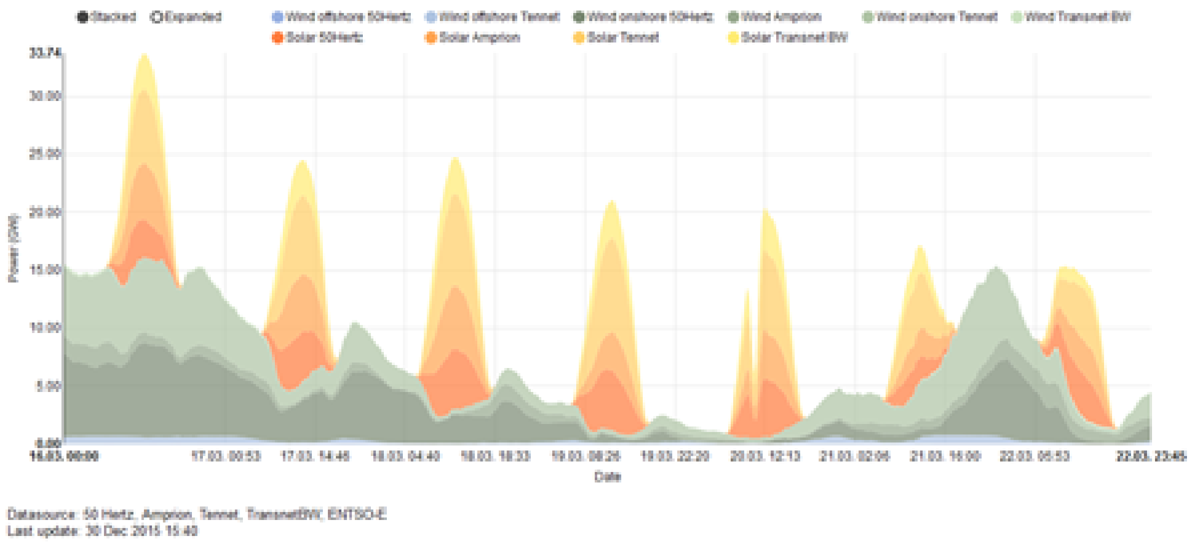

Figure 11: Electricity generation in Germany during the week with a solar eclipse in March 2015, Source: (Fraunhofer ISE, 2015)

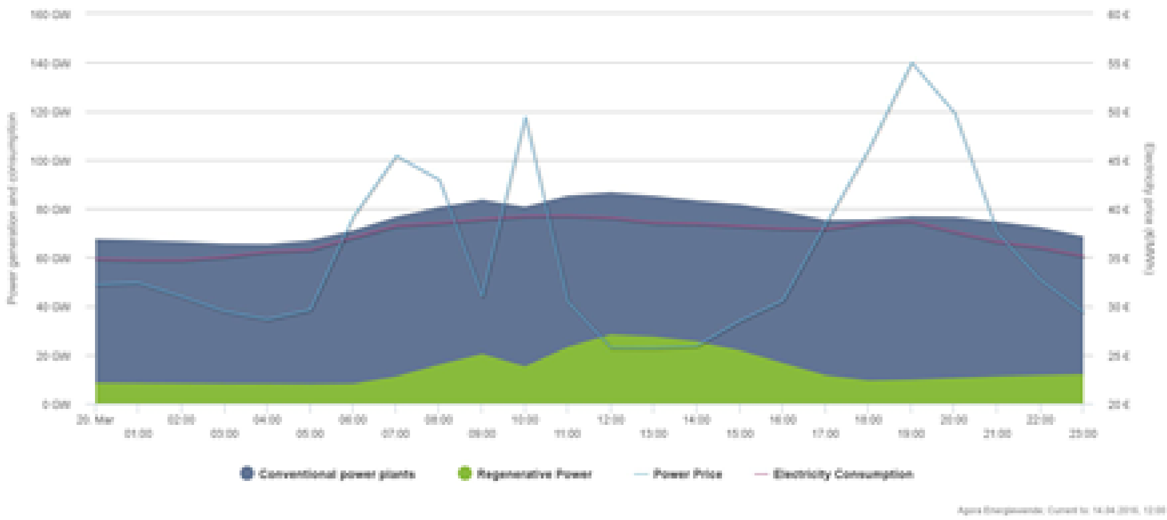

Figure 12: Effect of solar eclipse on 20 March 2015 on the electricity spot market, Source: (Agora Energiewende, 2016)

Figure 12 shows hourly average values of the renewable (green) and conventional (grey) electricity generation, the consumption (pink line) and the spot market electricity price (blue line). The average hourly electricity consumption did not change much during the eclipse. The dip in the total generation is about half the size of the dip in the PV generation.

A closer analysis shows that the lacking PV power was partially balanced by higher generation inside Germany, mainly (pumped) hydro power generation which rose by about 1.3 GW and then dropped by about 0.7 GW, and partially by lower electricity exports: the hourly average values of net exports dropped from 7.8 GW at 9:00 h to 3.8 GW at 10:00 h and rose to 8 GW at 11:00 h, i.e. accounted for about 4 GW out of about 8 GW which were needed to compensate the PV generation dip. The eclipse is clearly reflected by a spot marked price peak of almost 50 €/MWh compared to about 30 €/MWh at the beginning and the end of the eclipse.

Conclusion 2: There is no need for batteries to ensure the hourly national balance of generation and consumption at a level of 32.6 % RE contribution to the electricity consumption

The investigation of electricity generation and consumption in 2015 and the way how the gap between both is closed even when the generation is strongly fluctuating, shows that there is no need for additional flexibility to balance the average hourly generation and consumption at national scale though the contribution of renewable electricity generation has already reached 32.6 % in 2015, out of which 21.1 % were from strongly fluctuating PV and wind power generation. This conclusion leaves three points aside: (1) time-scales shorter than one hour, (2) sections of the grid without sufficient capacity to transport electricity such that imbalances are equalled out even over long distances, and (3) the situation if the contribution of strongly fluctuating renewable generation from PV and wind power is further increased. In fact, these three points outline the field of application for batteries as is shown in detail in chapters 4 and 5.

Before investigating the potential need for, and applications of batteries, options for cheap flexibility within a predominantly renewable electricity generation system need to be looked at in more detail. There are essentially two: (1) biogas plants could provide a considerable potential for highly flexible renewable power generation, and (2) conventional natural gas power (and heat) plants could be run more flexibly at little additional cost. The latter can also provide a bridge towards a 100 % renewable power supply by smoothly switching from natural gas to synthetic hydrogen and methane produced from surplus electricity at times of high renewable power generation (power-to-gas).

Biogas and natural gas-powered CHP: untapped potential for flexibility

At the end of 2015, about 9,000 biogas-fuelled combined heat and power (CHP) plants, including plants fuelled with biogas up-graded to bio-methane through removal of the CO_2 contained in the biogas, with a total nominal electric power of 4.2 GW were installed in Germany (Fachverband Biogas, 2015). They produced 32.5 TWh (5.4 % of the total electricity consumption, 73.5 % of electricity generated from biomass) in 2015. Those of them which were already installed until the end of 2014 had a gas storage able to buffer the biogas production of 4.2 hours on the average and the filling level varied between 21 and 81 %. Most of these plants generated electricity continuously and achieved 7,886 annual full load hours in 2014 on the average. (DBFZ, 2015)

Biogas is a fully controllable source of renewable electricity which can in principle follow exactly the demand as quickly as natural gas-powered plants, i.e. with a ramp rate of 100 %/15 min, thus meeting the requirements of tertiary control reserve – and those of secondary control reserve if complemented by batteries.

The fact that existing biogas plants are nevertheless operated more or less constantly is due to the high proportion of combined heat and power generation which is inflexible with regard to electricity demand variations as long as no specifically large heat storage is integrated, but also due to the remuneration scheme of the Renewable Energy Act which provides a bonus for flexible operation only since 2012.

In 2015, 50 % of the operators in terms of installed power capacity made use of this scheme and their number is quickly increasing (Holzhammer, et al., 2016). For this purpose, existing biogas plants are up-graded to run flexibly, thus being able to respond to the electricity demand. On the average, the generator capacity is increased by about a factor two in case of a refurbishment, and the biogas and heat stores are enlarged to deal with the flexible operation. The fermenter and the substrate feed-in do not need to be changed if the total biogas generation is not increased (DBFZ, 2015). In 2015, the increasingly flexible operation of biogas plants has led to the only slightly reduced number of 7,650 full load hours (Holzhammer, et al., 2016). That means that the already existing flexibility of biogas plants is not yet fully used.

If all the existing biogas plants in Germany were up-graded to these same level of flexibility, this would add about 4 GW flexible electricity generation capacity with a ramp rate of 100 %/ 15 minutes, able to compensate gaps between the remaining generation and the demand at a time-scale between 15 minutes and a day. This does not imply an increase in biogas production, but just a use of the same amount of biogas for electricity generation more in pattern with the electricity demand.

Biogas plants could also be used to compensate gaps between the residual generation and the demand at longer time scales, but this requires a modulation and thus a reduction of the total biogas production.

In a similar way as biogas plants, CHP running with natural gas can be used as flexible elements of the electricity system, provided they are equipped with sufficiently large heat stores, so that the electricity generation can be decoupled from the heat generation. Costs for shifting 1 kWh of electricity with thermal stores are the lowest of all flexibility options. They are below 1 ct/$kWh_{shifted}$ in the case of small CHP and can be as low as 0.1 ct/$kWh_{shifted}$ in the case of CHP coupled to district heating systems with large thermal stores (Sterner, et al., 2014). This potential is far from being explored in Germany at this stage.

Conclusion 3: There is no need for batteries to ensure the hourly national balance of generation and consumption even beyond 32.6 % RE contribution to the electricity consumption

The untapped potentials for generation management of biogas and natural driven CHP plants are just two examples among several options how sufficient flexibility can be provided in the German electricity system to deal with very high rates of renewable electricity generation beyond 32.6 % RE contribution to the consumption, without running into the need to install further storage systems than the existing pumped-storage hydropower plants. Among others, cost-effective flexibility measures are notably demand-side response. (Elsner, 2015)

Electricity spot and futures market

The average day-ahead market price for electricity was 31.60 €/MWh in 2015, the second lowest value in Europe behind Scandinavia. Long-term delivery contracts for 2017-2019 are already concluded at prices at about 26 €/MWh. These are historically low electricity market prices and they are a result of the high level of renewable electricity generation which has priority over conventional electricity and is sold first. Even without priority on the market, existing PV and wind power plant operators could offer electricity at a very low price on the market, because PV and wind power generation has nearly zero marginal costs.

As a result, there is a strong competition for covering the residual electricity demand which leads to very low market prices – above the marginal costs of conventional power plants, but below their life-cycle costs. For this reason, the present electricity market does not provide an incentive for further investments in electricity generation plants in Germany, neither conventional nor renewable ones. Even more, some plants are shut down, notably natural gas-fuelled plants, for lack of profitability. (Agora Energiewende, 2016)

About 10 % of the German electricity generation was sold abroad in 2015, a bit more than the physical exports of about 7.9 % of the generated electricity. Export and import prices were about 40 €/MWh in 2015 and thus higher than the average spot market price. This indicates that transboundary electricity exchange between Germany and its neighbouring countries is mainly driven by the electricity demand of the latter, and corresponding higher prices that electricity traders abroad are ready to pay, not by a lack of flexibility within the German electricity generation system. If the latter had been the case, electricity from Germany had been dumped more frequently at lower prices and electricity imported to Germany had reached higher prices. (Agora Energiewende, 2016)

Nevertheless, 126 hours (1.4 % of all hours) with negative spot market prices averaging at minus 9 €/MWh indicate that there was either a lack of available flexibility for technical reasons and/ or the existing market rules did not allow encourage using the existing flexibility. Closer analysis reveals that it is a combination of both. (Peek, et al., 2016)

Use of battery storage systems

Despite the little need for flexibility at national scale, battery storage systems are more and more installed in Germany, essentially for four different reasons:

(1) Conventional use: Batteries have been and continue to be a component of uninterruptable power supply (UPS) systems, back-up electricity generation, and off-grid applications. The latter are rather rare in Germany because the electric grid is very dense in almost all parts of

the country. Nevertheless, off-grid applications exist: telecommunication repeater stations, ticket vending machines, road safety devices, and a few houses such as alpine huts.

(2) The burden of electricity grid fees and the transaction costs of the energy transition are very unequally shared among different electricity consumers. Thus, private users and small enterprises pay much higher fees and have much higher electricity purchase rates than large industrial enterprises. The lower grid use fees for large industrial enterprises are due to their often very short distance to large power plants and the fact that they effectively use just a strong, but short power transmission line. The very low electricity purchase rates of large industrial enterprises are due to the fact that they can buy electricity directly at the electricity market where the prices have reached a historical minimum. The partial or full exemption of large industrial and commercial electricity consumers from the transaction costs of the energy transition in the electricity sector (EEG Umlage) is due to a political decision.

Private households, however, pay about 28 ct/kWh (280 €/MWh) for electricity, grid fees and various charges included. This is much more than electricity generated by small PV systems with a battery storage system costs. For this reason, battery storage systems are increasingly installed in connection with PV systems in order to maximise the share of self-consumed PV electricity for private house owners. This tendency has recently been attenuated by new charges put on self-consumed renewable electricity.

(3) Though the balance between generation and consumption is very easily achieved at national scale, it isn’t locally. High renewable power generation has increasingly led to congested electricity distribution grids, thus forcing notably wind power plant operators to curtail power generation below the instantaneous possible maximum power. In total, about 2.7 TWh of possible renewable power generation took not place between January and September 2015 (Bundesnetzagentur, 2016). Extrapolated to the entire year 2015, this means that about 1.8 % of the possible renewable power generation, essentially wind power, is not used because of local grid congestions.

(4) The high share of RE power generation implies that the stability of the frequency, up to now mainly guaranteed by the inertia of the rotating masses of turbines and generators in conventional power plants needs

to be ensured by new means. Battery storage systems provide a solution. They can offer “synthetic inertia” to stabilize the grid frequency at the time-scale of fractions of a second and above, and provide primary and secondary balancing power at the same time. This is the main reason for the installation of most of the MW-scale battery systems being installed at present as shown in Figure 13.

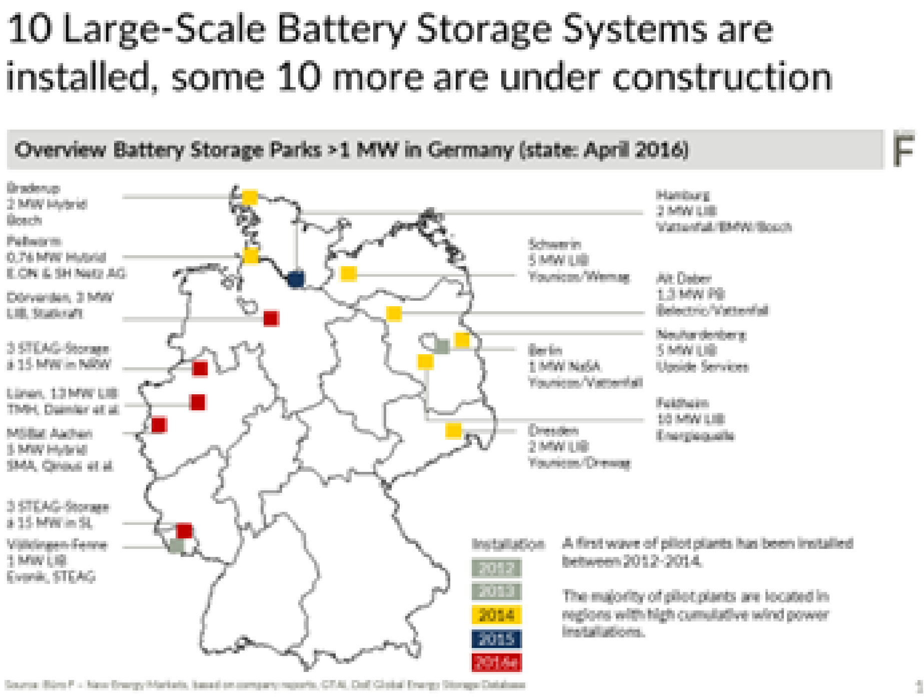

Figure 13: Existing and planned large battery storage systems in Germany, Source: (BüroF, 2016)

Outlook on further development

By 2016 new PV and on-shore wind power plants can generate electricity at the lowest cost of all new power plant types (about 8 ct/kWh). However, existing conventional power plants which have reached the end of their financial life-time can still generate electricity at even lower costs. Old coal and nuclear power stations reduce their output only when the electricity spot market price falls below about 2 ct/kWh – provided this is technically possible.

A major change will come along with the decommissioning of all nuclear power plants until 2022. Further, a closure of old and inflexible lignite and hard coal power plants is about to be discussed. This will lead to a much more flexible electricity generation park and higher and more constant electricity prices on the market, thus permitting a better return on investment for the operators of the remaining power stations.

The further expansion of renewable power generation has been strongly limited by the government since 2012. New installations are much less and the renewable capacity is growing much more slowly than a few years ago.

Hence, there will not be a need for flexibility in the electricity supply system at national scale provided by battery systems. However, the strongly falling prices for battery systems will lead to an expansion of the market for the applications mentioned above, in particular self-supply of households and small enterprises with PV-battery systems (battery capacity in the 1-10 kWh range) and local compensation of fluctuating renewable power generation in distribution grids (100 kWh – 10 MWh range).

3.1.2 France

Responsible Partner: Nissan Europe

The EU's Renewable energy directive sets a binding target of 20 % final energy consumption from renewable sources by 2020. To achieve this, EU countries have committed to reaching their own national renewables targets. France targeted 23 %.

The composition of the renewable electricity generation park in France continues to evolve in favor of wind and solar with 2,086 MW connected in 2014 and 1,894 MW in 2015. The Figure below represents the evolution of the total annually connected renewable energy capacity in France since 2002:

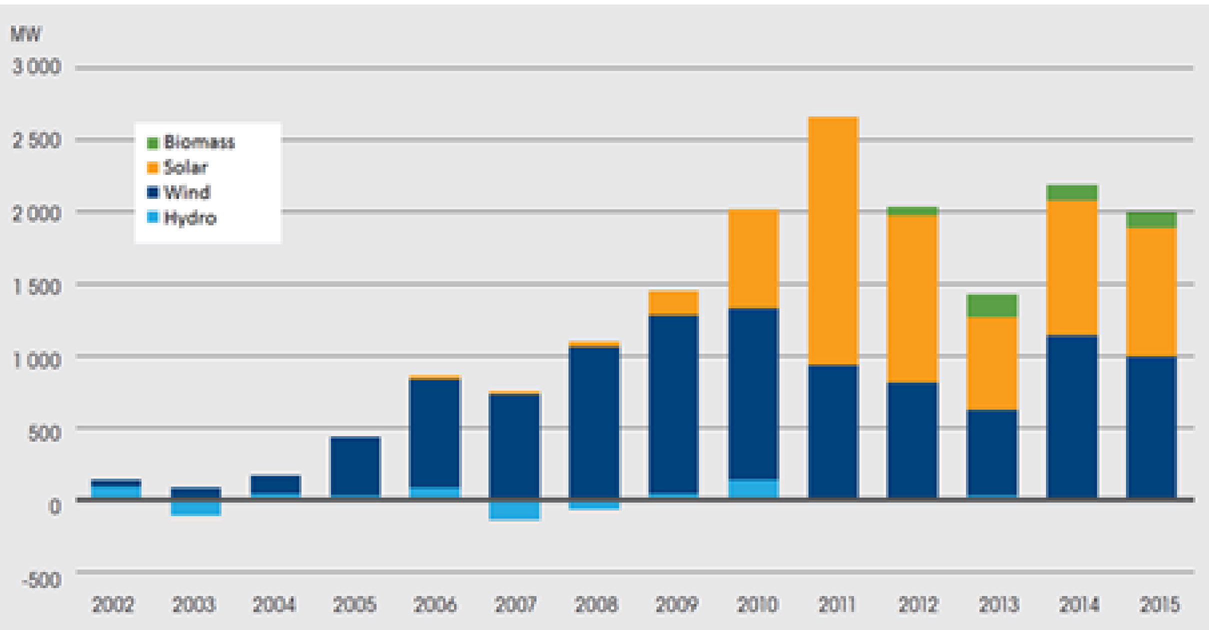

Figure 14: Evolution of the total annually connected renewable energy capacity in France since 2002, Source: (RTE, 2015)

The total renewable energy capacity installed in France in 2015 is 43,6 GW (RTE, 2015). The hydraulic park represents approximately 58 % of this capacity. The wind and solar sectors are experiencing the most significant growth the last years and take 38 % annual share. Approximately 60% of these sources are connected to the TSO.

The total renewable energy production in 2015 is 88,4 TWh, 54 TWh (61 %) from hydraulic, 21 TWh from wind, 7,4 TWh from solar and 6,4 TWh from bioenergy sources. The Figures below represent the total renewable energy capacities connected to the grid in France in 2015 and the corresponding produced energy:

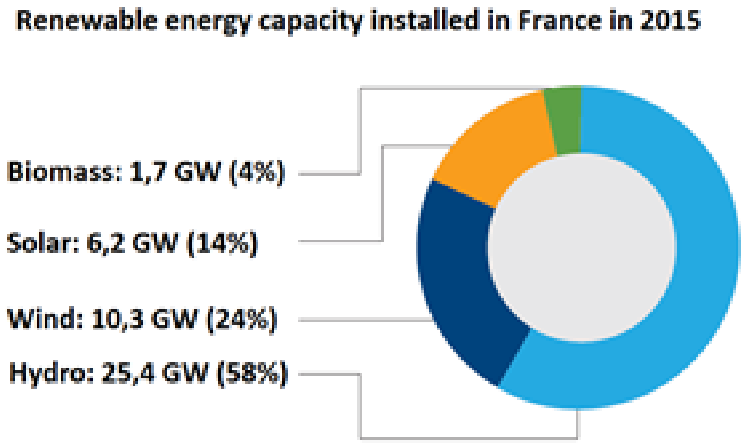

Figure 15: Total renewable energy capacities connected to the grid in France 2015, Source: (RTE, 2015)

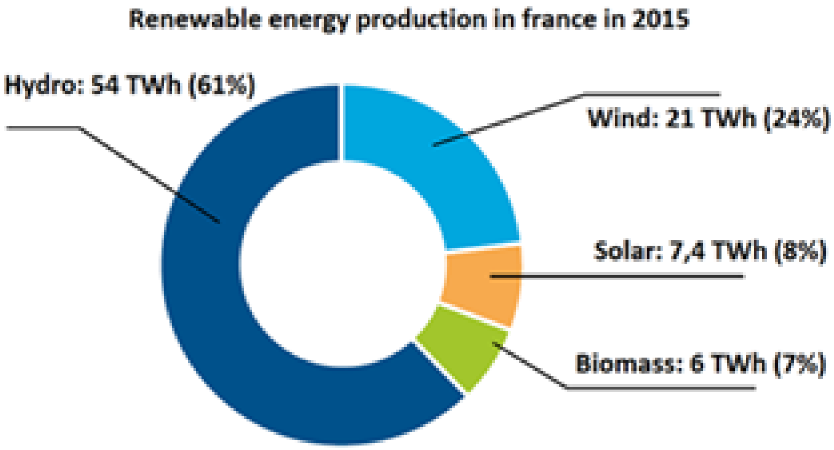

Figure 16: Total renewable energy production in France in 2015, Source: (RTE, 2015)

The average coverage of the electricity consumption by renewable electricity sources was 18.7 % between 1 January and 31 December 2015, of which 11.4 % insured by the hydraulic sector, 4.5% wind power, 1.6 % by the solar sector and 1.3 % by bioenergy. The average coverage is down compared to 2014 when it was 19.6 %. This variation of - 0.9 points is explained by an increase in consumption of almost 2 % and a drop in hydraulic output of about 14 % (or - 8.5 TWh), rainfall levels have been much lower compared to 2014.

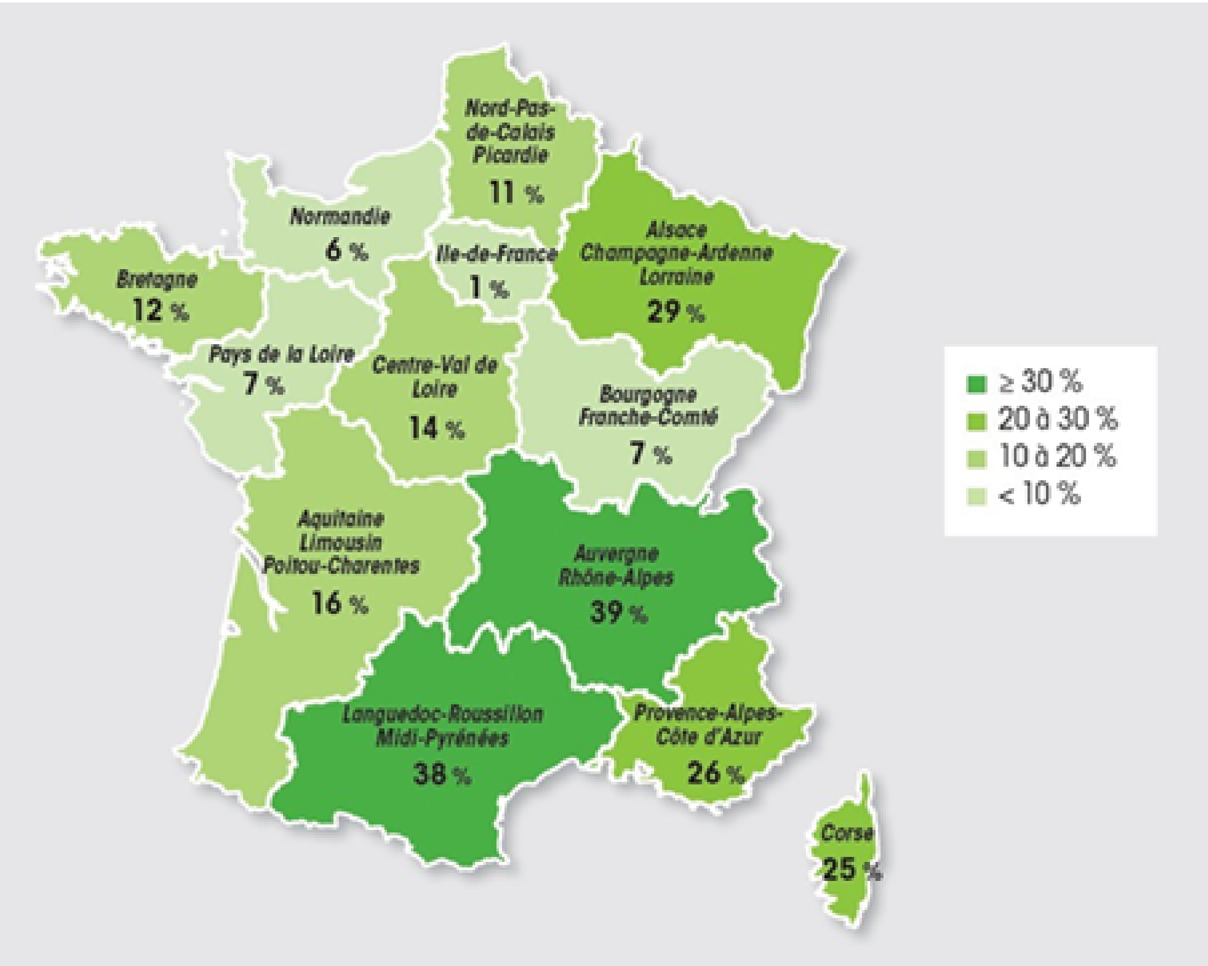

Figure 14: Average coverage of the electricity consumption by renewable electricity sources in 2015 in France, Source: (RTE, 2015)

Transmission and distribution networks have been dimensioned to transport and distribute energy produced by centralized generation, without regard of the weather conditions. The development of electricity networks has historically followed the growth of peak consumption. In recent years, the significant deployment of decentralized intermittent renewable energy production represents a new challenge for electrical transmission and distribution system.

This change in the structure of production has a significant impact on the distribution network. With the connection of 341,737 renewable energy installations and an average of about 25,000 new RE installations per year, the distribution network must be able to absorb this growth and adapt its operating rules in order to collect and distribute the produced energy locally or transfer it to the electricity transmission network.

The development of the renewable energy sector has also an impact on the transmission network. The deployment of renewable energy sources creates a new geographical distribution of electricity generation marked by wide disparities between regions and between countries. The generated electricity which is not consumed locally need to be transported by the TSO network to other consumption areas. Thus, the transmission network across both national and European level (via interconnectors) need to be developed in order to ensure the pooling of installations and maintain the supply-demand balance.

In order to be able to anticipate and better organize the renewable energy growth in France, the French TSO, RTE (“Réseau de transport d'électricité”), in agreement with the managers of distribution networks, introduced the “Regional Schemes for Connection of the Renewable Energy to the Grid” (S3REnR). These schemes aim to ensure visibility of the capacities of the transmission and distribution network to absorb renewable energies by 2020, to anticipate developments of networks and establish cost sharing mechanisms in order to ensure a fair distribution of the cost for the electrical network upgrade.

In November 2015, 20 of 21 regions have confirmed their S3REnR. The diagram below summarizes the capacities reserved for the development of renewable energies by 2020, and the cost for the development of the grid by region.

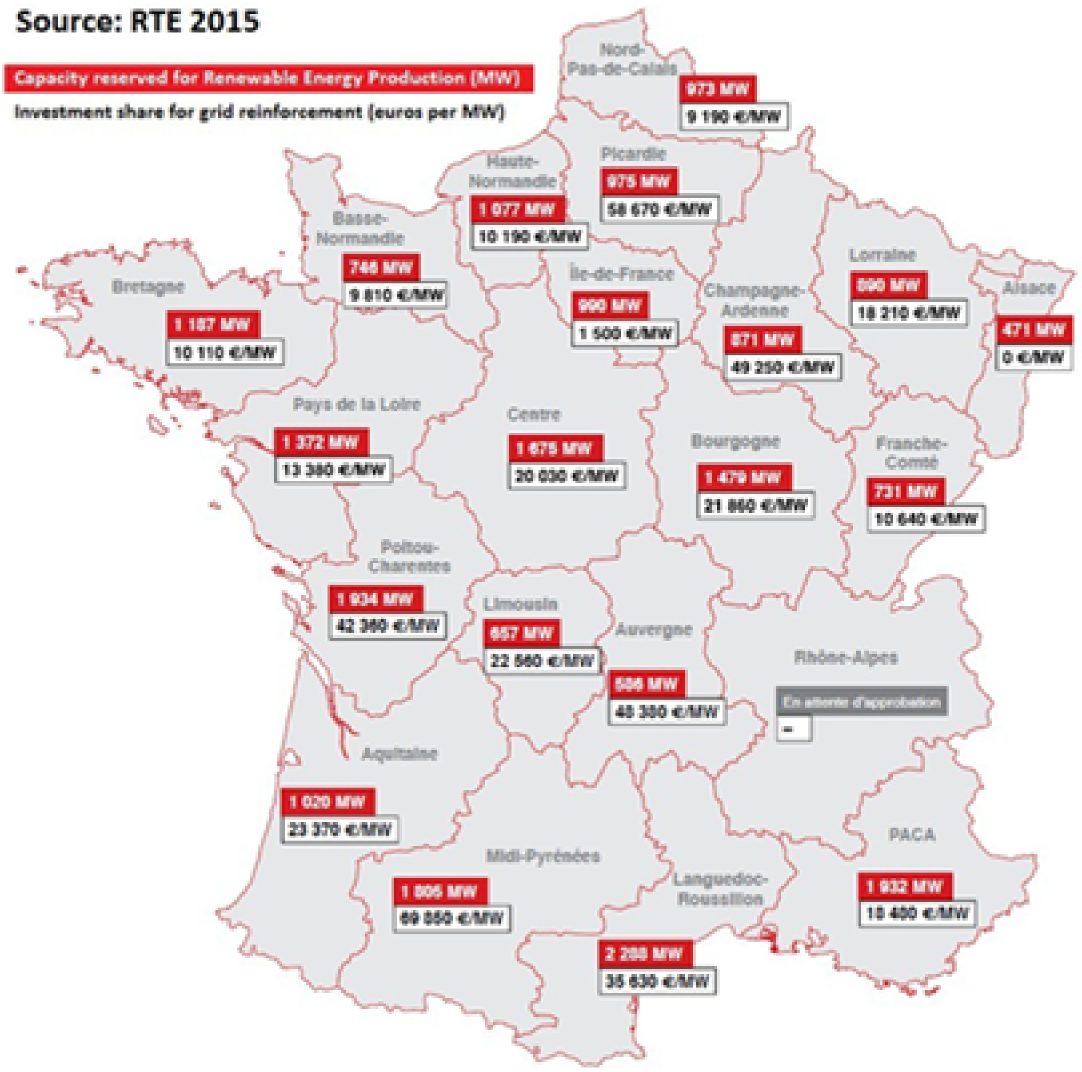

Figure 17: Reserved capacities by 2020 and regional costs for electrical network development, Source: (Observ'ER, 2015)

The observed regional disparities are significant. The reserved capacities range from 471 MW in Alsace to 2288 MW in Languedoc-Roussillon. The grid upgrade costs also vary from 0 k € / MW (Alsace) to 69.85 k € / MW (Midi -Pyrenees). These differences are explained by both initial available capacities of the local network and the ambitions for future development of renewable electric sources. Thus, in Alsace for example, the proposed scheme will not require an investment. In the Midi-Pyrénées however, 153 million euros of investment appear necessary on the transmission and distribution networks, 126 million euros of those will be charged on the producers (Observ'ER, 2015).

The French system has a significant resource of flexibility to ensure the balance between the production and the consumption and also to secure the electricity supply:

- Energy import/export via interconnectors to the neighbouring countries
- Primary, secondary reserve
- Tertiary reserve (« Mécanisme d'ajustement »)
- Control of the consumption of large industrial plants (« Effacement »)
- Capacity mechanism
- Energy storage

The energy storage capacity in France consists mainly of hydropower, the second highest installed capacity in Europe (after Norway). In 2014, hydropower generated 68 TWh, covering about 15 percent of French power consumption. It also provides about 50 percent of the balancing energy and thus playing a key role in balancing variable renewables (Mathieu, et al., 2015).

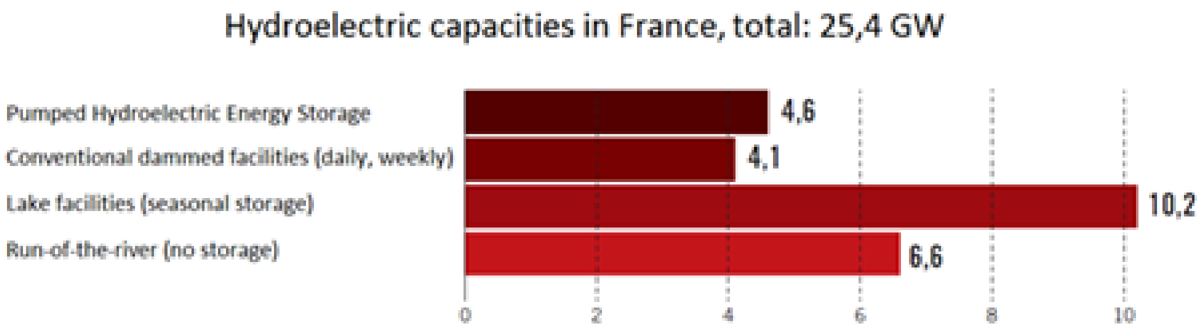

Figure 18: Hydroelectric capacities in France 2014, Source: (Mathieu, et al., 2015)

Considering the fact that the French system disposes with a strong flexibility potential and constantly reinforced transmission and distribution grid, the renewable energy expansion and the objectives for 2020 could be met with no particular need for additional energy storage.

Regarding the use of small scale storage in the residential sector, there are no incentives so far to encourage this development. Moreover, the feed-in tariff for the production from small residential photovoltaic systems (0-9 kWp) is more than two times higher than the average household electricity rate. (photovoltaique.info, 2011)

3.1.3 Italy

Responsible Partner: Engineering

According to latest data distributed by national TSO Terna, for 2014, Italy produces 86 % of its own electricity total demand. The remaining 14 % is imported. The imported portion come mainly from Switzerland (50 %), about 33 % from France and the complementary part from Slovenia and Austria. However, the national production is relying on raw material imported so creating a further dependency from foreign countries.

In 2014, the electric energy gross production was 280,000 GWh. Main part, about 150,000 GWh, generated by thermoelectric production exploiting fossil combustible; The distribution is: 65 % from natural gas, about 30 % from coal and the remain from fuel oil. A part of the thermoelectric production, about 37 % (120,000 GWh) are generated by renewable resources; Of this about 60,000 GWh are actually hydroelectric production; second in the list is the photovoltaic production with about 22,000 GWh produced in 2014; then there is biomass combustion with about 18,700 GWh, wind produced power with 15,200 GWh and geo-thermal production with 5,900 GWh. (Terna, 2016) Renewable resources distribution is reported in the following figures:

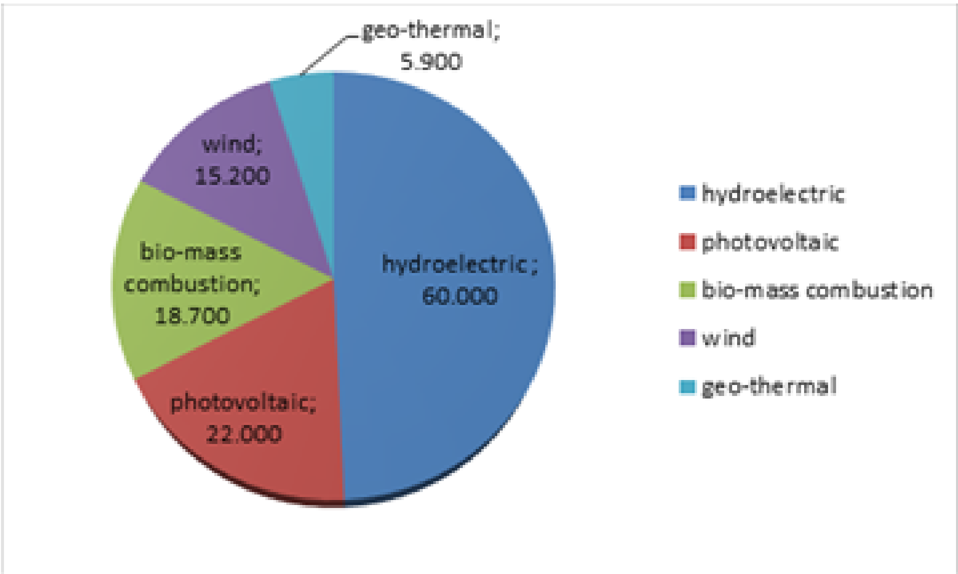

Figure 19: RES production in Italy in GWh; Source: (Terna, 2016)

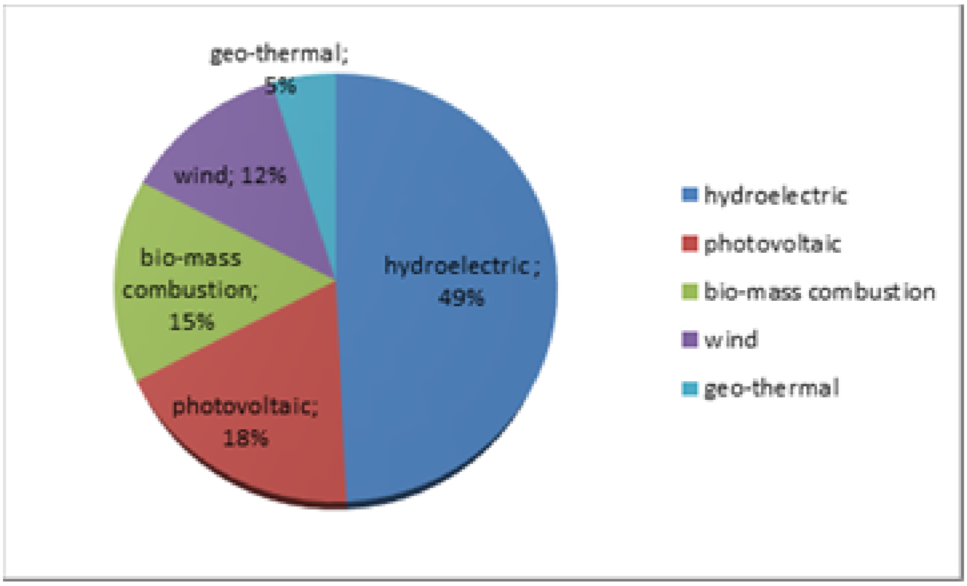

Figure 20: RES production in Italy - percentage sharing, Source: (Terna, 2016)

RES production had a relevant growth during the last years. Its share on national consumption has more than duplicated in the last ten years and is higher than the average in other European countries. Figure 21 reports the classification of the European countries per RES production.

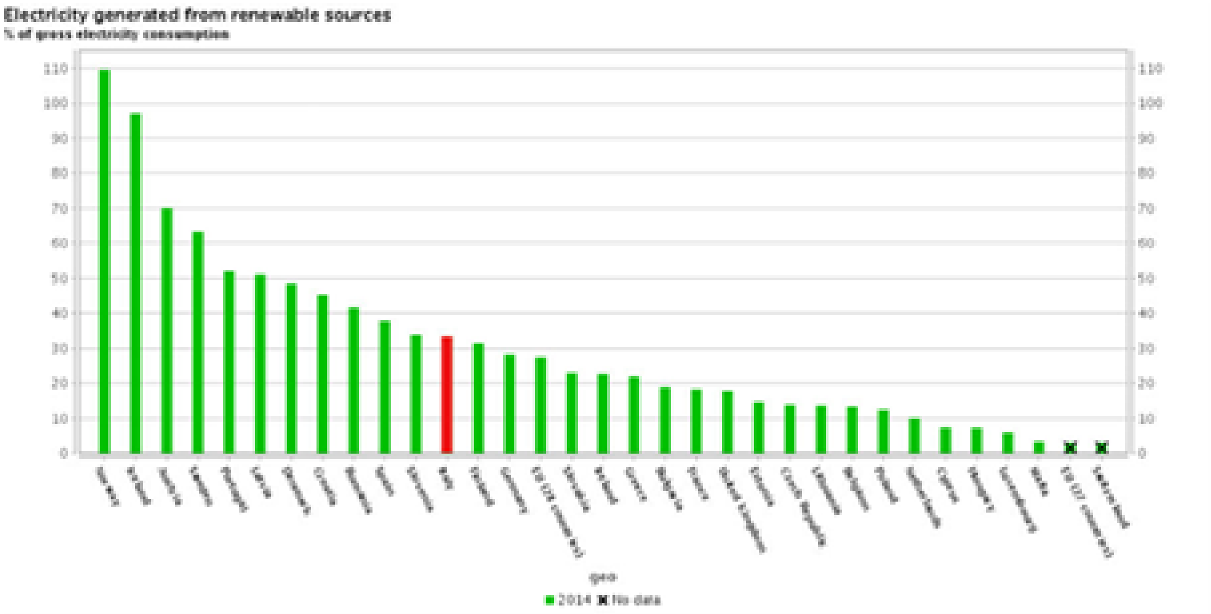

Figure 21: RES production in Europe 2014; Source: (GSE, 2014)

Renewable electricity generation capacity – the trend

During last decade in Italy an intense policy of incentives for RES installation was applied. Following this action, the overall national energetic panorama changed from 18 % of RES in 2004 to 43 % in 2014. Figure 22 reports the proportion of the different sources during the decade for electric production. (L'energia, 2016)

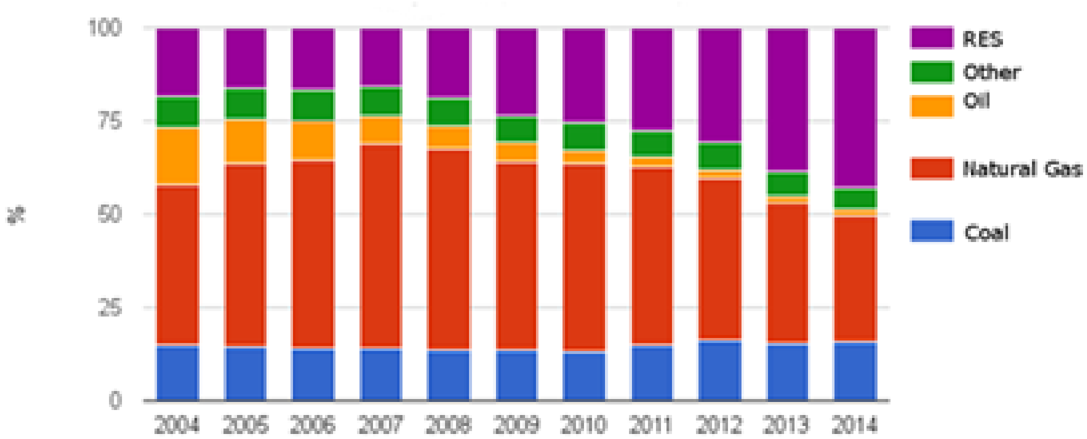

Figure 22: Electric production per source - Italy, Source: (stradeonline, 2016)

Figure 23 shows the data from the TSO Terna, for 2014, detailing the overall production per resource.

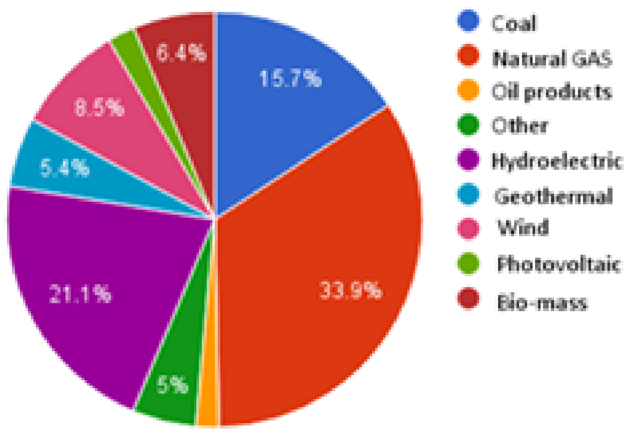

Figure 23: Energy production per sources – Italy 2014, Source (stradeonline, 2016)

600,000 RES-installations are connected to the Italian grid, with a gross installed power of 50,000 MW. In 2013, the overall RES was 112 TWh, in 2014 it was about 120 TWh. Some preliminary data on 2015 are available and visualised in Table 1.

Italian GSE (Gestore Servizi Elettrici – Electric services management authority) provided the trend for both installed RES power and gross production in the 2010-2015 timeframe:

	2010	2011	2012	2013	2014	2015 (Prelim. estimation)
Gross Power (MW)						
Hydraulic	17.876	18.092	18.232	18.366	18.418	18.531
Wind	5.814	6.936	8.119	8.561	8.703	9.126
Photovoltaic	3.470	12.773	16.690	18.185	18.609	18.910
GeoThermal	772	772	772	773	821	824
Bio (*)	2.352	2.825	3.802	4.033	4.044	4.087
Total	**30.284**	**41.398**	**47.614**	**49.919**	**50.595**	**51.479**
Gross Production (GWh)						
Hydraulic	51.117	45.823	41.875	52.773	58.545	43.902
Wind	9.126	9.856	13.407	14.897	15.178	14.883
Photovoltaic	1.906	10.796	18.862	21.589	22.306	22.847
GeoThermal	5.376	5.654	5.592	5.659	5.916	6.160
Bio (*)	9.440	10.832	12.487	17.090	18.732	18.894
Total	**76.964**	**82.961**	**92.222**	**112.008**	**120.679**	**106.686**
Gross Internal Consum (GIC**)	342.933	346.368	340.400	330.043	321.834	325.566
RES / GIP (%)	*22,4%*	*24,0%*	*27,1%*	*33,9%*	*37,5%*	*32,8%*

* Bio: solid biomass (including bio-degradable waste), biogas, bioliquid

** GIP = Gross production + Import – production from Produzione lorda + Saldo estero – hydroelectric pumping

Table 1: Gross Power produced by RES, Source: (GSE, 2016)

On the one hand, the analysis of the preliminary estimation in 2015 shows a reduced wind and hydraulic power generation. On the other hand, the remaining RES further increased in 2015. These trends are probably related to weather condition in 2015. However, it is improbable that the overall sector can grow without a clear schema of incentive strategy. In 2014, the last incentive provision campaign was concluded and it was followed by a further decree that can regulate the production plants installed in 2015-2016. The new campaign for the next period is expected soon.

RES production issues

In 2014, some issue risen up in relation to network problems related to the RES production in Apulia, Calabria and Sicily and in particular for wind generation. In fact, these areas have a relevant production but are quite far away from the part of the grid where the correspondent demand is located. To figure out these problems new high voltage distribution backbones lines were planned and in June this year the Sicily-Calabria connection was inaugurated. Wind and PV generation have a high level of unpredictability in relation to their dependency from weather conditions and it is still creating relevant issues that local storage adoption could mitigate. To have a sustainable production same thermal plant exploiting fossil raw material are usually activated; however, these kind of plants require to work close to an optimal production cycle level and are not offering necessary level of flexibility; it is representing the so called base load. During peak hours some more flexible plants are activated. However, in correspondence to clear and windy days the Wind and PV production exceed the normal production creating grid unbalances. Based on this development, the legal frame-work was adapted by curtailment policies to limit the instabilities/unbalances between generation and consumption.

Storage exploitability

The above described big picture demonstrates that the national grid is not ready to exploit the RES production yet without a certain level of additional flexibility. Therefore, two main lines are necessary:

- the increment of a green baseload from biomass, geothermal and hydroelectric production,
- the introduction of flexibilities in the grid management to reduce or avoid the RES curtailment.

These two macro-actions could bring the country towards and actual green approach to the electric power production and distribution. Storage systems could be part of the necessary flexibility in particular as part of local systems, aggregated or not, that can compensate the RES production fluctuation and mitigate the peaks.

RES effect on energy market

The level of un-programmable installed production, in particular PV, seems to be more stable than in past, in particular in 2014 after big increments of previous years. Comparing data from 2013 and 2014 and referring to the 24 hours' timeframe it seems that the hourly cost of energy on the market was slightly affected by fluctuation introduced by RES, with a small transition towards lowest prices. In 2014 fluctuation of non-programmable RES were confirmed on respect of 2013 data, and in particular it was observed:

- An increased necessity of reserve usage (total) related to the shutdown of power plants. The need of tertiary reserve was increased of about 4-5 % during the 2014.
- An increased necessity of rapid reserve (secondary and third) to accomplish peak loads during early morning and evening and compensate exceeding feed-in from RES.
- A reduction of starting and operational timeframes for production units using combined cycle to tackle the request of flexibility in the system.

Increased costs can be related to the necessity of the TSO Terna to install systems to tackle the unbalances between generation and demand and due to not only “out of order” plants but also to the unpredictability of the power generation from RES.

Outlook – National Grid updates via Storage systems

In order to have an increased exploitation of renewable energy in the national energy mix a technological upgrade towards a distributed and decentralized model is required.

In this model/system following cornerstones are essential:

- The development and implementation of storage systems in the national grid.
- Rational grid expansion, not only high voltage lines but also medium and low voltage lines to implement actual “Smart Grid”-technologies. A smart grid is a network that can put in place same level of intelligence thanks to the adoption of sensors and auto-regulation mechanisms, even at local level.

The TSO Terna reported that, at this stage, the hydroelectric plants are used as storage systems, these are activated to compensate unbalances even pumping back the water in the ponds when a load increment is required.

They suggested that benefits could be generate from the use of big electric storage, even mounted on tracks, to absorb the wind turbine production excesses when the lines are not able to dispatch the production. In some cases, the adoption of storage systems can be more convenient than the building of new electric lines.

Moreover, the TSO Terna is pushing to introduce in the national regulatory framework policies similar to the one existent in other European countries, aimed at allow to the grid manager –the TSO – to indicate where the RES production nodes can be connected, in order to mitigate unbalances; in fact, at this time RES are installed without a specific geographic distribution regulation, TSO is then in charge to manage network stability and unbalances. TSO would rationalize the installation concentring these in the area not affected by congestion.

The TSO Terna, in particular, is managing two pilot projects to validate storage systems (batteries). The two pilots are planned to exploit 130 MW and 40 MW, for a total of 950 MWh (Terna Innovation and Development, 2016); So far 50 MW are already installed and under validation. Moreover, the first project received an upgrading plan to increase the power from 130 MW to 240 MW. All these systems are aimed to improve the integration and management of intermittent RES.

Outlook – Storage systems electric grid support

Batteries, thanks to their characteristics, can perform in optimal way the function to integrate and manage the intermittent production resources in place of the programmable electric plant. Battery storage systems can provide different services to compensate and limit grid instability and unbalancing. Usually these issues are tackled exploiting the three level of operating reserve that are used to have a prompt reaction.

Among the reserves the primary is the first that is used, it consists of a regulation bigger than ±1,5 % of the power that all the plants have to offer to the electric systems. Obviously the RES - not programmable - are not able to offer this service, so their presence created a deficit in primary reserve for a maximum of ±1,5 % of the total power installed. As above described in the second development plan, the pilot project was updated to 240 MW that is exactly the 1,5 % of the total PV installed power peak. In this sense the installation of a few hundreds of MW of batteries is very relevant because it is able to figure out the primary reserve deficit introduced by national PV plants.

The amount of secondary and tertiary reserve is regulated in different ways, according to the specific needs case per case. On respect of those reserves the RES adoption is not creating a reserve deficit, it is requiring an increment of quality. In particular, tertiary reserve providing the largest proportion of rapid reserve. It is also called “cold reserve”, which means it is provided by plants that are normally off but have a good level of flexibility and have short turning on timeframe (usually turbo-gas turbines or combined cycle using natural gas or also hydroelectric plant operating in pumping modality). In this context the battery rapidity in not particularly necessary even in consideration that the cold reserve in not affecting the active power in a certain moment. The RES expansion doesn’t represent an issue as it is for the primary reserve. However, if there will be not the adoption of storage systems together with intermittent sources, it will remain necessary to rely on traditional resources such as the fossil based or the natural hydro-electrical plants (not pumping mode) to provide this reserve.

In the context of support that the batteries can provide to the national system there is another field – the lines congestion. It is actually related to portions of the grid and not to the whole grid, so it is geographically located. In this case the versatility and flexibility of the batteries is crucial, these can be installed in precise point providing a huge added value. In fact, batteries can be installed exactly where these are necessary, locally, offering a logistic advantage that classical system can't offer. In practice the peak shaving and load shifting can be applied exactly in the grid portions where the production surplus is present. Moreover, these batteries can, concurrently, provide stabilization and balance functions.

Summarizing it is possible to say that it is not necessary to have big capacity storage, the prevalent model involves the consumption of energy when it is produced; the batteries are more suitable for local services such as RES fluctuation management and to solve and to prevent local bottlenecks.

3.1.4 United Kingdom

Responsible Partner: United Technologies Research Center

Figure 24 shows the actual RE shares in the EU Member States for 2005 and 2013 and the approximated RE shares for 2014. To respect to EU Member States, UK has a low RE shares, which was one of the lowest back in 2005 and still is one of the lowest in 2013. The indicative RED (Renewable Energy Directive) target for 2020 is 15%.

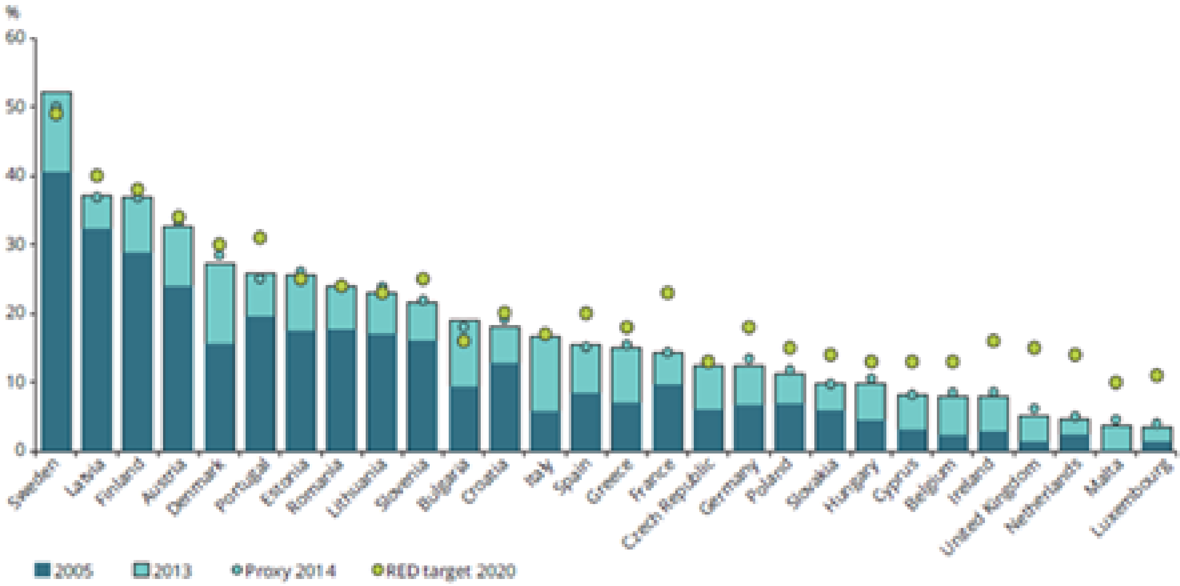

Figure 24: Actual and approximated RE shares in the EU-28 Member States. Dark and light blue bars show the level of RE shares in 2005 and 2013, Source: (EEA, 2014)

Renewable electric energy generation: contributions and variations of UK in Europe

- Hydropower: UK does not play an important role in renewable hydroelectric power. EU leader in hydroelectric production are Spain, Austria, Italy, France and Sweden. Obviously the main limitation of UK is the geographical conformation of Great Britain. (EEA, 2016)
- Onshore wind energy: Also in this case, the geographical distribution of Great Britain does not support an intensive penetration of onshore wind farms. Nevertheless, in 2014 UK (as also Austria and Poland, Romania) added more than 0.4 GW (very far to respect to the 4.4 GW of Germany). The location of onshore wind farms in UK is shown in Figure 25.

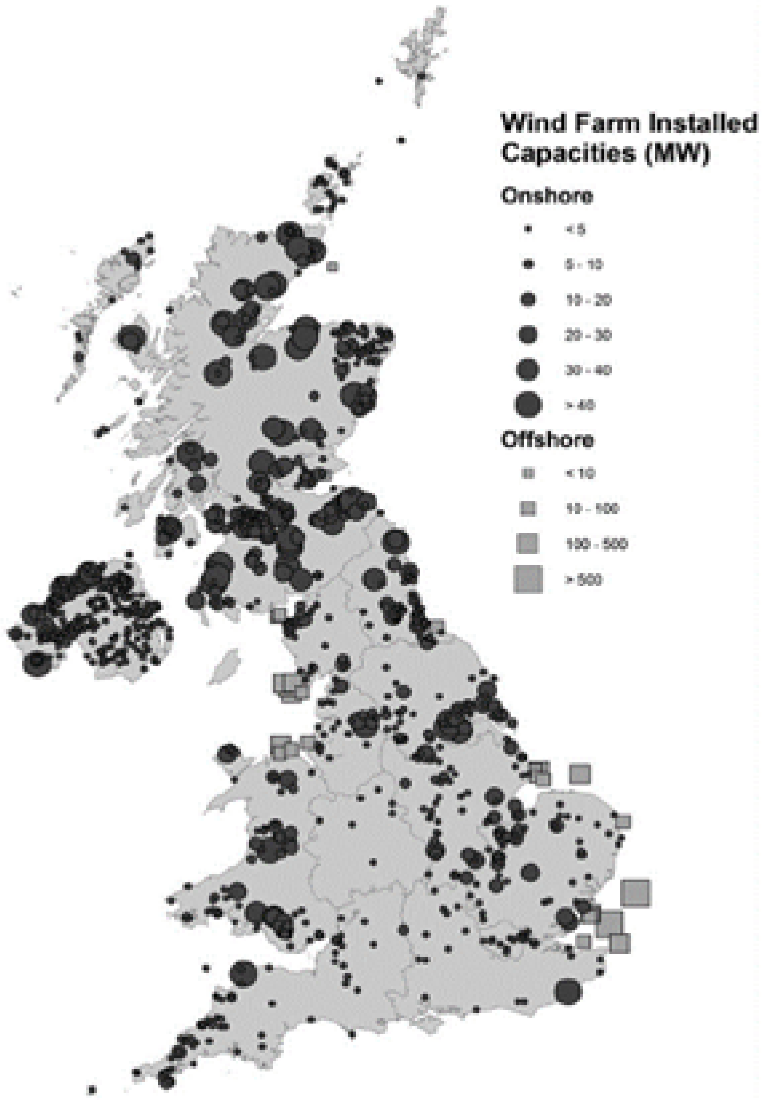

Figure 25: Location of wind farms installed in UK at 31st December 2014, Source: (DUKES, 2015)

- Offshore wind energy: Differently from the onshore case, UK is supporting the growth of the offshore wind energy growth in Europe, with an additional installed capacity of 0.7 GW. UK is the frontrunner, with a share of 59 % of the total normalized electricity generation from offshore wind power in the EU-28 in 2018 (EEA, 2016). The location of onshore wind farms in UK is shown in Figure 25.
- Solid biomass: The electricity generation from solid biomass grew with a rate of 8 % between 2005 and 2013. The use of solid biomass is related with the average weather conditions: indeed, in 2014 the warm weather created an unusual low demand for heating, which resulted in a decrease

of electricity generated by solid biomass. The most relevant data is from 2013: UK had a share of 13 %.

- Solar photovoltaic: UK is supporting the growth of electricity produced by solar photovoltaic panels. However, the contribution of UK in EU-28 is not comparable with Germany, Italy and Spain.
- Biogas: In 2013, UK had shares around 14 % second in EU-28 only to Germany (55 %). However, the growth of biogas in EU is expected to slow down in the next years.

Thanks to the increased penetration of RE sources, UK reduced the in gross inland fossil fuel use and the GHG emissions.

The penetration of RE sources in UK allowed reducing the gross inland fossil fuel use to around -5 %. On the other this number is relative small compared to Spain (-11 %), Italy (-13 %), France (-7 %) and Germany (-10 %). This can be also explained because of the more rigid weather in UK to respect to the other countries, requiring for longer periods heating capacity.

On the other hand, UK is playing a strong role in EU for reducing the GHG emissions. In particular, in 2013, the emissions have been reduced of 19.5 Mt CO_2, which was the 5 % of the total GHG. An important comparison can be proposed to respect to key players in EU: Italy (54 Mt, 11%), Spain (31.8 Mt, 9 %), Germany (95.6 Mt, 9 %) and France (27.1 Mt, 5%). It is clear that the penetration of RE in some countries is playing a crucial role to reduce GHG: however, in relative terms, UK is not far from the percentages of the leading countries (EEA, 2014).

Q2 2015: for the first time RE outstrips coal generation.

One of the most important results in UK has been obtained in Q2 2015 (DUKES, 2015). In Figure 26 we can note how in Q2 2015, RE outstrips coal production of +4.8 %, becoming the second source of production in UK. Very important is the comparison with Q2 2014, where RE was generating -11.5 % to respect to coal generation.

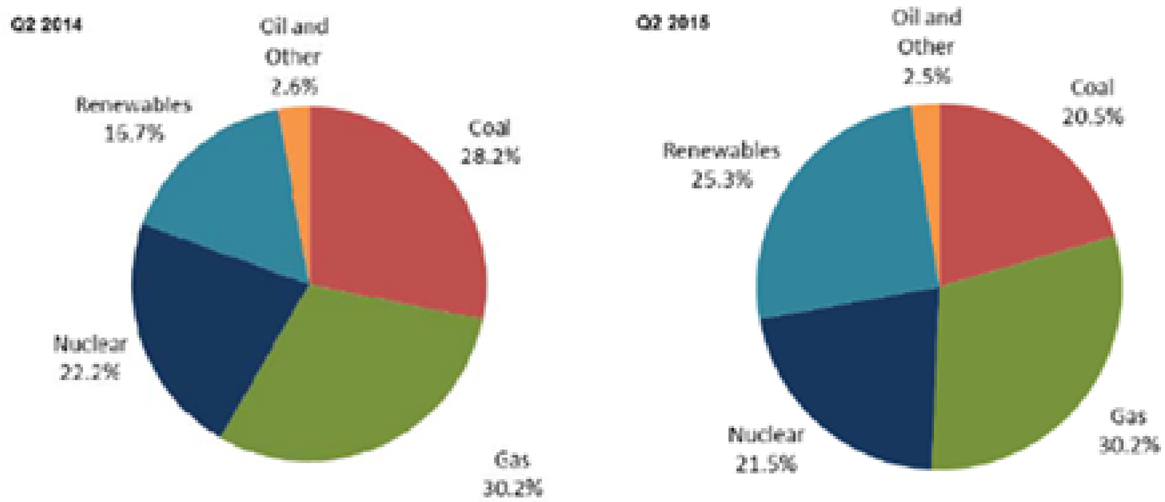

Figure 26: Electricity production, Source: (DUKES, 2015).

Storage in the current UK Energy System and potential use in the future UK Energy System

In the current UK Energy System the most energy storage capacity is provided by stocks of fossil fuels (Low Carbon Futures Association, 2012): in (Energy storage in the UK electrical network: estimation of scale and review of technology options, 2010) the electricity that could be generated from UK stocks of coal and gas is estimated around 30 TWh and 7 TWh respectively (Energy storage in the UK electrical network: estimation of scale and review of technology options, 2010). Few smaller electricity storage facilities are connected to the distribution system and spread in various parts of the country. However, they are mainly demonstration projects involving different types of battery.

In the future UK Energy System, energy storage is expected to provide the following services based on different time-scales. This study has been proposed in (Low Carbon Futures Association, 2012) and is reported in Table 2 for the sake of completeness.

Timescale	Challenge	Potential Storage Solution
Seconds	Some renewable generation introduces harmonics and affects power supply quality.	Very fast response/low volume electricity storage associated with generation, transmission or distribution.
Minutes	Rapid ramping in response to changing supply from wind generation affecting power frequency characteristics.	Relatively fast response electricity storage associated with generation, transmission or distribution.
Hours	Daily peak for electricity is greater to meet demand for heat and/or recharging of electric vehicles.	High-power bulk electricity storage to meet peaks in electricity. Distributed electrical battery storage to smooth out charging peaks. Household level heat storage in tanks or integrated into the building fabric.
Hours-Days	Variability of wind generation needs back-up supply or demand-side response. Increased use of electricity for heat causes increased variability in daily and weekly demand.	Large-scale or decentralized electricity storage to back-up wind generation. Heat storage at community or building level, use of CHP with storage to act as a buffer between electricity and heat.
Months	Increased use of electricity for heat leads to strong seasonal demand profile.	Large scale inter-seasonal heat storage associated with combined heat and power and district heating schemes or use of novel materials to provide longer duration heat storage in buildings.

Table 2: Challenges and potential storage solutions in the future UK Energy System,Source: (Low Carbon Futures Association, 2012)

Future developments in the UK Energy System

In (Low Carbon Futures Association, 2012) important developments are proposed for moving to the future UK Energy System. This study has been proposed in (Low Carbon Futures Association, 2012) and is reported in for the sake of completeness.

Development	Electrical energy storage	Heat energy storage
More variable renewable energy	Positive for all scales and for both power and energy storage	Could be positive if used with combined heat and power as a buffer between electricity and heat
Electrification of heat	Could be positive - particularly at macro and meso-scale (system operator and distribution network operators managing demand)	Positive at micro-scale (combined with heat pumps), but less so at meso-scale (less market for DH)
Plug-in hybrid vehicles and electric vehicles	Uncertain – could provide additional opportunities or compete for some services	Little impact
Low cost and flexible fossil fuel generation	Negative for macro-level reserve and response functions	Negative for macro-scale intersessional storage
Increased CHP and district heating	Negative for meso- and micro-scale storage	Positive for macro and meso-scale storage, but negative for micro storage at household level (unless combined with micro-CHP)
Increased demand for space cooling	Positive if can help smooth demand	Positive for systems that combine heating and cooling
Greater interconnection	Uncertain - depending on relative electricity prices	Little impact
Increased demand-side flexibility	Generally negative - although opportunities to contribute to increased flexibility at household level	May contribute to increased flexibility

Table 3: Future developments in UK Energy System, Source: (Low Carbon Futures Association, 2012)

The changes in the UK Energy System will have a profound impact on the markets for both electricity and heat storage. As also highlighted in the RTE roadmap in France (RTE, 2013), the majority of the scenarios for the future show a decreasing in the use of fossil fuels. On the other side two aspects should be highlighted:

- Presence of intermittent generation (increasing penetration of renewables);
- Presence of intermittent loads (increasing penetration of electric vehicles).

Because of the intermittent nature of generation and loads, the role of heat and electricity storage will increase.

Energy bills in UK

Another interesting point regarding the energy market in UK is the prices associated to electricity and gas. UK ranks above the European average on electricity prices and round average on gas prices (see Figure 27 and Figure 28).

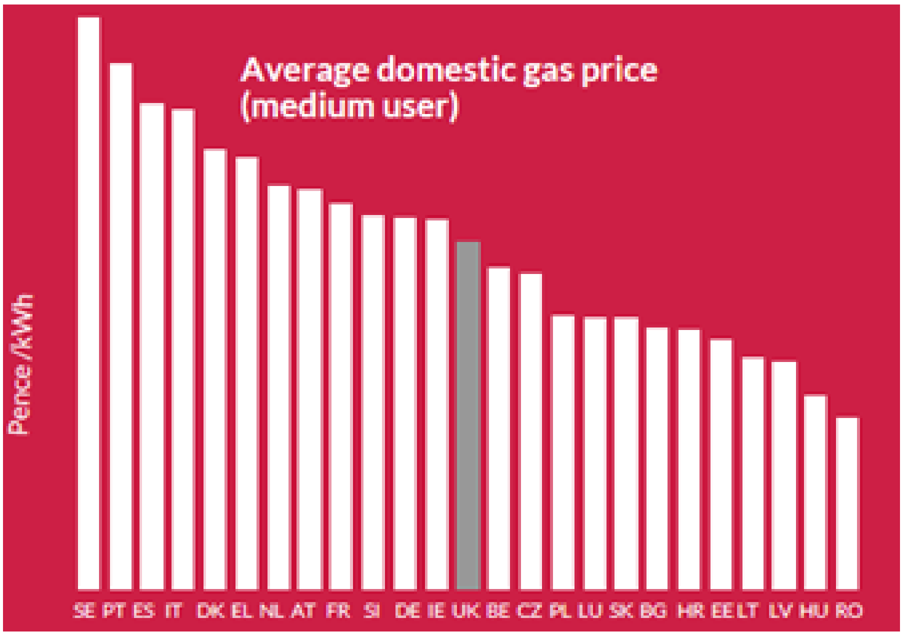

Figure 27: Average UK domestic gas price (incl. taxes) for medium user customer for period Jan to Jun 2015 is the median EU price, Source: (DUKES, 2014)

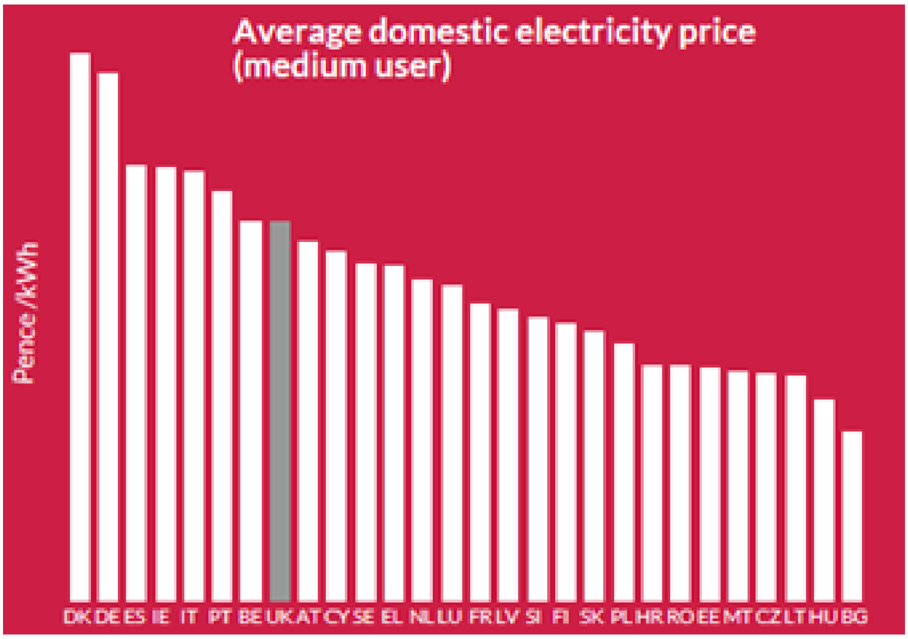

Figure 28: Average UK domestic electricity price (incl. taxes) for medium user customer for period Jan to Jun 2015 is above median EU price, Source: (DUKES, 2014)

An important aspect in the energy market is the social behavior of the customer, which will definitely play a role in the future market. Ofgem research shows that over 60 % of people don't recall switching energy supplier: this could lead to a save around £ 200 per year on their energy bills. Another interesting point is the costs associated to gas and electricity bills: network costs are around 22.93 % and 25.33 % respectively, which is the higher costs after wholesale costs (46.55 % and 39.43 %, respectively).

In the future UK Energy Market two scenarios can be analyzed associated to network costs:

- Network costs will decrease thanks to the presence of distributed generation and storage.
- Network costs will increase because with more distributed generation and storage, distribution operators will force higher costs for compensating the decreasing of gas/electricity supplied to the customer.

The above two scenarios will definitely depend on political choices and opening of the market to new energy entities such as aggregators.

3.1.5 Spain

Responsible Partner: Nissan Europe

Renewable electricity generation capacity

The truly integration of renewables energies is the one of the most challenges by the operation system. It asks important challenges and due the high complexity for the operator system, between others particularities, the limited interconnection capacity with continentals Europeans countries also the design of demand's peninsular curve.

By the beginning of the new interconnection with France, meaning an expansion of current capacity for both countries. The improvement of interconnections can allow few limitations requirements in the scenarios of high level energy production by RE, facilitating electrical energy exportation to others electricals systems.

Otherwise, the demand's peninsular curve changes in function of periods of year, day of week, temperature, etc. although its more remarkable characteristic by the difference in the consumption during pick hours and valleys. For these, the electrical energy production unities must work in a more exigence way and more flexible for covering the demand curve during the day. It was incremented, especially in the last years due the augmentation of RE in installed system also the use priority in comparison of the others technologies.

Energy production from renewable sources represented 37 % of the total generated in the Spanish Peninsula electricity system (REE, 2016). For yet another year, noteworthy is the important role of wind power generation, whose contribution to the annual energy production reached 19%, which ranks this technology in third place in terms of participation of the different types of energy for demand coverage, just behind nuclear and coal.

In addition, in 2015 the maximum values of wind production registered in recent years were exceeded: yearly maximums for instantaneous wind power production (17.5 MW), hourly energy (17.4 MWh) and daily energy (357.7 MWh). Also registered in the contribution of wind power to demand coverage reaching a figure of 70.4 %. To enable the operation of an electricity system with such a high penetration of renewable energy under safe conditions, the role of CECRE (Control Centre of Renewable Energies) is essential.

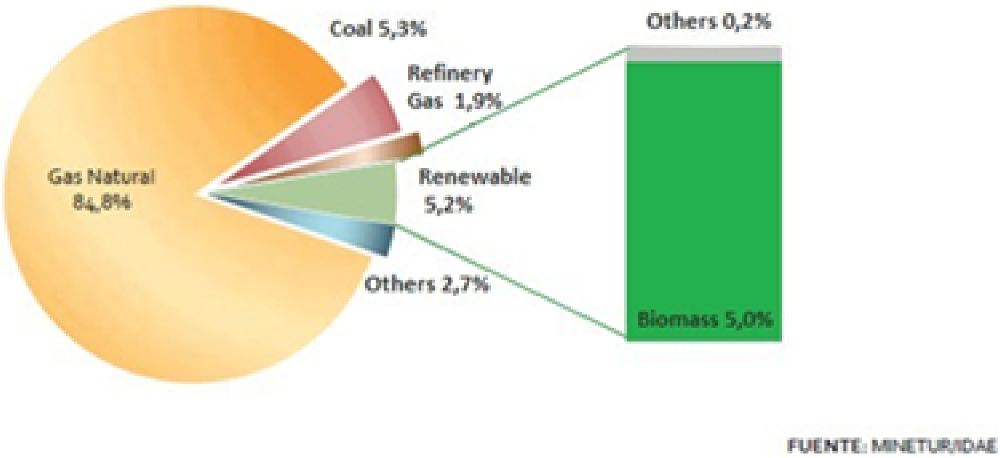

Figure 29: Electric Power generation resources, Source: (Ministerio de la Industria, Energía y Turismo, 2014)

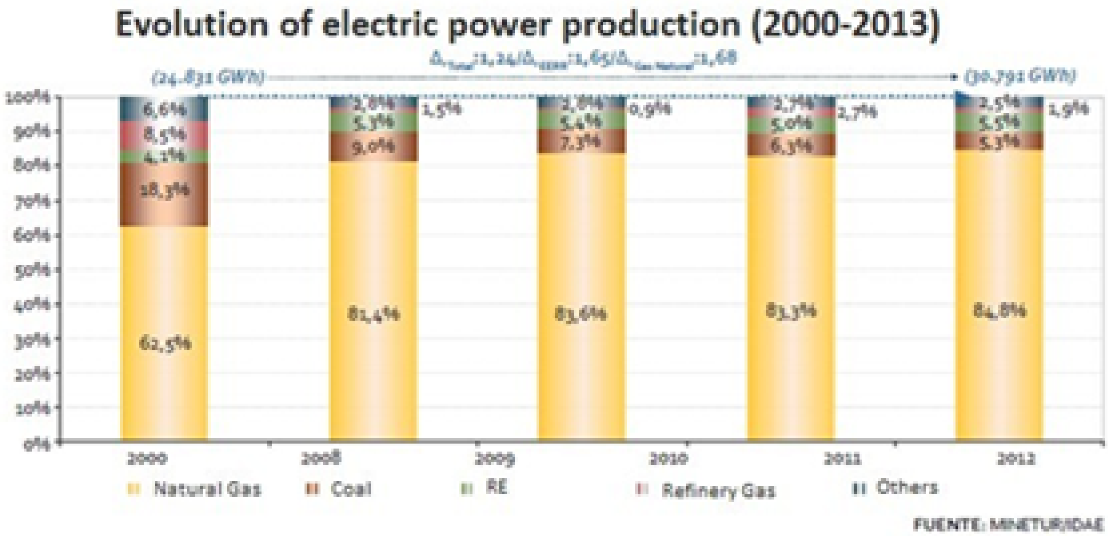

Figure 30: Evolution of electric power production (2000 - 2013), Source: (Ministerio de la Industria, Energía y Turismo, 2014)

The effort of Red Eléctra (REE) by the integration of renewable is revealed day after day by the effective functioning of the CECRE, the technological pioneering tool by means of which there is confronted the challenge of incorporating into the electrical system energies that have a great variability, difficult predictability and minor capacity of adjustment to the demand, for its dependence of the climatic conditions. The functioning of this control centre, world modal in the integration of renewable, offers a great capacity of response to identify the risks and to anticipate the behaviours of these intermittent energies and to compensating great variability, without compromising the quality and safety of the supply.

The role of CECRE is contribute to the production of renewable energies in the electrical peninsular system. It represents more than 40% of the annual production of energy during the last years, reaching in some case, values of hourly coverage superior to 80%, with the consequent reduction of the energetic foreign dependence.

Electric Power Production of RE in 2014

	Generación Eléctrica renovables en 2014		
	Potencia (MW)	Producción (GWh)	Producción Energía Primaria (ktep)
Hidráulica (1)	19.095	42.916	3.361
Biomasa	677	3.651	949
R.S.U.	224	585	122
Eólica	22.974	52.262	4.493
Solar fotovoltaica	4.786	8.198	705
Biogás	222	727	209
Solar termoeléctrica	2.250	5.455	2.142
TOTAL ÁREAS ELÉCTRICAS	50.228	113.793	11.981

Figure 31: Electric power production of RE in 2014, Source: (Ministerio de la Industria, Energía y Turismo, 2014)

As presented in Table 4, it is possible to analyse the integration of renewable energies (% on the demand). RE's have contributed for the electrical peninsular system represents more than 40 % of the annual production of energy during the last years, reaching in some case, values of hourly coverage superior to 80 %, with the consequent reduction of the energetic dependence.

	2009	2010	2011	2012	2013	2014	2015
Integration of RE (% on demand)	28	35	33	32	42	42,8	36,9

Table 4: Integration of renewable energies Spain, Source: (REE, 2016)

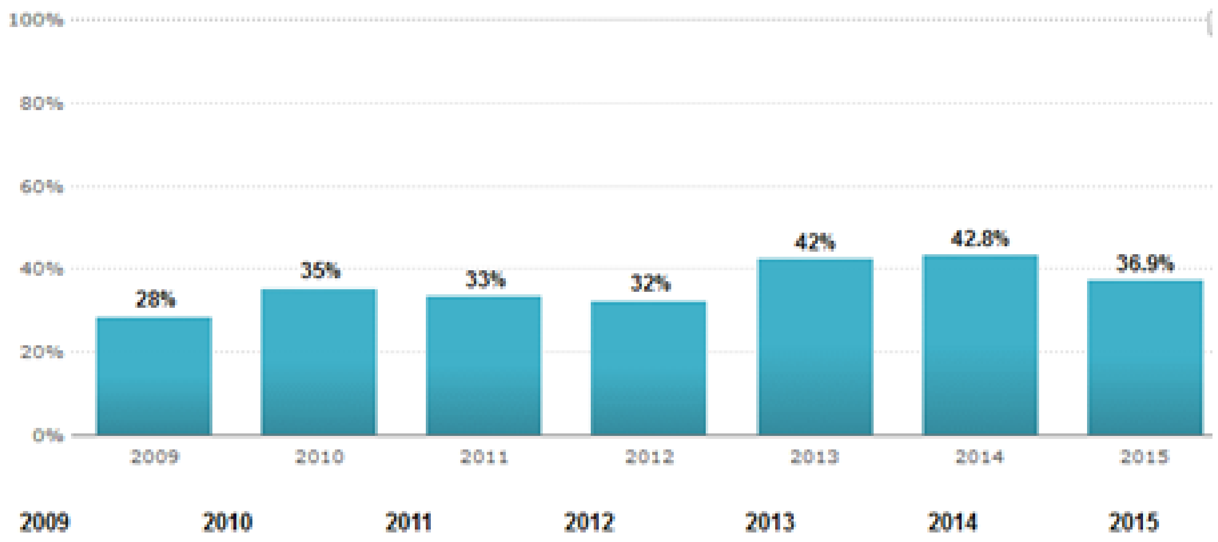

Figure 32: The integration of RE (% on the demand), Source: (REE, 2016)

Variation of different contributions to electricity generation

In 2015, Spanish consumption has been about 263.1 TWh. The electrical energy production in 2014 in the national set promoted 277.8 GWh, 2 % lower than that of the previous year (Ministerio de la Industría, 2014) The structure of generation shows an increase of the production with some renewable energies as hydroelectric or solar thermoelectric. The wind generation has increased its contribution about a 1 %, a percentage very lower than that of the previous year. Thus, the nuclear production power stations increased a few (1 %). The production with coal increased 5,5 % after the important decrease of 25.8 % that had the previous year, giving place to an increase of the participation of the coal inside the total national set and placing in 16.1 % in 2014.

The production with oil products, including use as fuel of support in some plants, that use principally other energies, has raised 3 % and weight in the structure of generation is 5,1%; continues the significant decrease of generation.

The gas cycle combined generation has gone down, in 12.8 %, continuing the trend of previous years and also the cogeneration with gas 15.5 %. The consumptions in generation have been 1,9% lower than those of the previous year, for the minor participation of the plants of natural and major gas of the generation with renewable energies. Finally, before transport and distribution and without reduced the consumptions of other sectors transformers of the energy, lowered a 1.7 % in relation with that of 2013, with decrease of the exporting balance of international exchanges and of the consumption in pumping.

In fact, for the Spanish grid, stationary storage systems can be helpful to adjust the balance between generation and consumption curve's profiles.

Electricity spot and futures market

Spanish wholesale electricity markets witnessed a gradual decrease in monthly average baseload prices in the first quarter of 2015. While in January 2015 the average price was 53 €/MWh in Spain, in March these numbers were 44 €/MWh, being the lowest since the second quarter of 2014. However, the January monthly price was above the December 2014 average, as the share of hydro and renewable generation sources decreased in the power mix. In February and March 2015, as the share of renewables and hydro started to rebound, wholesale electricity prices began to decrease (OMIE, 2015).

On 20 February 2015 a new electricity interconnector has been inaugurated between Spain and France, (between Baixas in southeast France and Santa Llogaia in northeast Spain, with a length of 65 km being the longest subterranean electricity interconnector in the world) increasing the interconnection capacities from 1,400 MW to 2,800 MW. This development is a definitive contribution to the implementation of internal electricity market in the South West European region; however, in spite of increasing interconnection capacity further investments in infrastructure are needed to achieve a full integration of the region to the North West European.

Although the absolute price differential between France and Spain was less than 1 €/MWh in March 2015 on monthly average, falling to several years' low, which might be related to the reinforced interconnection capacity between the two countries, the impact of the new interconnector can only be fully analysed by looking at the data of the next months.

In contrast to many other parts of Europe, where the end of the year saw a surge in wind power generation, in Spain wind availability remained limited. Low wind generation coupled with the dry season with dwindling hydro reservoir levels and subsequently low hydro based generation resulted in increasing electricity generation costs, as the share of fossil fuels went up in the power mix. However, decrease in natural gas and coal prices kept a lid on the increase in electricity generation costs.

The significant price fall in wholesale electricity prices in the Iberian-peninsula was mainly due to the arrival of rainier weather, enabling the ramp-up of hydro generation in the country in January 2016. Furthermore, wind generation also picked up in January and February, and in the second month of 2016 renewables and hydro together assured 54 % of the electricity generation in Spain, which was a remarkable increase compared to December 2015, when this share was only 28 %. Fossil fuel prices reached their lows in first quarterly 2016, which also helped in decreasing electricity generation costs.

Sudden price falls in the Iberian market resulted in increasing electricity flows from Spain to France in some periods, however, the limited electricity interconnections between the two countries, the existing market could not be fully exploited and price differentials.

Use of battery storage systems

In Spain, use of storage systems are quite usually for the main reasons below:

(1) To optimise the frequency control. Storage systems can be useful when the consumption is higher or lower than the system expects. Energy storage plants can also can regulate tension with very quickly response helping the system operation.

(2) Balance between generation/consumption. Motivated by increasing of the flexible generation and development of management tools of the demand, energy storage systems are able to improve the prediction at local scale as an adjustment service.

(3) RE integration. The widespread adoption of renewable energy resources, energy storage is equally useful. As is often noted, these energy sources are intermittent in nature, producing energy when the sun is shining and the wind is blowing. By storing the energy produced and delivering it on demand, these clean technologies can continue to power the grid.

As an illustration, Almacena's Project is a storage system with a power of 1 MW and a capacity of 3 MWh, established in 2013 in Carmona's substation 220/400 kV in the province of Seville. It stores and returns to the system, the equivalent of consumption of 100,000 homes during more than five hours. The project Almacena, has culminated satisfactorily its first year in service, in that the company has realized 180 daily cycles of load and total unload of this system of storage electrochemical of electric power. It has given the first steps to validate technically the opportunities of improvement in the guarantee of the supply and in the energy efficiency, betting for a major integration of RE in the system (REE, 2016).

Figure 33: Almacena's Projet in Sevilla, Spain, Source: (REE, 2016)

Due a control system designed specifically for REE, the system is prepared to store the energy in those occasions in that it cannot be absorbed by the system for lack of demand; so, energy allows to store in the period valley of the curve of the demand (hours of the day with minor industrial activity and consume, generally, in the night) to use it according to requirements of the system, in another moment. Almacena seeks to optimize the utilization of the renewable generation of the Spanish Peninsula. More than 43 % of the electricity stored in batteries of ion-lithium was produced from RE. Also, Almacena improve value of this technology for the management optimized of the curve of the demand. It has aptitude to support the stability of the grid and guarantying the functionality of the system in the technical ranges of tension established.

As shown above, the major presence of renewable generation and its variable nature, also with the need to manage important differences between the top and the valley of electrical demand to operate the system guaranteeing the safety and the quality of the supply. It makes systems of energy storage an effective mechanism to assure the integration of renewable and to improve the efficiency and sustainability of Spanish energetic model.

3.2 Bottlenecks in the power grid

Responsible Partner: Allgäuer Überlandwerk

Due to the fact of more and more distributed energy resources (DER), increase of international energy trading and at least in Germany nuclear phase-out, bottlenecks in the distribution and transmission grids will rise (Schmitz, 2013).

Basically, bottleneck-management describes all activities that a grid operator uses to avoid overloading of lines in its respective grid area (Bundesnetzagentur, 2013). The following bottlenecks are being managed already in the electricity grid. First, the actual problem or reason for a bottleneck will be explained in a short description. Furthermore, the current method respectively solution to solve/avoid the problem is described as well.

Transmission level:

Problem:	Limited transmission capacities between price zones, countries or regulation zones (f. e. interconnectors between Germany and France or France and Great Britain)
Actual solution:	The limited capacity between price zones is offered for sale by auction.
Problem:	Limited transmission capacities inside regulation zone (f. e. between northern and southern Germany)

Actual solution: 1. The limitation within price zones, which is mainly generated by DER, is managed proactively, i.e. before bottlenecks emerge, by redispatching of power production (see 5.1.3 and 5.2.5) as well as just in time by shutting down conventional and/or renewable power plants.

2. Grid extension

Problem: Loop flows which are unplanned power flows within the European grid, triggered f. e. by higher amount of power being traded than the real grid capacity between Germany and Austria allows. The power takes a detour by spilling over into the power grids of neighbouring countries (Russel, 2015), (Gawlikowska-Fyk, 2012).

Actual solution: None

Possible solution: Splitting into smaller market zones, limiting amount of tradable energy to available grid capacity, phase shifters on the sides of the spilling area or increase of grid capacity (Russel, 2015).

Future solution TSO: 1. Further extension of transmission grid

2. Use of different storage systems in order to provide peak shaving of high production or load cycles.

Distribution level:

Problem: Limitation of power rating of maximum DER feed in capacity into low and middle voltage grid

Actual solution: In case the distribution grid has free capacity DER can be connected. In case the capacity is limited the grid expansion has to be paid by the grid operator, DER operator, both of them or can be refused, all depending on the national law of the countries of the European Union. (RES LEGAL, 2012).

Problem: Feed in from DER and conventional power plants into distribution grid exceeds actual loads and no free transformation capacity to transform surplus electricity to higher grid level, or higher grid level does not have capacity to absorb electricity from distribution grid.

Actual solution: 1. Reduction of feed-in from DER and conventional power plants. If possible start of big loads in the distribution grid like pump storage hydro power stations.

2. Extension of grid and transformation capacities between grid levels

Future solution DSO:1. Grid extension

2. Use of different storage systems in order to provide peak shaving of high feed-in production or loads.

3. Extend controllability of feed in plants or loads like heat pumps in order to lower need to transform surplus energy in distribution grid level to transmission grid

The European Network of Transmission System Operators for Electricity (ENTSO-E) states in its 10-year network development plan from 2014 that the investment cost for the European transmission grid from now till 2030 would reach 110 - 150 billion euros in order to prevent bottlenecks. The countries with the biggest investment needs are Germany (ca. 50 billion €), Great Britain (ca. 16 billion €) and France, Norway, Italy, Spain and Belgium (together ca. 30 billion €) (entsoe, 2014).

The study furthermore states that 80 percent of the needed extensions are necessary in order to integrate DER into the grid and distribute their electricity. The other 20 percent are to guarantee system reliability and to be ready for the period 2030 to 2050. (entsoe, 2014). The main expected bottlenecks can be seen in Figure 34.

Other voices like the study “Der zellulare Ansatz” (the cellular approach) (VDE, 2015) state that up to 50 % of the costs for grid expansions can be saved by introducing small scale energy cells which balance their demand and production locally (Heinz Wraneschitz - Bayrische Staatszeitung, 2016) . The energy cells are very similar to the Block of Energy Units defined in ELSA project.

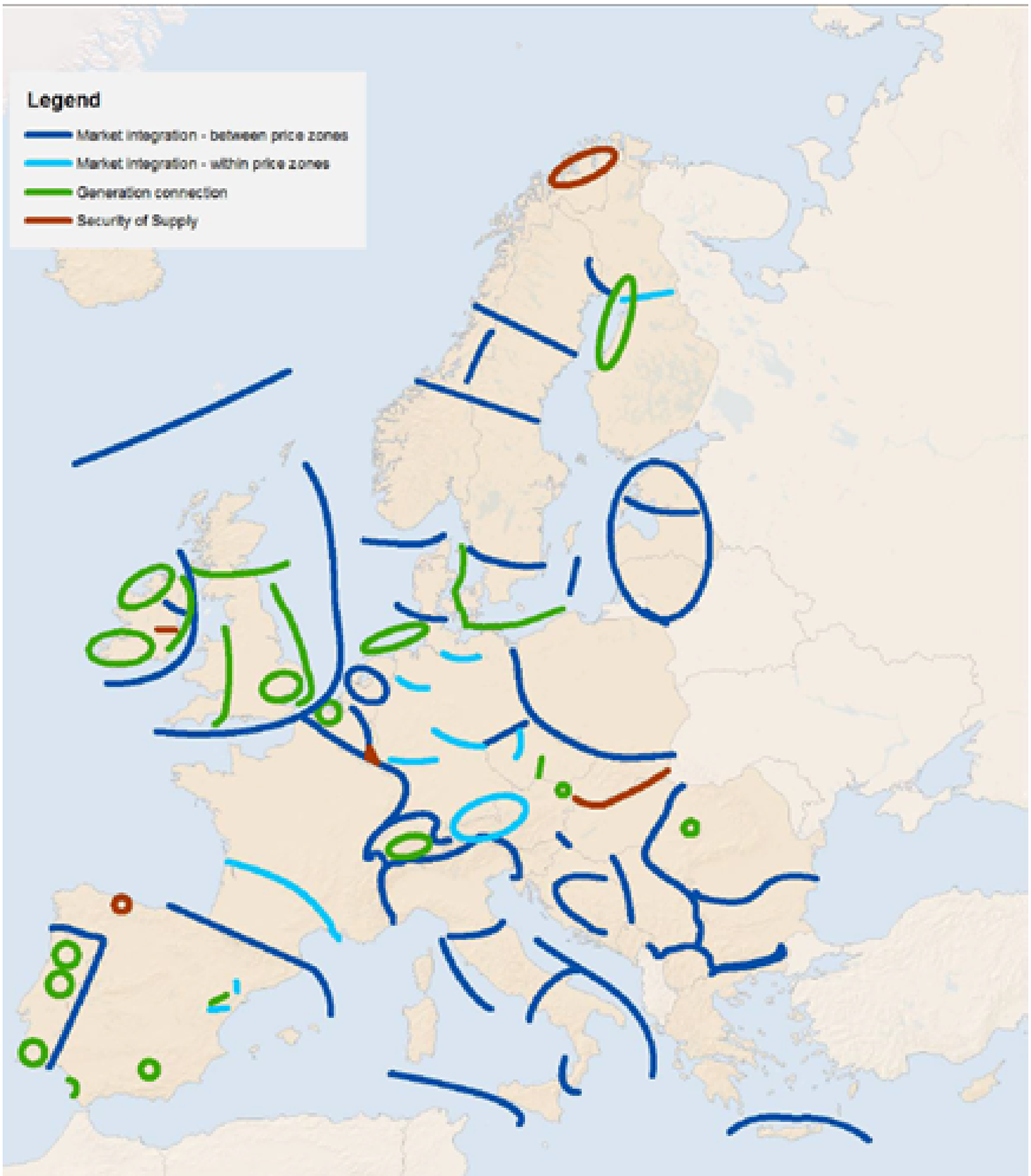

Figure 34: Main bottleneck locations and typologies expected from ENTSO-E; Source: (entsoe, 2014)

Therefore, it seems that the solution in order to prevent bottlenecks in the power grid will be a mix between increasing the grid capacity and the simultaneous introduction of small/medium scale energy cells. Such energy cells are very similar to the Block of Energy Units defined in ELSA project, with their advantages of regulating generation – demand matching locally. For more information about this topic please have a look at deliverable 1.2 of work package 1.

3.3 Need for additional flexibility in generation-demand matching

Responsible Partner: B.A.U.M. Consult

In this subchapter, the need for flexibility in generation-demand matching as a function of the rate of renewable electricity generation contributing to the electricity supply is examined. Conventional electricity supply systems require flexibility, but usually to a lesser extent than predominantly renewable electricity supply systems. Hence, there is a need of additional flexibility in most cases when an electricity supply system is transformed to a mainly renewables-based one, and potentially a market for battery systems.

It is important to note that the flexibility need identified in this subchapter is different from the market for flexibility. First of all, the considerations presented in the following reflect the need for flexibility from a perspective of overall system optimisation. The optimised parameter is usually the average levelised cost of electricity (LCOE) under the condition that a certain technical performance is achieved. Inappropriate market rules and regulations and aspects such as a desire for partial or complete supply autarchy or fascination with storage technology which influence real market behaviour of customers are disregarded. Not taken into account are also aspects of current or forthcoming market designs which might prevent the market to move into a direction which is optimal from a technical system or overall economic point of view.

3.3.1 Flexibility in the conventional electricity supply system

In the case of conventional electricity supply, energy storage is used at large scale, but it happens essentially at the beginning of the energy service provision chain in the form of coal or biomass piles, petrol or natural gas reservoirs, nuclear fuel rods, or storage reservoirs of hydropower stations. Storage at the end of the chain is used to a much lesser extent and happens mainly in form of the energy service that is provided: heat, cold, products and others. Freezing and cooling houses store cold, and hot water reservoirs and the building fabric store heat. In each production process, storage of auxiliary means such as pressurized air and of intermediate and final products takes place. This is equivalent to the storage of energy.

Rather small quantities of energy are stored along the energy service provision chain or at its end. Examples are fuels in mobile and stationary tanks, heat stored in district heating grids, rotational energy of turbines and generators in power plants, electric energy stored in capacitors and inductances. Direct storage of electricity is only possible in small quantities in capacitors and inductances. All other forms of electricity storage involve the conversion into another form of energy and back into electricity, and thus conversion losses.

Examples are pumped hydropower plants, batteries, compressed air storage, flywheels, and other forms of mechanical energy storage. Hence in contrast to the storage of heat and fuels, the storage of electricity is rather difficult and more expensive. In the conventional electricity system, it is widely avoided.

Fossil fuel storage and generation management of thermal and storage hydropower stations provide the major part of flexibility in the electricity sector. Coal, petrol and natural gas storages, combined with at least partially dispatchable[3] power plants allow generating electricity very much in pattern with the demand. The dispatchability of conventional power plants varies quite a lot between different technologies. Lignite and nuclear power plants have a low maximum ramp rate that means their power output can be modified only slowly. For this reason, such plants are little dispatchable. Further, their power output is restricted to a limited range, e.g. between 40 % and 100 % of their nominal power. Hard coal power plants can vary the power output quite flexibly. In Germany, they provide a major part of the conventional generation management today. Gas power and storage hydropower plants can vary their power output between 0 and 100 % within a quarter of an hour about. Thus, a mix of nuclear and different fossil power plants combined to a strong electric grid as it exists in many European countries is sufficiently flexible to avoid major storage at the end of the service provision chain and demand-side response.

Short-term differences of generation and demand are mainly balanced by adaptation of the generation, thus making use of the huge fuel stores at the beginning of the service provision chain, and very little by storage at the end of the chain. If applied, the latter is mostly pumped hydropower storage. At the time-scale of a few seconds and below, storage comes into play in the sense that the inertia of rotating turbines and generators in large power plants represents a kind of inherent mechanical storage of energy in the form of rotational energy. If the demand is higher than the instantaneous generation, these rotating masses are slightly slowed, and when the demand is less, the rotation is accelerated.

3.3.2 Features of renewable energies impacting flexibility need and choice

Unlike the mainly non-renewable conventional energy sources, renewable energy sources do not consist of reservoirs of energy, but of flowing sources: solar irradiation, wind, hydrocurrents. The French expression “énergies de flux” highlights this aspect. Exceptions from this rule are biomass, geothermal energy, and storage hydropower. Geothermal heat is also flowing, but the earth represents a huge heat storage and the power of a geothermal plant

[3] The Italian expression „energie/ fonti programmabili“, opposed to „energie/ fonti non programmabili“ used for solar and wind power, put the crucial point a bit better into perspective. See for instance: http://www.rinnovabili.it/energia/rinnovabili-non-programmabili-sunrise-666/ [retrieved on 13 June 2016]

depends on the pump rate at which hot water is taken out of the soil, not on the natural geothermal heat flow. Biomass and storage hydropower are only flowing sources in a wider sense. Flowing water fills the latter, the former is an intermediate step in a system of closed cycles of energy, carbon-dioxide, water and nutrients. Their actual manifestations are storages, not flows.

Hence, renewable energy provision cannot rely on storage at the beginning of the service provision chain in most cases and the first step of using renewable energies, except biomass, geothermal energy, and stored hydropower, consists in the conversion of the source energy into an energy carrier which can be directly used or stored. In most cases, the primary renewable energy flow is converted into electricity, because the conversion devices with the highest potential, PV and wind power plants, generate electricity. In some cases, the primary energy flow is converted into heat, e.g. by solar thermal collectors, and very rarely into a fuel, mainly through processing of biomass. Direct conversion of sunlight into a fuel, e.g. hydrogen exists, but is done only at experimental scale. That means the majority of renewable energy is made available in the form which is the most difficult to store: electricity.

The devices needed for the conversion of the primary renewable energy flows into electricity, PV and wind generators, hydropower plants, geothermal power plants and others cause investment costs, but only biomass plants have significant operating costs. Once, the conversion devices are installed, it is reasonable to let them generate electricity as much as the instantaneous availability of solar irradiation, wind, water flow etc. allows. In economic terms: the marginal costs of renewable electricity generation are almost zero for all renewable energy sources except biomass.

Generation management of renewable power is very simple and can be done within fractions of seconds by electronic regulation or by adjusting the blade pitch angles of wind turbines or the water throughput of a hydropower plant, but the power can only be varied between zero and the instantaneous maximum power. The latter depends on the primary renewable energy flow which is often fluctuating, in the case of solar radiation or wind power even highly fluctuating, or even very low or zero. Therefore, the resulting generation can often not match the instantaneous demand even if the option of generation management is fully exploited. This is a fundamental difference to conventional power generation. Further, generation management of PV and wind power between zero and the instantaneous maximum power (curtailment) is not desirable because they have merely zero marginal cost.

Theoretically, the power demand can always be met by fluctuating renewable power generation up to a certain level, e.g. 98 % in the case of remote electrification, by oversizing the renewable power generation capacity and curtailing the generation if the instantaneous demand is lower than the generation. However, acceptable levels of supply security imply a significant oversizing of the generation facilities and very high costs. Hence, the need for appropriate combination of different and complementary fluctuating renewable power generation, e.g. PV and wind power, and its combination with dispatchable power generation from biomass or hydropower, and the application of storage and/ demand-side response in addition to generation management.

In summary, the point which marks the essential difference between a mainly conventional and a mainly renewable energy system with regard to storage is that the renewable energy technologies which have by far the highest potential, PV and wind power convertors, generate electricity and are highly fluctuating. This implies that (1) a shift towards renewable energies goes along with a shift towards electricity as main energy carrier, (2) storage, other flexibilities and cross-energy carrier options need much more attention because electricity is a form of energy which is very difficult to store compared to fuels and heat, and (3) storage happens somewhere along the energy service provision chain or at its end, not at the beginning.

3.3.3 Predominantly dispatchable renewable electricity supply of entire countries

A high share of dispatchable renewable power generation from hydropower, geothermal energy, biomass or biogas provides sufficient potential for generation management allowing to match the instantaneous power demand without a significant need for other flexibility in the system, even if renewables meet 100 % of the power demand. An example of countries supplied predominantly by dispatchable renewable energy sources are the Latin American countries. As (WWF, 2014) reports, several of them are already close to 100 % renewable power supply. The list is led by Costa Rica[4] with a high hydropower, geothermal and wind power use, followed by Uruguay[5], Brazil, Chile and Mexico. A major driver of investments into PV and wind power in Latin America is climate change which increases the risk that hydropower generation drops as a consequence of long draughts as recently seen in Venezuela[6].

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[4] The national utility Compañía Nacional de Fuerza y Luz S.A.(CNFL) generates electricity essentially from hydropower and wind power and has been certified as carbon neutral utility on 8 April 2016, https://www.cnfl.go.cr/index.php/perfil-cnfl/noticias-sobre-la-cnfl/260-cnfl-celebra-75-aniversario-con-carbono-neutralidad [retrieved on 14 June 2016]

[5] In the first months of 2016 renewables covered 98 % of the electricity supply of Uruguay, in 2015 the contribution was 92.8 %, but that of PV only 0.4 %, http://www.pv-magazine-latam.com/noticias/detalles/articulo/presentan-proyecto-solar-en-el-aeropuerto-de-montevideo_100023304/ [retrieved on 14 June 2016]

[6] BBC News, 22 April 2016, Venezuela cuts power for four hours a day to save energy, http://www.bbc.com/news/world-latin-america-36108295 [retrieved on 14 June 2016]

3.3.4 Predominantly fluctuating renewable electricity supply of grid-connected areas

For a few hours per year, the contribution of fluctuating renewables to the overall German power supply comes close to 100 %, thus showing that even a densely populated industrialised country with little natural energy resources can be supplied predominantly with fluctuating renewable energies at least for short periods of time. For smaller areas, fluctuating renewables contribute up to 100 % or even more than 100 % to the power supply even all year round. For instance, the State of Mecklenburg-Western Pomerania had a renewables rate of 130 % and the State of Schleswig-Holstein a rate of 100 % on the average in 2015.[7] In both states, wind energy provides the major part of this fluctuating renewable generation. There are basically two ways how the difference between generation and demand is balanced in those areas which are occasionally or even most of the time generating as much electricity from wind or PV power as is consumed in the same area: (1) adjustment of conventional power generation, and (2) export of surplus generation to, and compensation of lacking generation through imports from, other areas and neighbouring countries. The former will no longer be possible when conventional power generation will be phased out, the latter will no longer be possible when neighbouring areas and countries switch to predominantly fluctuating renewable electricity generation, too. Then, areas with a predominantly fluctuating renewable electricity supply will have a high need for flexibility in form of either storage or demand-side response even though they are connected by electric grids to other areas.

3.3.5 100 % renewable electricity supply of smaller entities

100 % renewable electricity supply from PV-battery storage systems exists for several decades already. A few millions of small decentralized PV-battery off-grid systems for applications including ticketing machines, solar home systems supplying lighting, radio and TV, solar powered medical centres, PV drinking water systems, PV irrigation systems, telecommunication repeater stations, and others have been installed worldwide. Most of them are in use in countries at low geographical latitude and the storage simply needs to balance generation-demand differences for a period of several hours up to several days. Some systems such as urban ticketing machines or telecommunication repeater stations which have to function with a very high reliability, are installed in countries with a very strong imbalance between the solar generation in summer and winter and therefore equipped with a comparatively large battery designed to ensure smooth operation for several days even in the month with the lowest solar irradiation.

7 Germania, 2 Länder producono già il 100% d'elettricità da rinnovabili, http://www.rinnovabili.it/energia/eolico/germania-lander-100-elettricita-rinnovabili-666/ [retrieved on 8 June 2016]

Evaluating the need for flexibility, this is the need for storage of such applications, is an established engineering practice. Table 5 shows some examples of 100 % PV electricity supply based on (Wagner, 2010).

Table 5: Stand-alone electricity supply with PV-battery systems, Source:

Application	daily electricity demand [kWh/d]	average power demand [kW]	PV generator power [kW]	battery capacity [kWh]	PV / demand [kW/kW]	storage time [d]	average availability	loss of load probability
solar home system in Philippines	0,44	0,02	0,16	1,2	8,8	2,8	0,88000	0,12000
village in Senegal	60,00	2,50	21,30	207	8,5	3,5	0,96000	0,04000
medical refrigerator at equator	1,52	0,06	0,96	9,6	15,2	6,3	0,99900	0,00100
week-end cottage in Berlin	0,17	0,01	0,08	1,2	11,6	7,2	0,99000	0,01000
single family house in Bozen/ Italy	1,17	0,05	0,8	4,8	16,4	4,1	0,90000	0,10000
repeater station	0,273	0,01	0,68	3,12	59,8	11,4	0,98000	0,02000

Recently, a study has been presented by the Australian energy management consultant Energeia which indicates which 40 Australian towns should be the first to cut the link to the existing electricity transmission grids as reported by (Parkinson, 2016). Australia is an extreme case of an industrialised country. There exist two transmission grids, one along the eastern coast, another one along the central part of the southern coast. The major part of Australia is not connected to a transmission grid, but supplied with electricity locally. Much used are diesel generators. Within the areas covered by the transmission grids, the density of the electricity demand is very low and the transmission grid is over-dimensioned. The resulting grid costs alone are as high as 20 €ct/kWh.

Rapidly falling prices for PV systems and batteries have now led to a situation where off-grid supply of many Australian towns, mainly with PV-battery systems, is cheaper than conventional power generation and transmission via the grid. In order to prevent an uncontrolled disconnection of Australian towns from the transmission grid, thus leading to a rapid increase of the grid costs for those who remain connected, Energeia has evaluated for which towns off-grid supply is most cost effective compared to remaining grid-connected, and recommended that these towns should disconnect first. The recommendation of Energeia is in line with numerous statements of the Australian grid operators.

The Australian example shows that even the maintenance of the electric transmission grid might be less cost-effective than electricity storage. Though the situation in Europe is much different, it highlights that in the case of very low electricity consumption and long distances from central power plants, local off-grid supply with renewable electricity and battery storage to balance generation and demand might be a suitable option. In Europe such situations can be found in mountainous regions, on islands, and in sparsely populated parts of the countryside.

3.3.6 Model calculations for high fluctuating renewable supply of large areas

Various model calculations have been performed in order to assess the need for flexibility in electricity supply systems at the level of entire countries, parts of countries or groups of countries. Several of these models evaluate the upper limit of flexibility needs by investigating only solar and wind energy converters as electricity generators, thus studying the extreme case of exclusively fluctuating electricity generation. In real electricity supply systems extending over entire countries, the generation mix will usually contain other sources and the need for flexibility will presumably be lower than these models predict.

An outcome of these model calculations is among others the optimum mix of solar and wind power generators. A common result of several calculations is that a mix of roughly equal parts of wind and PV power generation in terms of generated electric energy is the optimum mix. That means, if energy storages are the only flexibility option considered, the storage capacity needed to deal with the fluctuations of such a generation mix in a way that the equally fluctuating demand is always matched, has a minimum for roughly equal contributions of PV and wind power to the electricity supply. A further common result is that this flexibility minimum is very broad and deviations from it do not increase the overall system costs very much.

Generally, the farer an area is situated away from the equator, the higher is the optimum share of wind power. The closer it is situated to the equator, the higher is the optimum share of PV. In southern Europe a higher share of PV in the generation mix is better. This is due to the better seasonal balance of PV power generation at lower latitudes and the related lower need for seasonal storage if PV power provides a significant share of the power generation.

For Denmark for instance, an optimum mix of 80 % wind and 20 % PV electricity supply in terms of generated electric energy has been identified (Andresen, 2012). Considering that wind energy converters in Denmark achieve approximately a three times higher number of full load hours than PV plants, this corresponds to a mix of 42 % PV and 58 % wind in terms of nominal power.

For the purpose of the ELSA project, it is important to understand that such model calculations tend to overestimate the overall need for storage, if they investigate the extreme case of 100 % fluctuating power generation, but tend to underestimate the need for short-term storage such as it can be provided by batteries. The reason is that all models have a limited spatial and temporal resolution. The area considered is usually cut into a limited number of elementary spatial elements, the area cells, with a minimum size, for instance 10 km x 10 km.

The model algorithms balance the total generation and the total consumption at a given moment within the cell area and calculate the required need for flexibility, including electricity imports and exports. The real demand for flexibility is a bit larger because the exchange of power within the cell area is not perfect - it's not a "copper plate" – thus putting restrictions on the balancing effect of the grid within the cell.

A similar effect has the choice of the time-step of the calculations. If the calculation is made with a time-step of one day, the daily variation of PV power generation is completely blurred and the amount of short-term storage at time-scales up to one day is strongly underestimated. The same applies for shorter time-steps and storage for shorter durations. Always, the amount of storage is underestimated which is needed at time-scales shorter than the chosen time-step.

In the light of these considerations it is not surprising that models investigating the extreme case of 100 % PV and wind power supply come out with very low estimates of the required short-term storage capacity, but noteworthy that the identified need for long-term storage is very modest, too, though much larger than that identified for short-term storage.

3.3.6.1 MOSES model calculation for East Germany

For the east of Germany (50hertz zone), a model calculation of the optimum PV-wind mix in a PV-wind-only supply scenario has been executed in the model MOSES by the NEXT ENERGY - EWE Research Centre for Energy Technology with high temporal (15-minute time-steps) and spatial (10 km x 10 km) resolution.[8] A mix of 71 % energy from wind and 29 % from PV has been found for meteorological and consumption data of the year 2011. This is coherent with the findings for Denmark which is situated at slightly higher latitude for which a mix of 80 % energy from wind power and 20 % from PV was found.

Further calculations of the optimum mix were executed with time-steps of one day and one week. This is equivalent to assuming the existence of short-term balancing of supply-demand differences at these time-scales by appropriate measures (demand-side management and short-term storage) and it provides an estimate of the optimum mix of wind and PV electricity generation with regard to the need for long-term storage. The result is that the optimum is shifted to about 40 % wind and 60 % PV energy if intermittent generation is balanced at the scale of one day, and to about 50 % wind and 50 % PV energy if it is balanced at

[8] S. Weitemeyer, T. Vogt, C. Agert, Energy system modelling – a comprehensive approach to analyse scenarios of a future European electricity supply system, in: proceedings of IRES 2012, p. 426 et seqq.

the scale of one week. The remaining need for storage decreases in the model with increasing time-step what shows that the need for long-term storage is reduced if sufficient daily and weekly storage or equivalent flexibility is provided. However, the MOSES calculations do not provide information about the amount of short-term flexibility implicitly assumed to be available when doing the model calculation in daily or weekly time-steps.

3.3.6.2 GENESYS model calculation for EUMENA region

(Bussar, et al., 2015) describe a model calculation performed with the simulation tool GENESYS which allows to optimize the allocation and size of different generation technologies, storage systems and transnational grids of a European power system. The source code for the simulation tool is available free of charge under a public license. It can be freely parameterized by the user which allows the study of different electricity systems under the users' assumptions with regard to load, generation potential and cost structure of the different system components. The area simulated in the work underlying (Bussar, et al., 2015) is the EUMENA-region, comprising Europe, the Middle East and North Africa. It is broken down into 21 regions connected via 49 modelled high voltage direct current (HVDC) connection lines. The countries France, Spain, and Italy are considered as a single region, respectively, UK and Ireland form one region jointly, Germany is broken down into 3 regions, etc. The demand is taken from ENTSO-E load records. The generation is calculated based on historic measurements provided by MeteoGroup. Batteries, pumped hydropower storage (PH) and hydrogen (H2) are considered as flexibility elements to compensate the fluctuating generation from PV and wind generators. The modelled HVCD lines are considered as flexibility next to storage.

The results of the standard scenario which represents the economic optimum show a generation power of 4,550 GW, split up into PV and wind power generation capacity, i.e. in terms of nominal power, in a ratio of 60:40 on global scale for the EUMENA region. Within the individual regions, the split can deviate very much from this overall optimum mix. The total generated electricity from PV is 3,900 TWh/a, which corresponds to an average of 1,400 full load hours (FLH), while wind power contributes 3,700 TWh/a, which corresponds to 2,000 FLH. The capacity of long-term storage systems needs to be 800 TWh (10.5 % of the total electric energy demand), the total electrolyser power 900 GW, and the total power of combined cycle gas turbines required to generated electricity from the stored hydrogen 550 GW. For short and medium term storage, only 2.7 TWh of hydropower storage (0.04 % of the total electric energy demand) and 1.6 TWh battery systems (0.02 % of the total electric energy demand) are needed with a hydropower capacity of 190 GW (18 % of peak load) and 320 GW (30 % of peak load) battery power. The peak load of the system is 1,060 GW which equals the amount of all storage output units[9]. 36,000 km of HVDC lines with a grid momentum of 503,000 GW*km ensure a strong spatial balance thus limiting the storage need to the mentioned values. The average HVDC connection has a net transfer capacity (NTC) of 14 GW. The maximum is 50 GW, but most connections are in the 5-10 GW range, and only three above 20 GW (between the UK and France, between France and Italy, and between Turkey and the Balkan countries). The levelised cost of electricity (LCOE) is 9.67 $ct_{€2014}$/kWh which reflects the generation, storage and HVDC-transmission cost. Out of this wind generators account for 38 % of the LCOE, PV for 30 %, hydrogen storage (electrolysers and combined cycle gas turbines) for 17 %, batteries for 4 %, pumped hydro storage for 3 %, and HVDC grid lines for 8 %. The cost assumptions for grid lines and generation and storage units reflect today's prices. Hence, the LCOE will in fact be even lower if current forecasts of PV and wind power cost reductions are considered.[10,11]

A sensitivity analysis has been performed in order to evaluate the effect on the LCOE of reducing one or the other flexibility element. Limitation of the NTC between the modelled regions results in a stronger mix of PV and wind power within the regions, especially in central Europe, and a strong increase of the need for long-term (hydrogen) storage if the maximum NTC falls below 10 GW. Removing batteries and pumped hydro storage, that is the short and mid-term storage options, leads only to a slight increase of the LCOE to about 10 $ct_{€2014}$/kWh. Removing long-term (hydrogen) storage leads to an increase of the LCOE up to about 12 $ct_{€2014}$/kWh. All the storage would be provided by pumped hydropower in this case and no batteries would be used.

As specified by (Bussar, et al., 2014) who describe a slightly different previous version of the modelling, the time-step of the simulation is one hour, the simulated time 5 years. The power flows for each generation and storage type are aggregated within each region. Assuming that no higher resolution was used in the calculations presented by (Bussar, et al., 2015), it can be concluded that the time resolution is quite high, but the spatial resolution too rough,

[9] The source is inconsistent at this point and indicates a peak load of 1,030 GW, but the indicated storage power adds up to 1,060 GW. There might be a confusion of input and output power of storage units at the origin of the inconsistency.

[10] The International Renewable Energy Agency (IRENA) predicts LCOE of PV and wind electricity (without storage systems and grids) of 5-6 US$/kWh for 2025; http://www.pv-magazine.de/nachrichten/details/beitrag/irena--kosten-fr-photovoltaik-sinken-um-59-prozent-bis-2025_100023422/ [retrieved on 21 June 2016]

[11] Bloomberg New Energy Finance (BNEF) predicts a further decrease of LCOE for PV of 60 % and for wind energy of 41 % until 2040 in its New Energy Outlook 2016 published on 13 June 2016; http://www.pv-magazine.de/nachrichten/details/beitrag/bnef--kohle-und-gas-bleiben-gnstig--aber-photovoltaik-und-windkraft-haben-mehr-kostensenkungspotenzial_100023377/ [retrieved on 21 June 2016]

thus leading to an underestimation of the (short-term) storage needed to deal with limited grid resources within the distribution and national transmission grid. It can be assumed that the total short-term storage will in reality be higher than 2.7 TWh of hydropower storage and 1.6 TWh of battery systems if the power generation system is built up exclusively with PV and wind power generation units.

(Bussar, et al., 2014) specify also that the model calculation includes the assumption that the modelled regions (in fact entire countries in most cases) have to be at least 80 % self-supplied. It is further assumed that all generation and storage plants are to be installed from the outset, except existing pumped hydropower storage reservoirs. That means that existing PV and wind power capacity, and existing transnational power exchange capacity are not taken into account. Further, the costs of the distribution and national transmission grids within the 21 regions are not included in the calculated LCOE.

3.3.6.3 VDE study for different levels of renewable electricity supply in Germany

An often cited study investigating the effect of different levels of RE penetration into the electricity supply system in Germany has been presented by (Adamek, et al., 2012). The work is based on the long-term scenarios (Langfristszenarien 2010) for the development of the German electricity system of the German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety which include a strong increase of renewable electricity generation, essentially from PV and wind power plants. The study of VDE investigates the need for storage for a contribution of renewables to the electricity supply of 40 % (government target for 2020), 80 % (government target for 2050) and 100 % (for comparison) on the basis of a set of widely shared assumptions on the development of the demand, technology costs and the development of the German transmission grid. Generation management of power plants and demand-side response are considered as flexibility in addition to storage and the existing, respectively forecasted grid.

The study assumes that the use of storage is governed by the need to balance the predominantly renewable and fluctuating generation and the demand. Other use cases which might increase the need for storages such as provision of system services for stable grid operation are not taken into account. It is also assumed that the current electricity market design will not significantly be altered. Exports and imports of electricity which can reduce the need for storage and/or transmission grid extension and cross-energy synergies resulting from a stronger coupling of the electricity, heat, gas, fuel and chemicals sectors are disregarded. Renewable electricity generation data are modelled on the basis of the meteorological data of the year 2007. The calculations are made for entire years and the time-step is one hour.

Key conclusions of the study are:

- With increasing renewable electricity generation and decreasing residual load (difference between load and renewable generation) the fluctuations of the residual load increase and the number of hours in which the residual load is negative (more renewable generation than demand) increases. Hence, the need for flexibility in the electricity supply system increases.
- A renewables rate of 40 % can be dealt without new storage systems in Germany. The generation flexibility of the conventional power plants combined with a tiny curtailment of renewable power generation is sufficient and storages essentially optimise the operation of the latter. The residual load is negative only for about 44 hours per year, but its maximum value (minus 9.8 GW) is quite high (can be dealt with by curtailment).
- At a renewables rate of 80 %, 14 GW/70 GWh of short-term storage (about twice the capacity of existing pumped hydropower storage) and 18 GW/7.5 TWh of long-term storage (power-to-gas) are needed in the overall most economic scenario. The total storage power and the energy storage capacity correspond, respectively, to 43 % of the present peak load, but only and 1.3 % of the present annual electric energy demand. Less than 1 % of the renewable generation needs to be curtailed. The energy turnabout in the long-term storages corresponds to less than 2 % of the present natural gas consumption.
- At a renewables rate of 40 % the LCOE are about the same as in 2010, at 80 %, they are 10 % higher.
- Further increasing the renewables rate to 100 % triples the need for storage compared to 80 % (2.5 times more short-term and 3.5 times more long-term storage) and further raises the LCOE by 19 %.
- Positioning storages close to generators or close to consumers makes no difference.

3.3.6.4 The Neo Carbon Energy Study

(The role of storage technologies for the transition to a 100% renewable energy system in Europe, 2018) is one of the most recent studies. It presents a model of a transition towards 100 % renewable electricity supply of the EU + Norway + Island + Switzerland + Balkan Countries + Ukraine + Turkey in five-year time-steps from 2015 until 2050, with only one 1.6 GW nuclear power plant remaining in 2050 due to remaining lifetime (about 2.4 % of electricity demand) and gas power plants successively fuelled by renewable gas (biogas, biomethane and finally synthetic natural gas produced from surplus electricity).

The investigated area is broken down into 20 regions, most of which are identical with entire countries and connected among each other by HVDC interconnection grid lines. The model time-step is one hour, the spatial resolution 0.45° x 0.45° (about 50 km x 35 km at 45° latitude). The electricity demand is assumed to rise from 4,000 TWh in 2015 to 5,300 TWh in 2050.

According to the results of this work, a 100 % renewable electricity supply can be cheaper than the present predominantly fossil and nuclear mix: LCOE decrease from 69 €/MWh in 2015 to 51 – 56 €/MWh in 2050. A significant need for increasing interconnections between regions is found and 15 % of the electricity is consumed outside the region where it is generated. As regards storage, 3,320 GWh of batteries, 396 GWh of pumped hydro storage, and 218,042 GWh of gas storage (in terms of heating value; 8% for synthetic natural gas and 92% for biomethane) are needed. I.E. batteries provide about 90 % of the total short-term storage in the scenario investigated in this work.

3.3.7 Model calculations compared to real generation-demand data

The results of the model calculations are in line with the fact that a renewables contribution of 32.6 %, including 21.1 % from fluctuating PV and wind power generation, to the German electricity consumption is possible without further storage systems and other flexibilities than those set up for the predominantly conventional electricity system that is about to be phased out. The existing pumped hydropower storage plants combined with generation management of conventional power plants, essentially applied to hard coal power plants, a small level of renewable power curtailment and little demand-side response are sufficient to deal with the fluctuations of the residual demand, which is governed by the fluctuating PV and wind power generation covering 21.1 % of the consumption. The average electricity price achieved for imports and exports of about 40 €/MWh, that is (1) not differing between imports and exports, and (2) above the average day-ahead market price for electricity of 31.60 €/MWh in 2015, indicates that transboundary electricity exchange is not predominantly used as an additional flexibility, but rather driven by market aspects. If imports and exports were driven by a need for flexibility, the export prices were lower than the average day-ahead market prices, and lower than the import prices.

For higher fluctuating RE penetration rates than 21.1 %, a comparison of the presented three model calculations, out of which two focus on Germany, with real consumption-generation data cannot be performed for longer periods, but for a few hours or days per year when the contribution of PV and wind power to the German electricity supply is between 80 and 100 % of the consumption. Such events regularly occur in the month of May or June at weekends combined with a public holiday the day after (Monday of Pentecost) or on a Thursday before (Ascension Thursday and Feast of Corpus Christi).

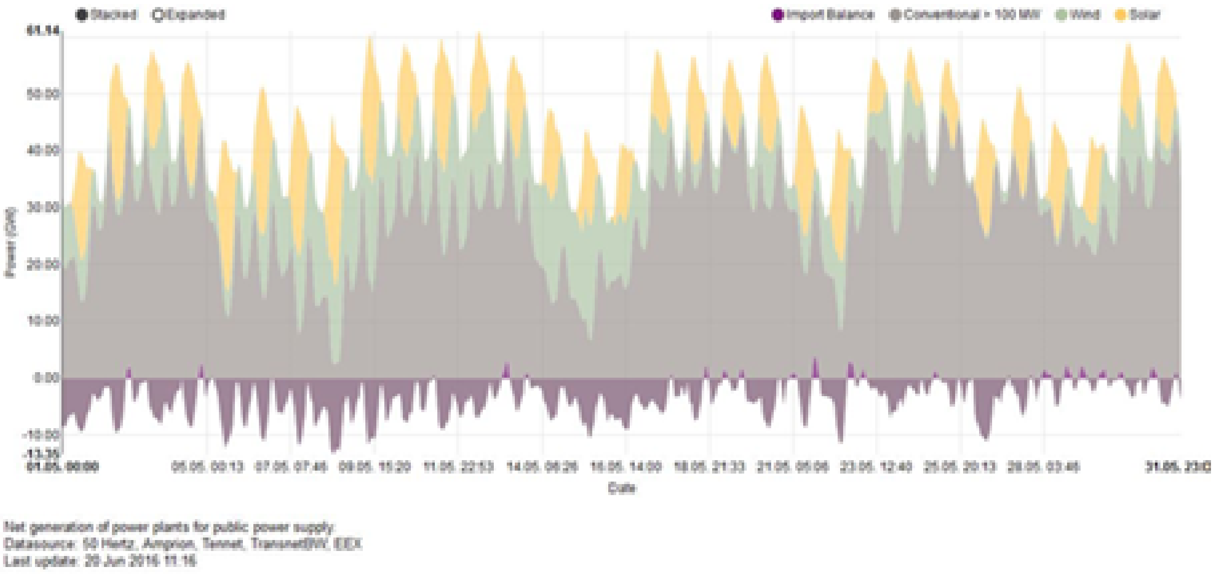

Figure 35: PV (yellow), wind (green), conventional (light grey) power (>100 MW) generation in, and power exports (dark grey) from, Germany in May 2016, Source: (Fraunhofer ISE, 2016)

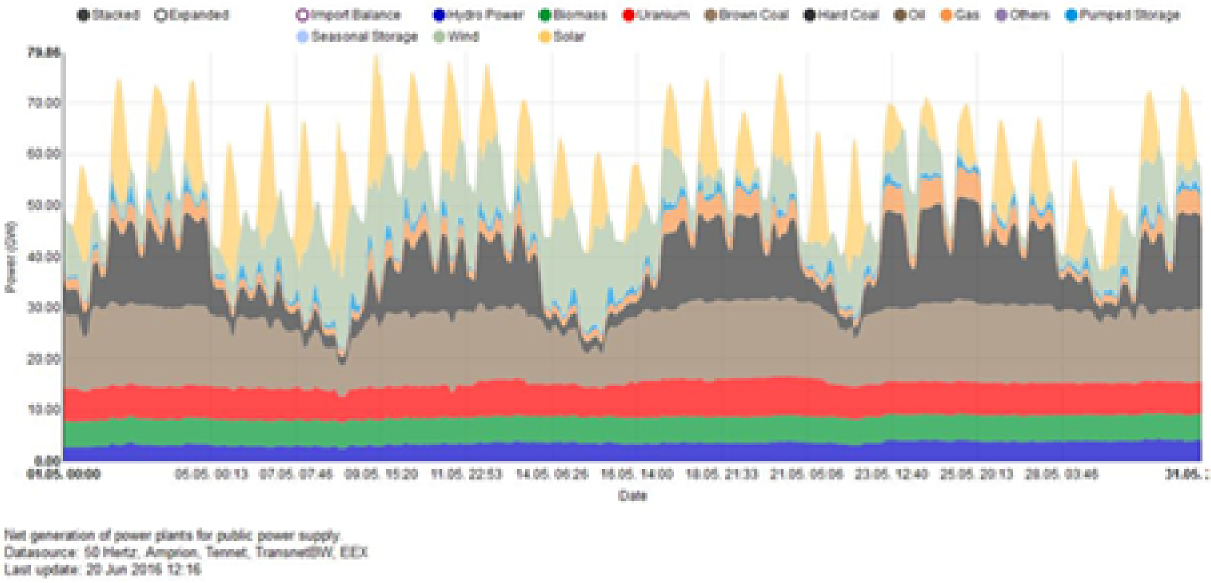

Figure 36: Power generation mix in Germany in May 2016, Source: (Fraunhofer ISE, 2016)

As Figure 35 and Figure 36 show, extreme high contributions of renewables to the electricity supply were achieved on Sunday, 8 May (following Ascension Thursday), Sunday of Pentecost, 15 May, and Sunday 22 May (not linked to a public holiday, but in the mid of school holidays in Baden-Wuerttemberg and Bavaria). On 8 May 2016, renewable power generation covered 97.7 % of the power consumption between 12:00 and 13:00. PV and wind power alone covered 81.8 %. For one hour, the German electricity supply system was in a status for which models forecast a strong rise in flexibility demand, including a high need for seasonal storage.

Generation and consumption data for one hour cannot tell much about the need for seasonal storage, of course, but can be used to check if the predicted need for short-term storage exists. In fact, the latter is displayed in the strongly negative electricity price of minus 130.09 €/MWh at the day-ahead market as shown in Figure 37. Similarly, negative day-ahead market prices occurred on 15 and 22 May. They are clear signals, that the electricity system was lacking flexibility when the RE contribution to the supply was extremely high.

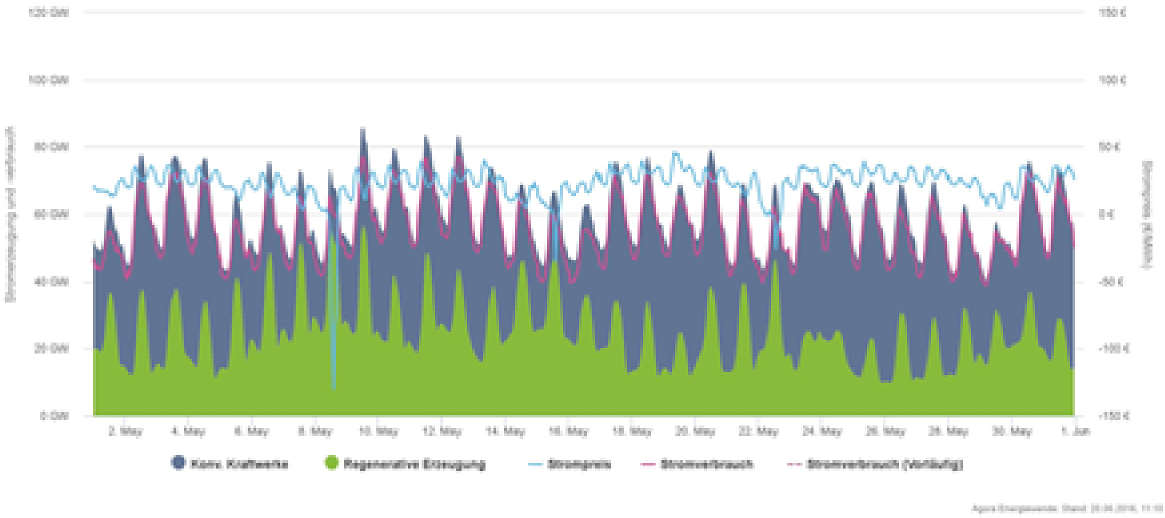

Figure 37: Renewable (green) and conventional (grey) power generation, consumption (pink line) and electricity spot-market price in Germany in May 2016, Source: (Fraunhofer ISE, 2016)

A closer look in Figure 36 shows that the power generation from hard coal was merely reduced to zero when the renewable power generation was close to 100 %, the lignite power generation to about 40 % of the normal generation power, and nuclear power generation was just reduced by a few percent. This reflects the technical minimum for the power generation from hard coal, lignite and nuclear power. Power generation from biomass was not reduced. This is essentially an effect of an unsuitable regulatory framework respectively market failure and did not happen for technical reasons. At least biogas plants would have been technically able to reduce the power generation.

3.3.8 Conclusions on need for storage

The need for storage in a given area has been discussed here from a technical and national economy point of view. This must not be confused with an evaluation of the market for storage which depends on the design of the energy market and individual market player behaviour in the context of concrete energy markets. The technical need for storage is strongly dependent on the strength of the electric transmission and distribution grid within this area and is dependent on the capacity of the power connections crossing the area's boundary. If the latter are strong enough, there might be very little need for storage and other flexibility options within the area itself, because the balance between generation and consumption can be achieved by simply adapting power imports and exports accordingly. This is even possible if the share of fluctuating renewable power generation is very high. An example coming very close to this case is the State of Mecklenburg-Western Pomerania in the north-east of Germany where the percentage of renewable generation to the consumption is 130 % and fluctuating wind power generation builds the dominant part of this. However, the efficiency of use of existing network operating resources (grid lines, transformers, etc.) can be very much improved and curtailment of fluctuating renewable generation can be reduced by using storage systems whenever the power generation within a geographic entity is frequently close to or even above the demand within the same area.

Model calculations mapping European regions or wider areas of Europe and neighbouring countries supplied with various shares of renewable power, including the extreme case of 100 % PV and wind power, confirm this statement. They come out with rather modest energy storage needs compared to the annual energy demand, in particular a modest short-term energy storage need which can be met with battery systems, but with a rather high need for storage power compared to the peak power demand. A common finding is that the need for energy storage increases very modestly for renewable shares up to 80 % and very steeply between 80 and 100 %. This corresponds to what can be observed in Germany where the annual average share of renewables was 32.6 % in 2015 out of which 21.1 % were PV and wind energy, but the contribution of PV and wind power is very close to 100 % in some hours. Negative prices on the electricity market indicate a clear lack of flexibility at these moments, while the existing flexibility of the system is sufficient during most of the year.

A significant share of dispatchable renewable power generation from hydropower, biomass and geothermal energy in 100 % renewables scenarios reduces the need for short-term storage, and also for long-term storage if dispatchable renewables make up a significant part of the power generation. Most Latin American countries are in this situation because of their high hydropower generation capacity. Further, other flexibilities such as demand-side response, coupling of the electricity, heat and gas sectors, and other kinds of storage strongly reduce the need for short-term energy storage compared to situations dominated by fluctuating renewable power generation.

A crucial point however is that the mentioned model calculations tend to underestimate inherently the need for short-term storage inasmuch as they generally do not map the real electric network operating resources. If the latter are taken into account, a clear need for storage becomes apparent and battery storage systems are the most suitable option to meet this because they can deal with a broad range of required services better and more cost-effectively than other flexibility options. In quite a number of cases, batteries are also more cost-effective already today than reinforcement of electric network operating resources, at least until the next regular replacement of existing equipment. Unfortunately, the need for storage complementing cost-efficiently network operating resources cannot be quantified yet.

Last but not least, batteries remain the preferred storage option complementing off-grid PV or wind power supply of smaller entities such as single appliances, households, villages or islands. The Australian example shows that even the supply of entire towns with off-grid systems including storage might be more cost-effective than conventional power generation and transmission over very long distances. Though the situation in Europe is much different, it highlights that in the case of very low electricity consumption and long distances from central power plants, local off-grid supply with renewable electricity and battery storage might be a suitable option. In Europe such situations can be found in mountainous regions, on islands, and in sparsely populated parts of the countryside.

3.4 The technical potential of 2nd-life battery storage systems

Responsible Partner: B.A.U.M. Consult

3.4.1 Technical characteristics assumed for 2nd-life battery storage systems

For assessing the technical potential of 2nd-life batteries, it is assumed that all 2nd-life batteries have the technical characteristics of the batteries going to be used in future commercial ELSA battery systems (ELSA-DT5-ESS). For keeping in mind that this simplification is made, the notions “ELSA-type 2nd-life battery storage systems”, “ELSA-type ESS” or “single ELSA-type battery” will be used in the following. Though there will for sure be a wide range of 2nd-life battery systems on the market in the future, the major lines of the conclusions drawn from assuming that all 2nd-life batteries will have similar characteristics as the ELSA-DT5-ESS can be considered to be a good approximation. Figure 38 shows the general architecture of ELSA battery storage systems. A system is composed of a number of batteries, power electronics and control units.

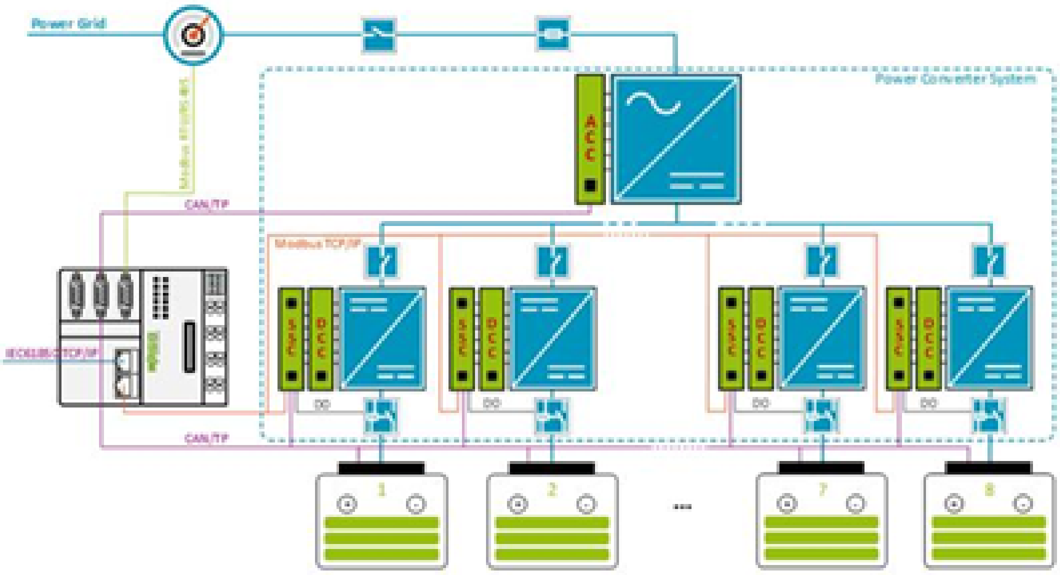

Figure 38: Architecture of a future commercial ELSA battery system

The technical characteristics of a single ELSA 2nd-life battery, which are relevant for the assessment of the technical potential of ELSA-type 2nd-life battery storage systems, are:

- maximum energy that can be discharged from a single battery: e_{2nd} = 11 kWh
- permitted range state of charge (SOC): 0 < SOC < 100%
- maximum charge / discharge power of a single battery: p_{2nd} = 12 kW
- reaction time: short enough to provide all services discussed in the following, i.e. in the range of milliseconds[12]

3.4.2 Available 2nd-life battery storage capacity and power

The technical potential of 2nd-life batteries to provide various services to the electric grid in the EU depends at first on the amount of energy which can be stored in all 2nd-life batteries which are used for stationary applications and are connected to the electric grid. This amount is estimated as follows:

$$E_{2nd} = e_{2nd} \cdot N_{vehicles} \cdot r_{el} \cdot r_{reuse} \cdot \frac{t_{2nd}}{t_{1st}}$$

Where E_{2nd} designates the amount of energy which can be stored in all 2nd-life batteries and e_{2nd} the amount of energy which can be stored in a single ELSA-type battery. $N_{vehicles}$ desig-

[12] The information on the measured reaction time of the installed DT5-ESS was not available for the establishment of this deliverable.

nates the number of all vehicles, r_{el} the rate of vehide electrification, r_{reuse} the rate of vehide batteries which are reused for a 2nd life, t_{1st} the time of use of a battery in the vehicle and t_{2nd} the time of use for a 2nd-life application.

The following assumptions have been made as regards the values of these parameters:

- e_{2nd} = 11 kWh, the energy storage capacity of a single future commercial ELSA battery as mentioned above.
- N_{2nd} = 300 million, approximately the number of vehicles in the EU (see Table 6)
- r_{reuse} is the rate of stationary and grid-connected 2nd-life use of electric vehicle batteries. It has been set at 50 %.
- The time of battery use in the vehicle, t_{1st}, is supposed to be 10 yrs and the time of 2nd-life use, t_{2nd}, to be 10 yrs.

The vehicle stock electrification rate, r_{el}, is the remaining free parameter. It represents the electric vehicle fraction of the EU's vehicle stock. A vehicle is considered to be electrified if it is equipped with one or more batteries whose later 2nd-life capacity is 11 kWh. Thus, a vehicle electrification rate of 100 % does not mean that each vehicle is fully electric. Instead, it designates a vehicle fleet where an individual vehicle might be a battery-only, hybrid or fossil-fuel powered one, but on the average each vehicle releases a 11 kWh 2nd-life battery at the end of its 1st life.

The vehicle stock electrification rate and the reuse rate have been combined to a further parameter, the 2nd-life availability rate, a_{2nd}:

$$a_{2nd} = r_{el} \cdot r_{reuse}$$

A 2nd-life availability rate of 100 % means that (1) on the average each vehicle, including electric, hybrid and combustion engine vehicles, provides an ELSA-type battery, i.e. one with a capacity of 11 kWh for a 2nd-life use of 5 years, after such one has been used for 10 years in a vehicle, and (2) each ELSA-type battery is recovered for 2nd-life use.

Taking further into account that the maximum power of a single ELSA-type battery is 12 kW, the total available power of ELSA-type 2nd-life batteries, P_{2nd}, is calculated as:

$$P_{2nd} = \frac{12\ kW}{11\ kWh} \cdot E_{2nd}$$

In order to get a meaningful idea of the potential 2nd-life battery capacity in terms of energy and power, it needs to be put into relation to the present most important short-term storage technology in the EU, that is pumped hydropower. According to (European

Commission)[13] there are no official figures reported to Eurostat for existing pumped storage capacities in Europe, but some sources (e.g. ecoprog) put the total capacity in terms of power at the beginning of 2011 at almost 45 GW.

Table 6: Stock of vehicles per EU country in 2016, Source: (EUROSTAT)

GEO/TIME	2016
Belgium	6.640.318
Bulgaria	3.661.320
Czech Republic	6.032.825
Denmark	2.919.455
Germany	50.374.203
Estonia	:
Ireland	2.509.446
Greece	6.512.139
Spain	28.451.448
France	39.501.237
Croatia	1.727.173
Italy	42.842.641
Cyprus	620.551
Latvia	753.992
Lithuania	1.425.807
Luxembourg	437.219
Hungary	3.860.650
Malta	333.511
Netherlands	9.281.741
Austria	5.838.027
Poland	25.512.108
Portugal	:
Romania	6.470.693
Slovenia	1.212.192
Slovakia	2.470.833
Finland	4.027.610
Sweden	5.413.029
United Kingdom	35.798.084
TOTAL	294.628.252

A correlation exists between the energy storage capacity and the power for small and medium pumped hydro power plants: According to (Gimeno-Gutiérrez, et al., 2013)[14], the energy

13 https://setis.ec.europa.eu/setis-reports/setis-magazine/power-storage/europe-experience-pumped-storage-boom [retrieved on 19 July 2018]

storage capacity is roughly 6 hrs times the plant's power. From this, the EU's existing pumped hydro power capacity in terms of energy is calculated to be 270 GWh for the purpose of the technical potential assessment presented here.

Table 7, Figure 39 and Figure 40 show the potential 2nd-life battery capacity in the EU compared to the present EU's pumped hydro capacity in terms of energy and power for different 2nd-life availability rates.

It can be seen that the potential of 2nd-life batteries is comparable with the present pumped hydro power potential even at a modest 2nd-life availability rate. At the upper end, the 2nd-life battery capacity is much larger than the present pumped hydro capacity, notably in terms of power.

Table 7: Potential 2nd-life battery capacity vs present pumped hydro capacity in terms of energy and power

total number of vehicles, $N_{vehicles}$ (millions)	300	300	300	300	300	300	300	300
vehicle stock electrification rate, r_{el}	0.33%	1.0%	2.0%	5.0%	10%	20%	50%	100%
reuse rate of vehicle batteries, r_{reuse}	50%	50%	50%	50%	50%	50%	50%	50%
2nd-life availability rate, a_{2nd}	0.2%	0.5%	1.0%	2.5%	5%	10%	25%	50%
life-time in vehicle, t_{1st} [yrs]	10	10	10	10	10	10	10	10
use time of 2nd-life batteries, t_{2nd} [yrs]	5	5	5	5	5	5	5	5
available 2nd-life batteries, N_{2nd} (millions)	0.25	0.75	1.5	3.75	7.5	15	37.5	75
usable capacity of single 2nd-life battery, e_{2nd} [kWh]	11	11	11	11	11	11	11	11
total available 2nd-life battery nominal capacity, E_{2nd} [GWh]	2.75	8.25	16.5	41.3	82.5	165	413	825
maximum power from 2nd-life batteries, P_{2nd} [GW]	3.0	9.0	18	45	90	180	450	900
total available pumped hydro storage capacity in EU [GWh]	270	270	270	270	270	270	270	270
maximum power from current EU pumped hydro storage [GW]	45	45	45	45	45	45	45	45
ratio of 2nd-life battery capacity vs pumped hydro capacity [GWh/GWh]	0.01	0.03	0.06	0.15	0.31	0.61	1.5	3.1
ratio of 2nd-life battery capacity vs pumped hydro capacity [GW/GW]	0.07	0.2	0.4	1.0	2.0	4.0	10	20

[14] p. 19

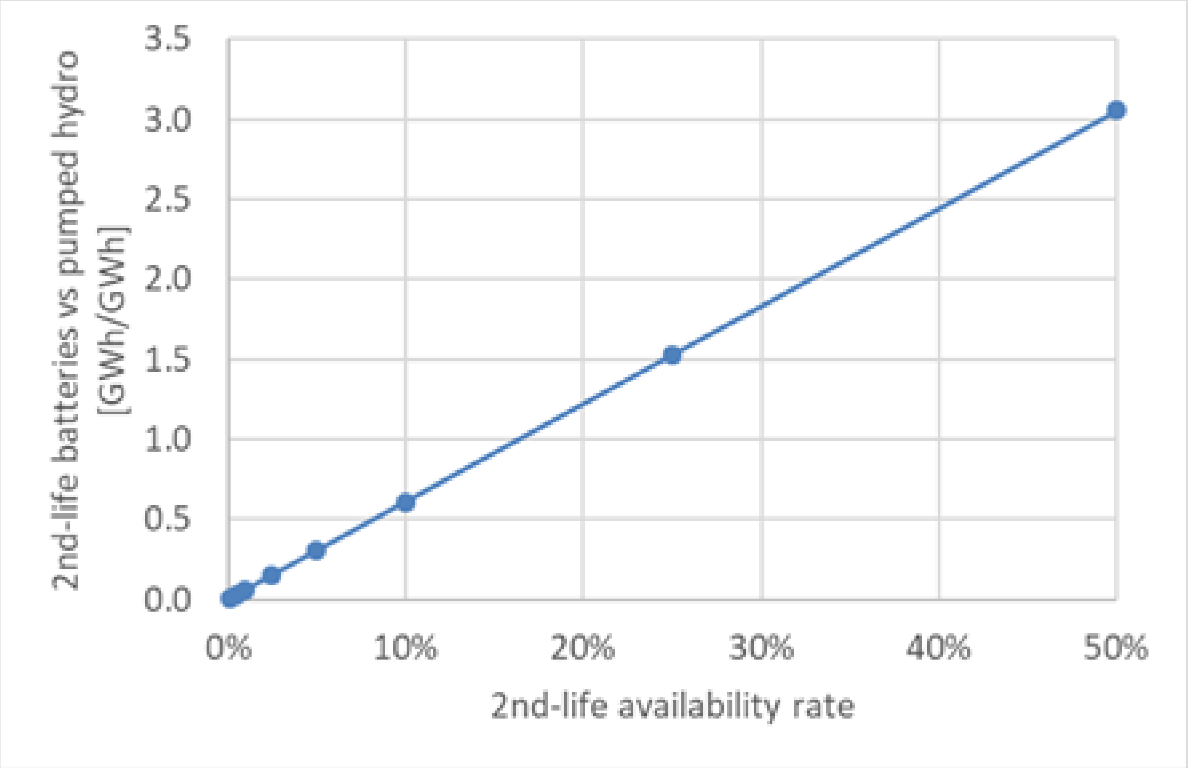

Figure 39: Energy storage capacity of 2nd-life batteries compared to present pumped hydro storage capacity

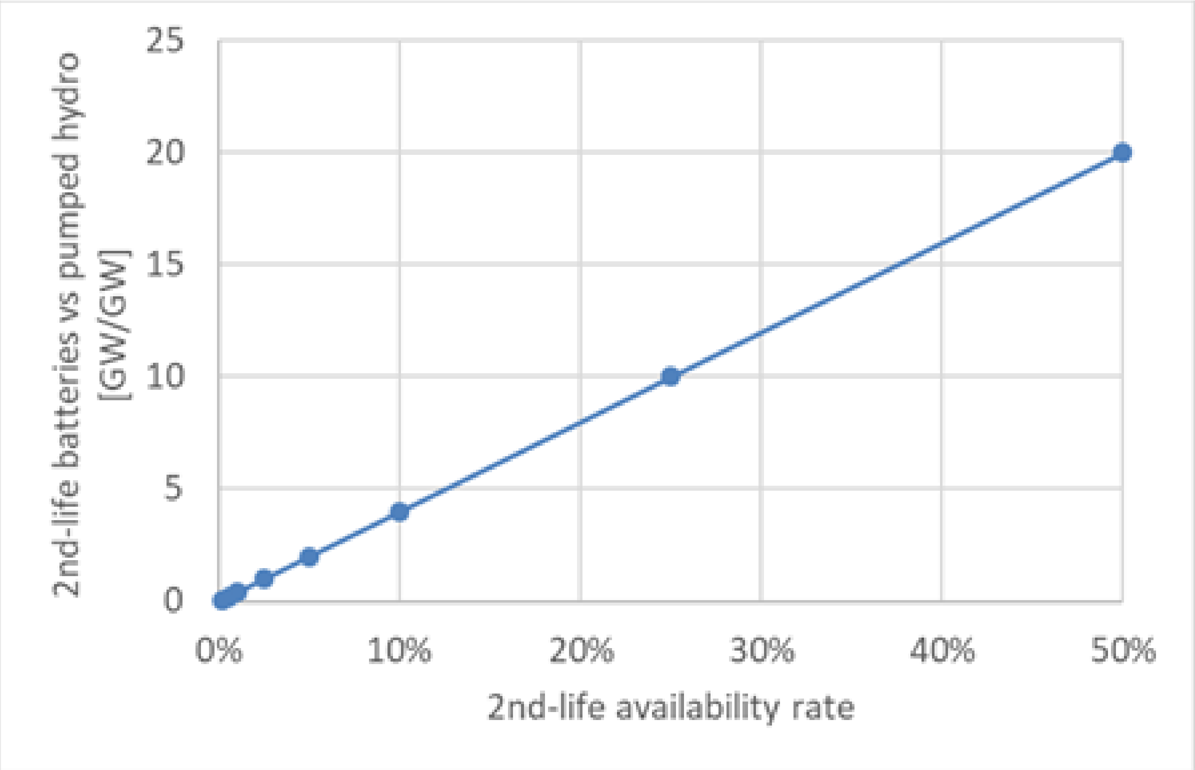

Figure 40: Power of 2nd-life batteries compared to present pumped hydro power

Contrary to pumped hydro power plants, 2nd-life batteries can be installed much faster and more easily and much closer to the site where storage capacity is needed than pumped hydro power plants. They have also a shorter response time: while pumped hydro power plants can change between charging and discharging within minutes (see e.g. (Gimeno-Gutiérrez, et al., 2013), p. 5), 2nd-life battery systems can do this within fractions of seconds. This makes them suitable for applications which require very fast response such as enhanced frequency response and primary reserve provision. Pumped hydro storage is also used for the latter but fails to be suitable for the former.

3.4.3 Technical potential for primary reserve provision

One of the most promising 2nd-life applications of electric vehicle batteries is the provision of primary reserve (PR) to transmission grid operators. For assessing the technical potential of this application, it is assumed that all available ELSA-type 2nd-life batteries are used for providing PR, independently from other applications they are used for.

In order to get a meaningful idea of the potential of ELSA-type 2nd-life batteries to provide primary reserve, this potential must be put into relation to the need for primary reserve in the same area for which the potential is assessed. As data for the EU's need for primary reserve could not be assessed, the ELSA-type 2nd-life batteries potentially available in the EU for different vehicle stock electrification rates and a reuse rate of vehicle batteries of 50 % are put into relation here with the need for primary reserve in the Union for the Coordination of Transmission of Electricity (UCTE, see Figure 41) area which amounts to ±3,000 MW at present and is mainly provided by fossil thermal power plants (VDE, 2015)[15].

[15] p. 72

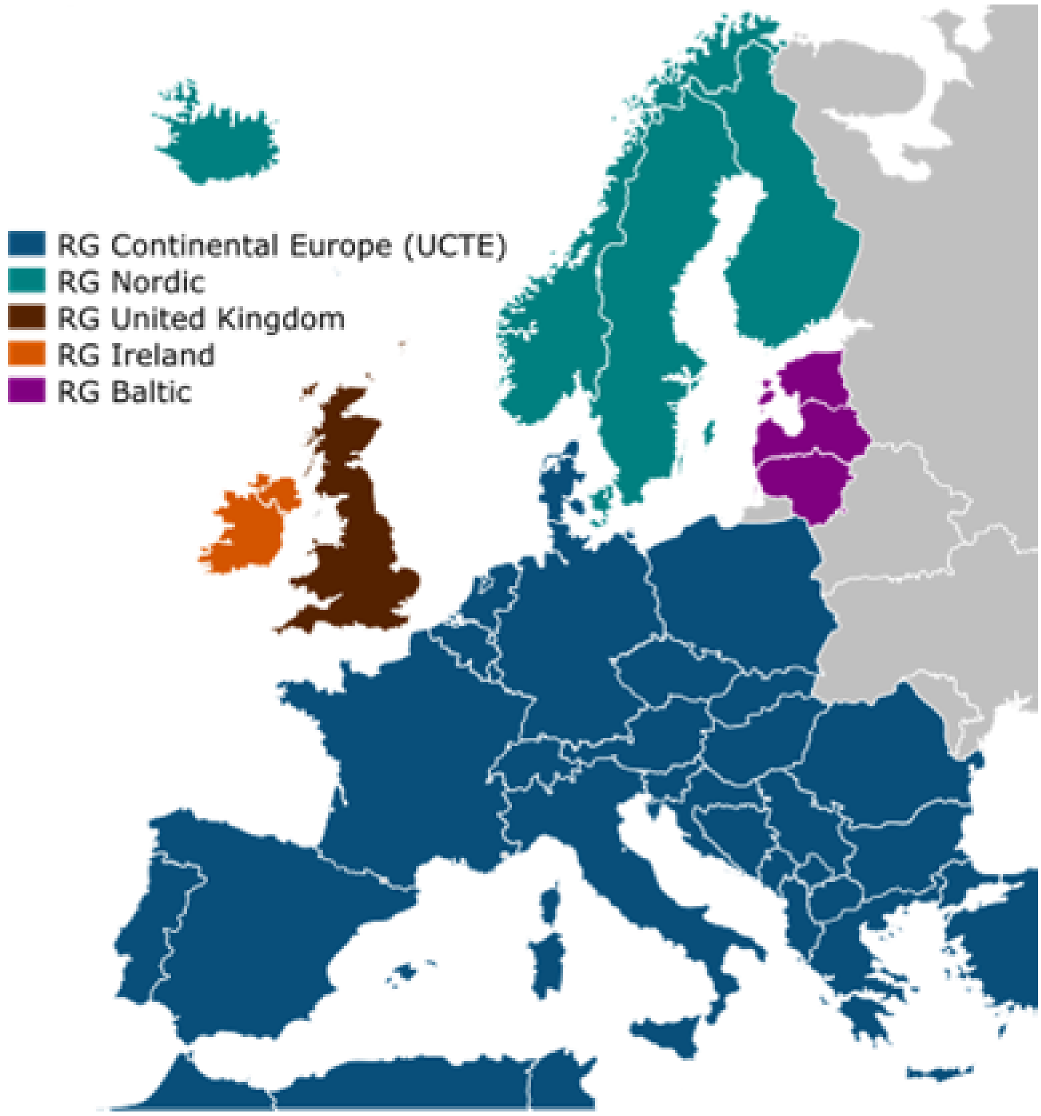

Figure 41: UCTE zone. Source: Wikipedia, https://de.wikipedia.org/wiki/Union_for_the_Co-ordination_of_Transmission_of_Electricity#/media/File:ElectricityUCTE.svg, [retrieved on 20 September 2018]

For the rules governing the provision of PR, the following is assumed for the purpose of calculating the technical potential[16]:

- PR must be offered symmetrically. I.E. the provider must be able to provide the same power for positive PR as for negative PR at any request. If legislators remove this requirement in the future, the technical potential of 2nd-life batteries will be even higher than calculated here.

[16] There are other rules which are not relevant for this calculation. All rules, including those relevant here, are subject to change. This is why the notion “assumption” is used here.

- At each single request, the provider must be able to provide PR for at least 30 minutes. This complies with the requirements formulated by the German transmission grid operators for batteries providing PR (Anforderungen). If this duration is shorter, the technical potential of 2nd-life batteries is also higher.

Then, the maximum energy which must be discharged from 2nd-life batteries in case of a request for positive PR or charged in case of a request for negative PR, E_{PRmax}, is calculated as follows:

$$E_{PRmax} = P_{PRmax} \cdot 30\ min$$

where P_{PRmax} is the maximum PR which is considered to be needed in the investigated grid area in terms of power.

The minimum average SOC of all 2nd-life batteries in case of a request for positive PR (battery discharging), SOC_{min}, is:

$$SOC_{min} = E_{PRmax}/E_{2nd}$$

and the maximum average SOC in case of a request for negative PR (battery charging), SOC_{max}, is:

$$SOC_{max} = 1 - E_{PRmax}/E_{2nd}$$

In order to comply with the requirement of symmetrical PR provision capability, the following relation must be observed:

$$SOC_{min} \leq 50\ \% \leq SOC_{max}$$

The smaller the fraction E_{PRmax}/E_{2nd}, the broader the range [SOC_{min}, SOC_{max}] and the higher the chance that the average SOC of all 2nd-life batteries is in this range and the maximum PR can effectively be provided. Table 8 and Figure 42 show the range [SOC_{min}, SOC_{max}] for different 2nd-life availability rates.

Table 8: Required average SOC of 2nd-life batteries providing all the primary reserve in the UCTE zone

total number of vehicles, $N_{vehicles}$ (millions)	300	300	300	300	300	300	300	300
vehicle stock electrification rate, r_{el}	0.33%	1.0%	2.5%	5.0%	10%	20%	50%	100%
reuse rate of vehicle batteries, r_{reuse}	50%	50%	50%	50%	50%	50%	50%	50%
2nd-life availability rate, a_{2nd}	0.17%	0.5%	1.3%	2.5%	5%	10%	25%	50%
life-time in vehicle, t_{1st} [yrs]	10	10	10	10	10	10	10	10
use time of 2nd-life batteries, t_{2nd} [yrs]	5	5	5	5	5	5	5	5
available 2nd-life batteries, N_{2nd} (millions)	0.25	0.75	1.88	3.75	7.5	15	37.5	75
usable capacity of single 2nd-life battery, e_{2nd} [kWh]	11	11	12	11	11	11	11	11
total available 2nd-life battery nominal capacity, E_{2nd} [GWh]	2.75	8.25	22.5	41.3	82.5	165	412.5	825
maximum power from 2nd-life batteries, P_{2nd} [GW]	3.0	9.0	24.5	45	90	180	450	900
primary reserve (PR) need in UCTE zone, P_{PRmax} [GW]	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
maximum duration of primary reserve provision per request [hrs]	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
maximum energy per PR request, E_{PRmax} [GWh]	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
minimum average SOC for serving a request for positive PR	50%	18%	7%	4%	1.8%	0.9%	0.4%	0.2%
maximum average SOC for serving a request for negative PR	50%	82%	93%	96%	98.2%	99.1%	99.6%	99.8%

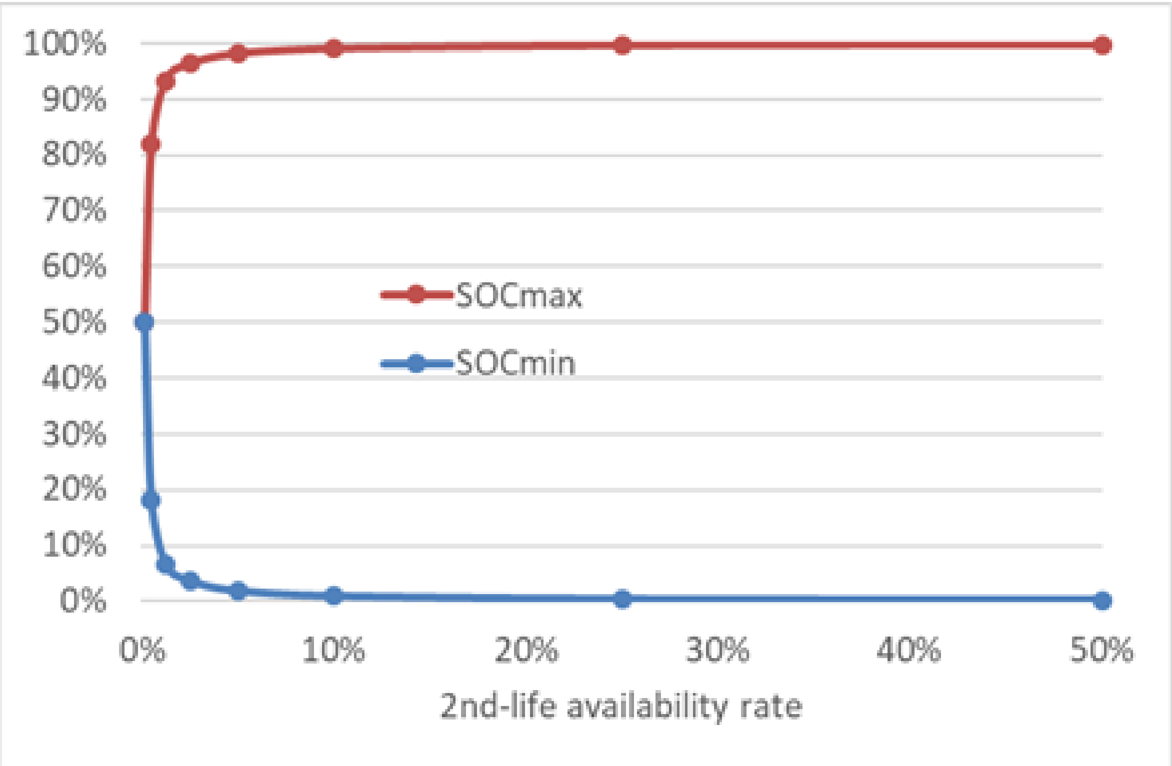

Figure 42: Range of average SOC required for PR vs 2nd-life availability rate

The results show that from a 2nd-life availability rate of 0.17 % on the maximum power of ± 3,000 MW (3 GW) which might be requested in the UCTE zone can be provided. However, the energy which can be stored in the batteries is insufficient to provide the maximum PR if the request is for 30 minutes. This is expressed by $SOC_{min} = SOC_{max}$ = 50 %.

If the 2nd-life availability rate is increased to 0.5 %, the then available 2nd-life batteries can provide almost for sure PR at any moment. This is because it is very likely that the 2nd-life batteries are on the average in a SOC between 18 % and 82 % at any moment. A request for PR will shift the average SOC, but assuming that the minimum time between two successive requests is at least two hours, the average SOC will be very likely back in the required range.

If the 2nd-life availability rate is increased further, the range of SOC within which the batteries must be on the average for being able to provide the maximum PR, approaches very quickly the full range between 0 % and 100 %.

From this result, it can be deduced:

- Even at a very tiny 2nd-life availability rate, ELSA-type ESS from EU vehicles can provide the maximum PR needed presently in the UCTE zone.
- From a very small 2nd-life availability rate of a few percent on, they can provide the maximum PR in parallel to other ESS applications if the provision of PR gets priority over these other applications. This might also make sense for the operator if because PR provision might provide a higher income than savings obtained by electricity purchase optimisation or higher rate of PV self-consumption.
- Very likely, ELSA-type ESS can provide the maximum PR in parallel to other applications even at a low 2nd-life availability rate if PR does not always get priority, because it is very rare that PR is requested for 30 minutes. Secondary response should already be fully available after 5 minutes and tertiary response after 15 minutes (see 5.1.1 for details).

3.4.4 Technical potential for short-term storage

Beyond the provision of operative reserve - that is enhanced frequency response from the sub-second range up to 30 seconds, primary reserve in the range between 30 seconds and 30 minutes, followed by secondary and minute reserve up to 1 hour – ELSA-type ESS can also be used for balancing electricity generation and demand in the overall electricity system at time-scales between 1 hour and a few days. When the balance between generation and demand in the grid as a whole exists, single grid lines might run into overload and short-term storage can be used to redirect the power flow from overload to less loaded grid lines, thus avoiding re-dispatch of power plants. The need for short-term storage increases when fluctuating renewable power generation takes on a larger part of the generation mix, long before long-term storage is required (see chap. 3.3).

The technical potential for short-term storage has been assessed by putting the total available 2nd-life battery energy storage capacity and power into relation with relevant figures in different contexts of application where flexibility is required that can be met by short-term storage. This has been done for different combinations of the vehicle stock electrification rate and the 2nd-life use rate.

The following contexts of application have been considered:

- **Use of 2nd-life batteries to provide short-term storage for up to one hour in an energy system which is increasingly characterised by fluctuating renewable electricity generation, but still at a low level (e.g. below 50 %)**
  For this, the fraction of the average power, respectively, peak power in the EU that can be provided for one hour by the available 2nd-life batteries has been calculated.
- **Use of 2nd-life batteries to provide short-term storage for up to one hour in an energy system which is dominated by fluctuating renewable electricity generation (above 50 %)**
  For this, the maximum time for which all available ELSA-type 2nd-life batteries can jointly provide the average power, respectively, peak power in the EU has been calculated.
- **Use of 2nd-life batteries in a 100 % renewable European electricity system**
  For this, the total 2nd-life battery capacity in terms of energy has been put into relation with the battery capacity needed for 100 % EE supply according to a most recently investigated European 100 % EE-scenario, (The role of storage technologies for the transition to a 100% renewable energy system in Europe, 2018) (see 3.3.6.4). According to this work, 3,320 GWh of batteries are needed for an optimum 100 % EE-supply of the EU + Norway + Island + Switzerland + Balkan Countries + Ukraine + Turkey.

The EU's average gross power demand excluding electric vehicles has been calculated by dividing the EU's annual electricity generation of 2,786 TWh in 2016[17] by 8,784 hrs. Official statistical figures for the EU's peak power demand could not be found. For the purpose of extrapolation, the peak power demand of Germany, amounting to 81 GW[18], and of France,

[17] (EUROSTAT), Supply, transformation and consumption of electricity - annual data [nrg_105a]

[18] https://www.bundesregierung.de/Content/DE/Lexikon/EnergieLexikon/S/2013-09-25-spitzenlast.html [retrieved on 18 July 2018]

amounting to 102 GW[19], were put in relation to the respective annual electricity demand according to (EUROSTAT). Assuming that the relation between the peak power demand and the annual electricity demand for the EU is in between the relations of Germany and France, the EU's peak power demand was estimated at 550 GW.

In order to take the additional consumption of electric vehicles into account, the following assumptions have been made:

- On the average an electric vehicle consumes 1,960 kWh per year. I.E. it might be driven 14,000 km per year and have a specific consumption of 14 kWh/100 km. Note, that this is an assumption on the average of a mix of electric and hybrid vehicles such that on the average each vehicle provides an ELSA-type battery at the end of 10 yrs use of the battery in the vehicle.
- The increase of the average power equals the increase of the annual energy consumption divided by 8,784 hrs,
- The ratio between peak and average power remains unchanged.

The results are shown in Table 9 and the figures below.

- The curves are slightly bent down. This reflects the increase of the overall electricity demand with increasing number of electric vehicles.
- Even at a relatively low availability rate, ELSA-type ESS can meet a significant fraction of the EU's average / peak power demand for 1 hour.
- At an 2nd-life availability rate of 20 % the entire EU's average power demand can be met for one hour.
- At a 2nd-life availability rate of 40 % the entire EU's peak power demand can be met for one hour.
- At higher availability rate ELSA-type ESS can provide a significant contribution to covering the EU's short-term storage demand. In the extreme case even 50 % of the battery storage needed in a 100 %-EE energy system can be met. Hence, there is a perfect synergy between vehicle stock electrification and energy transition if vehicle batteries get a 2nd life in stationary grid-connected applications.

19 https://www.lesechos.fr/02/04/2013/LesEchos/21408-089-ECH_electricite---pas-de-pic-historique-malgre-un-hiver-long-et-rigoureux.htm [retrieved on 18 July 2018]

Table 9: Potential of 2nd-life batteries to provide short-term storage in the EU

total number of vehicles, $N_{vehicles}$ (millions)	300	300	300	300	300	300	300	300
vehicle stock electrification rate, r_{el}	0.33%	1.0%	2.0%	5.0%	10%	20%	50%	100%
reuse rate of vehicle batteries, r_{reuse}	50%	50%	50%	50%	50%	50%	50%	50%
2nd-life availability rate, a_{2nd}	0.2%	0.5%	1.0%	2.5%	5%	10%	25%	50%
life-time in vehicle, t_{1st} [yrs]	10	10	10	10	10	10	10	10
use time of 2nd-life batteries, t_{2nd} [yrs]	5	5	5	5	5	5	5	5
available 2nd-life batteries, N_{2nd} (millions)	0.25	0.75	1.5	3.75	7.5	15	37.5	75
usable capacity of single 2nd-life battery, e_{2nd} [kWh]	11	11	11	11	11	11	11	11
total available 2nd-life battery nominal capacity, E_{2nd} [GWh]	2.75	8.25	16.5	41.25	82.5	165	412.5	825
maximum power from 2nd-life batteries, P_{2nd} [GW]	3.0	9.0	18.0	45	90	180	450	900
EU annual electricity generation [TWh]	2,788	2,792	2,798	2,815	2,845	2,904	3,080	3,374
EU average gross power demand [GW]	317	318	319	321	324	331	351	384
EU peak power demand [GW]	551	551	553	556	562	574	608	666
fraction of average power that can be supplied for 1 hr	0.9%	2.6%	5.2%	13%	25%	50%	118%	215%
fraction of peak power that can be supplied for 1 hr	0.5%	1.5%	3.0%	7.4%	15%	29%	68%	124%
maximum time average power demand can be met [hrs]	0.0	0.0	0.1	0.1	0.3	0.5	1.2	2.1
maximum time peak power demand can be met [hrs]	0.0	0.0	0.0	0.1	0.1	0.3	0.7	1.2
coverage of battery storage required for 100% EE supply	0.1%	0.2%	0.5%	1.2%	2.5%	5.0%	12%	25%

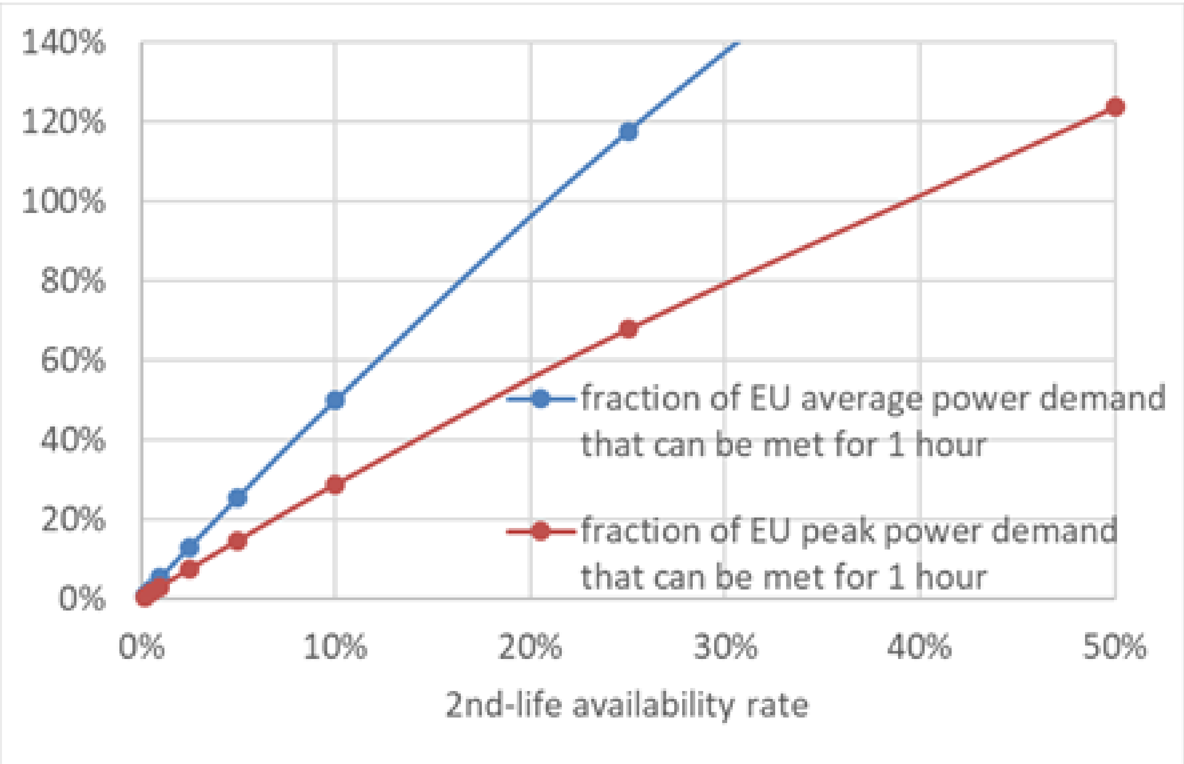

Figure 43: Potential of ELSA-type ESS to meet EU average / peak power demand for 1 hour

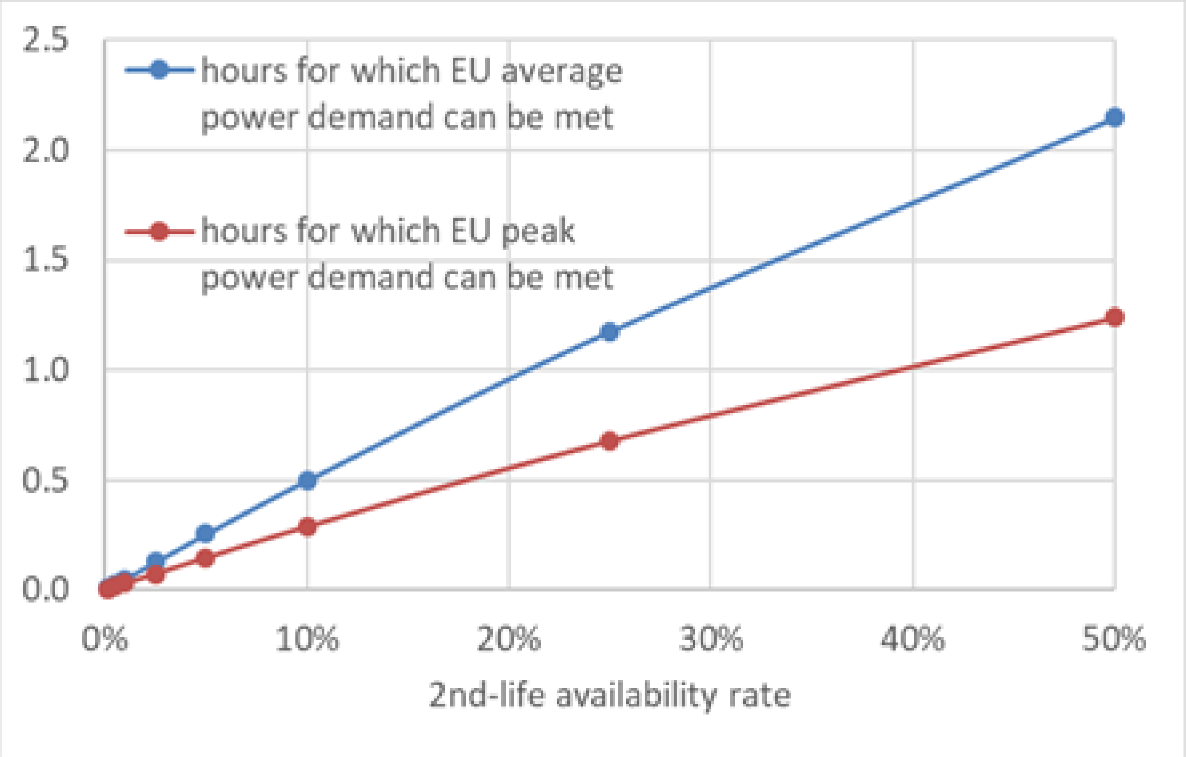

Figure 44: Number of hours for which the EU average / peak power demand can be met

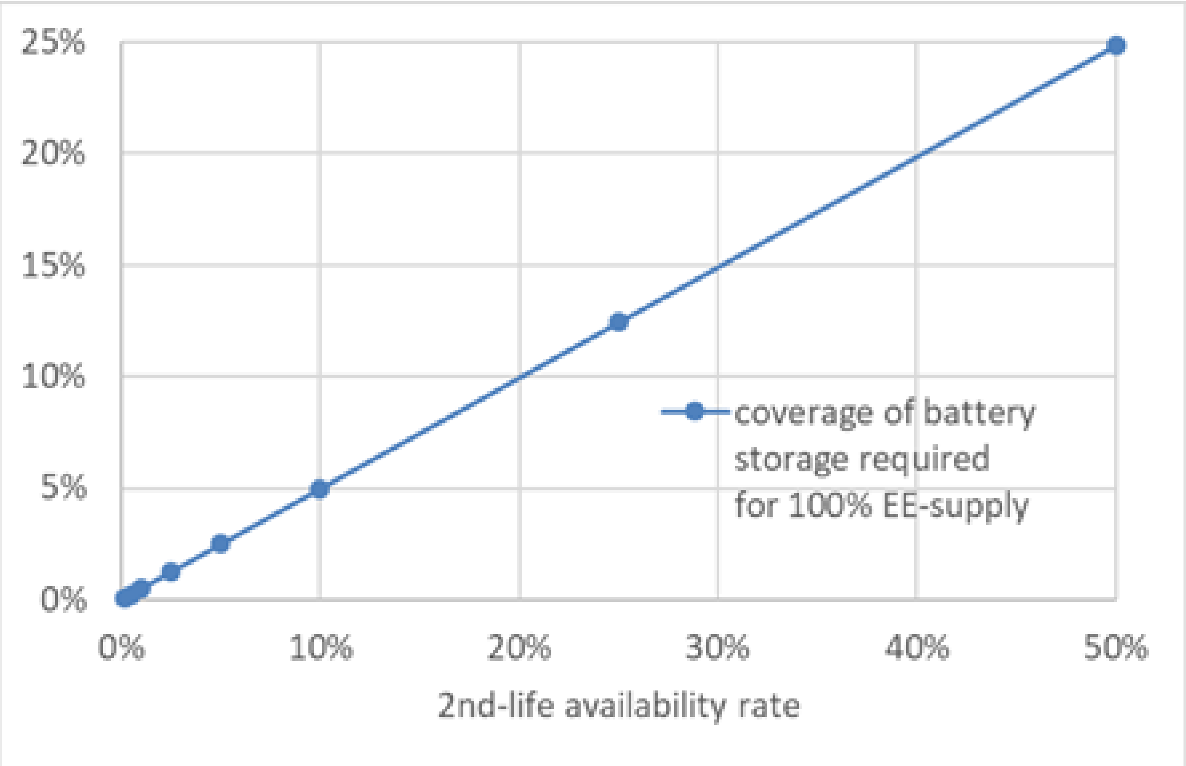

Figure 45: Coverage of battery storage required for 100 % EE-supply in EU + neighbouring countries as a function of 2nd-life availability rate

3.4.5 Conclusions on technical potential of 2nd-life batteries

The main findings as regards the technical potential of ELSA-type batteries are:

- The potential of ELSA-type batteries is comparable with the present pumped hydro power potential even at modest vehicle stock electrification and battery reuse rates. At the upper end, the ELSA-type battery capacity is much larger than the present pumped hydro capacity, notably in terms of power.
- Contrary to pumped hydro power plants, ELSA-type batteries can be installed much faster and more easily and much closer to the site where storage capacity is needed than pumped hydro power plants.
- ELSA-type batteries have a response time below one second and thus much below that of pumped hydro power plants (a few minutes). This makes them suitable for applications which require very fast response such as enhanced frequency response and primary reserve provision.
- Even a relatively low availability of ELSA-type batteries can provide a significant fraction of the EU's average / peak power demand for 1 hour.
- A medium availability of ELSA-type 2nd-life batteries can meet the EU's average / peak power demand for a few hours.
- If the entire vehicle stock is electrified and 50 % of the vehicle batteries are used for a 2nd-life application connected to the grid, 2nd-life batteries can provide about 45 % of the short-term storage, respectively 50 % of the battery storage, required for an optimised 100 % renewable electricity supply of the EU + Norway + Island + Switzerland + Balkan Countries + Ukraine + Turkey.
- There is a perfect synergy between vehicle stock electrification and energy transition if vehicle batteries get a 2nd life in stationary grid-connected applications.

4 Framework

4.1 Available flexibility options

Short innovation cycles, deregulation of market sectors and a high economic integration have made the markets more dynamic, more competitive and especially more complex. Strategies, organisations and products are subject to constant pressure for change. In this context, the threat of substitutes is a relevant factor for the assessment of the economic impact. Most relevant substitutes are products/services which provide the same function for the equal or better price/performance ratio. Therefore, chapter 4.1 provides an overview of the main available flexibility options which are competing directly with each other.

4.1.1 Generation management

Responsible Partner: B.A.U.M. Consult

Generation management is the common practice to deal with fluctuating electricity demand. Grid operators are entitled and obliged to eliminate risks for the electricity supply system by default measures. The generation management is one of these system security measures in the electricity grid.

Depending on the technology, generation management can be more or less easily implemented. In the conventional electricity supply system, generation management is cascaded and a distinction is made between continuously running plants (base load plants), plants more or less continuously running for several hours (medium load plants) and plants whose power output can be quickly changed within a few minutes (peak load plants). Below the scale of a few minutes, generation management is complemented by short-term storage in the conventional electricity supply system at the time-scale of seconds, and below by the spinning reserve of large power plants, i.e. the rotational energy stored in the large rotating masses of large electrical generators. (Stöhr, 2013)

Grid operators use also energy management systems to monitor power grid operating conditions and control grids in a reliable, secure and economical way. Usually, grid operators use a SCADA (supervisory control and data acquisition) system. The SCADA system transmits thousands of measurements at critical points of a power system in real time to the energy management system and command signals from the energy management system to field devices to take control actions. (NREL, 2014) Within the conventional electricity supply system, essentially the transmission grid is monitored while information about the status of the distribution grids is widely lacking.

Renewable energy generation whose share is rising within the European grid differs from conventional generation in terms of dispatchability, variability, and the point of feed-in into the grid. Contrarily to conventional power plants, renewables are generally connected to the distribution grid whose status has only little been monitored so far. For this reason, monitoring and energy management systems are sorely needed at the distribution grid level. The systems enable an effective generation management on medium and low voltage grid level. Besides storage and demand-side response, generation management is a feasible flexibility option which offers an effective way to match generation and demand.

The exact amount of data needed for sound distribution grid management in case of a high share of decentralized generation is still subject to research. Preliminary results in EU FP7 and H2020 projects allow to assume that full data sets of the most important generation units and consumers are sufficient for effectively managing a distribution grid section with a high rate of fluctuating renewable power generation.[20]

4.1.2 Demand response

Responsible Partner: RWTH Aachen University

Among the various flexibility options demand-side response concepts are a promising solution. The Expert Group 3 of the Smart Grid Task Force (Smart Grid Task Force, 2015) gives regulatory recommendations for the deployment of flexibility, in particular focusing on the consumer engagement and the demand side participation. In general, also within the ELSA project, a network user might provide flexibility as an individual service to the energy system. In response to an external signal the user might change its generation or consumption patterns. Such an incentive signal can be a specific value of the energy price for example. (Smart Grid Task Force, 2015) designate several benefits that can be achieved by usage of flexibility of industrial, commercial and residential consumers respectively distributed generation.

A portfolio balancing on system level as well as an efficient cost management for system operators, a portfolio optimization for energy supplier or an improvement for network operators by avoiding reinforcement or delay within their network are a few examples where the availability of flexibility for Demand Response will be beneficial on system level.

In this sense, this deliverable defines Demand Side Flexibility based upon the definition in (Smart Grid Task Force, 2015). As response on market signals the end-use customer, which can include both residential and commercial customers, do a change in their energy usage from their planned respectively current consumption. Such market signals might be variable energy prices in time or any incentive payments. Further, the usage of Demand Side Flexibil-

[20] Discussions of M. Stöhr with several representatives of respective FP7 and H2020 projects during poster session at InnoGrid2020+, 27-28 June 2016, Brussels

ity might also be to sell of demand reduction or increase based upon a certain price in organized energy markets. This is possible both alone and within an aggregated scenario. The concept of Demand Side Response is very close. The above mentioned market singles or incentive payments serve as incentives for the end-consumers/producer or even at storage level to voluntary change their planned energy, i.e. electricity, gas or heat flow. (Smart Grid Task Force, 2015)

In recent research literature DR concepts including battery systems are introduced. Authors in (N. Siebert, 2015) describe, based upon the ReFlexE project, how a smart electric battery scheduling solution provides flexibility for DR. Within 8 real-life field trial implementations aggregated commercial and industrial locations that were connected to an energy storage system including a management system could provide a significant amount of flexibility for an aggregator´s portfolio.

Looking into the DR potential within the European Union Level, the authors in (J. Torriti) did quantification for the UCTE countries, where 5 of 6 ELSA field trials are located in. Although the research is from 2009, the quantified amount of DR in those countries was already promising. A rather recent study on the DR potential in Europe in given in (Smart Energy Demand Coalition, 2013). The balancing market is seen as the key domain for DR services. The work is looking mainly in primary, secondary and tertiary balancing power markets. That fits to DR being one option for ancillary services.

Further, for Germany (Deutsche Energie-Agentur GmbH, 2010) defines the potential for increasing flexibility in the electricity system and gives in particular focus on DSM potential use cases. In total around 2 % of the negative balancing energy and approximately 60 % of the demand for positive balancing energy will be covered by DSM in the year 2020 according to the model defined in (Deutsche Energie-Agentur GmbH, 2010).

4.1.3 Storage

Responsible Partner: B.A.U.M. Consult

An energy storage unit can be defined as an energy system, consisting of 3 processes – charging, storing and discharging (Sterner, 2016). Furthermore, the central purpose of a storage unit is to match energy generation and demand in place and time. Basically, energy storages can be divided in four categories (Stöhr, 2013):

- Stores for solid, liquid or gaseous energy carriers such as biomass, biofuel, or bio-methane at the first stages of the energy conversion chain;
- Stores converting electrical energy in another form of energy and back into electrical energy (batteries, hydrogen, flywheels, pump storage, compressed air storage) which might be connected to the electric grid or not;

- Stores for thermal energy converting heat into chemical energy and back into heat (phase change materials, zeolite, etc.);
- Stores for energy in the form in which it will be used, i.e. at the end of the energy conversion chain. This indudes electricity stored in capacitors and inductors, e.g. superconducting coils; heat stored in hot water tanks, district heating grid lines, etc.; cold stored in cold storages, freezing warehouses, liquefied gases, etc.; mechanical energy, e.g. in compressed air for industrial processes; and last but not least any kind of industrial intermediary or final product.

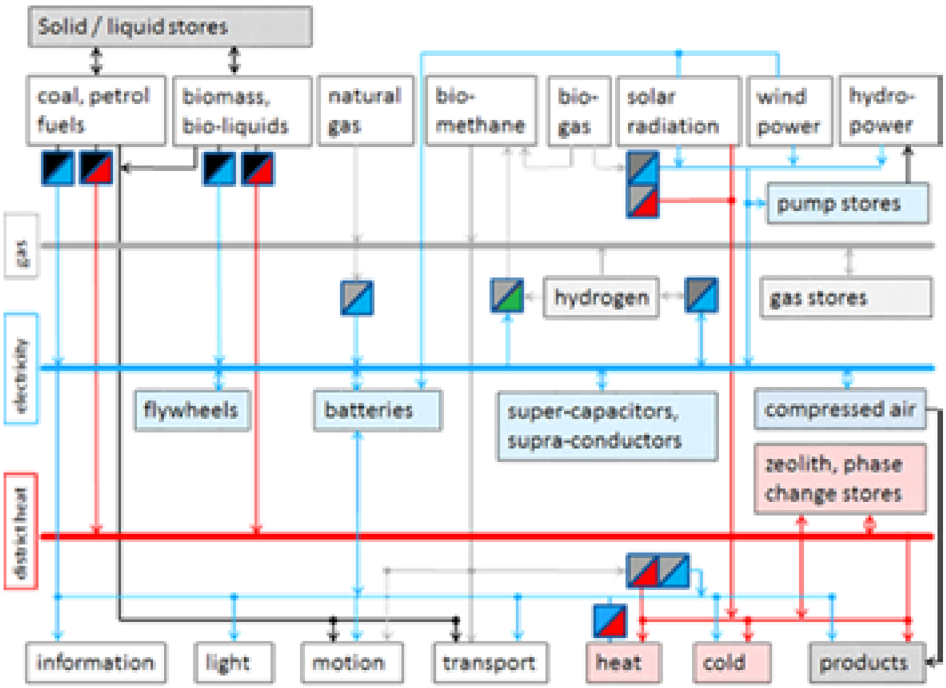

Figure 46: Energy pathways with energy storage, Source: (Stöhr, 2013)

The whole picture of storage options and their interdependence with energy generation and use is quite complex. An overview of the most important interdependencies is given in the figure shown above. The diagram distinguishes notably (1) gas (natural gas, bio-methane, hydrogen and mixtures of these gases whose physical and chemical properties are within the limits defined by the norms for natural gas, thus allowing distributing them via the existing natural gas grid; shown in grey colour), (2) electricity (blue), and (3) heat (red). Conversion facilities that convert energy between these forms are indicated by diagonally divided two-coloured squares. Further, solid and liquid fuels, water and products - all of them also a kind of an energy store - are shown (black) (Stöhr, 2013).

4.2 Grid topology

4.2.1 Germany

Responsible Partner: RWTH Aachen University

The following section gives a short introduction about different grid levels respectively typologies and their characteristics. The electrical energy is transported within the high voltage level of 220 kV -/ 380 kV- in the transport energy system to the lower distribution systems and end-users. Within substations the energy is transformed to a voltage level of 110 kV and distributed into several 110 kV networks. The high voltage is transformed, depending on the load density within the network into the medium voltage of 10 kV / 20 kV / 30 kV. From this point the energy flow is oriented towards the local network station located in the streets of residential or industrial areas. Within the local network stations, the medium voltage is transformed to the low voltage level of 400 V and distributed to the households either via overhead lines or cable. Intensive power consumers are usually directly connected to the HV, or MV and do the distribution within their own substation. The LV and MV level are usually clear distribution networks, whereby the HV networks are mainly installed for the sake of energy transport. (Aufnahmefähigkeit von Niederspannungsverteilnetzen für die Einspeisung aus Photovoltaikanlagen, 2011)

In general, we distinguish between radial, ring and meshed distribution networks. Depending on the geography of the landscape, integrated buildings etc. these typologies can diversify in detail. A simple overview of the different typologies is given in Figure 47.

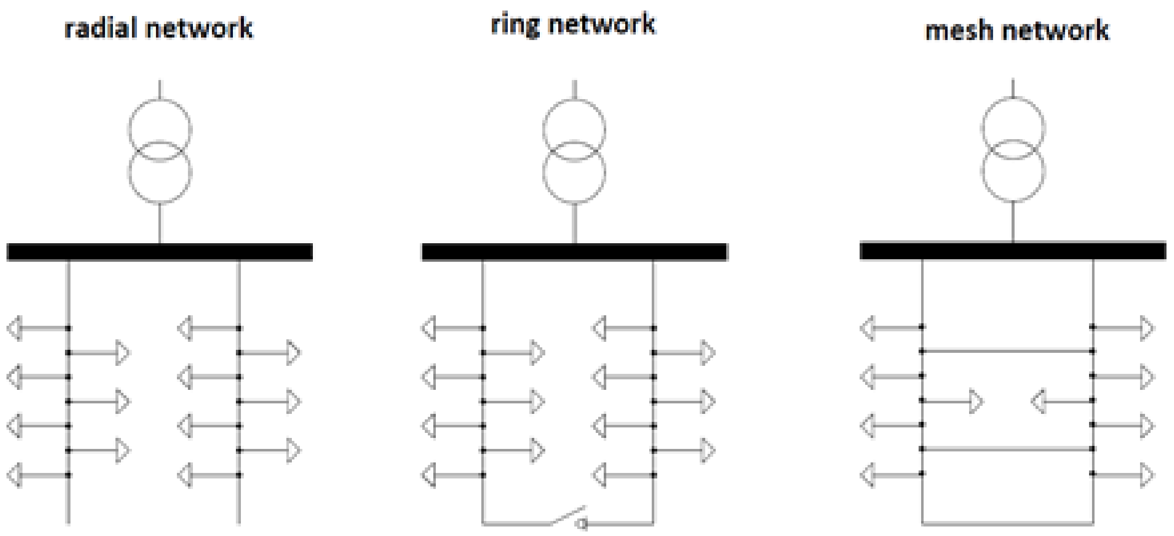

Figure 47: Overview of different network typologies based upon, Source: (Aufnahmefähigkeit von Niederspannungsverteilnetzen für die Einspeisung aus Photovoltaikanlagen, 2011)

However, in the following lines main advantages and disadvantages of such typologies are explained. (Schwab, 2009)

Radial Distribution (feeder)

Within a radial distribution grid the feeders are installed as branches from the main supply point which usually would be the transformer. Main advantages are less planning effort, better overview for failure detection and less accounting for grid protection. However, the voltage drops are increasing towards the end of the feeder and the line losses are higher compared to other typologies. Also the grounding requirements are more difficult to follow. Radial networks are usually used within LV networks of public supply networks. (Schwab, 2009)

Ring distribution networks

Ring distribution networks are the connection of two feeders, which leads to a half-open ring structure. Consequently, this typology allows the supply from both sides in case of a closed ring. The typology compensates some of the disadvantages of pure radial networks. Main advantages are a higher service security and, in case of closed rings, a better voltage stability together with less losses. However, the effort for maintenance personnel is higher than in radial networks. Ring distribution networks are mainly installed in LV street networks, and further MV and 110kV networks which themselves cover other substations. (Schwab, 2009)

Meshed distribution networks

Meshed networks use the introduced both side supply concept of ring networks. All nodes and lines are supplied in multiple ways so that this network typology leads to the highest service security. So in case of a meshed distribution network that contains multiple supply transformers, this typology leads to the optimal service security, best voltage stability and minimal losses. However, the investment costs of such typology, the effort for personnel and high short circuit currents are main disadvantages. So, to conclude with an increasing load density the following typologies are usually used within the following order: radial networks, ring networks and single- or multiple supplied and single- or multiple feeder meshed networks. The decision is part of a complex planning and expansion process. (Schwab, 2009)

For more information, we refer to (Aufnahmefähigkeit von Niederspannungsverteilnetzen für die Einspeisung aus Photovoltaikanlagen, 2011) and (Schwab, 2009).

The extensive grow of distributed generation in LV and MV networks, such as through photovoltaic (PV) units or wind turbines, and also an increasing amount of distributed loads, such as heat pumps or electric vehicles are major challenges for the existing grid infrastructure. Whereas in the past the system was purely demand driven in a unidirectional manner, the system more and more turns into a generation driven system. In other words, the demand needs to be coordinated towards the generation since renewable generation is non-flexible. The network is faced with bidirectional energy flows caused for example by PV units or micro combined heat and power plants.

In the course of the cost pressure caused through the electricity market liberalization in Germany, the trend goes to larger meshes instead of multiple smaller ones with the main objective of reducing costs.

The Dena 2 Net study (Deutsche Energie-Agentur GmbH, 2010) prognosticates the workload of the grid in Germany for 2020. As a result, about 70% of all borders between neighboring regions list significant power that is not transferable. For these reason, different solution possibilities are presented and analyzed.

The study shows three different variants for integration of nontransferable power. The first variant analyses integration by grid expansion (variant 000), the second storing of 50 % of the regional power that cannot be transmitted without extending the grid (variant 050) and the last storing of 100 % of the regional power that cannot be transmitted without extending the grid (variant 100). In addition to that, these key variants each were linked with three distinct versions of the assumption of the overhead line carrying capacity. In detail, the first variant represents the basic grid with the standard transmission capability (BAS), the second usage of overhead line temperature monitoring (FLM) and the last usage of high temperature conductors. (Deutsche Energie-Agentur GmbH, 2010)

Furthermore, the study analyzes possible technologies of power transmission that can be installed to realize the variants mentioned before. The following technologies are taken into account: conventional 380 kV and 800 kV three-phase current overhead line, 380 kW three-phase current underground cable, high voltage direct current transmission (both overhead line and underground cable) and gas-insulated conductor. The study achieves the result that overhead lines are more suitable. For a lower transmission capacity (1,000 MW) and a shorter length of transmission route (100 km) the conventional 380 kV three-phase current overhead line performs best in terms of available technical properties, economical effectiveness, environmental effects, system reaction and system compatibility. Additionally, for a high transmission capacity (over 4,000 MW) and a high length of transmission route (over 400 km) the advantages of the high voltage direct current transmission predominate. Concerning other point-to-point transmission tasks with transmission capacities between

1,000 MW and 4,000 MW and transmission routes from 100 km up to 400 km all technologies often proved virtually equal. (Deutsche Energie-Agentur GmbH, 2010)

Following this, the study surveys in addition to the nine already mentioned variants some sensitivity variations with the aid of alternative transmission technology. The first variation (VSC 1) analyzes a meshed direct current voltage overlay network, based on self-guided VSC-HVDC technology and underground cables. As a result, there is a need of addition to the transmission route of 3400 km and costs of 1,994 billion € a year. In contrast, if the direct current voltage transmission route is based on point to point connections (VSC 2) instead of a mashed grid, the costs will raise to 2,715 billion € a year.

The last variation analyzes a hybrid solution with an overly transmission route with high power (4,400 MV) and a length of 824 km starting in Schleswig-Holstein and ending in Baden-Württemberg to transport the main transmission load from north to south. In this case, the resulting need of addition to the additional transmission route is 3,100 km and the costs are 1,297 billion € a year. (Deutsche Energie-Agentur GmbH, 2010)

Furthermore, the AGORA Energiewende study (Agora Energiewende) analyzes the need of energy storages devices in the energy turnaround regarding the generation balance, system services and distribution grid. The study considers a renewable energy portion between 40 % and 60 % for the next 10 to 20 years. According to this, it results that power plants, demand management and electricity trading with countries abroad can provide the flexibility for the balance between demand and supply and are additionally more cost-effective. In contrast to the medium-high voltage grid, energy storage devices can optimize the cost in low voltage grids. Moreover, combined with solar panels it is possible to optimize the private consumption and thereby unload the distribution grid. This usage can be implemented without any investments in communication technology by suitable parameterization and dimensioning. (Agora Energiewende)

Variant	Need of addition to transmission route	To be modified transmission route	Costs
BAS 000	3,600 km	0 km	0,946 billion €/year
FLM 000	3,500 km	3,100 km	0,985 billion €/year
TAL 000	1,700 km	5,700 km	1,617 billion €/year

Table 10: Overview about the grid expansion for the three analyzed variants relating to the load ability of the overhead lines without storages based upon; Source: (dena, 2010)

4.2.2 France

Responsible Partner: Bouygues

Two operators manage the infrastructure of the French electricity grid:

- ERDF for distribution to consumers.
- RTE (Réseau de Transport d'Electricité) for long-distance electricity transmission.

ERDF:

Electricity generated by power stations is first transmitted over long distances using high and very high voltage lines (above 50 kV) managed by RTE (Réseau de Transport d'Électricité). It is then transformed into medium voltage electricity (usually 20 kV) for distribution through the ERDF distribution network. This transformation takes place in substations.

Once in the distribution network, medium voltage electricity is supplied directly to industrial customers. For other customers, (private consumers, businesses, etc.) it is converted into low voltage electricity in transmission substations before delivery.

The quality of electricity that users receive depends ultimately on the quality of the whole system through which the electricity is carried.

The figures below provide an overview of the electricity network managed by ERDF (ERDF, 2016):

- 1,3 million kilometres of lines,
- 751,000 medium voltage / low voltage transformation substations
- 232,636 production sites linked to the network
- 2,240 ERDF substations (interfaces with the transmission network managed and used by RTE)
- 35 million customers served

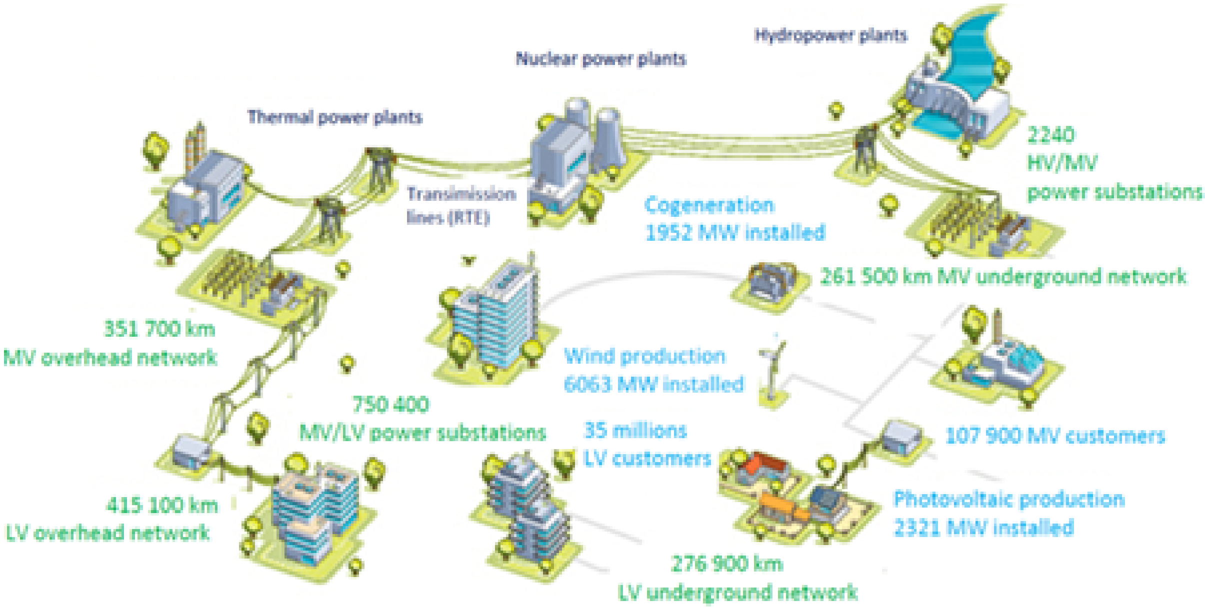

Figure 48: French electricity network overview, Source: (ERDF, 2016)

RTE:

RTE, independent subsidiary of EDF (Électricité de France), the second largest energy producer in the world, is in charge of the grid operation, maintenance and development for the electrical transmission lines above 50 kV, unless exceptional cases.

At the end of 2014, RTE was operating 105,331 km of underground and overhead lines. The following tables providing a good overview of the electricity lines, substations and power transformers in the scope of RTE.

RTE's overhead and underground lines		
	Overhead lines (km)	Ungerground lines (km)
400 kV	21 751	3
225 kV	25 653	1217
150 kV	1061	2
90 kV	16538	801
63 kV	35265	2617
≤ 45 kV	342	81
Total	**100 610**	**4 721**

Table 11: Breakdown of the underground and overhead lines, Source: (RTE, 2016)

It can be noticed that the French electricity grid is mainly composed of overhead lines although the share of overhead lines decreases whereas the share of underground lines increases.

Table 12 indicates the sites where RTE electricity substations are installed. RTE is the owner of a substation if it consists of a feeder or a bus bar owned by RTE within the substation.

RTE's Electrical Substations		
Voltage level	RTE's Substations	Total Substations
400 kV	154	186
225 kV	558	748
150 kV	27	37
90 kV	559	800
63 kV	1393	2147
45 kV	6	42
Total	**2.697**	**3.960**

Table 12: RTE electrical substations per voltage level, Source: (RTE, 2016)

The half of the RTE stations are composed of 63 kV substations. This is a common percentage share, because 63 kV is the minimum limit voltage level.

The large numbers of transformers and their cumulated installed power provide a good overview of RTE capacity to transport the energy through its network among the regions. Table 13 summarizes them per voltage level.

RTE's Power Transformers		
Primary Voltage	Number of transformers	Rated Installed Power (MVA)
400 kV	301	137322
225 kV	845	92047
150 kV	28	1419
90 kV	26	1215
63 kV	23	756
Total	**1.223**	**232.759**

Table 13: RTE power transformers per voltage level, Source: (RTE, 2016)

The existing network covers the national territory as shown in Figure 49. Some areas such as the west and southwest of France are less networked than other areas. In comparison, the border zone areas to other EU countries are cross-linked in a higher extend through several connecting points.

Figure 49: Existing grid network, Source: (RTE, 2016)

Medium-term electricity consumption evaluation

Since 2011, the electricity consumption in France is stable whereas in the last decade, there was an average yearly growth rate of 1.4 %. In September 2014, RTE has provided a medium-term electricity consumption estimation for 2020 with four scenarios.

- The reference scenario refers to a scenario with an increase of GDP growth rate of 1.5 % per year from 2016.
- The lower scenario based on a pessimistic demographic evolution and economic growth.
- The demand-side response (DSR) scenario takes into account the acceleration of DSR development.
- The upper scenario based on the one hand on an optimistic demographic evolution and economic growth and on the other hand, on a slighter energy efficiency improvement and an electricity price propitious to large electricity consumers' development.

Table 10 provides the evolution of the medium-term consumption at 2020.

Scenario	Lower scenario	EDC scenario	Reference scenario	Upper scenario
Yearly consumption (TWh)	464.7	476.3	484	498.4

Table 14: Medium-Term consumption at 2020 per scenario, Source: (RTE, 2016)

Long-term electricity consumption evaluation

The total electricity consumption in the metropolitan areas of France was 477 TWh in 2014. The future evolution of the consumption is difficult to assess, because it will depend on many and major parameters such as:

- demography,
- economic situation,
- lifestyle evolution (use of electrical vehicle, expansion of information technology, etc.),
- the application of energy efficiency regulations.

RTE has forecasted four different scenarios for 2030 with a large range uncertainty of 100 TWh.

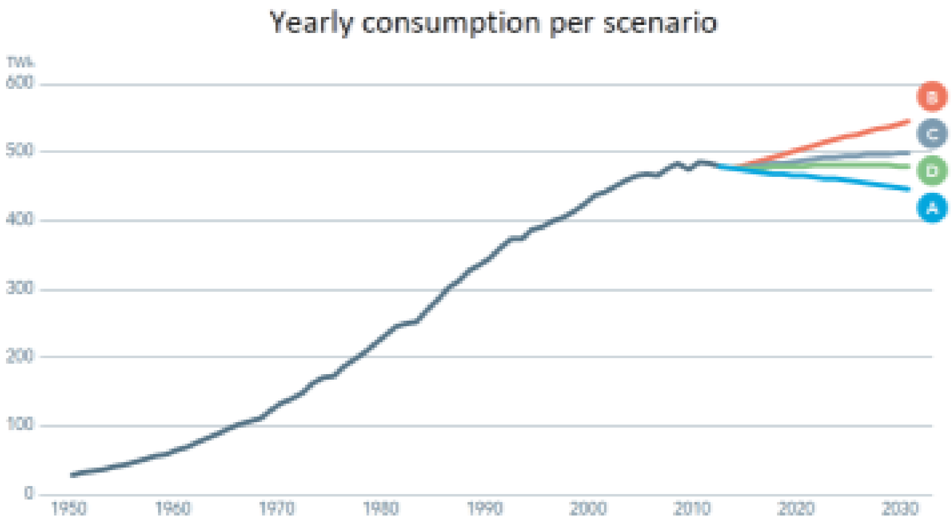

Figure 50: Consumption after 2014 following scenarios, Source: (RTE, 2016)

The scenario A represents the low economic growth scenario based on a pessimistic economic tendency and the nuclear production part still maintained in the production mix.

The scenario B represents the high consumption scenario, which forecast a transfer of the major uses from the fossil energies to the electrical sources, development of the renewable energies policy and a cap to 63.2 GW for the nuclear capacity.

The scenario C represents the diversification scenario, which takes into account the energy efficiency increases and the renewable energy expansion and lead to a power mix diversified with the nuclear part limited at 60 % in the production mix.

The scenario D represents the new mix scenario with a decrease of the consumption, a development of the renewable energies and the nuclear part limited at 50 %.

It is important to note that there are regional discrepancies in term of energy consumption based on local demography and economic dynamism (see Figure 51).

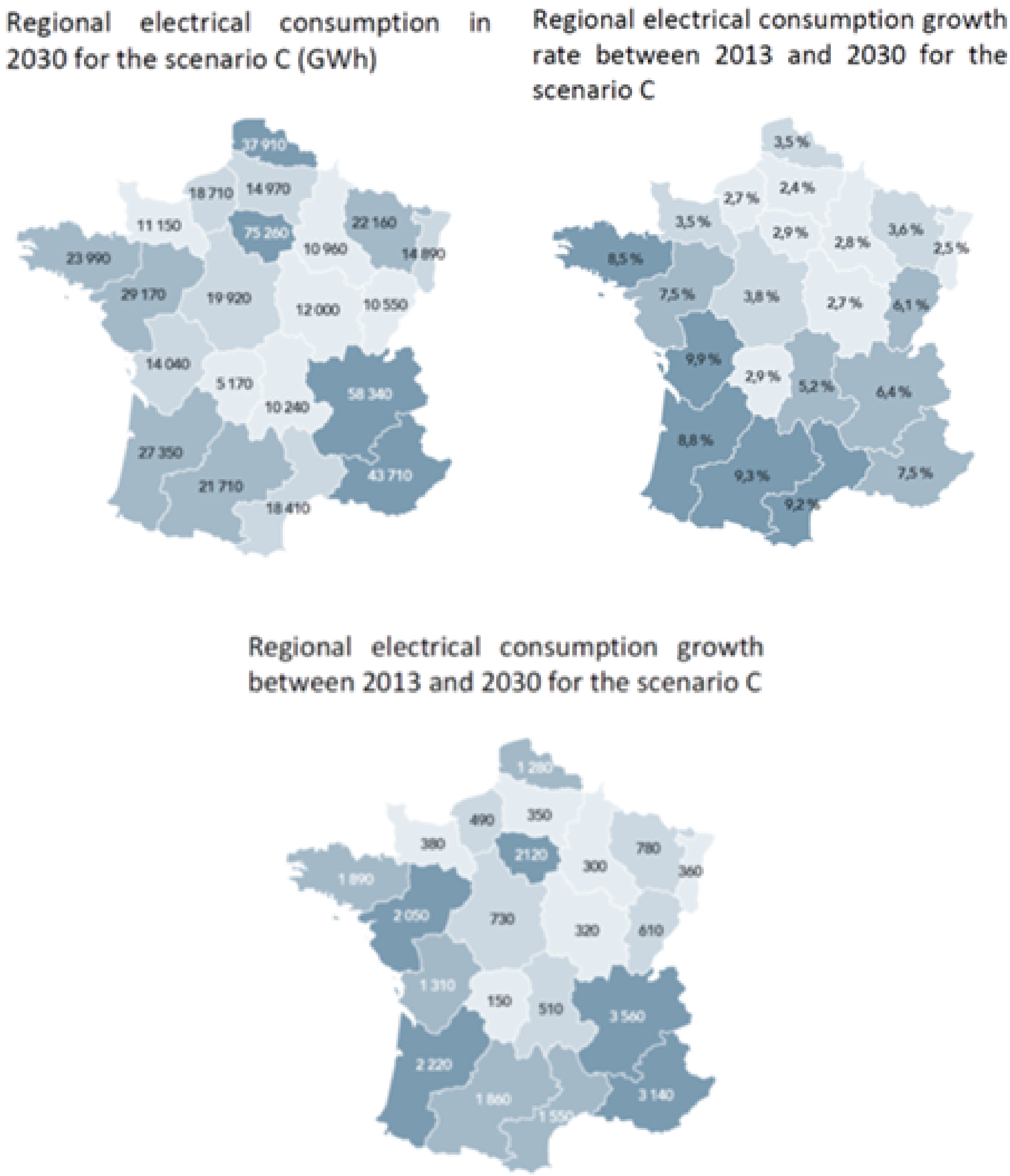

Figure 51: Consumption per region for the scenario C, Source: (RTE, 2016)

Mid-term electricity production evaluation

The development of the renewable energies increasing in the electricity production is taken into account by RTE in its ten yearly strategy.

Figure 52 show the medium-term power forecasted for wind and photovoltaic energies in 2020. The different colours represent different expansion stages for the wind and photovoltaic capacity in the respective regions.

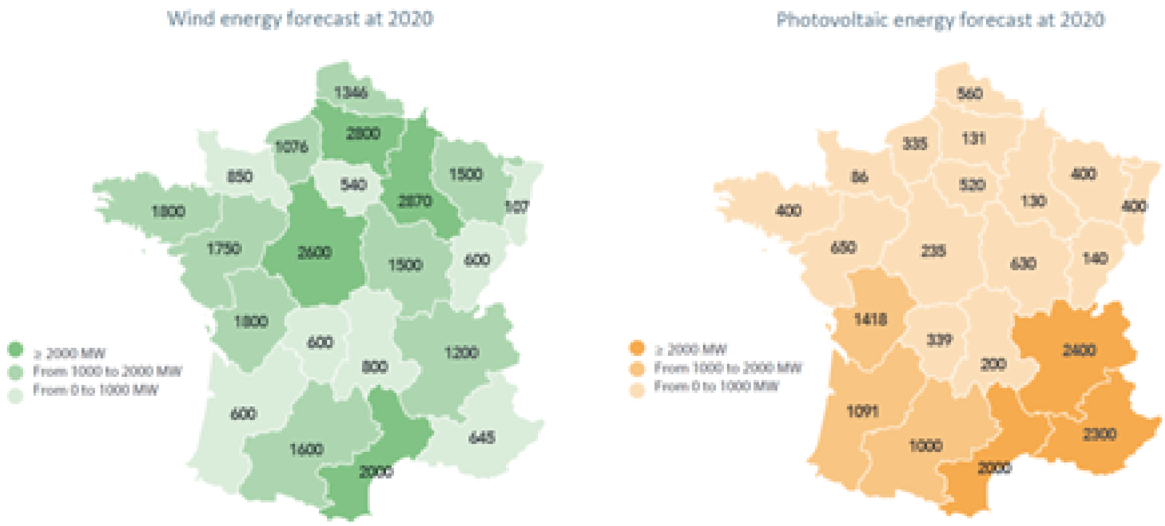

Figure 52: Wind and photovoltaic capacity objectives per region in 2020, Source: (RTE, 2016)

Even if, the renewable energies development represents a key challenge of the network development in the coming next years, the main production is still based on nuclear, hydraulic, coal and oil sources.

The nuclear part is considered stable until 2020, the coal and oil power plants will be closed from 2013 to 2020 which will represent 6 GW. The gas turbines power plants are temporary closed due to unfavourable context for its electricity price. There will be no evolution for the hydraulic part. The development of the capacity of consumption cut-off during peak periods should compensate the end of historical electricity prices by maintaining the consumption cut-off capacity at a minimum value of 3 GW.

Table 15 provides the details of the total production offer in 2020.

Total forecasted production in 2020 (GW)						
Energy	2015	2016	2017	2018	2019	2020
Nuclear	63.1	63.1	61.4/63.1*	61.4/63.1*	61.4/63.1*	63
Coal	4.2	2.9	2.9	2.9	2.9	2.9
Combined cycle gas	5.7	5.7	6.3	6.3	6.7	6.7
Oil and comubstion turbine	7	6.9	5.6	3.1	3.1	3.1
Non renewable decentralized thermal	6.5	6.5	6.5	6.5	6.5	6.5
Renewable decentralized thermal	1.1	1.3	1.3	1.4	1.4	1.4
Hydraulic	25.2	25.2	25.2	25.2	25.2	25.2
Wind	9.2	10.1	11.1	12.1	13.1	15.1
Photovoltaic	5.2	6.2	6.9	7.6	8.3	9
Consumption cut-off	3.3	3.2	3.1	3.2	3.3	3.4

*With the hypothesis of Fessenheim units stop and the FA3 EPR operating

Table 15: Production capacity estimations in 2020, Source: (RTE, 2016)

Long-term electricity production evaluation

At the moment, there are 58 nuclear reactors operated in France which represent an installed power of 61.6 GW. They have been installed during a short period from 1977 to 1999. Therefore, the forecasted operation period of these units is a key parameter of the French production evolution.

It is important to note that if an operation period of 40 years is kept, there will be 51 units out of the 58, which will be stopped until 2030. For RTE, this uncertainty has a major impact on the production forecasted by RTE.

Whatever the strategy path taken by the nuclear sector in France, RTE shall forecast the consequences in term of energy flux on the network. Yet, RTE can only at the moment forecast a total production capacity per the operating lifetime of the current nuclear power plants. The planning for nuclear power plant definitive shutdown or new power plant construction is unknown for RTE. Yet, the location of the new production units for each scenario is essential for the GRID in order to forecast its expansion.

Figure 53: Power capacity evolution until 2040 with the planned units' shutdown, Source: (RTE, 2016)

The main renewable energy comes from the hydraulic source with a yearly production of 60 TWh. There will be no forecasted improvement on the current hydraulic units in the next ten years. Regarding the other renewable energies such as photovoltaic, off-shore and on-shore wind, tidal and biomass energies, significant development is expected. Due to this increase of production, RTE is obliged to adapt its grid to the new production capacity.

Regarding the thermal power production, the shutdown of the oldest coal power plant is planned for 2016. Besides, to take into account the regulation and the power plant operating period, a production capacity decrease of about 10 GW from oil and coal power plant is expected until 2030.

Future progress of the grid

The investments to be performed during the next ten years shall create sufficient infrastructure for an additional 4 GW off-shore wind production capacity and 10 GW of interconnection capacity. These investments shall also follow the regional economic and demographic development with a safe and high quality power grid.

52 % of the investments are dedicated for the electrical stations installation or outage, the underground or undersea lines improvement represent 27 % of the investment. The overhead lines improvement and dismantling represent respectively 16 % and 5 %.

Figure 54 shows the main projects to be performed in the next decade and the long-term key issues under study.

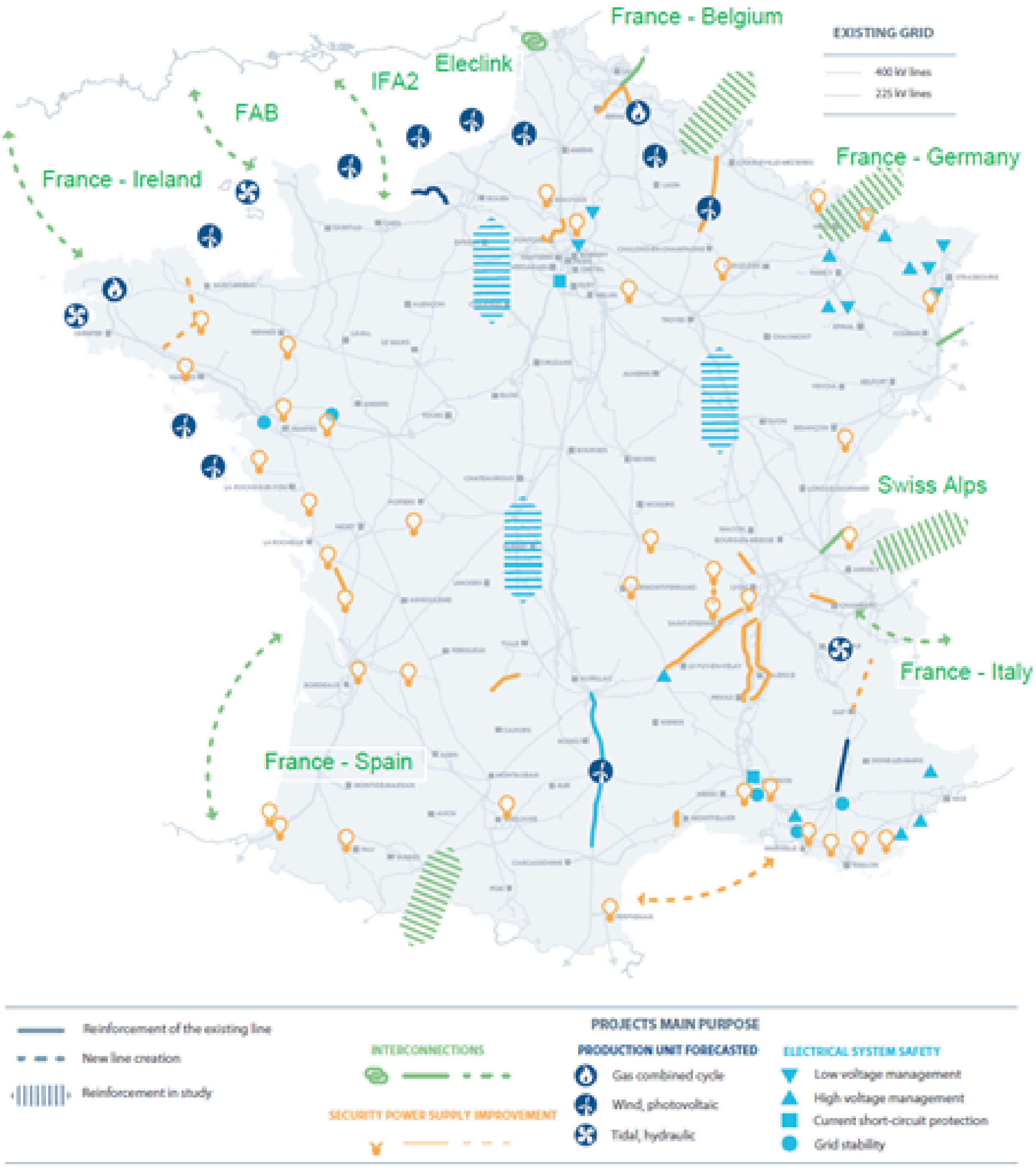

Figure 54: Energy transition key investments, Source: (RTE, 2016)

4.2.3 Italy

Responsible Partner: Engineering

Main elements and actors of Italian electricity systems

Italian grid is including a national TSO and other actors that participate to the value chain (Lucia, 2014):

- Power producers: mostly private companies, no operator can own more than 50 % of the installed power, they sell to wholesale operators or directly to the clients.
- Importers: mostly private companies, they have an interconnection capacity and they arbitrate the power flows between Italy and the neighbouring countries.
- Transmission: a national monopoly. TERNA (www.terna.it) is the national transmission system operator, operating under concession and regulated by AEEG. TERNA owns over 98 % of the transmission grid and is responsible of planning, operating and maintaining the transmission system. TERNA's major stakeholder is a public institution.
- Distribution: local monopolies – 140 DSOs operate the electricity distribution networks in Italy (49 DSOs with less than 1,000 customers) and 1 main distribution company: ENEL Distribuzione (www.enel.com) is the first national DSO, covering 86 % of Italy's electricity demand. The most important local operators are A2A (www.a2a.eu), ACEA (www.acea.it), IRIDE, DEVAL, HERA.
- Retailers: mostly private companies, they buy energy from generators and they sell it to final users.
- Regulator: Autorità per l'Energia e il Gas (AEEG): establishes and updates the base electricity tariffs, the related parameters and the reference elements, proposes schemes for the renewal and the variation of licenses, supervises the compliance to competiveness rules, acts to protect the final user (www.autoritaenergia.it).
- Electricity market manager: Gestore del Mercato Energetico (GME): manages the electricity exchange market, dispatches power plants and sets their remuneration, manages energy efficiency certificates and emission trading shares (www.gme.it).

- Operator for the "higher safeguard" customers: Acquirente Unico (AU): acts as the intermediate between the market and the household customers not willing to access the free market: buys on the wholesale market at conditions defined by the AEEG and delivers, through the local distribution companies.
- Energy services operator: Gestore dei Servizi Energetici (GSE): promotes the development of renewable energy sources and energy efficiency by granting economic incentives and supporting the policy makers. Is the head company for GME, AU and RSE (www.gse.it).
- Research operator: Ricerca sul Sistema Energetico (RSE): carries out the research activities of general interest in the frame of the Ricerca di Sistema (RdS) framework. (www.rse-web.it).
- Before the liberalization the electricity system was a virtual monopoly with a single vertically integrated national and public operator Enel.

In Italy, the installed power of photovoltaic plants in 2012 was 18,210 MW (3,470 in 2010), based on 530.000 plants; the energy contribution from PV peaked from 1,900 GWh in 2010 to 18,300 GWh in 2012. The installed power of wind plants in 2011 was 6,936 MW (5,810 in 2010), based on 800 plants; the energy contribution from wind increased steadily from 6,500 GWh in 2009, to 9,100 GWh in 2010 and to 9,800 GWh in 2011. At the moment, no specific aggregator role is officially existent.

Terna is the national TSO managing the main high voltage national transmission network (380 kV). Elements constituting the network are mainly:

- AAT Alta Altissima Tensione (very high voltage) transformers, that extract the energy from national production plants (or from border hub for imported energy);
- AAT (very high voltage) lines and AT Alta Tensione (high voltage) lines that transport the electricity;
- Transformation stations that feed-in the energy to the DSO that – via retailers – transport the energy to the end consumers (residential / commercial and industry).

The infrastructure of the TSO Terna is mainly composed by:

- More than 72,000 km of lines
- 841 transformations and dispatching stations
- 1 National control centre (CNC)
- 8 Distribution centres (CR)
- 3 Telco centres (CTI)
- 21 interconnection lines with external networks – foreign countries for import - (CTI)
- SA.PE.I. Sardegna-Penisola Italian (Sardinia-Italian Peninsula) cable the world longest submarine cable, 435 km, supporting 1,000 MW of power.

Figure 55 on page 125 provides an overview about the Italian very high voltage and high voltage network morphology. The network is completely analogical and mono-directional (from the concentred production towards the consumers); it is still including a few big nodes (many thermoelectric plants) at large chain (maglia larga). The transmission network is defined as a set of lines and electricity stations that enables the transport of electricity from the generation side (power plants) to the distribution network (and some consumers). The network is constituted by three different connected systems (sistemi magliati) each having different voltage levels (132/150, 220 and 380 kV).

Figure 55: Morphology of Italian electricity transmission network, Source: (Sauro, 2013)

National network development plans

Among its roles Terna, the national TSO, is also responsible for the implementation of the operations related to the development of the national transmission network according to the 10-years plan "Piano di Sviluppo della Rete Elettrica" (electric network development plan) which is approved each year from the Ministry of economic development. The long term plan includes the realization of new lines for about 4,600 km and 111 new transformation stations with a total transformation power improvement of 22,458 MW. Among the relevant initiatives there are 10 projects for sustainable development. The biggest rationalization programme so far done in Italy including the reduction of old network lines in the amount of 1,200 km. The latest development plan “Piano di Sviluppo della Rete Elettrica di Trasmissione Nazionale" (National transmission electric network development plan) was presented by the TSO Terna in January 31st 2012 and is covering the timeframe 2012-2021. It includes investments for more than 7 billion euro aimed to improve the effectiveness of the electricity system including the reduction of losses and CO_2 emission.

The strategic plan 2013-2017 budgeted 4.1 billion euro for new investments for development and maintenance of the electricity network with a specific focus on new technologies and new storage systems exploitation (Huffington Post, 2013); the latest are considered fundamental for the network stabilization and the optimal management of not-programmable resources such as wind turbines and PV. For storage systems, 300 million euro € are planned.

Among other projects there are some big projects distributed over the national territory with a specific attention on import-export and in particular for the southern area of Italy. In fact, this area has the main concentration of wind turbines and PV plants. The actions are classified according the following typologies:

- New long distance power lines (12 power lines including 10 AAT at 380 kV);
- New interconnections (3; 2 HVDC are connected to France and the Balkans on high voltage level);
- Realization of new transmission networks (3);
- Palermo and Naples network re-arrangement;
- Expansions (1);
- Italy-France interconnection empowering;
- New Stations (3 of which one aimed to reinforce and area with high concentration of RES, mainly wind turbine).

Other actions are aimed to reduce the bottlenecks in many critical areas determined by the introduction of RES; the bottleneck elimination will empower the RES exploitation.

More details about the "Piano di Sviluppo della Rete Elettrica" can be found in the annual development plans published by the authority, such as “Piano di sviluppo 2016” - http://www.autorita.energia.it/allegati/operatori/pds/Piano%20di%20Sviluppo%202016.pdf.

Current situation vs development plan

In June 2016, with the activation of the connection Sorgente-Rizziconi between Sicily and Calabria the latest structural bottleneck in the network was removed. There are still some reinforcements planned as part of a whole framework re-arrangement such as RES production improvement, determining main part of network instability, creating needs of new activities including the electricity connection with the main islands. After the connection with Sardinia in 2012 and Sicily in 2016 the connection with Capri island will be the next step in this ongoing process. Additional replacement of connection with Corsica, even if it is not part of national territory, is planned due to the fact that it represents an important export for Italy towards France. Moreover, there are some actions planned for South-Adriatic backbone and lines connecting Veneto and Friuli towards Slovenia.

The new development plan budgeted 6.6 billion euro for this connection measures. However, a rate of 1.5 between benefit and costs must be reached that this plan will be approved., For example, the connection Calabria-Sicily cost 700 million euro and it is estimated that this connection will save 600 million euro per year.

For islands that are quite small and very far away a specific programme called “smart island was initialised”. Giglio, Giannutri and Pantelleria islands initialised innovative projects that combine RES production and storage systems and high-tech solutions for demand management.

At last 25 new electricity lines are in the planning phase. These are new interconnections with France under Frejus tunnel and through Montenegro towards the Balkans. This new electricity lines enable a connection for RES production exchange (including hydroelectric generation) for the first time. Furthermore, analysis for a connection with Tunisia are audited. This development-plan was already inserted in the plan of Entso-E, the European networks association and includes 150 billion euro investments for about 200 projects including the mentioned development-plan. On the storage side there is not a specific plan yet. In fact, as reported in chapter 3.1.3 and 4.2.3 the storage adoption benefit is under validation with the two big pilot projects that the TSO Terna is managing. It is expected to have specific planned activities in the next national development plan, once the validation results will be more consolidated.

4.2.4 United Kingdom

Responsible Partner: United Technologies Research Center

From 1957 to 1990 the main supplier in the UK electricity industry was the Central Electricity Generating Board (CEGB). CEGB was responsible for the electricity generation only in England and Wales. Differently in Scotland the electricity generation was controlled by the South of Scotland Electricity Board and the North of Scotland Hydro-Electric Board.

In the 1990s, during the phase of the liberalization of the electricity markets, the operations of CEBG were divided in two categories and four companies

1. Generating activities
    a. PowerGen (now known as E.ON UK)
    b. National Power
    c. Nuclear Electric (then British Energy, finally EDF Energy)
2. Transmission activities
    a. National Grid

Nowadays, National Grid is the English TSO which is driving the activities in the area of demand-side response and more in general the activities related to demand side management.

Figure 56: Electricity transmission in UK; Source: (National Grid, 2016)

As one can see in Figure 56 UK has four different TSOs.

- National Grid, England and Wales;
- SP Energy Networks, South Scotland;
- Scottish and Southern Energy, North Scotland;
- Northern Ireland Electricity, North Ireland.

One of the most important activities of National Grid is to re-plan the transmission operations in presence of faults or unexpected spike in consumer demand. National Grid uses one of the following tools to communicate shortfalls to the energy market:

1. **Notice of insufficient system margin (NISM)**. This is a formal communication that lets market players know that the marginal over production is not as big as it was predicted for that particular time of the day.
2. **High risk of demand reduction (HRDR)**. This communication is used when there is no enough time to notify the market of a sudden shortfall.
3. **Demand control imminent (DCI)**. In the case the market does not react to a HRDR communication, an DCI notice is issued asking the electricity distribution companies to reduce demand across their networks. Two are the consequences.
    a. A slight reduction in the electricity voltage will solve the problem with minor impact on the final consumers.
    b. The distribution companies may need to implement controlled power cuts to final consumers if there is a severe supply disruption.

At the distribution level, the UK grid allows Distribution Network Operators (DNOs) to own and operate the distribution network, bringing electricity from transmission network to final consumers. In UK it is important to distinguish between DNOs and Suppliers: the DNOs do not sell electricity to consumers. This responsibility is owned by electricity suppliers.

In Figure 57 the DNOs in UK are shown: they are responsible for specific regions in England, Wales, Scotland and North Ireland.

Finally, the suppliers are responsible for selling the electricity to the consumers. In the UK media, the largest energy (gas and electricity) suppliers are often recognized as the Big Six Energy Suppliers: they supply energy to over 50 million consumers and over 90 of the domestic demand.

Among the Big Six, EDF Energy, E.ON UK, npower, Scottish Power and SSE sell electricity to the consumers.

In the last decade, National Grid started interesting programs for allowing consumers to participate to balancing services. Obviously not all the consumers can directly support grid services, but they are allowed to be aggregated.

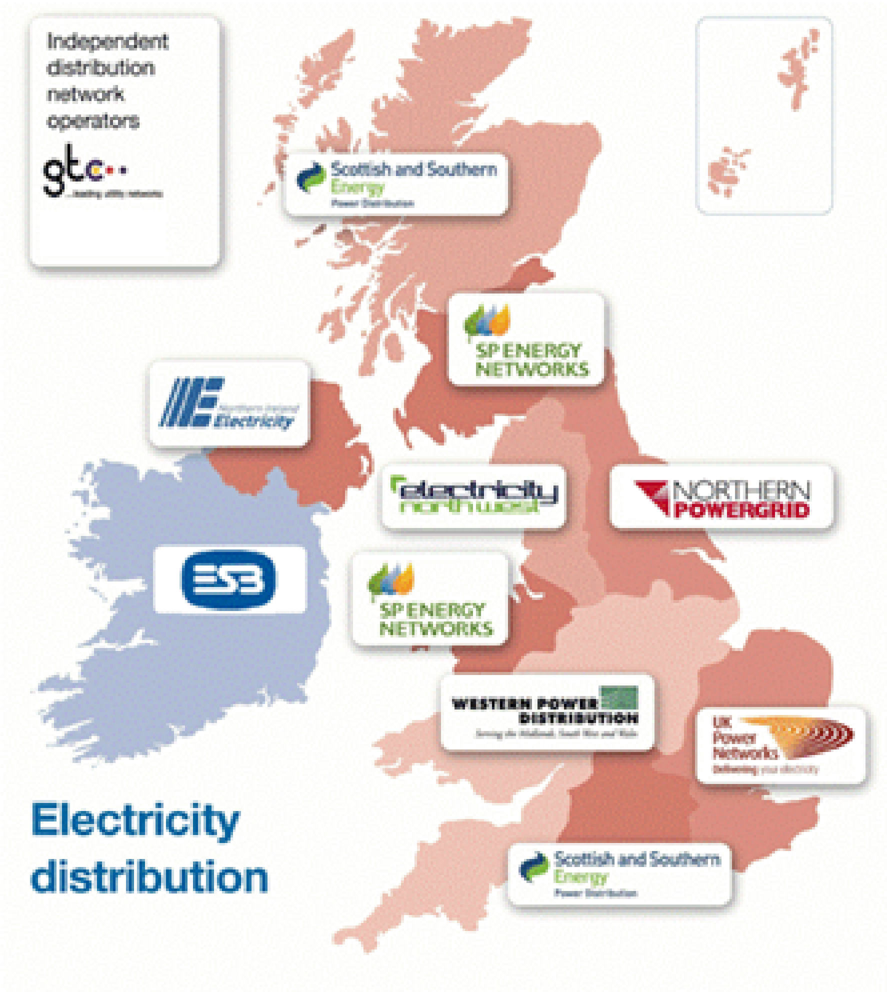

Figure 57: Electricity distribution in UK, Source: (National Grid, 2016)

The presence of aggregators in the grid allows a new opportunity for consumers. Instead of establishing a contract only with the suppliers, a consumer can establish a contract with the aggregator and hence receiving rewards for supporting the grid. The aggregators legally recognized by National Grid are shown in Figure 58.

Figure 58: Aggregators recognized by National Grid; Source: (National Grid, 2016)

Future progress and development of UK grid

National Grid in the role of TSO, together with UK Transmission Owners including Scottish Hydro Electric Transmission and Scottish Power Transmission, publishes a yearly report called Electricity Ten Year Statement (ETYS). The first ETYS was published in November 2012 (National Grid). Usually ETYS captures the important needs at transmission level, in particular system reinforcement needs. Another important report is the Future Energy Scenarios (FES) which captures all the challenges related with the future development of the overall UK grid.

Last ETYS has been published in November 2015 (National Grid, 2015) and some of the needs at transmission level are derived from the FES 2015.

In Figure 59 the Future Energy Scenarios proposed by National Grid are proposed.

First of all, one should note how the scenarios can be characterized based on two main aspects: green ambition and prosperity. The four proposed scenarios are the followings.

1. **No progression**. In this scenario the limits imposed by economic, political and social decisions result in a no progression scenario, where little innovation is introduced in the electrical grid.
2. **Slow progression**. In this scenario the social behaviours push for a more green energy scenario. On the other hand, economy and political decisions push back possible investments for improving the grid, which results in a very medium level of innovation in the energy sector.

3. **Consumer power**. In this scenario, thanks to the increase of prosperity, the economy is able to invest in high technological innovation focusing on market and consumer needs. On the other hand, social behaviours do not allow for a total green scenario since the consumers are pushed to act green, without a conscious decision.
4. **Gone green**. In this scenario, the green ambition and a prosper economy are able to push for more energy innovation, new green policies and the society is actively engaged in moving to a more green energy sector.

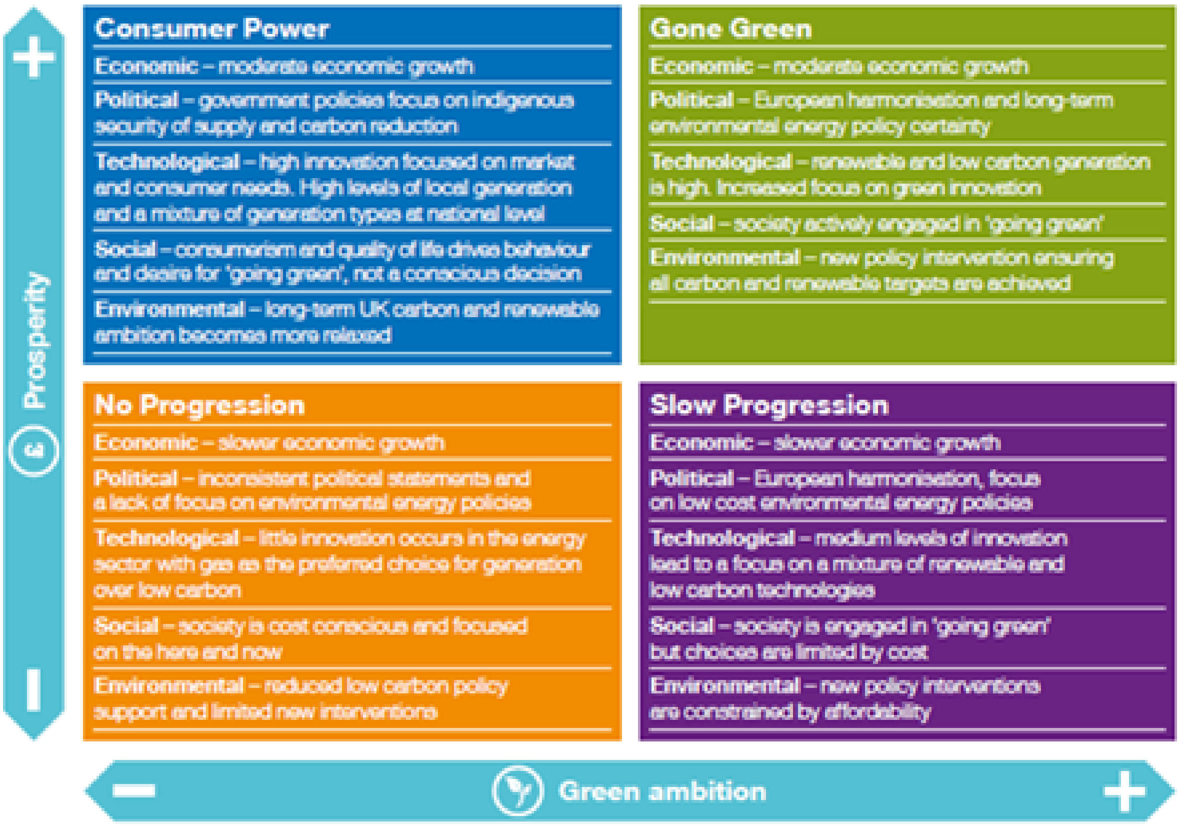

Figure 59: Future Energy Scenarios 2015, National Grid (National Grid, 2015).

At the transmission level, one of the clear analyses in the ETYS 2015 is that the UK grid is already designed to have enough capacity to carry power from generation to demand. However, moving to a low carbon future is imposing the following challenges at the transmission level (see (National Grid, 2015)).

- Wind generation will increase in Scotland, meaning the transmission system has to be improved for carrying capacity from Scotland to southern parts of UK.

- New nuclear plants will be installed and thanks to the technological innovations, they will be larger than those currently operating.
- Depending on the political decisions at EU level, more interconnectors could exist between UK and Europe, meaning more capacity can be transferred from/to continental Europe.
- Based on the more recent and future regulations many thermal generators have closed or will be dismissed in the coming years. This will correspond to a need of redistributing the capacity in the grid.
- Embedded generation (in particular solar power in south UK) is expected to continue is growth as well as the decreasing of the reactive demand.
- Given the changing energy landscape, off-peak conditions become increasingly important as a driver of investment.

For addressing some of those challenges two projects are currently in progress and are suggested to continue:

a. Upgraded Beauly to Denny circuit, which can improve transmission across Scotland;
b. Construction of series and shunt reactive compensation and Western HVDC Link across the Anglo-Scottish boundary.

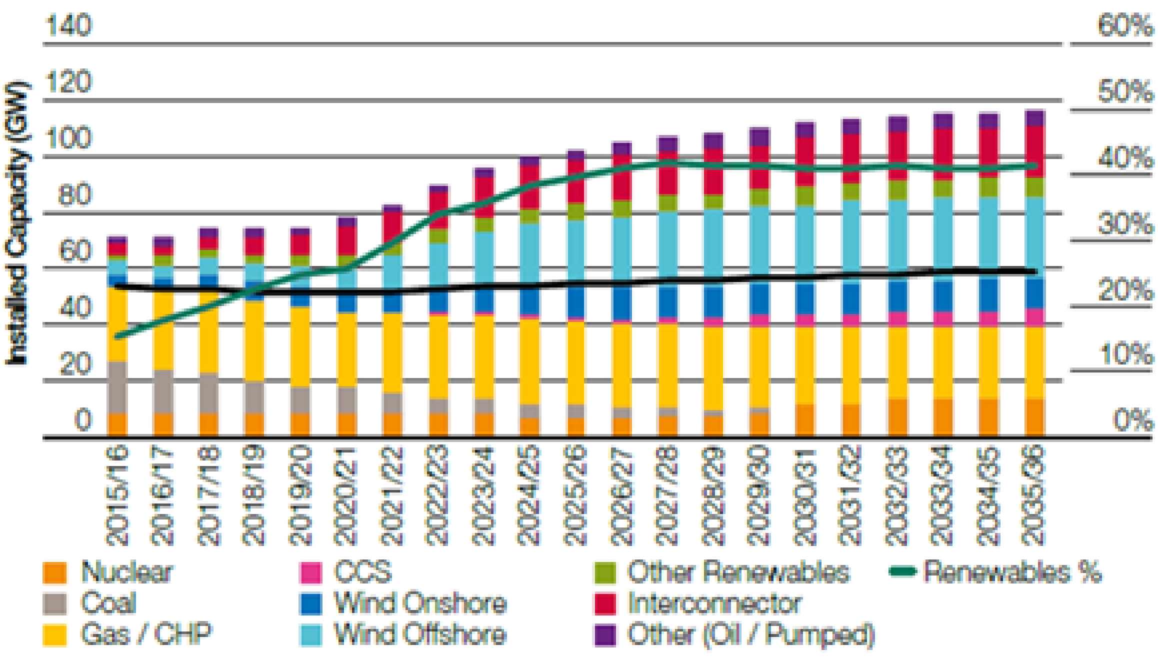

Figure 60: Gone green scenario, Future Energy Scenarios 2015, National Grid (National Grid, 2015).

Another interesting analysis at the transmission level is reported in Figure 60 where the need of storage system is very limited at Carbon Capture and Storage (CCS) and pumped storage.

So far electricity storage systems have been not included in any FES. However, the stakeholder meeting in preparation of the FES 2016 (National Grid, 2016) clearly stated that electricity storage should be included in the Gone Green and Consumer Power scenarios. The opportunities given by electricity storage will be proposed in the FES 2016 analysis covering the opportunities at transmission, distribution and behind the meter level of the electrical grid. FES 2016 will be launched in July 2016.

5 Possible applications of the energy storage system

5.1 Transmission grid level

5.1.1 Providing operating reserve

Responsible Partner: B.A.U.M. Consult

The permanent balance between power generation and consumption is an important prerequisite for a stable and reliable grid operation. This includes among others the maintenance of the grid frequency within a narrow range around the defined norm of 50 Hz. The TSOs are responsible for reliable grid operation in their respective transmission grid area and subordinate distribution grids. In order to ensure the balance of power generation and consumption on time scales from a few seconds to one hour, the TSOs provide operating reserve, that is, they apply measures for adjusting the generation or consumption or both of them such that they are equal. On a time-scale shorter than a few seconds, the inertia of turbines in thermal power plants is used for keeping the grid frequency with a narrow range around the defined norm (50 Hz).

Operating reserve is needed, if generation and/or consumption are not balanced because of unexpected deviations of the consumption and/ or the generation from forecasted/ planned values. On part of the consumption, deviations can result from variations in purchase behaviour. According to power industry terminology, deviations of distributed generation from forecasted values are equally accounted as demand deviations. On part of the generation, deviations can be due to failures, e.g. break down of a power plant or failures in the forecast (VDE, 2015). According to the regulations of the ENTSO-E (European Network of Transmission System Operator for Electricity), the German TSO purchase the operating reserve from power generators and large consumers with flexible loads.

The operating reserve can be divided in three categories – primary control, secondary control and tertiary control (see Table 16). They are used to ensure the grid balance for up to one hour and are distinguished by their engaging and modification speed. After one hour, the responsibility for establishing the grid balance is transferred from the TSO to the balance responsible parties. Figure 61 provides a schematic overview of the different categories of operating reserve.

Categories of operating reserve					
Product segment	**Tender**	**Minimum volume**	**Activation**	**Time slices**	**Reward**
Primary reserve	weekly	1 MW	< 30 seconds automatically	1/Week	demand rate
Secondary reserve	weekly	5 MW	< 5 minutes automatically	Peak & off-peak	demand rate & energy rate
Minute reserve	each working day	5 MW	< 15 minutes partly automated	6x4h/day	demand rate & energy rate

Table 16: Overview categories of operating reserve in Germany, Source: (Clean Energy Sourcing, 2014)

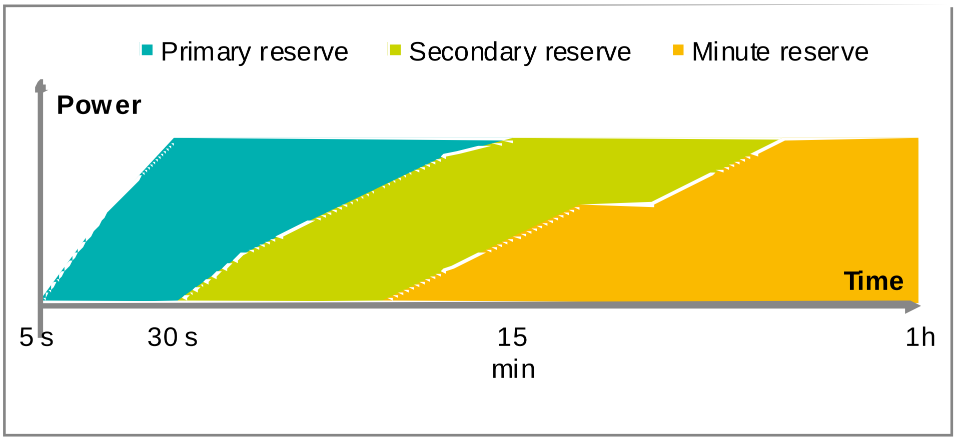

Figure 61: Illustration of the different categories of operating reserve Germany, Source: (B.A.U.M. Consult GmbH, 2014)

Furthermore, the operation reserve can be differentiated into positive and negative operating reserve. Positive operating reserve is needed, if the demand (unexpected) is higher than the actual power generation. In this case, the TSO need short-term additional power feed-in into the grid (respectively the shut-off of a load). Negative operating reserve is needed, when the power input into the grid has to be reduced (respectively loads have to be are activated).

Primary reserve

In case of a power imbalance, the primary control needs to be activated within 30 seconds and must be available for at least 15 minutes. The provision follows the principal of solidarity through all synchronous connected TSOs in the European integrated grid. Within the Continental-European grid (former UCTE-grid), about +/- 3,000 MW of primary reserve is available. This is presumably insufficient at high penetration level of fluctuating renewable power generation, and thus a potential forthcoming field of application for battery storages.

To participate in the primary reserve market, a pre-qualification of the respective power plant is necessary. The owner of the power plant must prove that the power plant is technically able to provide primary reserve. Aggregated production units, consumer load and battery storage systems can provide primary reserve if operated accordingly. In addition, renewable energies sources can provide operation reserve, notably negative operation reserve. For example, in Ireland it is specified that wind turbines should provide primary reserve (legal framework of the Grid Code) (VDE, 2015).

Secondary reserve

The secondary reserve replaces the primary reserve. It has to be activated within 5 minutes, the first megawatt within 30 seconds. This happens directly and automatically on demand by the respective TSO. The secondary reserve must be available for a period from 5 to 15 minutes. In contrast to primary reserve, secondary reserve is used for balancing the power generation and demand in a specific control area.

Such as on the primary reserve market, a potential market actor needs a pre-qualification for providing secondary reserve by a power plant or by other flexible operating resources. Based on their quick response, battery storage systems are technically able to provide secondary reserve.

Minute reserve

The minute reserve takes over the role of the relatively expensive secondary reserve after 15 minutes. Through instruction by phone, the TSO requests the needed minute reserve by one and/or more providers. After the request of the TSO has been made, the minute reserve must be activated within 15 minutes. The minute reserve must be available for a period of 15 minutes (min.) to one hour (max.).

Beside the primary and secondary reserve, the minute reserve can be a further field of application for battery storage systems. However, it should be noted that battery storage systems providing minute reserve must be available for a quite long period of operation. This usually requires a large storage capacity. Alternatively, cascades of battery storage systems or combinations of battery systems with other flexibilities are a feasible option.

Project example:

The project "Swarm" in Germany is a good example for a battery storage system providing operating reserve. 65 pre-qualified, interconnected, decentralized battery storage systems provide operating reserve for the primary reserve market. Every battery storage system consists of lithium-ion batteries. Siemens has provided the power electronics. What makes it special is that each one of the 65 battery storage systems have a control unit and can respond independently of the others to deviations of the grid frequency from the norm. The individual battery storage systems are installed in private households and are connected via UMTS with the control centre. The control centre monitors and regulates the charging level of each system. Thus, the offered primary reserve is available at any time. The project shows that interconnected, decentralized lithium-ion battery storage systems can contribute to a reliable and stable grid operation by providing positive and negative primary reserve (energy 2.0, 2015).

5.1.2 Enhanced frequency response

Responsible Partner: B.A.U.M. Consult

When conventional thermal generation is going offline while increasing amounts of intermittent renewables are connected, the system inertia decreases resulting in an increased frequency volatility. The deployment of a balancing service with a sub-second response time is improving the control of the frequency deviations and reduces the response required in times of low system inertia. Enhanced frequency response (EFR) is a new service complementing operation reserve at the lower end of the time-scale. A market exists at present in the UK which is almost exclusively served by battery storage systems. Presumably, Germany will become the next large market for EFR response when nuclear power is phased out by 2022. More generally, EFR will be required in all areas with a high contribution of generation without rotating masses (e.g. PV plants) or without direct coupling of the output frequency to the rotating mass (e.g. wind power plants).

For more details see ELSA deliverable D5.3.

5.1.3 Temporary redispatch

Responsible Partner: B.A.U.M. Consult

While the operating reserve is used to balance deviations of generation and consumptions in time, redispatch measures do this in space, that means, they are used to avoid or eliminate bottlenecks in their respective transmission grid area. The responsibility rests with the TSO. Basically, the term dispatch designates the establishment of an operation plan for power plants through power plant operators. The term redispatch designates a temporary modification of this operation plan. More precisely, redispatch is defined as a measure which is activated by one or several system operators and which consists in altering the generation and/or load patterns within an area, in order to change the physical electric power flows in the transmission system and relive a physical congestion. (Weyer, 2013)

If a bottleneck to a power flow impedes at a certain point in the grid, power plants upstream this point are instructed to reduce their feed-in, while power plants downstream this point are instructed to increase their feed-in. In this way a modification of the load flow is generated which counteracts the bottleneck. (BNetzA, 2016)

Figure 62 shows a possible scenario for a redispatch measure. Within country A, an unexpected wind power feed-in increase happens. This leads to an increase of the electricity export from country A to country B such that the connecting cable between country A and B is overloaded. To eliminate this bottleneck, plant A decreases its power generation and plant B increases its. This measure generates a modification of the load flow which counteracts the bottleneck.

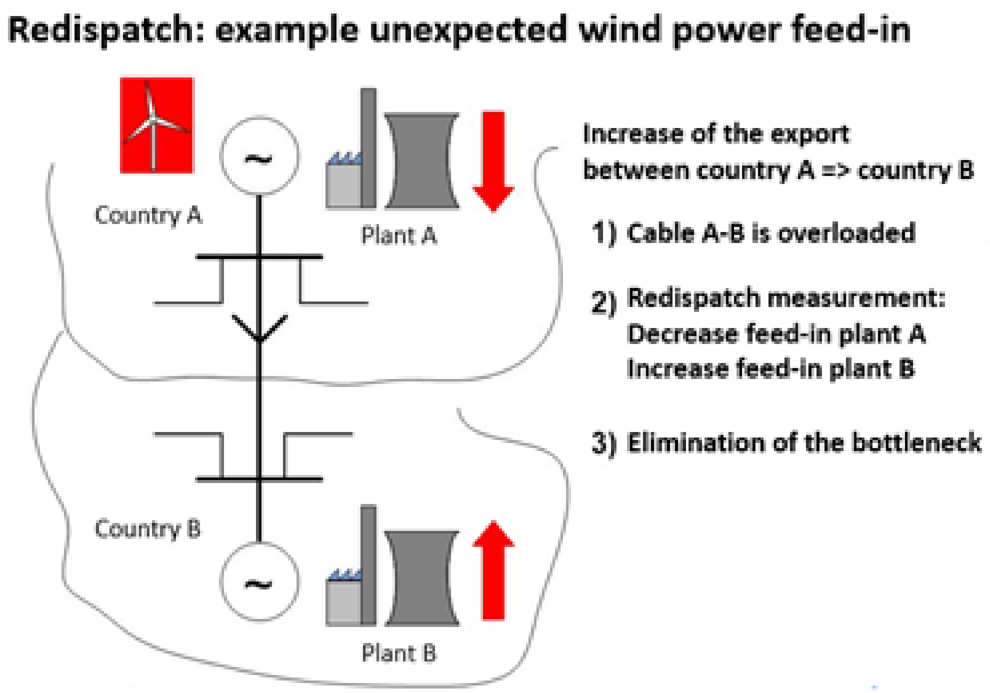

Figure 62: Example redispatch concerning unexpected wind power feed-in, Source: (Fraunhofer IWES, 2014)

For example, in Germany the costs for redispatch measures were about 1 billion euros in the year 2014. The TSO Tennet alone accounted redispatch costs amounting to 700 million euro. Out of this 225 million euros were costs of increasing and decreasing the feed-in of power plants. 152 million euros were costs of activating emergency reserves, and 329 million euros were compensations paid to wind power plant operators because of curtailments. The second largest TSO 50 Hertz accounted costs for redispatch measures amounting to 300 million euros. (energie-tipp, 2016)

These figures show that redispatch measures cause substantial costs. Experts forecast that the costs of redispatch measures will increase in the next years not only in Germany, but in the whole European Union. Therefore, storage technologies, e.g. battery storage systems could be used as an alternative variation of redispatch that can substantially reduce the costs because of their specific technical characteristics. On one hand, surplus electricity can be stored without decreasing the feed-in of power plants. On the other hand, the stored electricity can be fed back into the grid, once it is needed.

In this context, a further possible application of battery systems could be preventive bottle-neck-management (see chapter 3.2). Power generation peaks can be shaved by temporary storage and the stored energy can be used later, when it is needed. The result of this measure is a more even use of the power grid during the day.

5.1.4 Black start capability

ELSA ESS do not have the capability to support black start of power plants after a black-out. For this reason, this application of battery storage systems is not discussed here.

For more information on this application see the ELSA deliverable D5.1.

5.1.5 Compensation forecast errors

Responsible Partner: B.A.U.M. Consult

The operation of power plants must be scheduled in advance to ensure the balance of load and generation. Especially fluctuating power generation challenges the so called "timetables". For example, the contribution of wind and solar plants to the general power generation can only be determined by predictions. Due to the uncertainty of these predictions, this leads to deviations between the forecasted and actual power generation which is the higher the longer the forecast. Respective deviations from the forecast must be balanced by increasing the generation or demand within 15 minutes.

TSOs are responsible for the compliance of the grid frequency (50 Hz) in their respective transmission grid area and subordinate distribution grids (see 5.1.1). Therefore, TSOs have to buy control power/operating reserve to cover deviations in energy production due to prediction errors. (Cai, et al., 2015) Based on the further expansion of wind and solar power in Europe, TSOs have to face additional operation costs to balance unexpected large forecast deviations.

The study "Untersuchung verschiedener Handelsstrategien für Wind und Solarenergie unter Berücksichtigung der EEG 2012 Novellierung" showed that a sophisticated trading strategy can avoid costs caused by short-time forecast errors. (Möhrlen, et al., 2012) An alternative are virtual power plants which compensate forecast errors. Within a virtual power plant, battery storage systems can provide the part of the requested power that cannot be provided by generation units. Despite their limited energy storage capacity, battery storage systems can contribute to balance forecast errors, related to the relevant period of 15 minutes thanks to their ability to provide a rather high power for a short period of time. (VDE, 2015)

Furthermore, battery storage systems can be built as backup energy resource for wind and PV power plants. Based on the technical characteristics, battery storage systems can offer not only positive but also negative control reserve. (Based on: (Cai, et al., 2015))

The study "application of battery storage for compensation forecast errors of wind power generation in 2050" showed that battery energy storage systems are an outstanding alternative for short-term balancing in order to reduce the cost of forecast errors. (Cai, et al., 2015)

In the following, selected results and explanations of the study are shown in more detail.

Figure 63 shows that the income from balancing increases significantly and the cost of balancing decrease when a battery storage system is operated, because the system can not only balance the prediction errors but also serve as a supplemental supplier to provide balancing energy in the power system. (Cai, et al., 2015)

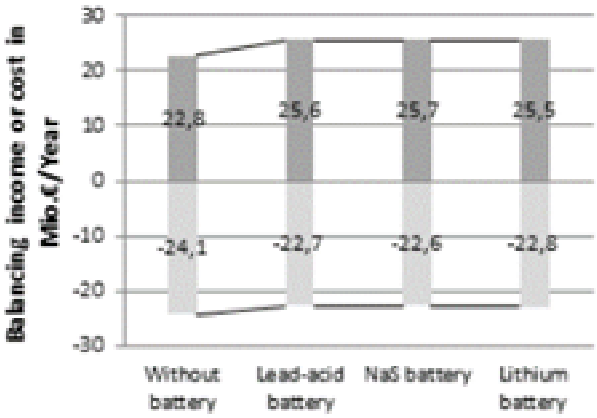

Figure 63: The income and cost due to balancing energy, Source: (Cai, et al., 2015)

The gain of the wind power plants can be improved by operation of a joint battery storage system. Compared with the scenario in the years 2011-2012 for the wind power plants, the gain per MW could increase by approximately 33 % in year 2050 (see Figure 64). (Cai, et al., 2015)

	Without BESS in 2011	Lead-acid Battery in 2050	NaSBattery in 2050	LithiumBattery in 2050
Day-ahead income (Mio.€/year)	21.8	24.7	24.7	24.7
Balancing income (Mio. €/year)	22.8	25.7	25.7	25.5
Balancing cost (Mio. €/year)	24.1	22.7	22.6	22.8
Battery cost (Mio. €/year)	-	0.429	0.319	0.856
Gain (Mio. €/year)	20.5	27.3	27.5	26.5
Gain per wind power (€/MW)	41.0	54.6	55.0	53.0

Figure 64: Results of different scenarios using different types of battery storage systems, Source: (Cai, et al., 2015)

Besides the compensation of forecast errors on transmission grid level, it is also possible to use battery storage systems directly at distribution grid level to provide this service. In Germany, a control area consists of different balancing groups. The balance responsible party acts as an interface between the end costumers and the transmission grid operator. It bears the economic responsibility for deviations in its grid zone and has to regulate appearing imbalances. The deviations between generation and demand are calculated daily for each balancing group by the balancing group grid operator and are communicated to the balancing group operator. In the future, it could be possible that balancing group and grid operators use battery storage systems, in common consultation, to balance forecast errors on distribution grid level.

5.2 Distribution grid level

5.2.1 Temporary deferment grid expansion

Responsible Partner: B.A.U.M. Consult

Usually, the grid expansion follows the development of the grid load and the requests for connection of the costumers. In case of modified costumer projects or deferred development of the demand, a hastily grid expansion can lead to surplus capacity by electricity cables, stations and substations. The consequences are a poor use and non-profitable operation of the grid assets. (VDE, 2015)

This leads to capital commitment for non-profitable grid assets. The fixed capital could be used effectively in another area of the grid respectively the fixed capital leads to a deterioration of the efficiency factor. Both causes higher financial burden for the respective grid operator. (VDE, 2015)

Based on these facts, temporary deferment of the grid expansion leads to a financial advantage for grid operators. This advantage is reflected in a cash-value benefit. As it is permitted or acceptable, the basic measure is the limit the feed-in of power plants or to restrain the demand. (VDE, 2015)

In this case, another possible scenario is the use of battery storage systems. It can be assumed that only temporary power peaks will appear in the first phase of the development of the demand. This temporary power peaks can be easily intercepted by battery storage systems. Generally, grid expansion is necessary but battery storage systems could play an important role in an efficient way of grid expansion. A corresponding procedure probably needs mobile battery storage systems. These systems should provide an easy plug-and-play function. Depending on demand, this function allows an efficient use of the battery storage systems at different grid points. As the case may be, the battery storage systems compete with mobile backup power systems. (VDE, 2015)

Depending on technical requirements, the ELSA battery storage systems can be used for the addressed service.

Project example:

A case study and pilot projects on Magnetic Island, conducted by Ergon Energy (energy supplier in Queensland Australia) within a Solar Cities project, proofed energy storage in combination with another source of renewable energies to be an alternative to cost-intensive grid extensions of about $18.6 million, including the instalment of a third undersea cable to the island.
Because it is an island of the, Magnetic Island is connected to the Australian Mainland and National Electricity Market via two undersea cables. The island has about 2,500 inhabitants but meanwhile it is a popular tourist destination during holiday seasons, so that energy demands can vary strongly between an average demand of 5 MW in winter (2012) and an average demand of 3.4 MW in summer, mostly because of air conditioning. For what the energy storage is concerned, it is not clear yet, in how far it contributed to reduce peak demand, since there is not enough data until now. (Bruce, et al., 2013) Still, peak demand on the island could be reduced by approximately 16 per cent down to 2005 levels, and had deferred the need to build a third undersea cable. (Parkinson, 2013)

5.2.2 Providing reactive power

Responsible Partner: Allgäuer Überlandwerk

With alternating current, the forces and direction from current and voltage are changing. In Europe both of them have a sinus-shaped form with a frequency of 50 Hertz. When current and voltage are swinging simultaneous the product of both pulsing values are resulting in an also pulsing power which has always a positive value, this is pure so called active power as you can see in Figure 65.

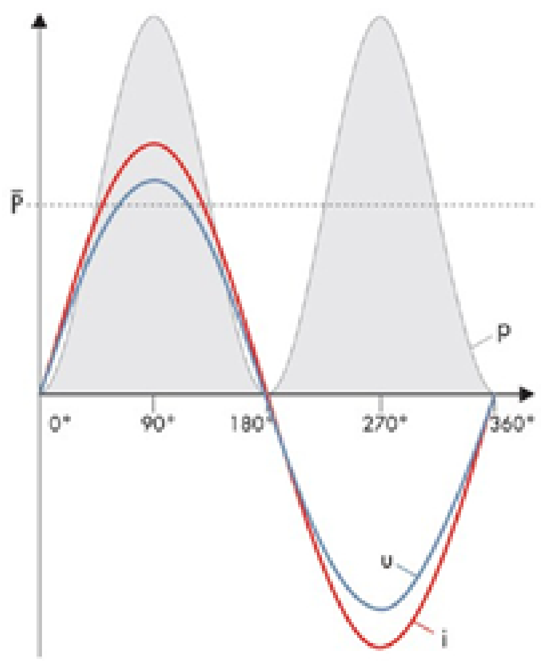

Figure 65: Current and voltage are oscillating Simultaneous; Source: **(SMA Solar Technology AG)**

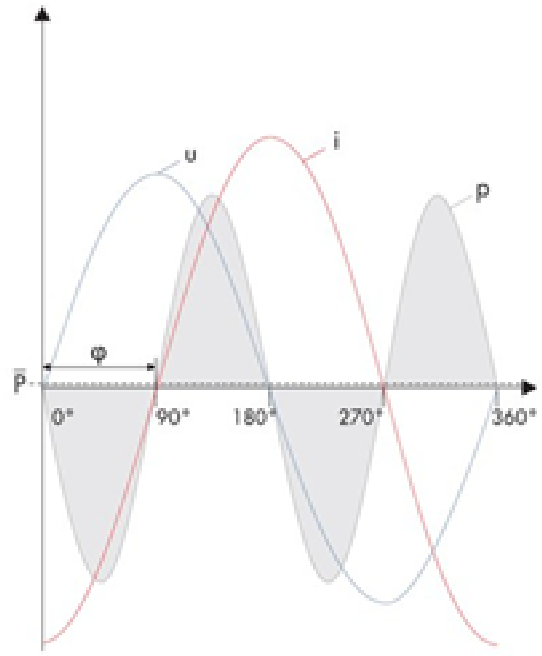

Figure 66: Current and voltage are oscillating with an off- set of 90°; Source: **(SMA Solar Technology AG)**

As soon as the oscillation of current and voltage are being shifted against each other the product of them is alternating between positive and negative values. The most extreme case is a shift by a quarter period (90°), as you can see in Figure 66. Which means when the current is reaching its highest point the voltage is zero and the other way around. The result is pure reactive power. The shift between voltage and current is called phase shift and it can have two different directions. The shift is happening when coils or capacitors are within alternating current, which is almost always the case. Coils are used in almost all engines and transformers cause an inductive shift, capacitors cause a capacitive shift. Multi core cables are behaving like capacitors and long high voltage power transmission lines like long stretched coils. Therefore, there is always a certain phase shift and therefore a reactive power in the grid. The degree of shift is given in cos(φ) it can have values between 0 and 1.

Only active power can be used, reactive power cannot fulfill work it only commutes through the power grid and encumbers it. The whole grid infrastructure like cables, transformers, switches et cetera have to consider reactive power, have to transport it or transform it. They have to be constructed for the apparent power which is the resulting power from active and reactive power as shown in Figure 67.

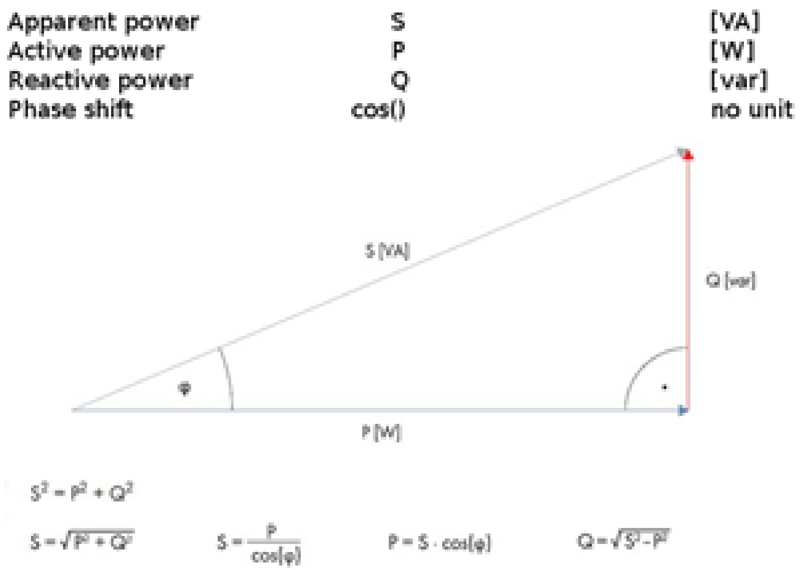

Figure 67: Mathematical relationships between apparent, active and reactive power; Source: (SMA Solar Technology AG)

Of course the phase shift between current and voltage can be compensated, it only needs an opposite phase shift which can be done through compensating coils or compensating capacitors. Therefore, transport loses in the grid can be lowered as well as the apparent power which frees capacity for active power to be distributed. Reactive power can be used to participate in the voltage control in power grids. For example, big power plants are feeding their production already with a capacitive reactive power into the grid in order to compensate the voltage raise done by inductive transmission lines.

The effect of voltage raises or drop by reactive power can also be used to enlarge the number of DER in a certain grid section without having to extend the grid because of voltage reasons.

Since modern converters are able to provide either inductive or capacitive reactive power the ELSA battery system can be used to:

- Compensate reactive power and therefore unload the grid
- Feed in reactive power to help balance the grid voltage

Project example:

An example for providing reactive power is IREN2. The project represents a small micro-grid, developed by a research group of Siemens between 2010 and 2013, and is located in Wildpoldsried that in 2010 already produced twice as much electricity as the community needed for consumption by using wind, solar and biomass facilities. The purpose was to realise, and analyse a "micro-grid prototype with islanding capabilities as well as a topological power plant prototype" to find out, how sustainable resources and their systems services can secure reliable grid operation.

"Two controllable distribution transformers and a battery storage installation" helped the smart-grid to be able "to flexibly balance the community's fluctuating electricity supply and power demand, thus to maintain grid stability" within the community. "The community's smart grid is also equipped with a sophisticated measurement system, a state-of-the-art communications infrastructure, and distributed, renewable power generation systems such as photovoltaic and biogas units. As a result of these systems and its smart grid, Wildpoldsried now produces more than five times more electricity than its residents consume, which is significantly more than what is needed to meet its peak loads." For the time to come, the aim is to find ways so that the micro-grid operates as a "topological power plant" which refers to a grid section in which systems, using renewable energy sources, interact with additional components to regulate the grid like todays' conventional power plants do today. (Webel, 2014)

5.2.3 Reducing grid losses

Responsible Partner: B.A.U.M. Consult

The term grid losses or transmission losses describe the difference between the generated electrical power and the used electrical power. The grid losses in the European three-phase-system are calculated at 6 % of the generated power, taking the whole performance of the grid into account (average of all voltage levels). Transmission losses appear due to the ohmic resistance of the transmission lines and, to a lesser extent, electromagnetic radiation emitted from grid lines. The electricity transmitted through transmission lines heats the lines. This physical process is described as ohmic losses. Further, voltage-dependent losses by corona discharge, losses of providing reactive power and losses in power transformers are also relevant. (Wikipedia, 2015)

Transmission efficiency is greatly improved by devices that increase the voltage, (and thereby proportionately reduce the current) in the line conductors, thus allowing power to be transmitted with acceptable losses.

"The reduced current flowing through the line reduces the heating losses in the conductors. According to Joule's Law, energy losses are directly proportional to the square of the current. Thus, reducing the current by a factor of two will lower the energy lost to conductor resistance by a factor of four for any given size of conductor." (Wikipedia, 2016)

Figure 68 provides an overview of the transmission grid losses in 2013 within the European grid. The losses caused by transits in each transmission system are determined by: (ENTSOe, 2014)

- Recording the load flow Situation for each ITC (Inter Transmission System Operator Compensation for transits) Party for 6 monthly snapshots T (3rd Wednesdays and preceding Sundays at 03:30h, 11:30h and 19:30h CET/CEST):
  - with transit represented on interconnected system;
  - with transit represented on disconnected system;
- The losses caused by transit for the particular hour ΔPlossk (t) is then determined as the difference of losses observed in the two situations;
- Based on a mapping that attributes every hour of the month to one of the six snapshots timestamps t, each snapshot timestamp is given a weight w(t);
- The overall monthly amount of transit losses for each ITC party is derived by aggregating the weighted transits for the particular hours.

Further explanation/specifications of this calculation method can be found in the Commission Regulation (EU) No838/2010.

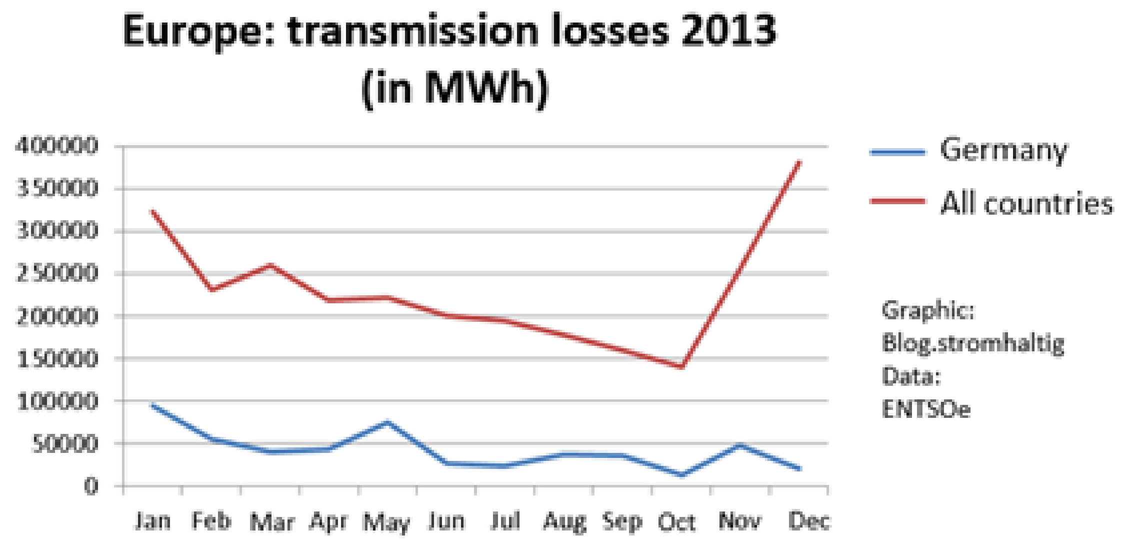

Figure 68: Overview transmission losses in 2013 in the European Union, Source: (Zoerner, 2014)

With a share of 18,7 % (516 GWh) most transmission losses appeared in Germany. In summa, the transmission losses in the European grid are estimated around 2,766 GWh. However, based on the geographical location of Germany in the middle of Europe and the relatively large north/south expansion the transmission losses are always higher than in the Scandinavian countries. (Zoerner, 2014)

In principle, balancing of the load flows is a possible application or service, that battery storage system can provide to reduce grid/transmission losses. Battery storage systems, that are used for bridging bottlenecks (see chapter 3.2) contribute automatically to the balancing of load flows.

However, several studies assume (VDE, 2015) that battery storage systems which are only used to reduce transmission losses might cause more losses during the charging and discharging process of the battery storage systems.

In this context, further R&D projects addressing this topic could provide a common view of this possible application of energy storage systems.

Project example:

A field test carried out by SMA confirmed that decentralized storage systems have the ability to increase self-sufficiency and to improve supply security, for which SMA collected “operation data from 10 PV plants with grid-connected storage systems over a period of 12 months. […] The result: No performance data recorded from any PV plant, on any day, indicated higher grid exchange capacity caused by the storage system.” In contrast: “given constant maximum values, the average rates of change in the grid exchange capacity actually went down by a significant degree in all cases. In the system with the smallest PV peak power, the rate decreased by about 26 %, and this despite an operational control designed for maximum self-consumption. “ (Kever, 2012)

5.2.4 Voltage control

Responsible Partner: Allgäuer Überlandwerk

Once the electrical power grid was built to distribute power from few large scale central power plants to many small scale consumers, now where more and more distributed energy resources are feeding into the grid in decentralized places the power grid has to manage different difficulties one of them is to keep the voltage within the given tolerances.

The TSO and DSO have the responsibility to keep the quality of the voltage in their grid area within defined boundaries. Furthermore, they are responsible to limit the voltage drops in case of a short circuit. (Agricola, 2014)

In general, there are four different scenarios which can cause the voltage to leave their tolerances.

1. Higher production than consumption in the grid section without having adjustable transformers who are able to adjust their working band to the changing voltage. Leads to an ascent of voltage
2. Higher consumption then production in the grid section without having the capacity of transforming and distributing more power from the higher grid level. Leads to a decent of voltage.
3. Fluctuation of reactive power. Lead to an ascent or descent depending if inductive or capacitive reactive power
4. Short circuit in the grid. Leads to a voltage drop

There are different solutions to regulate the voltage for case 1 to 3:

- Use of adjustable transformers
- Reduction of feed in production respectively lowering of consumption
- Using reactive power to lower or raise grid voltage.

In case 4 the section of the grid where the short circuit appeared needs to be disconnected and the problem has to be fixed. Nevertheless, DER can help supporting the grid by staying connected even the grid voltage is dropping out of their operating range. By keeping connected and still feeding in they can prevent massive production drops which would cause an even higher decent of the voltage.

The ELSA battery system can support the grid by providing voltage control through different services.

1. Broadening load

   By charging the battery system during times of lower demand in the grid section and feeding the stored power back in case of high demand an unbalance between demand and available power can be lowered. Because of that voltage decants can be reduced.

2. PV peak shaving

   In times were many DER are feeding their power into the grid and causing a voltage rise, the ESLA battery system is able to store the overproduction and feed it back into the grid at a later time period. For example, can the battery cut the middle day peak from PV plants and feed-back at the evening or at night.

3. Providing reactive power

   By providing reactive power the voltage can be raised or lowered. It has to be clear that it can be necessary to compensate the feed in reactive power on other points of the grid, due to agreements between the DSO and TSO or in order to reduce grid loses. See also point 5.2.4.

Project example:

Developing a 32 MW/ 8 MWh grid energy storage solution at the Laurel Mountain, AES Wind Generation built the largest facility of its kind referring to the year of 2011. The storage system consists of an advanced lithium-ion battery technology in interaction with the AEROS™ management system and a wind generation plant. Results show this energy storage system to provide frequency regulation as voltage control services with an additional revenue stream and an operation capability which often is not available from wind generating plants as well as an overall grid reliability. The storage system also shows its capability of moderating the output of the wind generation to manage ramp rates. (ESA - Energy Storage Association, 2016)

5.2.5 Redispatch

Responsible Partner: B.A.U.M. Consult

Analog to chapter 5.1.3, also DSOs could use redispatch measures to avoid or eliminate bottlenecks in their respective distribution grid. For the definition of the term “redispatch”, respectively “redispatching”, refer to chapter 5.1.3.

As has been pointed out on previous chapters, decentralized power production leads to complex grid situations. Therefore, local measures for grid services become more important. For example, multiple megawatt of flexibility is needed at a network note on the distribution grid level. Redispatch measures could be used to provide the requested flexibility (generation or demand). DSOs use contractual guaranteed flexibility, e. g. in the form of battery storage systems. The retrieval of the flexibility will be provided directly to the DSO by the respective grid user or supplier of the flexibility. The study “dena-Studie Systemdienstleistungen 2030” pointed out that distribution grids can be used for redispatch measures for the superior transmission grid. In this case, a sufficient regulatory flexibility at any time must be guaranteed to ensure the (n-1) security of the transmission grid. “A system is N-1 secure if any element in the system may fail without overloading any other element”. (ETH, 2005) As mentioned before, battery storage system could provide this distribution gird service, based on the technical requirements.

5.3 At power plants

Applications of battery storage systems on the premises or next to power plants are the reduction of the ramp rate or starting assistance. However, ELSA ESS are conceived for systems up to 96 kWh of storage capacity which is too small for these applications. For this reason, they are not discussed here.

5.4 At consumer / prosumer level

5.4.1 Power purchase optimisation (peak shaving etc.)

Responsible Partner: RWTH Aachen University

As already introduced in D1.1 we define Peak Shaving according to (Smart Grid Task Force, 2015) as the flattening of an electricity consumption load curve. The power purchase is moved from midday for example to a time period which might be characterized by e.g. lower electricity prices.

With respect to the ELSA project and the integration of 2nd Life electric vehicle batteries within the distribution network, we find many research activities that develop intelligent coordination strategies for Plug-in electric vehicles or Plug-in hybrid electric vehides, such as in (Vandael, et al., 2013) or (Alam, 2015). Within peak load periods electric batteries in general might be used to support the electrical network and in particular the feeder where it is connected to.

Authors in (Alam, 2015) explain the main advantages of peak shaving with electric vehicle batteries. Since the electrical energy prices are high in times of peak loads, peak shaving probably provides a direct monetary benefit for the stakeholder. However, next to this technical benefits are also achieved, such as network voltage improvement or equipment utilization/loading. Voltage regulators within distribution grids might also be relieved due to lower voltage limits which leads to a reduction in the tap operation of the regulator.

The mentioned description is mainly related to the integration of electric batteries; however, the benefits of peak shaving are reachable whenever a portfolio provides flexibility, such as electro-thermal heating units. In such cases the electrical demand is decoupled from the necessity of thermal generation through the usage of thermal storages.

Project example:

An existing application for power purchase optimisation can be seen at the BMW Technology Office in Mountain View where a 2nd life battery storage system has been installed. The utility consists of 8 used battery packs from former MINI E EVs and a 100 kW inverter. Additionally, the system is integrated into an advanced building energy management systems, and is connected to a network of EV charging stations, including several DC fast charging stations, as well as to a 100 kW solar array. (Sania National Laboratories, 2013)

5.4.2 Uninterruptable power supply

ELSA ESS do not have the capability to provide uninterruptable power supply. For this reason, this application of battery storage systems is not discussed here.

For more information on this application see the ELSA deliverable D5.1.

5.4.3 Increasing the quote of self-consumption

Responsible Partner: B.A.U.M. Consult

A common terminology of terms and their use is a necessary tool within scientific European research projects. It helps to avoid misunderstandings and difficulties associated with different meanings of same terms. Therefore, it is indispensable to explain the difference between self-consumption and autarky (chapter 5.4.4).

- Self-consumption describes the share of generated electricity, which is directly, or after having been stored on-site, consumed by the operator of, for example, a photovoltaic system. The quote of self-consumption describes the amount of self-consumed PV-electricity compared to the whole amount of the (for example) PV-system.
- Autarky can be defined as the degree of self-sufficiency. The purpose of energy-autarkic habitats is to be independent of third parties concerning energy consumption for living. (Wikipedia, 2016) The quote of autarky is different to the quote of self-consumption. The quote auf autarky describes how independent a household is from its supplier.

The following example clarifies the differences between the quote of self-consumption and the quote of autarky. Even the private use of the PV-generation is equal the result for each quote is different.

Quote of self-consumption		Quote of autarky	
Purchase: PV-generation		Purchase: overall consumption household	
$\frac{\textit{private use of the PV generation kWh/a}}{\textit{overall geneation of the PV plant kWh/a}}$		$\frac{\textit{private use of the PV generation kWh/a}}{\textit{annual electricity consumption kWh/a}}$	
Example*		Example*	
$\frac{2{,}000\ kWh/a}{6{,}000\ kWh/a}$	33 %	$\frac{2{,}000\ kWh/a}{4{,}000\ kWh/a}$	50 %
*annual electricity consumption:		4,000 kWh	
overall generation of the PV plant:		6,000 kWh	
private use of the PV generation:		2,000 kWh	

Figure 69: Difference between the quote of self-consumption and the quote of autarky, Source: (AÜW, 2015)

Basically, wind-, PV-, biomass- and CHP-plants are suitable for auto-production. All varieties need a special concept, owed the different ways of generation. For simplification purposes, the further statements refer primarily to private households with installed PV-systems.

Due to massive loads in times of high production rates of renewable energies (such as PV-generation), energetic recovery to the higher-level of the national power grid appears for several hours. As an alternative or supplement to the conventional grid expansion, battery storage systems installed in private households as well as companies could help to stabilize the voltage grid, offering additional services and increasing the quote of self-consumption. (Albrecht, et al., 2015)

The principle is simple: the generated electricity will be temporarily stored in the connected battery storage system until it is needed for self-consumption.

However, there are two major interests in the decentralized operation of battery storage systems. The grid operator would like to use the decentralized storage systems to stabilize/balance the distribution grid, because more than 2/3 of all PV-systems are installed in the low voltage grid. At the moment, the battery storage systems installed in private households do not contribute to the grid stabilization. The private battery owners aim is to optimize primarily its self-consumption, independently from the status of the grid.

These different interests are illustrated in Figure 70. The graph on the left shows the aim of a private battery owner. The installed battery storage system does not contribute to the aim of grid stability. The midday peak load generated by the plant is directly fed into the low voltage grid. The graph on the right shows the optimal contribution of a battery storage system to relief the grid. (Albrecht, et al., 2015)

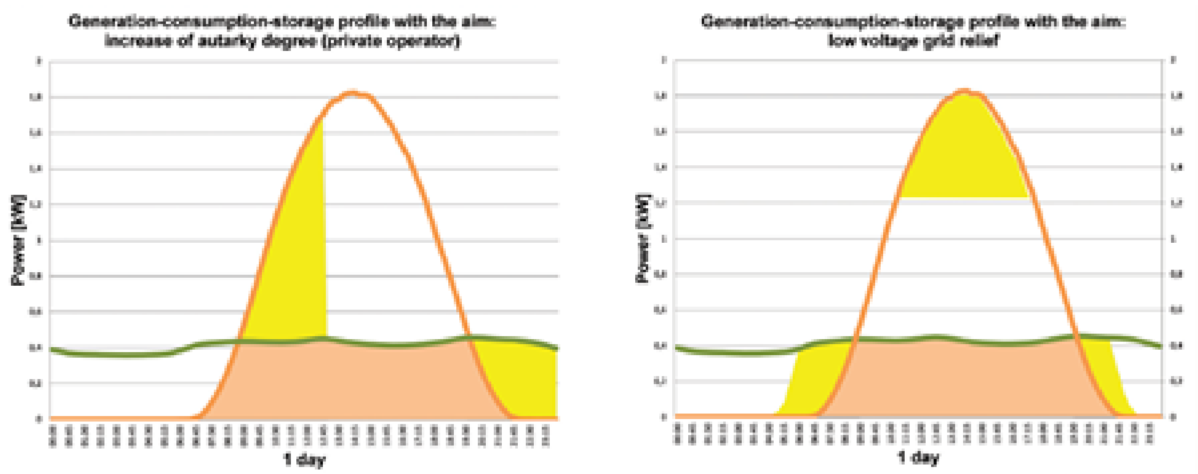

Figure 70: Different generation-consumption-storage profiles, Source: (AÜW, 2015)

The overall goal is to combine both interests. To reach this goal, a smart energy management control system is necessary. Different studies (Fraunhofer ISE, HTW Berlin, BSW-Solar e.V.) shown that private households can increase their quote of self-consumption up to 30 % by putting an PV-plant into operation. Further, private households can increase their quote of self-consumption between 30 % and 60 %, if they install a battery storage system, which is connected with the PV-plant. (Albrecht, et al., 2015)

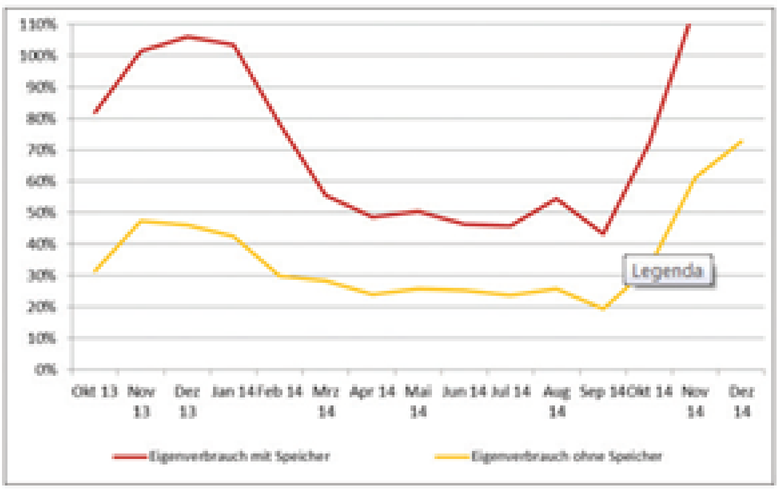

Figure 71: Quote of self-consumption increasing by using a battery storage system, Source: (eza!, 2015)

Figure 71 shows an example of a private household with and without an additional battery storage system. The red line shows the quote of self-consumption of a private household with a PV-plant and an installed battery storage system during the year 2014. In yellow, you can see the quote of self-consumption of a comparable household with only an installed PV-plant.

The statements confirm that increasing the quote of self-consumption, for example in private households or districts could be a possible application for the ELSA battery storage system.

Project example:

Since 2012, for instance, Pellworm Island is equipped with an Saft's Intensium® Max 20 system which provides 1MW of positive and negative "minutes to hours" flexibility and so contributes to the E.ON hybrid energy storage scheme for Pellworm. The 20-foot container contains a storage system with about 560kWh of energy storage whose operation life is expected to last 15 years. (ESA - Energy Storage Association, 2012) Together with a decentralized storage in the form of domestic night storage heaters and heat pumps as well as with a centralized Vanadium-Redox-Flow battery, the storage system relieves not only the island's network structure and upstream electricity grids, but also increases a higher level of self-consumption. (SAFT, 2013)

5.4.4 Increasing the quote of autarky

The ELSA consortium decided that this application is of little interest for ELSA ESS. For this reason, this application of battery storage systems is not discussed here.

For more information on this application see the ELSA deliverable D5.1.

5.4.5 Local energy communities

In the context of the implementation of the EU's Winter Package (European Commission, 2016), local energy communities can play a prominent role. Local energy communities are widely energy self-sufficient communities of energy producers, consumers and prosumers who make use of locally available renewable energy sources. Energy storage is a prerequisite for ensuring that locally produced energy is also consumed locally. Here, ELSA-type ESS can play a role as electricity storage at city quarter or village level, like the ELSA pilot site in Kempten. This application is close to increasing the quote of self-consumption.

5.4.6 Distributed battery swarms

Distribute battery swarms are networks of battery storage systems which are situated in different areas, but which are operated centrally like a single large battery system. Existing distributed battery swarms have been realised e.g. by the company sonnen GmbH[21]. The individual storage systems are PV battery storage systems installed in private households.

ELSA ESS are not suitable for private households, but distributed battery swarms could be built of ELSA ESS with individual batteries being installed in larger buildings, city quarters, enterprises etc.

5.4.7 Controlled charging of electric vehicles

Charing of electric vehicles can be an additional burden to the grid because of the high power drawn during charge. If a stationary storage is installed as a buffer between the vehicle charging station and the grid, the power drawn from the latter can be controlled. In this way, a grid reinforcement might be avoided. Model calculations established by (Stöhr, et al., 2018) for stationary energy storage facilitating the operation of high-power electric agricultural machinery in weak rural grids – an application very similar to electric vehicle charging – have shown that in most cases the combination of a grid reinforcement and a stationary battery storage is the most cost-effective solution. As described in (Enhancing Synergy Effects Between The Electrification Of Agricultural Machines And Renewable Energy Deployment, 2018), synergy effects can be created with local generation of PV power.

5.5 Relocatable applications of storage systems

ELSA ESS are not planned to be certified for being relocated. For this reason, this application is not discussed here.

For more information on this application see the ELSA deliverable D5.1.

[21] https://sonnen.de/

6 Economic impacts of selected applications

6.1 Influencing factors

6.1.1 Customer, consumer and societal acceptance

Responsible Partner: B.A.U.M. Consult

For companies investing in technology it can be very problematic to deal with unpredictable acceptance behaviour of customers "because they [the companies] allocate money, time and effort from other areas of their business. Unpredictable behaviour is problematic for technology vendors, because they gain margin and reputation from fast and widespread technology diffusion. And it is problematic for projected users that are usually challenged with an increased investment of time and effort to get efficient with the new technology. Thus new technology implementation is often considered a stressful project for all involved parties. Increased understanding of the relationships and mechanisms involved in technology adoption may reduce the effort, time and stress involved in new technology implementation for all." (Hillmer, 2009)

The success of the roll out of smart grids and storage technologies therefore strongly depends on the social and societal acceptance. For a deeper understanding, it is necessary to develop a refined view on the end user and the societal background regarding the introduction and diffusion of specific new technologies.

Within smart grids there are different social roles for the end-user. The end user can act as a consumer who uses a service, but not obligatory paying for it, like e.g. employees in an office. The aim of so called 'smart' consumers is to reduce the energy consumption and the energy costs by changing e.g. lifestyle routines (e.g. heating, showering, using appliances, etc.) or installing new more efficient technologies. On the other hand, customer are person or institution who really buy a concrete service. "As a smart customer, an end user can be challenged and enticed to enforce his market position with respect to the energy providers, offering consumption flexibility, or even becoming a commercial partner as 'co-producer' of energy or provider of energy services (e.g. generation, storage facilities, controllable loads)" (S3C, 2015). It is important to keep in mind, that there is not one consumer or customer, but different segments with different attitudes and behavioural patterns. An overview of existing population segmentation models and target group segmentation models can be found in the framing document of the S3C project.

6.1.1.1 State of knowledge social acceptance and technology diffusion

Due to the strategically importance of social acceptance of new technology and its successful diffusion a growing number of theories and models have been developed to investigate technology diffusion. A categorisation of those theories based on (Hillmer, 2009) can be found in the subsequent figure.

Diffusion Theories	User Acceptance Theories	Decision Making Th. (incl. Problem Solving Theories)	Personality Theories	Organisation Structure Theories
Innovation Diffusion Theory IDT also called Diffusion of Innovation Theory DOI (Rogers 1962) Technology Lifecycle Theory (Rogers 1962; Moore1995) **Focus on technology, on the environment and on the using organisation**	Theory of Reasoned Action TRA (Ajzen and Fishbein 1973, 1975) Theory of Planned Behaviour TPB (Ajzen 1991) Technology Acceptance Model TAM 1; TAM 2 (Davis 1989) Motivational Model (Vallerand 1997) User Acceptance of Information Technology UTAUT (Vankatesh et al. 2003) **Focus on the rational employee interest**	Rational Choice Theory/ Game Theory Decision Making under Uncertainty Risk Management Change Management Media Richness Theory (Daft and Lengel 1984) **Focus on the rational organisational/management interest**	Technology Lifecycle Theory (Rogers 1962; Moore 1995) Non-technology related approaches are : Social Cognitive Theories SCT (Compeau and Higgins 1995) **Focus on the individual cognitive interest**	Disruptive Technology Theory (Bower and Christensen 1995) Creative Destruction Theory (Schumpeter 1912, 1942) **Focus on the strategic organisational interest**

Figure 72 Overview of technology adoptation theories, Source: (Hillmer, 2009)

Technology diffusion theories and studies investigate the spread of technological innovations within social networks. Diffusion hereby is defined as the "process by which an innovation is communicated through certain channels over time among the members of a social system" (Rogers 1995, p.5). The four main elements are the innovation itself, the communication channels, the time frame and the context of the social system. Rogers determined different key factors for the success of new technologies: 'relative advantage', 'compatibility', 'complexity', 'trialability' and 'observability'. (Rogers, 2003) The „speed of diffusion of an innovation depends primarily on the attributes of the technology, a good diffusion network that starts by word-of-mouth, and continues by imitation, supported by change agents and stakeholders."

(Rogers, 2003) Rogers distinguish between 'innovators', 'early adopters', 'early majority', 'late majority' and 'laggards'. The actors in those categories adopt new technologies at different points of time (see Figure 73).

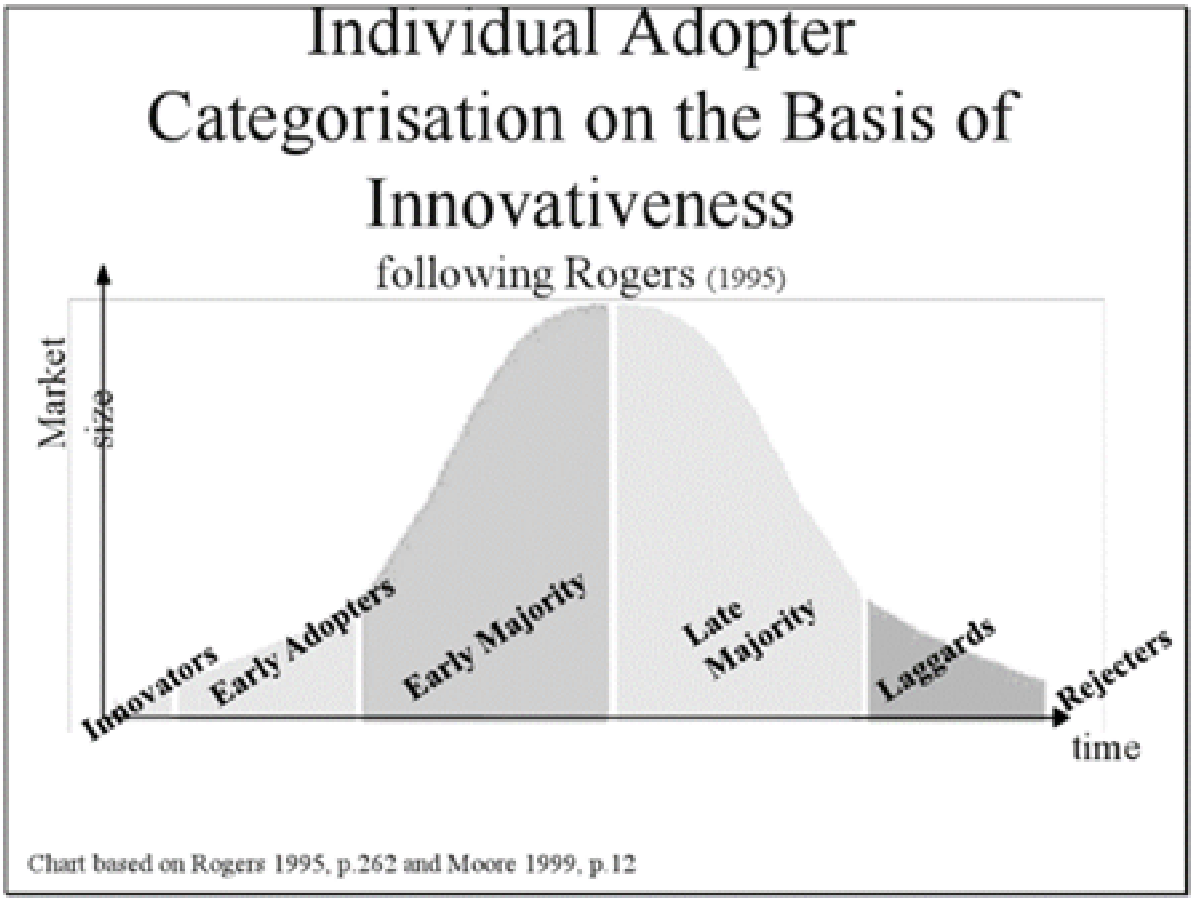

Figure 73 Individual adopter categorisation on the basis of innovativeness (Hillmer 2009 based on Rogers 1995)

User acceptance theories are based on persuasion models of psychology. The 'theory of reasoned action' (Ajzen Fishbein 1973), the 'theory of planned behaviour' (Ajzen 1991), 'the technology acceptance model' (Davis 1989) and recent approaches like the 'user acceptance of information technology model' focus on the influence of individual intention on behaviour.

The 'theory or reasoned action' – based on social psychology – describes behaviour as a function of behavioural intention. The intention for a behaviour is seen as the product of attitudes, subjective norms and their individual weighting. The 'theory on planned behaviour' additionally takes the concept of perceived behavioural control into account.

While the last two theories do not specifically focus on technology acceptance, the 'technology acceptance model' (Davis, 1989) recognizes 'perceived usefulness' and 'perceived ease' as the main factors for the social acceptance of technology. Venkatesh et al. focus with their meta theory 'unified theory of acceptance and use of technology' on the performance expectancy, effort expectancy, and social influence of technology. (Venkatesh, et al., 2003)

Decision making theories focus on the individual rationality and organisation of interests. Personality theories focus on the individual cognition of interests. Organisation structure theories on the strategic organisation of interests and provide frameworks for social action and learning.

As described there is a broad range of different models and theories dealing with the social acceptance of technology "in sum, one can conclude that individuals accept technology more easily, if the technology replicates their social values, and if the technology implementation considers these social values." (Hillmer, 2009) This acceptance strongly differs between the different segments which can be defined as user groups for new technology. Theoretically applied onto the acceptance of a new technology, customers may be willing to invest in a new technology if made good experiences with the preceding technology in the past. The acceptance for new technology also raises if the new technology offers high profits. Additionally, other factors like the privacy can be an obstacle for the diffusion of technology.

6.1.1.2 **How to increase acceptance**

Within the S3C project (www.s3c-project.eu), which developed a toolkit (www.s3c-toolkit.eu) for the active engagement of consumers, customers and citizens in smart grid, a meta analyses of different approaches and projects to activate the end user in smart grids has been examined. The main results can be transferred to increase the acceptance of storage solutions, are described subsequently. That information based on practical guidelines and tools which have been developed within the project. The subsequent information derives directly from the S3C guidelines.

Segmentation to improve target user groups

Segmentation is a method that allows to understand the diversity of different target groups. It can be used for example in recruitment, communication, the tailoring of products and services, and in the evaluation of project results. Segmentation entails dividing a diverse target group of users into a limited number of (approx. 5-10) subsets ('segments') of users who have common lifestyles, preferences and/or needs. The approach was originally developed in marketing to understand which key categories customers fall into, and to estimate the size of those segments in the market.

The current trend – driven amongst others by the advances in 'big data' technology – is to move towards using segmentation as a way to characterize individual households to enable more 'tailor made' customer interactions. (SGCC, 2014a)

A key element is the segmentation model: the categories used to classify users. Traditionally, these models were often based on socio-economic and demographic variables, such as age, income, education level and household size. To be really useful, however, current segmentation models tend to take a broader scope of variables into account. (Sütterllin, et al., 2011); (Breukers, et al., 2013); (McKinsey, 2013); (SGCC, 2014a); (SGCC, 2014b) Besides the socio-economic and demographic variables traditionally considered, these may include psychological and social factors (such as key motivations, lifestyles, attitudes, and beliefs), technical-situational factors (such as housing type and features of a households' electricity system), and energy use and other behavioural characteristics. This is referred to as 'integrated segmentation' (McKinsey, 2013) or 'comprehensive segmentation'. (Sütterllin, et al., 2011); (Breukers, et al., 2013)

Segmentation is particularly helpful when the target group is diverse and 'one-size fits-all' approaches are not likely to work. There are four key application areas for segmentation, which are further described below: recruitment, communication about new products and services ('messaging'), the tailoring of products and services, and for evaluation.

More information on the concrete adaptation of segmentation models can be found in the guideline on segmentation, available via www.smargrid-engagement-toolkit.eu.

Co-creation – collaborating to develop smart energy solutions

Smart energy products and services, like storage solutions are more likely to succeed when they are directly based on user preferences and fulfilling a clear function in the everyday life of consumers. Co-creation (or co-design/user-centred innovation) is a way to tailor the design of smart energy products or service concepts to the needs and expectations of customers – thereby aiming to enhance the chance of achieving acceptance and adoption of these products or services. Co-creation takes place in interactive workshops, focus group meetings or other events, aimed at unleashing individual creativity and sharing ideas and experiences. It requires active involvement of consumers, project managers, developers and other relevant stakeholders. By giving centre stage to future users in the design and implementation practice, valuable information on how the users experience your product or service can be collected. Active participation also tends to enhance feelings of attachment and identification to a project or product, usually leading to a stronger sense of engagement. Thus, products and services that stem from a co-creation approach are more likely to succeed because their added value is more evident to the user.

More information on the concrete adaptation of co-creation approaches can be found in the guideline on co-creation via www.smargrid-engagement-toolkit.eu.

Engaging costumer through telling stories

Narratives or stories can be applied in an energy context as an effective tool for customer engagement and to raise the acceptance of new technology. Story-telling is a communication tool that can be used either for recruitment, marketing, or educational purposes in smart energy ventures. By using narratives, knowledge or experiences are transferred through individual stories that aim to engage the listener and make the content more tangible and understandable. Personal experiences are described in the form of testimonials, making use of metaphors or situational contexts that facilitate the listeners' understanding of the issue at hand. Through stories, you can reach different groups of listeners such as end users, policy makers, energy companies etc. It is an easy, intuitive, participatory and multipurpose method. Telling their story offers a voice to the individual and can highlight best practice examples from the user point of view. In recruitment and marketing, storytelling is commonly used, as people tend to better relate to stories told by their peers than to technical or factual information. Personal stories from staff members on the other hand give a face to a project or company that consumers can relate to. Last but not least, telling stories is a fun and intuitive way to engage people. Stories can be used as a source of (additional) qualitative information and method of outreach for a project, both when told by members of the project staff and the participants.

More information on the concrete adaptation of story-telling approaches can be found in the guideline on story telling via www.smargrid-engagement-toolkit.eu.

Monetary and non-monetary incentives

Another way to motivate an individual to consume stored energy via battery storage systems can be done with the help of monetary and non-monetary incentives. Common monetary incentives that are at disposal can be divided into three categories as followed:

- Cash awards
- Electricity bills (bonus, malus or discount)
- Gifts (merchandise, energy equipment, etc.)

Cash awards serve several purposes and can be offered in nearly all phases of a process or product cycle, but do not offer high memorable effects nor do they have highly ranked trophy values for the customer. Regarding the acceptance of battery storage systems, the supply of grid services by customers can be rewarded with cash awards.

Non-monetary incentives building on the psychological insights that everyday decisions are often made on the basis of people wanting to do the right thing (whether that be sticking to low price periods, selling grid services or to environmentally friendly periods). In fact, social comparisons, goal setting and other options can be used throughout a project or rollout to induce the intended behaviour. Commonly used non-monetary incentives are either information appealing to gather attention, appeal to social norms or educate the consumer in general. In general, non-monetary incentives appeal to intrinsic motivations like a positive self-image, sense of achievement, social competition, social integration or having fun. Those motivations can be triggered to raise the acceptance of new technologies as well.

To learn more about the different types of incentives please have a look on the S3C-Guideline on monetary and non-monetary incentives via www.smargrid-engagement-toolkit.eu.

Rewards and penalties

As stated in the S3C guideline for a Bonus/ Malus system, habits don't naturally come to people. This especially accounts for energy consumption which in our society mostly is taken for granted an undertaken with different goals in mind, for instance using hot water, simply switching on the light or make use of various energy driven devices. Principally, battery storage systems help to decrease peak load by providing energy stored in the batteries. And still, encouraging individuals to change their behaviour to use energy at other times of the day, for which they could invest in battery storage systems or be a customer of a smart grid, can be done by applying penalties and rewards.

Those so called Bonus/ Malus systems are already common means to change peoples' habits in many different areas. At universities, for examples, such systems are used to prevent students to fail too many exams during their studies, whilst in several countries bonus/ malus systems are applied in vehicle liability insurance systems. Depending on how much damage has been caused or prevented within a set observation period, the insurance rate increases (malus) or decreases (bonus) respectively. Concerning electricity, financial motivation, including different tariffs with dynamic pricing, is the most common tool to influence the individual's habits. Applied on battery storage systems, end user receives financial boni for shifting electricity consumption to off peak load periods. On the other hand, a malus is given, when energy is consumed in peak load periods.

According to the evaluations within S3C, the advantages of this proposed system not only fosters efficient energy consumption but also informs customers, and possibly consumers, about variations of energy production. Furthermore, greater energy prices (malus) are likely to increase the learning effect of customers and consumers more than if they correlate with market energy prices. An ideal example for this system is the eTelligence pilot project which concluded in 2013 and was funded by the German Federal Ministry of Economics and Technology and the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety. Within eTelligence, so called “event tariffs” have been applied onto energy prices per kWh depending on external events, e.g. the weather. Prices for the different time intervals (events) were pre-announced at least a day in advance via different IT communication channels (web portal, smartphone/ tablet app). All in all, the project showed that people strongly reacted to bonus and also malus- events as, for example, a decrease in consumption of up to 20 % for periods of malus- events and an increase of up to 30 % for periods of bonus- events could be observed. Alongside this, project marketing proved to be highly successful for the people’s behaviour as on top of them participating, people engaged in organising joint activities (bonus/ malus events) with high or low energy consumption.

More information on the bonus and malus systems can be found in the according S3C guideline via www.smargrid-engagement-toolkit.eu.

6.1.2 Development of the electricity prices

Responsible Partner: B.A.U.M. Consult

First, it is important to understand what is meant respectively what are the differences between energy prices and costs. For all European citizens the energy bill is partly driven by the quantity of energy they consume. Therefore, the use of more energy efficient products, processes or other energy saving goods can reduce the energy costs. The energy price that consumers pay for electricity is influenced by various factors (market forces and government policy). (European Commission, 2014)

One aspect is the wholesale price. This price reflects the costs incurred by companies in delivering energy to the grid. It includes the costs for fuel, generation, transport and operation and decommissioning of power plants. Another aspect is the end consumer price. Normally, it covers the costs for sale of electricity to the end consumer. The third aspect are grid costs. This costs reflect transmission and distribution infrastructure costs related to the maintenance and expansion of grids, system services and grid losses. Furthermore, taxes, levies or exemptions are added to the other costs /prices. Taxes can be part of regular taxation, e. g. VAT, or specific levies to support renewable energies or climate policies. (European Commission, 2014) Figure 74 summarize the different elements of the end consumer electricity price.

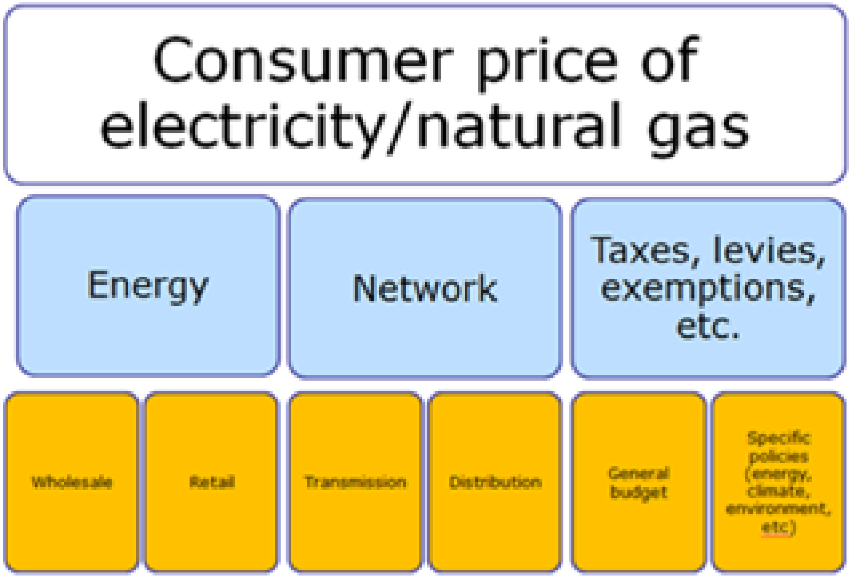

Figure 74: Elements of consumer prices, Source: (European Commission, 2014)

The pricing for electricity take place on regional and more often on national or sub national level. This affects the costs and prices for end consumers and can undermine the single market. Figure 75 shows the electricity prices for medium size households for the ELSA-countries Germany, Spain, France, Italy and United Kingdom.

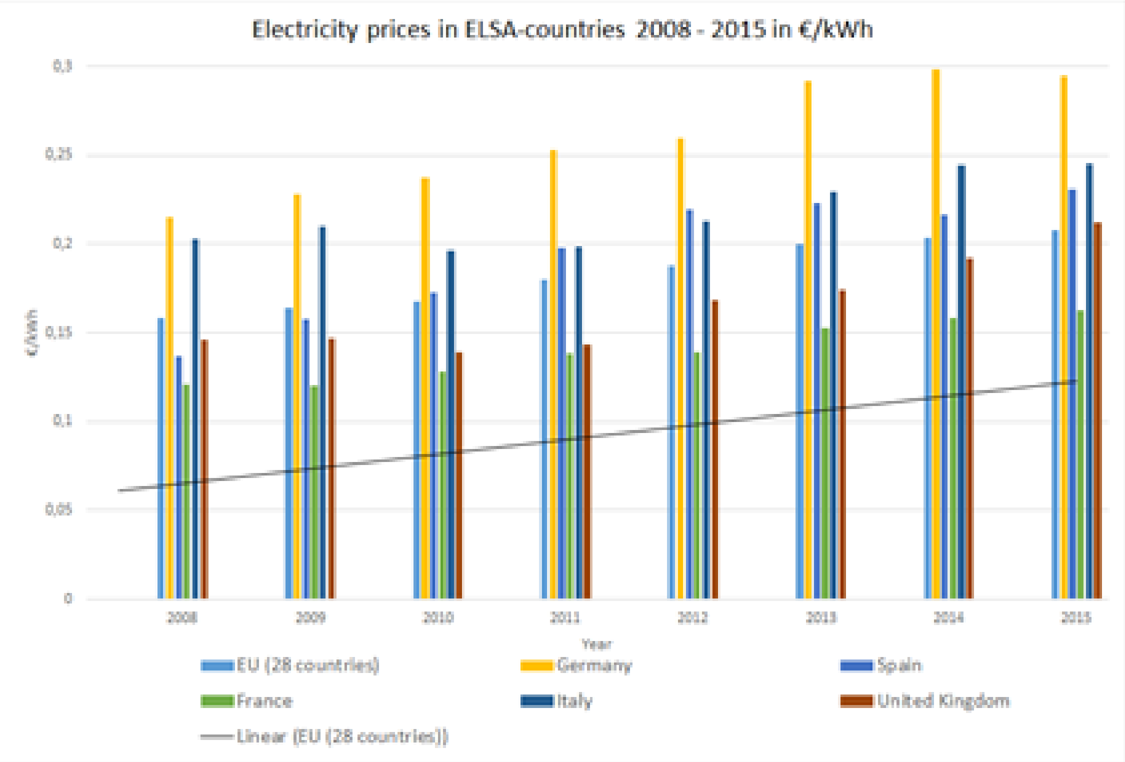

Figure 75: Electricity prices for medium size households in Europe 2008 - 2015; Source: (Eurostat, 2016)

Furthermore, Figure 75 shows the average of the electricity prices of the EU 28. The trend line illustrates the constant rise of the electricity prices within the European Union between 2008 and 2015 (for EU 28).

Figure 75 and Table 17 underline that in Germany has the highest electricity price with about 0.30 €/kWh and France has the lowest electricity price with about 0.16 €/kWh in 2015. However, if we have a closer look at the difference between the electricity price between 2008 and 2015, the electricity price in Spain increased the most by 69 % from 0.14 €/kWh in 2008 up to 0.23 €/kWh in 2015. The weakest increase has Italy with only 21 %.

Country	Electricity prices in €/kWh		Trend	Increase in %
	2008	2015		
EU (28 countries)	0.16	0.21	↗	32
Germany	0.21	0.30	↗	37
Spain	0.14	0.23	↗	69
France	0.12	0.16	↗	34
Italy	0.20	0.25	↗	21
United Kingdom	0.15	0.21	↗	46

Table 17: Development electricity prices medium size households 2008/2015, Source: (Eurostat, 2016)

In contrast to end consumer prices, wholesale prices for electricity decreased by 35 % to 45 % between 2008 and 2012 as major European wholesale electricity benchmarks show. In the same period the electricity prices for private consumers have risen in the average about 4 % every year. The retail price for industry has risen about 3.5 % in the same timeframe. (European Commission, 2014)

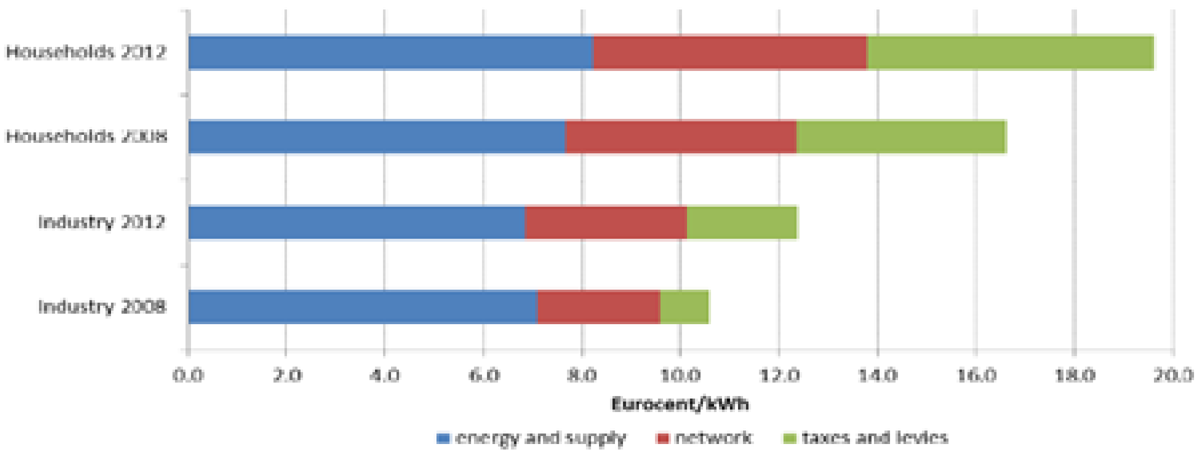

Figure 76: Electricity price evolution by component 2008-2012, Source: (European Commission, 2014)

Figure 76 illustrates the development of the three main parts of the electricity price (see Figure 74). The relative share of the part energy and supply has generally diminished over the last years. Based on the illustration of Figure 76, the relative share of taxes and levies increases the most. The costs for the grid rises about 18.5 % for private households and for industrial consumer about 30 %. The taxes and levies risen about 36 % for private households and about 127 % for companies, without exemptions.

Reasons for the increase of the relative share of the energy and supply costs

As illustrated in Figure 76, the costs for energy are generally the largest. As mentioned above, the wholesale prices declined the last years. The EU energy policies could be a possible cause for this process: the increase of the competition following market coupling, the unbundling rules (division of generation and transmission), the fall in EU emission trading scheme (ETS) carbon prices and the extension of generation capacities with low operating costs, e. g. wind or solar generation.

However, the decrease of the wholesale prices is not reflected in the end consumer prices, even though this is the part of the energy bill where energy suppliers shout competes with each other. The result is a weak price competition in a number of retail markets. (European Commission, 2014)

"The combination of weak demand and wholesale power price dynamics (stable or falling when hydrocarbon prices were on the rise) has put pressure on conventional generation assets. In many cases both the profit margins from the generation business and company share prices were affected negatively, and access to finance has been more difficult.

As a rule, EU utilities need to adapt to this new business environment and have done so by focusing more on downstream services, including decentralized generation and energy efficiency and by gradually divesting their conventional power generation assets." (European Commission, 2014)

Reasons for the increase of the relative share of the taxes and levies costs

It is important to differentiate between general energy taxes and levies. In comparison to the taxes the levies increased significantly in most Member States of the EU. Taxes and levies overtaken the share of grid costs and are now the largest part of the end consumer electricity price in few European countries. In most European Member States energy and climate-policy measures, e. g. supporting energy efficiency or renewable energies, are financed via taxes and levies. The share of renewable energy taxes and levies range from less than 1 % in Sweden up to 15.5 % in Spain and 16 % in Germany. (European Commission, 2014)

National levies cause differences between national markets. Government interventions in the energy sector must be as cost effective as possible to minimize such distortions. The EU regulation framework does not provide rules for a fully harmonized market. Therefore, EU Member States can modify their national taxes and levies individually. Furthermore, taxes and levies are used differently in the Member States, e g. for health and education but also for internalising the external costs for energy production and energy specific policies. (European Commission, 2014)

Reasons for the increase of the relative share of the network/grid costs

The share of transmission and distribution costs vary greatly in the EU Member States. The reasons behind that variety are complex and have different reasons. Figure 77 illustrates the relative share of estimated costs and charges for transmission and distribution across the Member States.

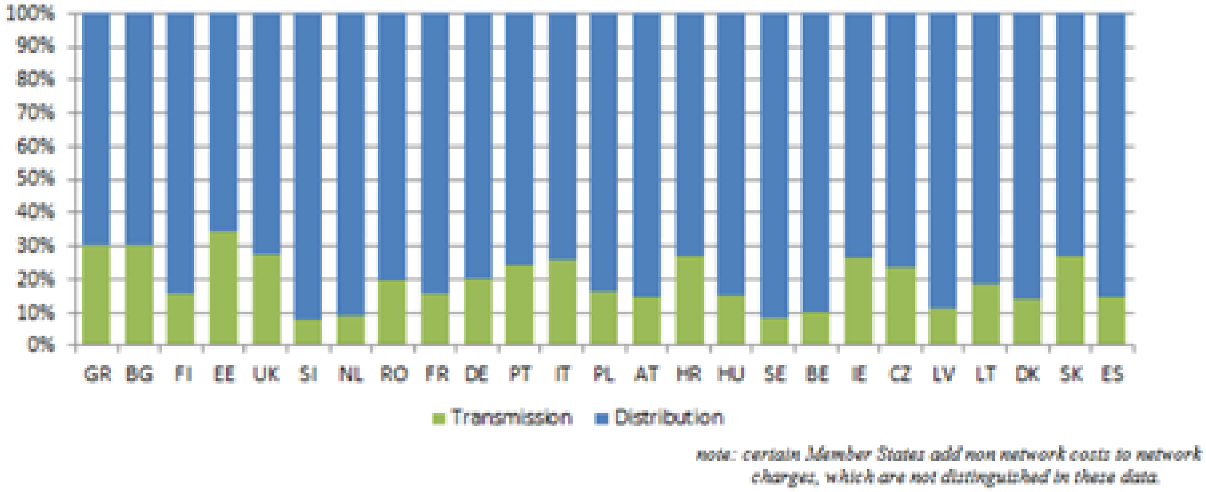

Figure 77: Estimated costs and charges at transmission and distribution level: relative share; Source: (European Commission, 2014)

Since 2008, the electricity grid costs for industrial consumer increased about 30 % and for private households about 18.5 %. “The sustained increase in network costs, in particular for households, is not unexpected in the context of energy sector transformation, but could be mitigated through better network governance.” (European Commission, 2014)

With a price range from 0,02 €/kWh to 0,07 €/kWh, the significant influence of this costs on the energy price is obvious. This leads to differentials across the Member States and trading partners. “Such differentials are also partly driven by widely differing national practices regarding network tariff regulation and cost allocation practices, as well as by physical differences in the networks and the efficiency of their operations.” (European Commission, 2014)

Future development of the electricity prices

Within the Energy Roadmap 2050[22] of the European Commission the future development of the electricity prices was elaborated. The roadmap includes different scenarios how the overall goal reducing the greenhouse gas emission by 80-95 % can be reached. All scenarios have shown that electricity will play a key role in the decarbonisation of transport and heating/cooling. However, the electricity demand increases even in the high energy efficiency scenario. (European Commission, 2011)

[22] The EU has set itself a long-term goal of reducing greenhouse gas emissions by 80-95% when compared to 1990 levels by 2050. The Energy Roadmap 2050 explores the transition of the energy system in ways that would be compatible with this greenhouse gas reductions target while also increasing competitiveness and security of supply. (European Commission, 2016)

Most assessed scenarios of the Energy Roadmap concluded that die price for electricity will increase until 2030, but fall thereafter. The largest share of the electricity price increase take place in the reference scenario. It based on the replacement of old, already fully written-off generation capacity in the next 20 years. In the scenario “high share of renewable energy generation” which implies a 97 % share of renewable sources in electricity consumption (not generation), the calculated electricity prices continue to rise, based on high capital costs and assumptions about high needs for balancing capacity. (European Commission, 2011)

“For example, RES power generation capacity in 2050 would be more than twice as high as today's total power generation capacity from all sources. However, substantial RES penetration does not necessarily mean high electricity prices. The High Energy Efficiency scenario and also the Diversified Supply Technology scenario have the lowest electricity prices and provide 60-65 % of electricity consumption from RES, up from only 20 % at present”. (European Commission, 2011)

6.1.3 Development of the costs for storage systems

Responsible Partner: B.A.U.M. Consult

To assess the development of the costs for storage systems, it is important to know that most information about storage systems, especially battery storage systems, based on the automotive sector. The assessments of the costs or the development of the costs varying but all analysis and studies conclude that the costs for battery storage cells and systems will decrease in high noticeable way. The reduction of the costs will be about 50 % in 5 years and 30 % in 10 years. (VDE, 2015) However, there exist no common view or reference for stationary battery storage systems. Therefore, different analysis will be explained in more detail. After the ELSA-storage system is a lithium-ion based system, the following statements focus on the development of the costs for lithium-ion battery storage systems.

The Boston Consulting Group assumed in the study “Batteries for Electric Cars – Challenges, Opportunities, and the Outlook to 2020” that the current cost of an automotive lithium-ion battery pack, as sold to original equipment manufacturers (OEMs), at between 1,000-1,200 $ per kWh. For consumer batteries, the current costs calculated about 250-400 $ per kWh. The reason for the significant price differential is that “consumer batteries are simpler than automotive batteries and must meet less demanding requirements, especially regarding safety and life span”. (Dinger, et al., 2010) Figure 78 shows the different parts of the battery cost structure.

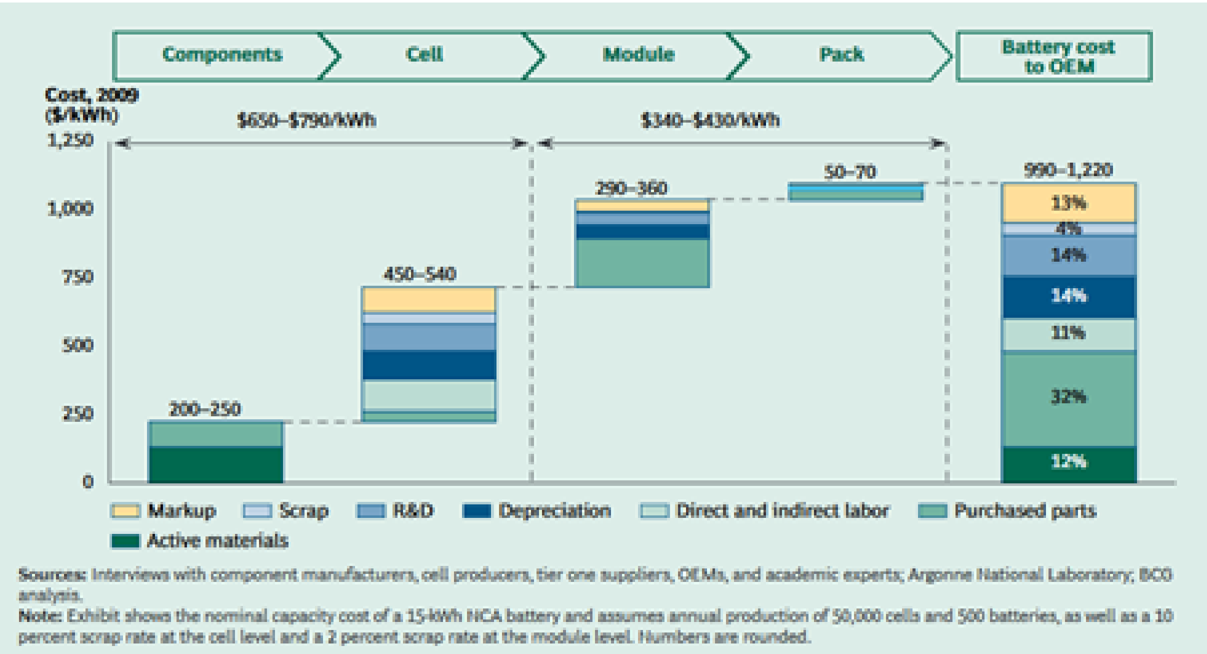

Figure 78: Battery cost OEMs about $ 1,100 per kWh at low volumes; Source: (Dinger, et al., 2010)

Based on the assumptions of the mentioned study, the price that OEMs pay for lithium-ion batteries will decrease around 60 % in 2020. Figure 79 shows the results of the calculations. The cost per kWh of a lithium-ion cell will decrease from 650-790 $ town to 270-330 $ and the cost per kWh of a 15-kWh lithium-ion battery pack will decrease from 990-1,220 $ down to 360-440 $. (Dinger, et al., 2010)

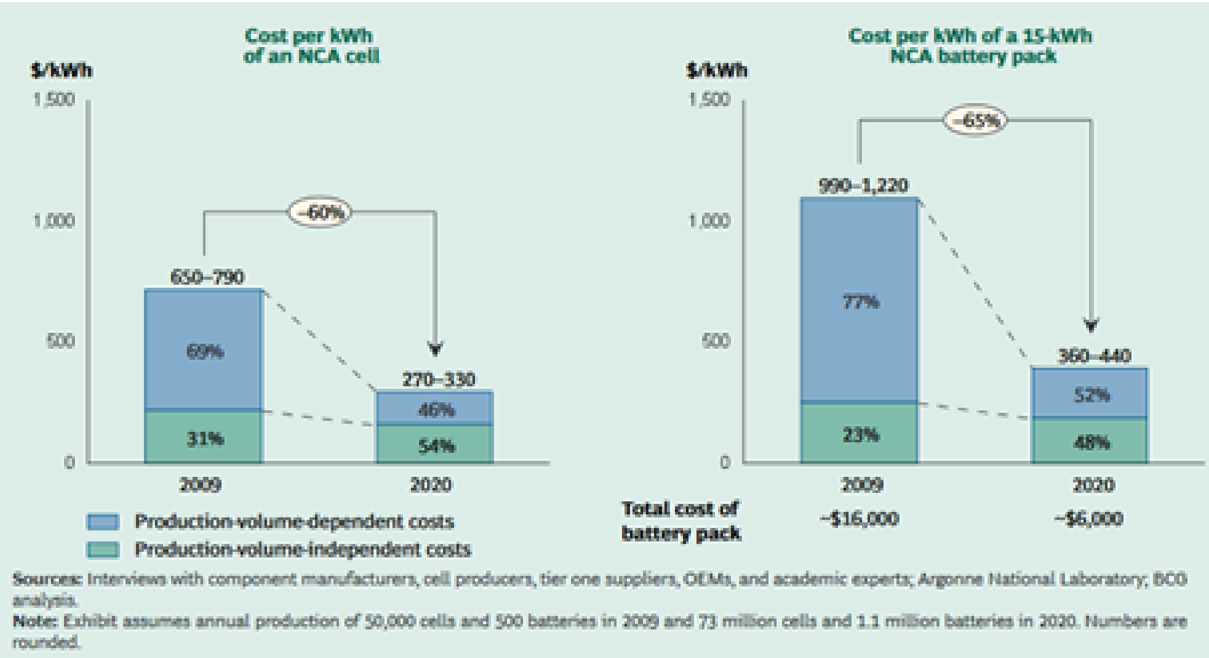

Figure 79: Decline of the battery costs from 2009 to 2020; Source: (Dinger, et al., 2010)

As well as the study of the Boston Consulting Group the German VDE estimate the costs for storage systems. Within the study the results based on the multiannual analysis of the ISEA institute of the ELSA partner RWTH Aachen.

The specific capacity costs for lithium-ion cells decreased in the last five years. The reasons for that are a growth in the production capacities for cells in Asia. At the moment the cell-market is dominated by a predatory competition and cell-producers sell their product to industrial customers on or less than the production costs. Table 18 list the estimated costs for lithium-ion cells for different systems until the year 2025. (VDE, 2015)

Cost categories	2015	2020	2025
Lithium-ion-cells	190-380 €/kWh	150-210 €/kWh	110-180 €/kWh
Lithium-ion-system vehicles	300-500 €/kWh	210-330 €/kWh	140-220 €/kWh
Lithium-ion-system MW-scale	450-600 €/kWh	280-420 €/kWh	150-250 €/kWh
Lithium-ion-system PV-storage	750-1,250 €/kWh	430-680 €/kWh	250-500 €/kWh

Table 18: Development of the prices for lithium-ion-cells and different lithium-ion-systems 2015-2025, Source: (VDE, 2015)

Within Figure 80 the figures of Table 18 are illustrated graphically for lithium-ion cells and different lithium-ion systems.

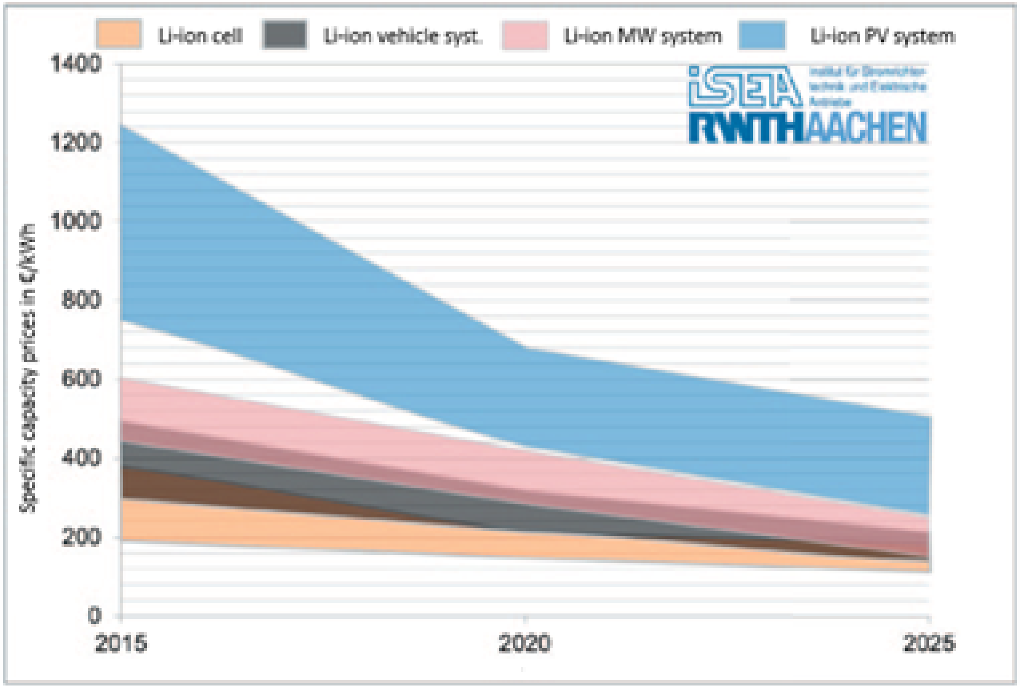

Figure 80: Development of the prices for lithium-ion cells and different lithium-ion systems; Source (VDE, 2015)

As written at the beginning of this chapter, the specialized literature and studies mostly assume the costs for battery systems in the automotive sector. However, separate studies for stationary battery storage systems are not necessary because cells for the automotive sector can be used for stationary applications. The technical requirements, such as mechanical strength are less restrictive for stationary applications. Therefore, cell of the automotive sector can be used for stationary applications without problems. Due to the high volume of production in the automotive sector the costs for cells will decrease over the next years. The development of the market-prices since 2013 confirm the assumed decreasing trend in costs. However, the study concludes that due to the smaller quantity in production the prices for PV-storage systems will be permanently higher that the specific prices (see Table 18) for batteries in the automotive sector. (VDE, 2015)

According to Swedish researchers, the prices for battery storage systems have decreased about 6-9 % in the past. At the end 2014, the market leaders are able to sell one kWh-capacity for 271 € (300 US-$). In 2018 the cost could reach a level around 208 €/kWh and 135 €/kWh in 2025. (Nykvist, et al., 2015)In comparison to the other studies the results assume less costs for one kWh. However, there is a great uncertainty in this research field. The researcher considered 80 assessments for battery costs between 2007 and 2014. The impact of this price-development for stationary battery storage systems is not clear. At the moment, the share of the costs for the battery be a third of the hole costs of the battery storage system.

The rest of the costs are for power electronics, sales, R&D and costs for electronics. Parallel to the other studies it is assumed that the electronics costs will decrease the next years. Figure 81 sums up the results of the considered studies for the estimated costs.

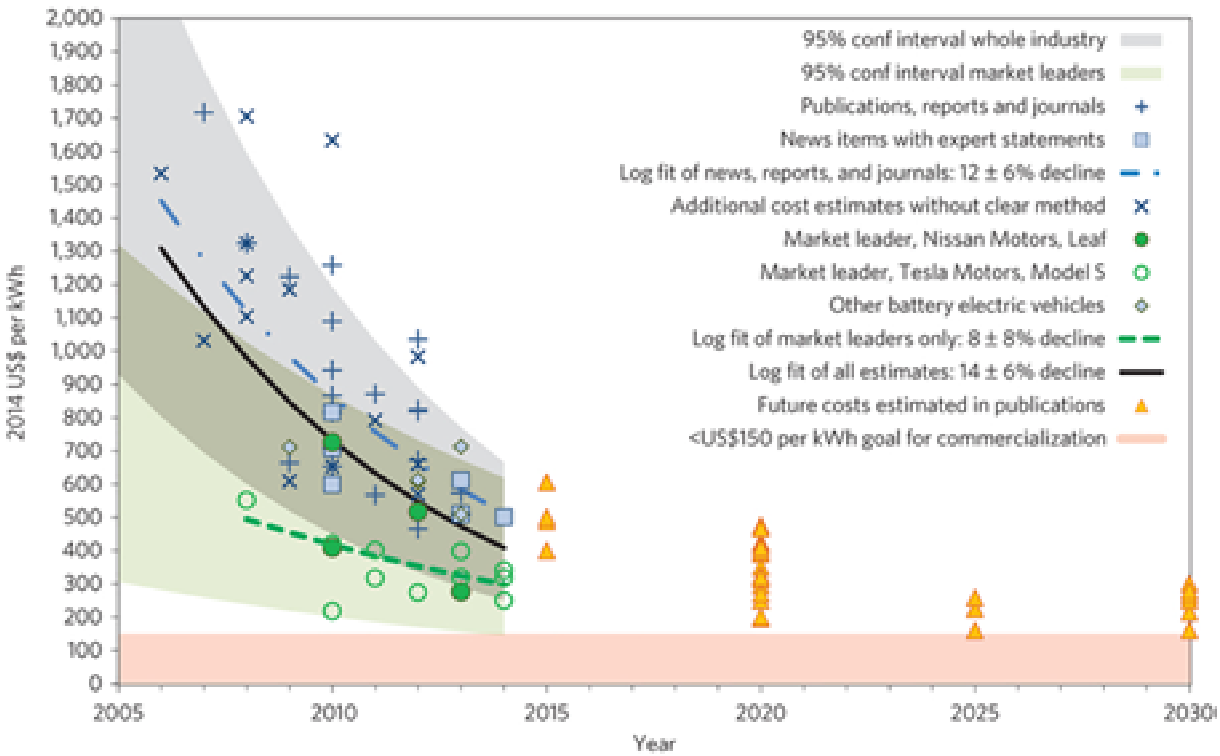

Figure 81: Cost of lithium-ion battery packs; Source: (Nykvist, et al., 2015)

6.1.4 Efficiency level storage system

Responsible Partner: B.A.U.M. Consult

The efficiency level describes the ratio between used and supplied energy in a system. The higher the efficiency level, the lower the losses of energy. The system efficiency level includes the efficiency level of the battery itself as well as the efficiency level of the charge controller and the inverter.

The efficiency level provides information about the charge loss of the battery. The main reason for efficiency loss of energy storages is the internal resistance of the battery cells during the charging and discharging process of the battery storage systems.

In general, a battery discharges over time even if it is not used. Besides the charging efficiency level this phenomenon reduces the efficiency level of the system of the battery storage. The self-discharge is sensitive to temperature changes. The lower the ambient temperature less often the battery self-discharges. (Energie-Experten, 2016) Figure 82 illustrates the efficiency level of different storage systems in 2012. Especially short-time storages as coils, capacitors, fly wheels and lithium-ion batteries have a high efficiency level. In comparison, hydrogen and compressed are storage have a lower efficiency rate.

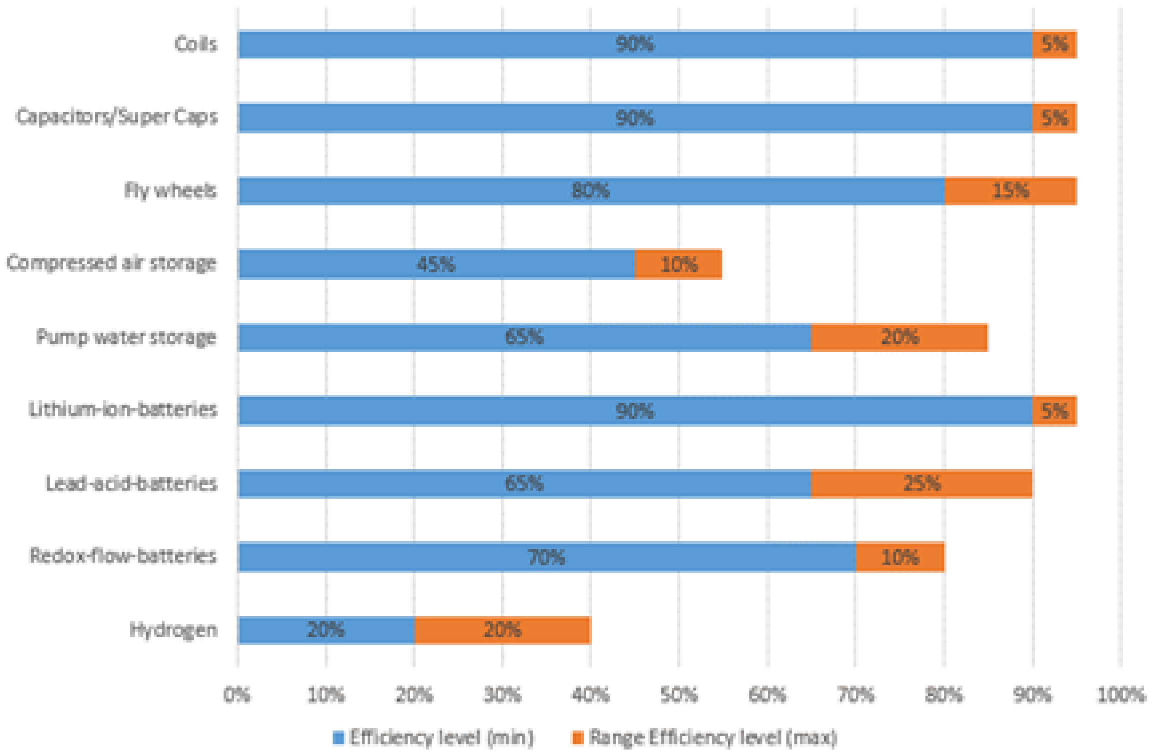

Figure 82: Efficiency level (in percent) of different energy storage systems 2012; Source: (Statista, 2016)

Efficiency level of battery storage systems via AC- and DC-coupling

The integration of the battery storage system affects the overall efficiency level in a significant way. Battery storage systems can be connected via AC- or DC-coupling. For example, if a household with an PV-installation want to use a storage system to increase the quote of self-consumption (see chapter 0) there are to options how the storage can be integrated and connected to the electricity network of the household. On the one hand, the energy storage can be connected to the AC-circuit of the household after the inverter of the PV-system (AC-coupling). Basically, a solar-battery is charged with direct current. Therefore, AC-coupled systems have an additional inverter to transfer the alternating current into direct current. For discharging the inverter transfer the stored electricity from direct current tot alternating current. This process reduces the efficiency of the storage system. As a rule, lead batteries only reach an efficiency level of about 70 %. (Leipziger Institut für Energie GmbH, 2014)

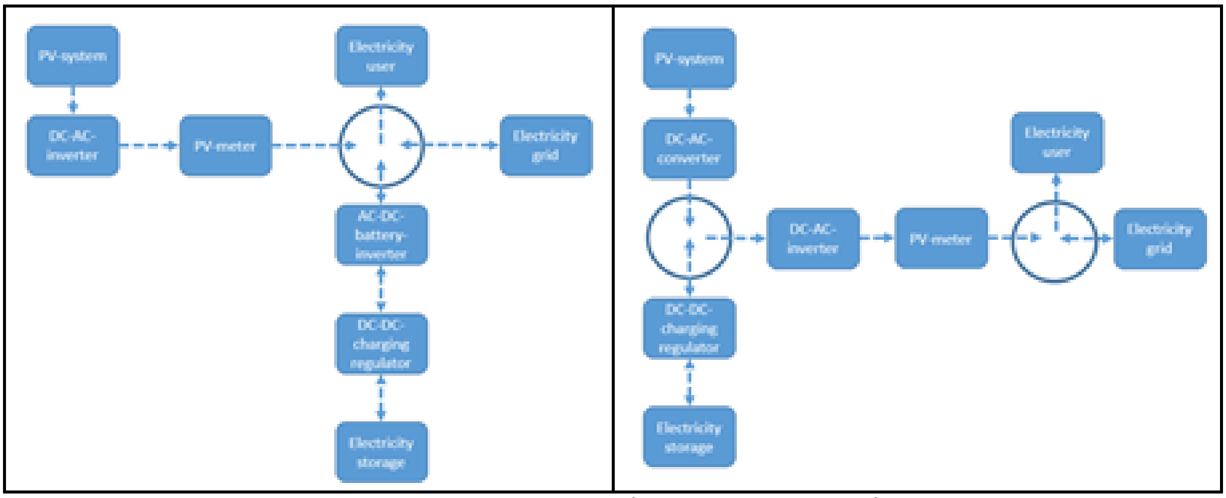

Figure 83: AC- and DC-coupling of an energy storage; Source: (Energie-Experten, 2016)

On the other hand, the energy storage can be integrated and connected to the DC-circuit in front of the inverter of the PV-system (DC-coupling). DC-coupled systems do not need an additional inverter because the storage system is charged directly with the generated direct current of the PV-system. Hereby, the efficiency level of the hole systems is higher. For example, lithium-ion batteries reach an efficiency level of about 90-95 % (see Figure 82). (Energie-Experten, 2016)

The German C.A.R.M.E.N. society (Centrale Agrar-Rohstoff Marketing- und Energie Netzwek e.V.) listed over 220 battery storage systems from 46 suppliers to provide a market overview about existing storage solutions for different applications (see chapter 5). The study contains following different categories, e. g. type of cells, storage capacity in kWh, efficiency level, or price for end customers. The study about the market overview for battery storage can be download via www.carmen-ev.de.

Influence of the efficiency level on the economic efficiency of the storage system

The different efficiency levels (see Figure 82) and the different ways to integrate storage systems, affect the economic efficiency of storage systems in a significant way. The basic principal is as follows: the greater the share of losses of electricity during the charging process, the higher the costs for the electricity storage. (Energie-Experten, 2016)

Regarding the efficiency level and the fact that the ELSA-storage system uses lithium-ion cells, three major cost effects should be considered for an economical assessment of a storage system:

- Lithium-ion batteries have a higher efficiency level as lead-acid batteries, but they are more expensive than lead-acid batteries. Considering the number of cycles, efficiency level and depth of discharge lithium-ion batteries are more cost-effective with regard to the life cycle.
- DC-coupled systems do not need an additional battery inverter which reduces the costs. However, if a DC-coupled system is installed afterwards, the inverter of the PV-system (if a system is installed) must be exchanged. This lead to additional costs for the exchange-measures.
- The lower efficiency level of AC-coupled systems can lead to additional costs for buying additional electricity. This increases the operating costs.

6.1.5 Market and regulatory framework

6.1.5.1 Germany

Responsible Partner: B.A.U.M. Consult

In Germany, the main regulations concerning the storage of electricity are specified in the "Energiewirtschaftsgesetz" (EnWG) and the "Erneuerbare-Energien-Gesetz" (EEG). However, the existing regulations are not a comprehensive regulatory framework. Different interpretations cause legal uncertainties in the field of storage systems. Based on these uncertainties, legal experts characterise the existing framework as "fragmented". The legislator bodies recognized this problem and the framework will be expanded and refined within the next years. In the following, an introductory overview of the existing legal framework for energy storage systems is given. Furthermore, current obstacles within the German energy market will be addressed.

With respect to the applied ELSA storage system, three types of electricity use are relevant for Germany – self-consumption, direct marketing of electricity and feed-in premium.

Self-consumption

The EEG defines self-consumption as the consumption of electricity by a natural or legal person who is directly linked to the generation unit in physical proximity. Furthermore, no public electricity grid is used for the transmission and the person must be the owner of the power unit (EEG, 2014). However, there are exceptions, for example leasing. To avoid a legal dispute, all relevant details should be required in a written contract.

Since 2014, the owner of new installed power units using self-consumption must pay partial the so-called EEG-apportionment[23]. Based on different criteria, the percentage share of the EEG-apportionment varied. For further information, please have a look at the § 61 Abs. 1 S.1 EEG 2014.

A special factor in case of self-consumption is the value added tax (VAT)-treatment of the self-consumed electricity. This is only relevant for entrepreneurs. Although the electricity is self-generated, VAT must be paid for the self-consumed electricity. This is a particular case in the German VAT-law (§ 3 Abs 1b S. 1 Nr. 1 UStG). If an operator of the self-consumed electricity is only a small-scale entrepreneur, no VAT must be paid for the self-consumed electricity.

Direct marketing of electricity

The EEG defines direct marketing of electricity as the disposal of electricity from renewable energies or firedamp to third parties. The direct marketing can be divided in two categories – direct marketing with market premium and direct marketing without market premium (EEG, 2014). The first variant is the preferred option in case of direct marketing of electricity in Germany, at the moment.

Renewable energy plant operators can claim the market premium if they sell the generated electricity directly and permit the DSO to brand it as “current from renewable energies resources”. Furthermore, the regular network tariffs must be paid and the plant needs a remote control feature. In addition, the electricity must be recorded in an accounting grid or sub-accounting grid to claim the market premium (EEG, 2014). Further information about the market premium and its calculation can be found in EEG 2014 Anlage 1. In contrast to self-consumption, direct marketing of electricity is not liable for VAT.

23 The EEG-apportionment is the difference between the costs for promoting renewable energies and the revenue of the produced and sold power from renewable energies. This difference is allocated to the end-consumer of electricity.

Feed-in premium

Based on the EEG 2014, two forms of feed-in premium are available – feed-in premium for small-scaled plants and feed-in premium for exceptions. § 37 EEG regulates the feed-in premium for small-scaled plants. The operators of small-scaled plants can claim the feed-in premium from the DSO if the respective plant put into operation before the 1st of January 2016 and the installed power is less than 500 kW. Moreover, an operator can claim the feed-in premium from the DSO if the respective plant put into operation after the 31st of December 2015 and the installed power is not higher than 100 kW. (EEG, 2014)

Small-scaled plant operators can claim the feed-in premium, even the generated electricity was stored temporarily in a battery storage system (Trockel, et al., 2014). However, the small-scaled plant operators don't get an additional fee for the temporarily stored electricity. Therefore, the incentive for temporarily storing is very low.

Grid connection and grid access for energy storage system

Operating battery storage systems, it is necessary that these systems are able to purchase and to feed-in electricity from and into the grid. It must be distinguished between the grid connection and grid access. Grid connection is the physical connection between a plant and the grid. Grid access enables the connection to use the grid. Based on the grid access, an operator of a plant can claim the grid connection. According to § 20 EnWG, grid operators must grant direct access to the grid. This also applies for battery storage systems. Grid operators can refuse the grid connection and grid access for battery storage systems. In case of bottlenecks, if the grid operator denied the grid connection and -access, § 11 EnWG must be observed. If a grid operator denied the access and connection regarding bottlenecks, the grid operator is obligated for grid expansion. (VDE, 2015)

According to § 8 EEG, the owner of a battery storage system can claim the right of priority grid connection, if the system only stores (temporary) energy from renewable energy resources. Priority grid connection means that this storage system must be connected firstly. Then, other assets can be connected with the grid. If a grid operator denied the grid connection regarding bottlenecks, the grid operator is obligated for grid expansion (§ 8 Abs. 4 EEG) (VDE, 2015).

Legal affiliation of the energy storage

Based on § 5 Nr. 1 clause 2 EEG 2014, a plant is a device for generating or temporarily storing energy from renewable energy resources. Simultaneously to the EEG 2014, an energy storage system is described as a plant in the EnWG, too. For that reason, the regulations of §

49 EnWG must be observed. In Germany, the technical regulations of the association for electrical, electronic & information technologies (VDE) are mandatory. This framework explains the technical connection rules for plants in relation to grid technique and grid operation. In addition, the federal network agency can issue additional rules (Werner, et al., 2015).

Energy storage systems can be seen as end consumers according to § 3 Nr. 25 EnWG and § 5 Nr. 24 EEG 2014, if the systems store energy from the public grid. For this definition end consumers are all natural or legal person buying electricity for their own consumption. A judgement from 2009 of the federal supreme court (BGH) supports this viewpoint. Operator of a pumped-storage power plant are end consumers within the meaning of § 3 Nr. 25 EnWG, because the pumped-storage power plant takes electricity for its operation from the public grid (BGH judgement from 17.11.2009, EnVR 56/08). As an end consumer, the operator/user of the storage system must pay all charges for grid usage, for example EEG-fee, concession fees or network charges. (Werner, et al., 2015)

Financial burden of the energy storage

As written before, the ELSA energy storage system can be seen as an end consumer. Therefore, the following remarks refer to the energy storage system as an end consumer with all financial burden. Based on the end consumer characteristic, the following costs, fees and charges must be paid for an energy storage system, if it is connected to the public grid and purchase electricity from the public grid:

- Grid use fee
- Electricity tax (StromStG)
- EEG-apportionment
- Concession fee
- CHP (combined heat and power)-apportionment
- § 19 clauses 2-StromNEV-apportionment (electricity grid access charges)
- Offshore-liability-apportionment
- § 18-AbLaV-apportionment (regulation on switched loads)

In addition, the VAT and the common electricity price must be paid in case of electricity purchase. The named costs must be paid if the system is only connected to the public grid. Decisive is purchase of electricity from the public grid.

Nevertheless, there are special regulations for new storage systems within the German regulatory framework. New installed storage systems put into service are freed of grid use fees for 20 years. This is only applicable for the procurement of electricity (§ 118 Abs. 6 EnWG) and if the following conditions are met (Bourwieg, 2015):

- the storage system was installed after the 31st of December 2008
- the storage system was put into service between the 4th of August 2011 and the 3rd of August 2026 (= 15 years)
- take up of the stored electricity from a transmission or distribution grid
- real electrical, chemical, mechanical or physical storage
- time lag feedback/feed-in into the same grid

Furthermore, according to the regulations of § 57 Abs. 3 EEG, storage systems can be permanently freed from the EEG-apportionment if

- the storage system takes the electricity from the public grid or uses self-generated electricity for its operation,
- the storing of energy is electrical, chemical, mechanical or physical,
- the stored electricity will be exclusively fed back in the public grid,
- the stored electricity will be used for production of stored gas.

Besides these regulations, electricity taken from the public gird which is used for generation has to be exempted from the electricity tax to avoid double taxation (§ 9 Abs. 1 Nr. 2 StromStG). However, in accordance to §12 Abs. 1 Nr.2 StromStV, this exemption is permitted only for pump water storage systems. Battery storage systems are not mentioned. (Bourwieg, 2015)

Within this context, the hierarchy of the different laws must be observed. The StromStG is on a higher level than the StromStV. Therefore, it could be possible that also other storage systems, besides pump water storage systems, could benefit from this exemption.

Current obstacles within the respective energy market

The existing regulations are not a comprehensive regulatory framework. Different interpretations cause legal uncertainties in the field of storage systems. Furthermore, battery storage systems need a definition regulated by law. At the moment, battery storage systems are plants and end consumers. This definition limits the economic operation of battery storage systems.

From a legal point of view grid operators cannot operate storage systems, because the unbundling rules must be observed. Grid operators can only be "consumers" of storage capacities. According to § 6 EnWG, grid operators are not allowed to run or operate battery storage systems. There is only one exemption, if the battery storage systems will be used as back-up power for the grid. If a third party is the operator of the storage system, it can participate in the regular energy markets. Only grid operators are forbidden to operate storage systems, because of the unbundling rules. This means, if the grid operator is the owner of the storage system, this system cannot participate in the regular energy markets.

With a view to the European energy union and the European internal market, storage systems in Germany have a competitive disadvantage comparing to storage systems in the other European member states. The charges for end consumers and several fees for energy storage systems leads to disadvantages for storages systems in Germany.

The investment costs for energy storage systems are at least higher than investment costs for conventional gas-turbines and gas turbines can provide a lot of the same system services. Within this context there are no real incentives for investors, based on the legal uncertainties in the field of energy storage systems.

Furthermore, there are technical and technological obstacles, such as the capacity and the quote auf efficiency. At this point further research and development effort is needed.

6.1.5.2 **France**

Responsible Partner: Nissan Europe

The electricity market in France is subject to the control of the CRE (Energy Regulatory Commission). CRE is a French independent administrative authority, established on 24 March 2000 (Comission de Régulation d'Energie, 2016) and responsible for ensuring the proper functioning of the energy market and to arbitrate disputes between customers and various operators, also the neutrality and the proper functioning of electricity grid, with the ability to take sanctions against recalcitrant operators.

There are also local regulators, all the municipal or regional authorities as concessionary, have a legal regard on the distributor's activities that must submit their annual report, particularly with the National Federation of the local authorities and concessionaries comprising nearly 500 local authorities who organize public services, including energy, water and environment.

Since the electricity is considered in France as basic necessity, the main concern of the French government still focuses on the security of electricity supply and the accessibility of electricity. Thus the electricity tariff, the obligation de purchasing PV electricity, and the electricity market are still highly regulated in France. This regulatory framework seems unhelpful and hindering to the development and implementation of ELSA services offer on the French market. In concrete terms, these regulatory barriers can be summarized into several following points:

- Flat tariff of electricity disadvantageous for economical application of ELSA service;
- High price of purchasing electricity generated by PV hindering its self-consumption;
- Certification of building energy efficiency regardless of ESS;
- Aggregation limited to Electricity consumption curtailment with minimal capacity requirement.

In respect to the applied ELSA storage system, three types of electricity use are relevant for France – self-consumption, direct marketing of electricity and feed-in premium.

Self-consumption

Self-consumption is the part of production plant consumed in the building where it is storage. For ENEDIS (ENEDIS), a customer is on total self-consumption mode when the storage system is not connected with the grid by a meter. In others words, all the energy produced is injected to the grid. Some consumers on the partial self-consumption mode can maybe connected to the grid by a meter if the production/consumption are made in different periods of the day.

The solutions of storage of energy divide into four main categories:

- The potential mechanical energy (hydroelectric dam, Station of Transfer of Energy by Pumping (STEP), STEP in maritime fascia, storage of energy by compressed air (CAES);
- The kinetic mechanical energy (flywheels);
- The electrochemical energy (piles, batteries, compensators, vector hydrogenates);
- The heat energy (latent or sensitive heat).

With the current rates of purchase, higher than the selling price of the electricity retail, it remains more profitable financially to sell the totality of production and to buy the totality of the electricity which we consume. Find an economic optimum in its consumption of energy by integrating the storage in the heart of its activity and of its processes motive the generation of the incomes of disappearance thanks to the current devices and anticipate the installation of the contract of capacities. So, help to reassure its supply in energy and to make sure of the quality of power feed for its installations.

Direct marketing of electricity

The imbalance between offer/demand of electricity are translated on main part markets by price differentials between the rush hours and the flat periods. The storage of energy allows a producer to benefit from an earning in flexibility grace into which he can choose to inject on the network the electricity when his price is raised, or to take away it when its price is lower. It is the main way of valuation of the storage of energy today. The uncertainties raised on the changes of the market the electricity impacting negatively the decisions of investment resting on the valuation of this service.

Feed-in purchase agreement characteristics

The French market has an application for purchase agreement with EDF (included in the grid connection application). So EDF attachment agreement to balance perimeter or other balance responsible entities. The date of application for grid connection determines PV feed-in tariff and a 20-year contract term. (SK & Partner, 2015)

A new framework, guidelines N. 2014/C 200/01 have been published in the Official Journal of the EU on June, 2014 relating to state aid for electricity from renewable energy sources. Some decisions below:

- Feed-in premium mechanism from January 1, 2016;
- Grant of a premium in addition to market price applies to plants with installed power capacity greater than 500 kW;
- Standard balancing responsibilities shall apply to the beneficiary of such premium;
- Competitive bidding procedure from January 1, 2017 for plants with installed power capacity greater than 1 MW;
- Procedure based on clear, transparent and non-discriminatory criteria;
- Failure of bidding procedure, the above-described feed-in premium scheme shall apply.

Feed-in premium scheme

EDF will have to enter into an “additional remuneration” agreement upon request of renewable energy producers (as listed under article L.314-1 of the Code de L‘Energie and to be further defined by decree). Such agreements with EDF are administrative contracts and plant benefitting from additional remuneration might be subject to an inspection upon commissioning or periodical inspections (conditions to be detailed by decree).

Also, the new rules will apply for new plants only (in specific cases to be defined by decree plants benefitting from a feed-in tariff purchase agreement with EDF will be entitled to switch to the new feed-in premium scheme). And existing power purchase agreements with EDF shall remain in force.

The "additional remuneration" might be partially or entirely suspended in the event it no longer fits targets of the "Programmation Pluriannuelle de L'énergie". However, the draft law explicitly provides that agreements in force (contrats en cours) shall remain in place. The draft law sets forth criteria to be taken into account for the calculation of the "addition-al remuneration" to be further detailed by decree (décret) and specific orders (arrêtés) for each renewable sector.

Grid connection and grid access for Energy Storage System

In France, like at European and international levels, there are not any legislative or normative initiative on the installation of Energy Storage Systems (ESS).

However, the French law is well attached to the electrical installation safety and the protection of persons through several government orders to strengthen audit, inspection and certification of regulatory and normative compliance and of these electrical facilities. All ELSA services systems in France, as an electrical installation, must comply with these regulatory framework and compulsory normative reference NF C15-100.

The annexes of government order of 26 December 2011 have particularly well detailed (INRS, 2011):

- the method and the scope of audits of electrical installations, covering both the calculation notes, schemas and diagrams, technical documentation, technical prescription, examination on site, work equipment, the measurement of continuity of the earthing and LV isolation, tests on the mechanical and electrical function of residual current protection devices in LV;
- the content of initial and periodic audit reports and definition of trace ability elements, including general information of the establishment, the main characteristics of the checked electrical installation, operations of verification, the summary of non-conformities, examination in function of regulatory provisions, results of measurements and tests.

The French standard NF C15-100 (French Energy Code, 2015) also provides devices for the installation and commissioning of low voltage electrical installations, particularly,

- the qualification of technician and the quality and conformity of electrical materials;
- the obligation of verification and testing of electrical installations prior to its commissioning and any significant changes.

Financial burden of Energy Storage

In the model of self-consumption, the need of direct subsidy of an installation by the CSPE (Contribution to Publics Services) will seem lesser than if it was in obligation of purchase: the cost of the installation stays the same in both cases but in the case of the model of auto-consumption / auto-production, the direct subsidy compensates for the distance between the normalized production is and the selling price TTC of the electricity, while in the case of the model of the obligation of purchase, the subsidy compensates for the distance between the normalized production cost and the price of the electricity on big market.

This reduction must be nevertheless put on the opposite page with the transfers of responsibilities led besides on the other consumers. Indeed, the savings realized by the auto-consumer his invoice, notably in terms of coverage of the costs of network and taxes must be recovered with the other consumers and the taxpayers. The amount of the public support necessary for the coverage of the costs of the installation is thus similar in both models: it is assured by the CSPE in the case of the obligation of purchase and corresponds to the sum of the direct subsidy perceived by the auto-consumer (financed by the CSPE echoed to the consumers) and transfers responsibilities caused (CSPE, TCFE, VAT and avoided TURPE who must be collected with the consumers and the taxpayers) in the model of auto-consumption (Anforderungen).

Current obstacles within the respective energy market

Technology and economic barriers can be reduced by supporting research, for example by funding programs. 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.

As a regulation issue, it needs a harmonization of European Energy Policy (Directorate General for Internal Policies, 2015). In others words, European countries have difficulties to find a common position concerning the future energy mix which has a negative effect on investment planning.

In the market sector, a single service may be insufficient for an economical use: comprehensible business models are needed. Besides, an appropriate market signals and schemes for storage are missing. So, utilities are risk averse and need planning security. Market pricing systems often do not enable time-of-use tariffs and do not accommodate for variation over time of production costs. Furthermore, operation concepts for storage are manifold, so the establishment of general regulations is challenging.

6.1.5.3 **Italy**

Responsible Partner: Engineering

General types of electricity use (for example if applicable self-consumption, direct marketing of electricity, feed-in remuneration)

In Italy, the exploitation of electricity storage is still in an early stage with limited possibilities of usage. However, the country is involved in a deep reformation of the market regulation framework that is planned to switch in its operational phase at the beginning of next year.

Original organizational model was based on a vertical monopoly controlled by Enel S.p.A. acting as leader and dominant operator. The overall transition is articulated in three main phased starting with a decree dated March 16th 1999, n. 79 (named Bersani decree); it established the public service principle in order to protect end customers and with the general goal to create favourable conditions for the emergence of a competitive market. It was established a unique manager for the national power network, Terna S.p.a., for about 90 % of the total national service. The following schema depicts the three phases and the correspondences with EU market and environment.

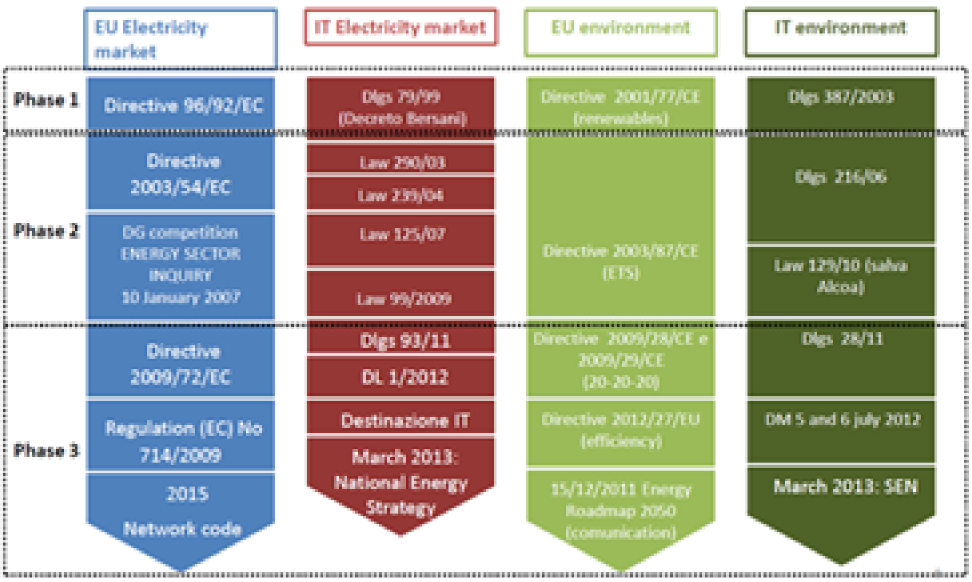

Figure 84: Italian market main regulation references, Source: (Virginia, 2014)

At this stage, the storage of electricity in Italy appears substantially as a solution to boost sustainable distributed generation in self-consumption, for both residential-commercial activities and for industrial sector. There are some pilot projects, essentially managed by big TSO Terna, that are experimenting storage technologies and modalities of network services exploitation. The following figure provides an overview of the on-going situation with some details on the dispatching market roadmap.

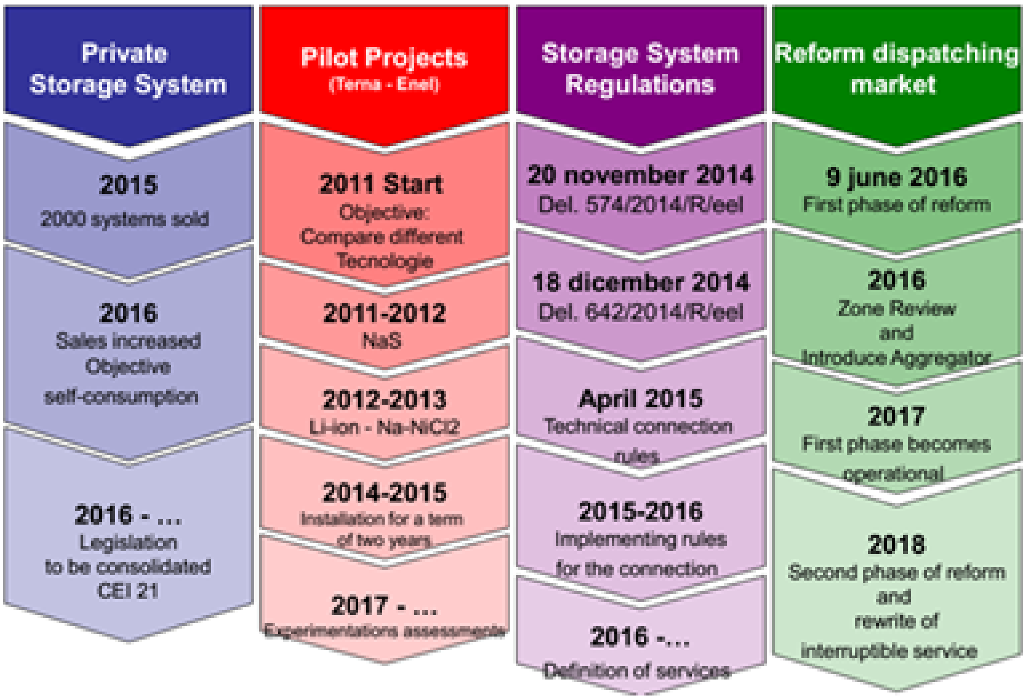

Figure 85: Storage System in Italy - Situation and RoadMap; Source (Engineering, 2016)

Grid connection and grid access for energy storage

As of the end of November 2014 AEEGSI (Authority for Electricity, gas and water system) issued two important resolutions that for the first time in our country determine the method of connection to the electricity grid in medium and low voltage, the performance characteristics and the fields of application of electrochemical storage systems, also combined with power generation plants from renewable sources.

With the publication of the said decision it was finally created the concrete and actual conditions for grid connection and access to energy. Both the publications took place in December 21, 2014; these are the latest variants of technical standards CEI 0-21 (for low voltage) and CEI 0-16 (for medium voltage), to enable industry, users and operators of energy services to plan their projects and investments in the presence of certain rules. Among the various applications of storage systems to enable this new energy paradigm, one of the most promising is the development of systems aimed at maximizing the consumption of self-produced energy from renewable energy plants in SEU regime (Of Utility Efficient System).

Legal affiliation of the energy storage

As the CEI 0-16 and 0-21 upgrade is still pending, and in order to define the technical requirements to provide network services, the Resolution 574/2014/R/ eel disposed provisions/regulations aimed to enable the management of storage systems connected to the distribution network.

AEEGSI defined first provisions on the integration of electricity storage systems in the national electricity system, with particular reference to their mode of access and use of the transmission network and distribution. With regard to the mode of access and use of the public network, the fee for the connection is the same used for high efficiency cogeneration plants. With regard to the dispatch, this resolution provides for such systems to be treated both as individual production facilities and as generation units that make up a single production facility.

In addition, it introduces the technical document with the requirements for storage systems contributing to the security of the national electricity system, similar to what already established for distributed generation, defining the network services required during the connection to the national network.

Financial burden of the energy storage

In general, for the purposes of the rules, a storage system is assimilated to a production facility powered by non-renewable sources. However, until the completion of the regulation rearrangement and as it is for the installation and use of storage, they are applying the same procedural and economic conditions than we have in the case of high-efficiency cogeneration plants.

Therefore, the connection of a storage system is managed as any request for connection of a production unit, and the applicant/user is required to pay:

- A fee to obtain the installation budget estimation
- A fee for the connection, calculated on the basis of power for the purpose of access, the distance to the nearest transformer substation and the distance to the nearest transformer station.

As for other types of production plants accumulation systems have the possibility to choose the mode of transfer electricity produced and fed into the network:

- Dedicated withdrawal (*Ritiro dedicato*): the price and economic conditions are defined by the Authority referring to the market;

- Net metering (*Scambio sul posto*): considering net difference between production and consumption via energy credits; Credits have a fixed expiration timeframe and have to be consumed locally in the specific timeframe. The user pays for the net difference.

Many domestic users are opting for the installation of storage systems for self-consumption, this is reducing the costs for transport and dispatch; in case of island mode it is avoiding to connect to the national grid, so not spend the general expenses of management of the system, such as transportation and dispatching.

Marketing of system services for the grid

Under the new legislation, it is determined the potential use of storage systems that is to participate in the dispatching market as production facilities.

Therefore, a storage system, may contribute to the flexibility of the electrical system participating at the balancing market as independent units, with appropriate energy provision and storage.

However, the legislation is not yet complete and there is still a lack in information on possible system services that will be provided.

In addition, currently, it is not possible to participate in the dispatching market with non-programmable renewable sources, which are often associated with storage systems. On this point we must wait for the outcome of the dispatching market reform launched in June 2016.

Marketing of the stored energy

A part the contribution of flexibility that will give storage systems to the power grid the new framework is starting the private market of domestic consumption.

Storage system for residential PV is experiencing this year a small boom. The market is proposing lithium or lead-acid systems together with the solar panels thus minimizing the traffic with the network.

For a domestic user it is estimated that, on average, the investment required can be recovered in 7-8 years. Prices for a 3 kW photovoltaic system with lead(Pb) accumulation are about 10 thousand euro; with lithium battery solution the price rise up to 15 thousand euro with the investment recovery remaining 7-8 years and the average system life is 10-12 years.

Current obstacles within the respective energy market

The legislation on the storage systems and the electricity market reform are not yet completed but it seems it is going in the right direction with regard to the market possibilities of these systems; the consideration is valid both from the point of view of system services to the network and from the point of view of self-consumption.

In recent years, both Terna and Enel have invested heavily on pilot projects, with the objective to evaluate different types of technology for energy storage.

First analyses are underling that in the near future we will need to have a mix of technologies to handle the produced electricity storage. To accomplish this goal, the hydroelectric pumping systems will continue to be the best in terms of installed capacity, but also different types of stationary storage systems become significantly important in the whole system, thanks to their flexibility, especially for small applications and in decentralized areas.

The success of the batteries will depend upon the reduction of technology costs, planned for the coming years. In the short term they batteries will have to compete with other technologies, for example there is a good business potential for the accumulation of compressed air systems, particularly suitable for centralized systems of electric generation. According to the study, in fact, since 2020 storage technologies that use hydrogen could replace compressed air systems and even hydroelectric pumping systems. The hydrogen technology guarantees high flexibility, store a large amount of energy with particularly high levels of efficiency.

There is also a success factor dependency on the feeling that investors will have on one technology instead than others; it will depend on the capability to reduce investment and maintenance costs to achieve profitable solutions ready for the market.

6.2 Potential impact of ELSA ESS on electricity system costs

Responsible partner: B.A.U.M. Consult GmbH.

6.2.1 Mechanisms for impact on electricity system costs

As any flexibility in the electricity system, grid-connected energy storage systems (ESS) can make an impact on the overall electricity system costs in several ways. The operation of the (national or other) electricity system as a whole and related operation expenditures (OPEX) can be modified in various ways:

- demand / generation profiles are flattened thus reducing variations of the market price of electricity; if this leads to a higher share of cheaper conventional fuels in thermal power plants, overall system OPEX are reduced
- redispatch of generation units is avoided thus allowing units with the respectively lowest marginal cost to cover the demand
- frequency response operations are provided by storage units or other flexibilities thus (1) avoiding expensive quick load changes of thermal power plants and (2) permitting them to operate closer to their nominal power without a margin for frequency response
- reserve operations are provided by storage units or other flexibilities thus (1) avoiding load changes of thermal power plants and related costs and (2) permitting them to operate closer to their nominal power without a margin for frequency response
- more renewable electricity generation with almost zero marginal costs can be used and the generation of non-renewable electricity with non-zero marginal costs can be decreased thus lowering the overall electricity generation OPEX
- carbon emissions and related costs (emission certificates) might be reduced through more efficient generation, avoided transmission losses and higher generation from renewables; however, this is not the case if the higher system flexibility leads to higher generation from lignite and coal power plants replacing gas power plants thus overcompensating the effects leading to reduced carbon emissions

Hence, there are many mechanisms by which ELSA-type ESS, like any flexibility in the electricity system, can reduce the overall electricity system OPEX though not every effect is created automatically. The changes affect operations of different stakeholders: generation unit operators, distribution and transmission grid operators, providers of frequency response and reserve. Depending on the way how the ESS is operated, some stakeholder might experience an increase of costs / loss of income, others might experience the opposite. The total impact on electricity system costs might also be positive or negative.

When operated on a longer time-scale, EES might not only make an impact on OPEX, but also on investment decisions, thereby reducing or increasing capital expenditures (CAPEX) incurred to different stakeholders:

- deferral or avoidance / additional grid infrastructure investments (grid lines, transformers, phase shifters, etc.)
- deferral or avoidance / additional generation unit investments needed for ensuring a sufficient level of security of supply is met

While modifications of investments in grid infrastructure affect either distribution grid operators or transmission grid operators, modifications of investments in generation affect stakeholders of generation units. Again, depending on the way how the ESS is operated, some stakeholder might experience an increase of costs / loss of income, others might experience the opposite. The total impact on electricity system costs might again be positive as well as negative.

The way how, more specifically, an ELSA-type ESS might make an impact on the income and costs of individual stakeholders or the electricity system as a whole depends on the specific features of ELSA ESS as they are described in section 3.4.1 and on the way how the system is operated.

6.2.2 Approaches for assessing the impact on electricity system costs

There is a range of approaches for assessing the impact of the operation of one or more ESS on the operation and further development (and thus income and costs of related stakeholders; environmental and other impacts) of parts of the electricity system or the entire electricity system as a whole. The range of approaches to assess this impact can be delimited by two opposite extremes:

1. Assessment of the (marginal) impact of a specific individual ESS application on an isolated part of the electricity system such as a single grid line or a small local low voltage grid.
2. Assessment of the (marginal and / or average) impact of a larger number of ESS operated in one or several ways on larger parts of the electricity system or the electricity system as a whole.

The first approach is suitable if a decision between two or more alternative investments has to be made which do not affect the wider electricity system. This is the case for instance if a new electricity consumer (e.g. electric car charging station along a road or electrified high-power agricultural machinery in a rural area) or a new generation unit (PV or wind park at a certain distance from the existing electric grid) is to be installed. The alternatives consist in these cases in combinations of a connection to the existing grid and a stationary ESS. Cost optimisation provides the combination of grid extension and stationary ESS at least cost for all stakeholders involved or for one of those who have to invest. An example of such a cost optimisation has been presented comprehensively in (Stöhr, et al., 2018), a short English presentation is available in (Enhancing Synergy Effects Between The Electrification Of Agricultural Machines And Renewable Energy Deployment, 2018). Though this first approach is relatively precise and can provide guidance for individual investments in specific contexts, it tells little about the impact of ESS on the electricity system and its stakeholders in general and cannot provide guidance for their wider deployment and required changes of the regulatory framework.

The second approach requires modelling of the electricity system as a whole. In most cases, the investigated system is limited to a country's or region's electricity system. A few cover larger areas such as the EU + neighbouring countries. In all cases, simplifications such as aggregation of generation and demand, abstraction from the real electric grid topology, larger time-steps than one hour at least for parts of the modelling etc. are made – the larger the investigated area, the more. Typically, the outcome of such modelling work depends more or less on some basic assumptions, notably it depends on forecasts of demand, generation and prices into the future which enter as input into the model. In spite of these limitations, this second approach is suitable for giving a more generally valuable insight in the impact of ESS and provides a basis for guidance for their wider deployment and suitable changes of the regulatory framework.

For this reason, the second approach is used here. The assessment presented in the following is based on results obtained for the UK by the Energies Lab of the Imperial College London and published among others in the study "Strategic Assessment of the Role and Value of Energy Storage Systems in the UK Low Carbon Energy Future" prepared in 2012 for the Carbon Trust[24], London. (Strbac, et al., 2012) In this study, the gross economic value of storage has been assessed for the UK for a number of different storylines, scenarios and cases and for three different time horizons (2020, 2030, and 2050). In the following, this study is referred to as "UK Carbon Trust Study" or CTS.

In the next section, the UK Carbon Trust Study is summarized and subsequently, conclusions for the impact that wider deployment of ELSA ESS can make are deduced first for the UK and then for Europe as a whole.

[24] https://www.carbontrust.com/home/

6.2.3 UK Carbon Trust Study

6.2.3.1 Scope and approach

That what distinguishes the approach followed in the UK Carbon Trust Study (CTS) from other approaches is that it allows to calculate the optimum combination and trade-off of grid infrastructure, storage and other flexibilities, and to evaluate the optimum size and location of power plants and storage units for a given level of flexible generation and demand-side control (DSC). This is achieved by using the Dynamic System Investment Model (DSIM) developed at Imperial College which calculates the overall minimum costs of the investigated electricity system.

More specifically, the CTS assesses[25]:

1. Cost and performance targets for grid-scale energy storage applications to facilitate a cost-effective evolution to a low-carbon future with emission targets of 130 gCO_2/kWh for 2030 and 50 gCO_2/kWh for 2050.
2. Sources of value of storage, i.e. savings in capital expenditure in all sectors including generation, transmission and distribution infrastructure, as well as savings in operation expenditure and the potential to enhance the ability of the system to accommodate renewable generation.
3. Impact of competing options including flexible generation, demand-side response (DSR), and interconnection of the national grid to continental Europe and Ireland.
4. Changes in the value of storage across key decarbonisation pathways and for different assumptions on fuel costs.
5. Impact of various storage parameters on its value, including the importance of additional storage duration, storage efficiency and the ability to provide frequency regulation services.
6. Impact of changes in system management on the value of storage, including generation scheduling methodology and the impact of improvements in wind output forecasting errors.

The CTS distinguishes between different possible futures. At the highest level, different pathways are identified. These describe a holistic narrative for the development of the UK's generation and demand from 2020 towards the year 2050. The study builds on pathways developed by the UK's Department of Energy and Climate Change (DECC) in its Carbon Plan. The central pathway is Grassroots with a high component of renewable energy. Pathways

[25] p. 19

with, respectively, significant Carbon Capture and Storage (CCS) and nuclear generation are calculated for comparison. The three pathways do not only differ by the generation mix, but also on the demand side. Scenarios represent deviations from a given pathway, used to explore the sensitivity of the value of storage to changes such as in the level of interconnection with neighbouring countries, in the flexibility of generating assets, different levels of demand flexibility and high or low fuel costs. Cases within a scenario are defined by the specification of storage itself: the installed capacity, storage duration, efficiency and costs.

DSIM calculates the need for generation units, interconnection, transmission and distribution grid infrastructure, and for storage alongside with power flows in the system. Demand includes charging of electric vehicles and heat pumps. Interconnection to continental Europe and Ireland are considered, but the UK is supposed to be self-sufficient both with regard to annual energy generation and peak power demand. The modelling time step is one hour.

6.2.3.2 Definition and calculation of value of storage for the electricity system

Gross benefit of adding storage to a system is defined as the reduction in total annual system costs [£/yr] enabled by storage, ignoring its costs. The net benefit is numerically equal to the difference between gross benefit and expenditure [£/yr] associated with the installation of storage.

The average value of storage is numerically equal to the ratio of the gross benefit created by a certain total installed storage power and this power [£/kW/yr]. The marginal value on the other hand is the value that is created if one additional unit of storage is added and the power of this additional unit [£/kW/yr].

In other words: the average value of storage is the value for the system divided by the total storage power installed, while the marginal value of storage is the first derivative of the value for the system with respect to the storage power at the point of the installed storage power.

The marginal and average values of storage decrease as the amount (power) of storage increases. For zero storage deployment, both take the same value. The marginal value decreases more quickly than the average value and is always smaller than the latter except for the first unit installed.

The value of storage is broken down to:

- Savings of operation costs, notably saving of renewable electricity curtailment displacing more costly generation.
- Saving of generation investment costs related e.g. to the construction of part-loaded fossil power plant ensuring sufficient response and reserve.
- Saving of interconnection grid investment costs.

- Saving of transmission grid investment costs.
- Saving of distribution grid investment costs (only accessible for distributed storage).

This break-down of value of storage permits to specify the stakeholders who benefit and the to which extend they benefit from the value of storage.

No specific storage technology is assumed, but specific characteristics were assumed for the storage deployed. For instance, the standard round-trip efficiency is assumed to be 75 % and the reaction time is assumed to be sufficiently short to provide frequency response. Storage is parametrised by its power[26]. Different stored energy[27] / storage duration[28] are considered for a given storage power. Bulk (connected to transmission grid) and distributed storage (connected to distribution grid) is distinguished.

Two different approaches are implemented[29]:

1. The total power of storage is fixed and DSIM calculates the optimum location and operation of storage, and the total [£/yr] and specific [£/kW/yr] marginal and average values.
2. The specific annuitised costs of storage [£/kW/yr] are fixed. DSIM deploys storage up to the value when the marginal value of storage becomes less than the specific annuitized costs and calculates its total [£/yr] and specific [£/kW/yr] marginal and average values.

6.2.3.3 Operation constraints and consideration of frequency response and reserve

Generator operating constraints considered by DSIM include: (i) Minimum Stable Generation (MSG) and maximum output constraints; (ii) ramp-up and ramp-down constraints; (ii) minimum up and down time constraints; and (iv) available frequency response and reserve.

Operation reserve constraints map the need for frequency regulation (response to an imbalance of generation and demand within a second up to half an hour) and reserve (fine-tuning the balance of generation and demand at a time-scale of half an hour to several hours). As power flows related to frequency response and reserve are shorter than the modelling time-step of one hour, and because of their non-deterministic occurrence, they cannot directly be included in a model into which enter deterministic demand and generation profiles. Howev-

[26] presumably the maximum discharge power

[27] presumably, the maximum discharged electric energy

[28] defined as ratio of nameplate values of stored energy and storage power

[29] p. 31

er, the frequency response and reserve requirements need to be known for different generation and demand situations in order to calculate the required capacity for those units which provide frequency response and reserve.

Frequency response and reserve requirements are calculated exogenously from the level of intermittent renewable electricity generation, demand and probability for plant failure and are entered as input into DSIM. Additional conventional gas and Open Circuit Gas Turbines (OCGT) are added and optimal commitment and dispatch decisions are determined using a stochastic scheduling tool with the Value of Lost Load (VoLL) as only remaining free parameter. VoLL is set as 10,000 £/kWh.

In DSIM, frequency response can be provided by:

- synchronised part-loaded generating units
- interruptible charging of electric vehicles
- a proportion of wind power being curtailed
- a proportion of electricity storage when charging
- smart refrigeration

While reserve services can be provided by:

- synchronised generators
- wind power or solar power being curtailed
- stand-by fast generating units (OCGT)
- electricity storage
- interruptible heat storage when charging

6.2.3.4 **Key findings**

Key findings of the UK Carbon Trust Study are[30]:

- The value of storage tends to be higher than previous studies suggest. This is a direct result of the whole-system approach employed that includes savings in generation capacity, interconnection, transmission and distribution networks and savings in operating cost. These savings all contribute towards the value of storage, but their relative share changes over time and between different assumptions.
- In the Grassroots pathway, the value of storage increases markedly towards 2030 and further towards 2050. Carbon constraints for 2030 and

[30] p. 96

2050 can be met at reduced costs when storage is available. At a bulk storage cost of ca. £50/kW/yr, the optimal volume deployed grows from 2 GW in 2020 to 15 and 25 GW in 2030 and 2050 respectively. The equivalent system savings increase from modest £0.12bn per year in 2020 to £2bn and can reach over £10bn per year in 2050.

- The value of storage is the highest in pathways with a large share of RES, where storage can deliver significant operational savings through reducing renewable generation curtailment. In nuclear scenarios the value of OPEX is reduced as the value of energy arbitrage between renewable generation and nuclear is lower. CCS scenarios yield the lowest value for storage.
- A few hours of storage are sufficient to reduce peak demand and thereby capture significant value. The marginal value for storage durations beyond 6 hours reduces sharply to less than £10/kWh/yr. Additional storage durations are most valuable for small penetration levels of distributed storage.
- Distributed energy storage can significantly contribute to reducing distribution network reinforcement expenditure.
- In the Grassroots pathway, storage has a consistently high value across a wide range of scenarios that include interconnection and flexible generation. Flexible demand is the most direct competitor to storage and it could reduce the market for storage by 50%.
- Bulk storage should predominantly be located in Scotland to integrate wind and reduce transmission costs, while distributed storage is best placed in England and Wales to reduce peak loads and support distribution network management.
- Higher storage efficiencies only add moderate value of storage [31]. With higher levels of deployment efficiency becomes more relevant.
- Operation patterns and duty cycles imposed on the energy storage technology are found to vary considerably, and it is likely that a portfolio of different energy storage technologies will be required, suited to a range of applications.
- There remain a number of important unknowns with respect to the technologies involved in grid-scale energy storage, in particular relating to the

[31] This is because storage allows notably to make better use of renewable electricity with zero marginal costs. As long as there is sufficient renewable generation, it is not important if otherwise curtailed generation is used with a higher or lower efficiency.

cost and lifetime of storage technologies when applied to real duty cycles within the electricity network.

- By indicating the cost target levels for storage at which it may become competitive in the future, the CTS helps identify which technologies offer the potential for innovation and development in order to further reduce their cost.
- Benefits of storage and corresponding value are “split” among operation, generation, transmission and distribution grid.

6.2.4 General impact of ELSA-type ESS on electricity system costs

6.2.4.1 Parameters of ELSA ESS restricting impact compared to EES assumed in CTS

The CTS considered no specific storage technology, but assumed ranges of ESS characteristics. ELSA-type ESS, i.e. battery energy storage systems with technical characteristics and costs close to those of ELSA-DT5 ESS, take specific values within these ranges:

- The ratio of maximum stored energy and maximum discharge power (storage duration in terms of the CTS) is 55 minutes[32]. Hence, the findings of the CTS for a storage duration of one hour are the most relevant for ELSA-type ESS.
- ELSA-type ESS take a much larger volume than first life battery systems because they are not dismantled after removal from electric vehicles. For this reason, it is assumed here that they are not suitable for bulk storage, and it is assumed that the findings of the CTS for the impact and value of distributed storage apply for ELSA-type ESS.
- The input and output voltage level of ELSA-DT5-ESS is 400 V. Hence, ELSA-type ESS can only be directly connected to the low voltage distribution grid, but not to the medium and high voltage distribution grids. The CTS does not distinguish between storage connected to the distribution grid at different voltage levels. For the sake of simplicity, it is assumed that ELSA-type ESS connected to the low voltage side of transformers connecting low and medium voltage lines have the same impact and value as ESS connected directly to the medium or high voltage distribution grid.
- The minimum power output of an ELSA-DT5-ESS is one twelfth of its maximum power. It is assumed here that the range of output power of ELSA-

[32] e.g. 11 kWh / 12 kW = 55‘

type ESS does not restrict the potential impact and value of their deployment.

- As the results of the CTS do not depend sensibly on the ESS efficiency in a wide range from 50 % to 90 %, the exact value of the ELSA-type ESS efficiency under real operating conditions is little important. It is assumed here that the finding of the CTS for an ESS round-trip efficiency of 75 % apply for ELSA-type ESS.
- ELSA-type ESS have a reaction time below 1 second, thus allowing to provide the full range of ESS services with respect to required reaction time, notably frequency response.
- It is assumed here that the wide range of cos ϕ (0.6 to 1) which can be provided by ELSA-type ESS allows using them for providing reactive power provision without restrictions.
- ELSA-type ESS have no black start and island operation capability. It is assumed here that this restricts very little the potential impact and value of ELSA-type ESS because such operations are very rare.

6.2.4.2 Costs of ELSA-type ESS specifying potential impact in cost-optimised systems

Table 19 shows the calculation of the specific annual costs (relative to energy and relative to power) of a future commercial ELSA-type ESS. The basic assumption is that such an ESS will be sold at a price of 580 €/kWh (initial investment costs for an operator) and the battery will be replaced after 5 yrs at 26 % of the initial investment, that is at 151 €/kWh. The entire lifetime is 10 yrs. In order to calculate the specific annual cost, further assumptions need to be made for the weighted average cost of capital (wacc) and the rate of annual operation costs relative to the initial investment costs. Here, it is considered that an ELSA-type ESS represents a high-risk investment compared to conventional electric grid infrastructure components. For this reason, a comparatively high wacc of 15.0 % is assumed. It is further considered that a 2nd-life stationary ESS needs presumably more maintenance and repair than a 1st-life stationary ESS. For this reason, the comparatively high annual operation cost rate of 10.0 % is assumed. The storage duration of 55 minutes enters in the ratio between the specific annual costs relative to energy and the specific annual costs relative to power. The resulting specific annual costs relative to power of 173 €/kW, respectively 154 £/kW[33], can be compared with the findings of the CTS for a pre-set value of 150 £/kW.

[33] exchange rate = 0.89 £/€; https://bankenverband.de/service/waehrungsrechner/ [retrieved on 2 August 2018]

Table 19: Specific annual costs of ELSA system

ELSA-type energy storage system				
specific investment costs full ESS	580	€/kWh	516	£/kWh
specific investment costs battery replacement	151	€/kWh	134	£/kWh
financial life time / technical life time of ESS	10	a	10	a
technical life time of battery	5	a	5	a
weighted average cost of capital	15,0%		15,0%	
annual value degression factor	0,8696		0,8696	
annuity	131	€/kWh	116	£/kWh
rate of annual operational costs	10,0%		10,0%	
specific annual operational costs	58	€/kWh	52	£/kWh
specific annual costs	189	€/kWh	168	£/kWh
specific annual costs	173	€/kW	154	£/kW

6.2.4.3 **Findings of CTS relevant for ELSA ESS**

In (Strbac, et al., 2012), p. 50, Figure 19 (right) and Figure 20 (right) show, respectively, the total national and the specific annual value of storage for different specific annual storage cost (top axis) which correspond to different total capacity deployed (bottom axis) in a cost-optimised electricity system. These figures have been obtained by the CTS for the UK's Grassroots pathway for the year 2030.

The values relevant for ELSA-type ESS is the column for 150 £/kW/yr which correspond to deployed optimum capacity of about 4.3 GW. If this capacity is to be provided entirely by 2nd-life batteries from electric vehicles and 50 % of the vehicle batteries are used for 2nd-life stationary grid-connected applications provided by ELSA-type ESS, it requires an electrification rate of the UK's vehicle fleet of only 2.0 %.

The net specific annual value of storage which corresponds to this level of deployment is 360 £/kW/yr which is more than twice the specific annual costs of an ELSA-type ESS. That means that the operation of an ELSA-type ESS is always profitable as long as at least a bit less than half of the value (43 %) that it generates for the electricity system as a whole is remunerated to the operator.

As the breakdown of the value of storage shows, almost 80 % is related to savings of operation cost. A bit more than 10 % are related to savings in generation investment costs (essentially part-loaded spinning and stand-by units needed for ensuring security of supply) and 5-10 % to savings in distribution grid investment costs. The tiny savings in interconnection investment costs are balanced by a tiny increase in transmission grid investment costs.

Though 2.0 % is a very small vehicle stock electrification rate, 50 % battery recovery and 2nd-life use permit annual net savings to the UK's electricity system of about 0.9 £bn which is about 1.0 €bn. With a projected UK final electricity demand of 379 TWh in 2030 according to (Strbac, et al., 2015) this is equivalent to savings of 0.27 ct€/kWh (2.7 €/MWh) relative to consumed electricity.

In (Strbac, et al., 2012), p. 50, Figure 21 (right) shows that at a level of 4.3 GW of deployed storage capacity the average value is 360 £/kW/yr, but the marginal value is exactly equal to the annual costs of ESS of 150 £/kW/yr which is close to the annual cost of an ELSA-type ESS of 154 £/kW/yr. This is because ESS are only installed until the marginal costs drop below the ESS costs.

If the total capacity of storage is further increased, the marginal value drops to about 100 £/kW/yr and remains approximately at this level. The average value continues dropping. One has to note that this is valid for the Grassroots pathway for the year 2030. If the carbon constraint becomes stronger as it is the case in the Grassroots pathway with a target of 130 gCO_2/kWh in 2030 and 50 gCO_2/kWh in 2050, the total capacity of optimally deployed storage and the related value increase.

Further, the following conclusions of the CTS are relevant for ELSA-type ESS:

- The value of storage for the overall electricity system is quite high.
- The optimal volume of storage deployed grows from with decreasing permitted carbon emissions and so does the value of ELSA-type ESS and the overall system benefit that ELSA-type ESS can provide.
- The value of storage is the highest in pathways with a large share of RES, where storage can deliver significant operational savings through reducing renewable generation curtailment. In nuclear scenarios the value of OPEX is reduced as the value of energy arbitrage between renewable generation and nuclear is lower. CCS scenarios yield the lowest value for ELSA-type ESS.
- ELSA-type ESS can provide a significant contribution to reduce peak demand and thereby capture significant value.
- ELSA-type ESS can significantly contribute to reducing distribution network reinforcement expenditure.
- ELSA-type ESS have a consistently high value across a wide range of scenarios that include interconnection and flexible generation. Flexible demand is the most direct competitor to ELSA-type ESS and it could reduce the market considerably.

- Higher storage efficiencies only add moderate value of storage[34]. With higher levels of deployment efficiency becomes more relevant.
- Benefits of ELSA-type ESS and corresponding value are "split" among operation, generation, transmission and distribution grid.

6.2.5 Impact of single applications of ELSA-type ESS

(Strbac, et al., 2012) have found that operation patterns and duty cycles imposed on the energy storage technology in scenarios like those investigated in the CTS vary considerably. They conclude that it is likely that a portfolio of different energy storage technologies will be required, suited to a range of applications, but do not specify the impact of single applications in the published study. With regard to the impact of single applications of ELSA-type ESS one can nevertheless conclude:

- A mixture of different applications is required to generate the impact described in the last section by ELSA-type ESS.
- If the operation patterns and duty cycles of the deployed ELSA-type ESS do much deviate from those required ones the positive impact on the overall electricity system might not be achieved.

An example of an ESS application whose operation pattern has a very different impact on the electricity system depending on the operation pattern has been discussed in section 0: increasing the rate of self-consumption of PV electricity might have a positive or negative impact on the grid operation.

In contrast, power purchase optimisation such as peak shaving has presumably a rather positive impact on the overall electricity system and thus provides a value: less peak power generation is needed and the electric grid is used more efficiently thus reducing capital expenditure in the medium and long term.

Generally speaking, it is quite difficult to assess the impact of a single application or even an individual ELSA-type ESS on the overall electricity supply system. While applications which provide directly grid services, such as frequency response, can be assumed to have always a positive impact, applications which serve first of all a consumer or prosumer can a have positive or negative impact and value for the overall electricity system.

[34] This is because storage allows notably to make better use of renewable electricity with zero marginal costs. As long as there is sufficient renewable generation, it is not important if otherwise curtailed generation is used with a higher or lower efficiency.

7 Conclusions and recommendations

Responsible partner: B.A.U.M. Consult GmbH.

7.1 Conclusions

7.1.1 The need for storage

The need for storage or other flexibility options in a given area is dependent on the topology and grid within this area and on the capacity of the power connections crossing the area's boundary. If the latter are strong enough, there might be very little need for flexibility within the area itself, because the balance between generation and consumption can be achieved by simply adapting power imports and exports accordingly. This is even possible if the share of fluctuating renewable power generation is very high.

A number of model calculations exist which determine the need for storage for different shares of renewable power for various European regions or wider areas of Europe and neighbouring countries. Several of them investigate the extreme case of 100 % supply by a mix of PV and wind power and calculate for which mix the need for storage takes a minimum. The need for storage found for such scenarios is small compared to the annual energy demand in the investigated area. In particular a modest short-term energy storage need is found which can be met with battery systems. In contrast, a high share of fluctuating renewables in the generation mix implies a high need for storage power compared to the peak power demand.

A common finding of these model calculations with regard to long-term storage is that it increases very modestly for renewable shares up to 80 % and very steeply between 80 and 100 %. This fits with what can be observed in areas which have a high share of renewables already today. In Germany for instance, the annual average share of renewables was 32.6 % in 2015 out of which 21.1 % were PV and wind energy, but the contribution of PV and wind power is very close to 100 % in some hours. Negative prices on the electricity market indicate a clear lack of flexibility in these moments, while the existing flexibility of the system, basically ensured by generation control of thermal power plants and pumped hydro energy storage, is sufficient during most of the year.

However, a crucial point is that these model calculations systematically underestimate the need for short-term flexibility because imbalances are time-scales smaller than the time-step are blurred out. Furthermore, imbalances over distances smaller than the spatial cell diameter are blurred out, because the models do generally not map the real electric network operating resources. If the latter are taken into account, a higher need for short-term storage becomes apparent and battery storage systems are the most suitable option to meet this because they can deal with a broad range of required services better and more cost-effectively than other flexibility options. In quite a number of cases, batteries are also more cost-effective already today than reinforcement of electric network operating resources, at least until the next regular replacement of existing equipment.

7.1.2 The technical potential for ELSA-type ESS

There is a perfect synergy between vehicle stock electrification and the energy transition towards predominantly renewable generation if vehicle batteries get a 2nd life in stationary grid-connected applications. Even at a modest vehicle stock electrification rate of a few percent and a medium battery reuse rate of 50 % the potential of ELSA-type ESS is higher than the present pumped hydro storage potential, notably in terms of power. ELSA-type ESS can provide a significant contribution to the short-term storage needed in electricity systems with a high rate of fluctuation renewable power generation – up to 50 % of the battery storage needed for optimised 100 % renewable electricity supply.

7.1.3 The economic impact of ELSA-type ESS

In the transition towards a predominantly renewable electricity system, ELSA-type ESS can generate significant value to the overall electricity system which is more than twice their costs in the case of the UK if the carbon target for 2030 is to be achieved mainly by renewable electricity generation. Notably, operation cost of conventional back-up power plants can be reduced thanks to avoided curtailment of renewable electricity generation. Further, investments in conventional back-up units and the distribution grid can be avoided. It can be assumed that these results are in principle transferable, at least to other large economies in the EU.

The value of an ESS for the system depends on the operation pattern. Operation patterns contributing to balance the residual demand, i.e. the difference between the demand and (fluctuating) renewable electricity generation, thus smoothing the required residual fossil and nuclear generation, create the highest value, notably by avoiding conventional back-up power plant operation and by reducing the required back-up capacity. This implies that ESS reduce business opportunities for operators of conventional back-up power plants in the short term. However, most of these plants are fired with natural gas and will be needed in the long term for combustion of synthetic natural gas produced from surplus electricity and CO_2. This gas-powered back-up power plants a strategic importance for a transition towards a highly renewable electricity generation with a share of 80 % and beyond.

Further, operation patterns leading to a more constant power flow in grid lines create value by referring or avoiding grid reinforcements. Here, the impact of ESS is directly beneficial to grid operators: a more constant power flow leads to a better use of grid infrastructure and a better return on investment.

Altogether, a mix of quite diverse operation patterns of individual ESS located at different sites in the electric grid is needed to generate the highest system value.

The main competitor to ELSA-type ESS with similar value for the overall electricity system is demand response. In some cases, provision of demand response is supported by battery storage systems and simply represents a specific case of their application. In other cases, demand response uses inherent thermal energy storage capacity or flexibility of industrial production and might be much cheaper than battery storage.

7.2 Recommendations

Stationary ESS can have a significant value for the overall electricity system and can provide a significant contribution to ensure cost-effective electricity supply notably in systems with a higher rate of fluctuating renewable electricity generation. For this reason, a regulatory and market framework should be created which allows for profitable operation of ESS, whenever the operation pattern creates a system value which is higher than the ESS costs.

ESS with 2nd-life batteries can provide this system value at lower costs than ESS with new batteries, provided the costs for dismantling the batteries from the vehicles and installing them in a 2nd-life ESS, and the costs of maintenance and repair do not overcompensate the savings achieved by using 2nd-life batteries. However, 2nd-life ESS have a positive environmental impact compared to new ESS thanks to a longer total lifetime of vehicle batteries and thus more efficient use of final resources (lithium and others) and grey energy (energy used for manufacturing the batteries) (see ELSA D5.3 and D5.6). If the resulting annual costs of 2nd-life ESS will turn out to be finally even a bit higher than those of new ESS, this positive environmental impact might be reflected by the regulatory and market framework.

The operation pattern of ESS has an impact on the exact value that is created for the overall electricity system. Hence, the regulatory and market framework should reward operation patterns with a higher system value more than those with a low one. In first instance, the following is recommended:

- ESS should be given free access to the market and new market mechanisms should be developed in order to allow deploying the maximum benefit for the overall electricity system. This includes notably markets for smaller amounts of electric energy and power and trade at shorter timescale. Aggregation and regional market places should be permitted as much as possible.

- ESS should be promoted by removing fees on electricity charged or discharged. The exemption from paying fees could be made dependent on the value of the ESS operation for the overall electricity system:
    - Charging might be exempted if it helps avoiding renewable energy curtailment.
    - Discharging might be exempted if it helps avoiding generation at high cost.
    - Charging and discharging might be exempted if it reduces ramp rates and related inefficient operation and stress on material of conventional thermal power plants.

ESS will most directly impact on the operation of mostly natural gas-fired peak and back-up power plants and might squeeze them out of the market. However, these power plants will be needed again when larger amounts of synthetic natural gas from renewable sources will be available, that is when the share of RES in the electricity generation mix approaches 80 %. They will then be a cornerstone of the presently only available long-term storage technology for the electricity sector, namely power-to-gas. Hence, a strategy is also needed for natural gas-powered plants though the need for them will drop in the short-term as a consequence of a strong deployment of battery storage systems.

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