ANNEX 6

Storage and balancing as key elements for future network planning and electricity markets design

ISGAN Discussion Paper

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ISGAN Annex 6 Power T&D Systems
Task 2

CLEAN ENERGY MINISTERIAL
Accelerating the Transition to Clean Energy Technologies

iea Energy Technology Network

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ISGAN discussion papers are meant as input documents to the global discussion about smart grids. Each is a statement by the author(s) regarding a topic of international interest. They reflect works in progress in the development of smart grids in the different regions of the world. Their aim is not to communicate a final outcome or to advise decision-makers, but rather to lay the ground work for further research and analysis.

In this instance, the authors of this report address options from a macro perspective; and are aware of the fact that local variations in the organization of electricity markets may create either looser or stronger links between investor related money streams and possible revenue streams within today's existing regulatory regimes. The authors are, however, convinced that the report will be useful to identify and discuss the technical options of future storage and balancing possibilities; and also to rank their relevance in relation to different technical presettings.

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Acronyms and Abbreviations

ACER	Agency for the Cooperation of Energy Regulators
AESO	Alberta Electric System Operator
BSP	Balancing Service Provider
CAES	Compressed Air Energy Storage
CoBa	Coordinated Balancing Area
DC	Direct Current
DOE	Department of Energy
DR	Demand Response
DSM	Demand Side Management
EC	European Commission
EDT	Electricity Demand Technologies
ENTSO-E	European Network of Transmission System Operators – Electricity
EPRI	Electric Power Research Institute
ESS	Energy Storage Systems
EST	Energy Storage Technologies
EU	European Union
EU30+	Albania, Austria, Belgium, Bosnia-Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg , FYR Macedonia, Malta, Montenegro, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom
FERC	Federal Energy Regulatory Commission
HVAC	High Voltage Alternating Current
HVDC	High Voltage Direct Current
ICT	Information and Communications Technology
IEA	International Energy Agency
IEM	Internal Energy Market
IESO	Independent Electricity System Operator (Ontario)
ISGAN	International Smart Grid Action Network
ISO	Independent System Operator
NCEB	Network Code on Electricity Balancing
NGC	Net Generating Capacity
PHES	Pumped Hydroelectric Energy Storage
PST	Phase Shifting Transformer
PTDF	Power Transfer Distribution Factors
PUC	Public Utility Commissions
PV	Photo-Voltaic
R&D	Research and Development
RES	Renewable Energy Sources
RTO	Regional Transmission Operator
SMES	Superconducting Magnetic Energy Storage
SO&AF	Scenario Outlook and Adequacy Forecast (by ENTSO-E)
SPHES	Seawater Pumped Hydroelectric Energy Storage
TGT	Transmission grid technologies
TSO	Transmission System Operator

Abstract

The aim of this report is to analyze the flexibility contribution that identified resources could provide as a contribution towards the achievement of efficient and cost-effective dispatching of the electric system, in presence of an ever increasing penetration of Renewable Energy Sources (RES) which are characterized by a variable generation pattern. Higher flexibility in network dispatching can be achieved either by increasing the deployment of bulk storage in the transmission network, or by widening the set of resources available as a base for energy balancing. The latter strategy could potentially be actuated by allowing reserve procurement across transmission operator jurisdictions. In a European context this strategy would be referred to as trans-national balancing; and could also be relevant to procurement across different Regions and Balancing Authorities in North America. A further positive could be achieved through participation in the balancing mechanism from generators and loads located in distribution networks. Beyond supporting dispatching efficiency, these flexibility elements make it possible to deploy a sustainable expansion strategy of the trans-national transmission corridors, taking into account the current difficulties faced in achieving public consensus for the building of new overhead lines. This report illustrates the potential of these strategies by referencing the results achieved in a number of important and ongoing European research projects.

Executive Summary

The aim of this report is to analyze the flexibility contribution that identified resources could provide as a contribution towards the achievement of efficient and cost-effective dispatching of the electric system, in presence of an ever increasing penetration of Renewable Energy Sources (RES) which are characterized by a variable generation pattern. Two sources of flexibility are analyzed in detail, namely:

- bulk storage or aggregated distributed storage that can participate in energy markets,
- trans-national coupling of balancing markets, widening the base for the acquisition of the resources needed for the balancing of the electric system.

Energy has to be consumed as soon as it is produced: power demand and supply have to remain balanced in real time in order to maintain frequency stability. Despite technological advancements, there is still a lack of commercially available storage technologies that can be employed in transmission networks for the accumulation of large quantities of energy ("bulk storage"): hydro pumping is the only mature technology but its application is constrained by the requirement for opportune environmental conditions (plenty of water, possibility to develop two reservoirs at different heights) and cannot be implemented everywhere, in particular not necessarily close to big RES generation locations. In order to maintain real time balancing, Transmission System Operators (TSOs) have to compensate imbalances with respect to real time injection/withdrawal programs declared in the electricity markets, by resorting to the usage of reserve generation. Thus, an amount of reserve generation has to remain available to compensate for any real time deviations from the scheduled generation and load programs. The reduction of real-time markets costs is a consistent economic driver in electricity markets. This cost reduction can potentially be achieved by the sharing of reserves among the EU (European Union) countries. The basis for the creation of a pan-European balancing market requires the coordination of relevant markets; and the removal of the present regulatory barriers affecting TSO operation and non-harmonized aspects that impact on real-time markets functioning.

In order to carry out a quantitative assessment of the benefits that could be extracted from an integrated balancing market, the European research project eBADGE developed models of both the present mechanism and the "target" model, with a focus on a region encompassing Austria, Italy and Slovenia. A comparison between the results of the Base Case (BC) and Common Balancing Market (CBM) scenarios was performed in terms of both cost and energy flows.

Table 1 Balancing Costs [M€] for Each Nation

Scenarios	Nation			Total
	Austria	Slovenia	Italy	
BC	3.5	37.3	137	177.8
CBM	5.2	20.2	54.2	79.7

It can be observed from the analysis that a common balancing market results in a total dispatching costs decrease for both Slovenia and Italy. The results do reflect higher costs for Austria - most likely because the cheapest Austrian generators are used to cope with imbalances in Italy and Slovenia, while more expensive generators are used in order to address Austrian imbalances. The marginal cost increases in Austria are substantially lower than the savings that can be achieved in Slovenia and in Italy. In Italy particularly, costs for secondary and tertiary activation amount to 137 M€ if imbalances are solved only with local generators and this cost decreases to 54.2 M€ in a scenario where a common balancing market is implemented, resulting in a potential saving of up to 60%. It must, however, be noted that the estimated potential saving is based on an optimistic case in which no internal network constraint is violated. The presence of internal constraints could make it necessary to resort to less optimal solutions and reduce the potential savings level. In any instance then, the presence of a strong transmission network is an important prerequisite for allowing a cross-border balancing market to function efficiently.

This report includes a selection of key results from the European research project GridTech, which has mainly focused on conducting a fully integrated assessment of new grid-impacting technologies and their implementation into the European electricity system; this has targeted the exploitation of the full potential of future electricity production from RES, with the lowest possible total electricity system cost. The project examined three time horizons (2020, 2030 and 2050) and various scenarios to assess the role and the impact of innovative technologies. Focus has been, in particular, on those technologies that could effectively contribute to the further development of the European transmission grid, fostering the integration of an ever-increasing penetration of RES generation and boosting the creation of a pan-European electricity market, while maintaining secure, competitive and sustainable electricity supply. The technology categories taken into account within the project include transmission, storage and demand technologies. The technology assessment has been conducted by both a pan-European study and regional case analyses. The pan-European study was carried out by modeling the whole European power system (EU30+ region) for the 2020, 2030 and 2050 time horizons, utilising a zonal approach.

In the current report, GridTech results for the 2020 and 2030 scenarios are reflected as a contribution to investigating the effects that innovative grid-impacting technologies, especially HVDC (High Voltage Direct Current), bulk storage and Demand Response (DR), may have on the future EU30+ system. Some benefits that these grid-impacting technologies may provide to the European system as a whole are included in the results, with a specific emphasis on the effects of bulk storage.

The application of additional bulk storage capacity has also been considered in the composition of the 2030 storage-oriented scenario. The implementation of such scenario by 2030 reflects the potential benefit of additional bulk storage over the baseline scenario in terms of a dispatch cost drop (800 M€) against a baseline dispatch cost of 106 b€, and more significantly in terms of a RES curtailment decrease (1444 GWh, with an improvement of 15% over the baseline situation) at pan-European level; though, the CO_2 emissions reduction results would be rather limited.

On the other hand, storage technologies may have a more limited impact if concentrated in some zones of the European system, especially where an increasing penetration of variable RES is not followed by an expansion of transport capacity. In such instances, further regional case studies, which deal with internal grid constraints and local sensitivities, are needed. Including internal zones and grid constraints in the analysis may then represent a further step to compare the effects of bulk storage with respect to HVDC and DR. Additional analyses towards a full quantitative techno-economic assessment of the impact of innovative technologies is currently being carried out within GridTech and will be reported on when available.

This report also presents a study case related to a new seawater hydro pumping power plant that could be located in Foxi Murdegu (east coast of Sardinia, Italy) in order to demonstrate what consequences the deployment of additional storage capacity could have on the Sardinian system.

This Sardinian island system is only connected to the main grid by means of HVDC links and hosts a massive amount of electric generation from Renewable Energy Sources. This leads to a system with strong peculiarities and constraints. The presented pumping solution, where the upper reservoir is located on the top of a steep shoreline and the lower reservoir is the sea, can be considered as an example of a viable alternative for hydro energy storage, especially for islands and coastal areas with significant density of non dispatchable renewable energy generation. It should be noted that in comparison with a traditional pumping station, the low environmental impact of the works and the potential number of sea coasts sites with suitable gradients point to the potential application and benefit of such a solution.

The analysis reported here has not demonstrated significant financial benefits. However further investigations and analyses performed elsewhere have concluded that whilst considering the high financial risk of the investment, the significant value of the indirect benefits to the electrical system can result in a package of incentive mechanisms through "certificates for pumping" being proposed, with a partial redistribution of the welfare. This certification should amount to at least 2.6 € cents per kWh exchanged with the network, for avoiding any financial risk. Such a fee could be acceptable since it would give rise to a total cost which is lower than the indirect benefit produced for the entire Italian electricity system.

A second study case related to the increase of interconnection capacity between Sardinia and the Italian mainland is presented in order to show the impact of an upgrade of the existing HVDC three-terminal link named SA.CO.I. (Sardinia-Corsica-Italy). This study aims at identifying how this upgrade might bring benefits to the national Italian electricity system by allowing a better interconnection of the market zones. In economic terms the flexibility of different dispatch has led to production costs savings (and Social Welfare increase) that amounts to about 40 M€/year.

The most important outcome of the two studies is reflected in the evidence that the two investments (Foxi Murdegu plus SA.CO.I.) provide for higher RES production and integration; but in considering a market situation similar to the today's Italian one, new system elements or reinforcements may result in the fostering of coal-based production (cheaper but also more pollutant) over gas-based generation (less cheap but also less pollutant). Some sensitivity cases showed that with higher CO_2 prices this phenomenon decreases. However, this would also result in lower benefits for the proposed investments.

Finally, in addition to the results of some studies on the European system, the discussion paper also presents some activities currently carried out in the United States and Canada in order to test the possibility of the integration of storage systems both at a local and at a federal level. Some regulatory implications are presented as well.

In conclusion:

- Transnational balancing markets could allow for the achievement of a greater dispatching efficiency in the balancing markets, by integrating more reserve resources and better exploiting the complementary characteristics of the generation set in the different interconnected countries. This approach could result in a cost reduction and requiring fewer generators to be in stand-by mode. By contrast, implementing transnational markets would be more complex, since ensuring cross-border dispatchability of balancing orders requires constant availability of the network state parameters (node by node and link by link) for all of the interconnected countries and consideration of all of this complex information as input into the clearing algorithm. Thus a huge amount of data would need to be acquired in real time and be made available for the clearing process. At a macro level, a better synchronization of the markets would be required as well as the harmonization of a lot of details in the set-up of the markets (such as gate closure and products offered in the market).
- Despite such complexities, additional bulk storage deployment could be very beneficial, especially in allowing for improved flexibility in network dispatch and price reductions in the real time markets. However, apart from hydro pumping (that is not feasible to deploy everywhere), no other mature technology is currently fit for storing large quantities of energy. Research is ongoing and some technologies (like Compressed Air Energy Storage) could be potentially mature in the next few years. The Foxi Murdegu case explained in the report also shows that, in order to interest private investors to look at storage facilities, a clear business case needs to be available which clarifies potential return on investments data. In a system that has an increasing penetration of RES generation, in particular photo-voltaic generators, peaks of the daily consumption curve are becoming flatter, thus reducing the justification of investment in devices that take profit from arbitraging between high and low cost hours. It would appear that potential profit opportunity is primarily within the real time market environment, but developing a sound business case within this market is a far more complex task.

The case for alternative storage technologies as a viable economic option is thus still open; and it is likely that regulation, in particular, will play a big role in the next few years in pushing the market in a specific direction.

Key Messages

- Bulk storage is beneficial to the network but there are still a number of barriers preventing utilities, developers and regulators from capitalizing on the deployment of energy storage resources.
- Whereas new technologies could become viable in the future, the only mature technology for bulk storage today is pumped hydroelectric storage.
- It may prove difficult to determine business cases for bulk storage and in many cases incentives may be required to encourage investment. Policies and regulations can create or inhibit market opportunities for electricity storage and may determine compensation models.
- There is a clear economic need to reduce real-time markets costs. This can be achieved by sharing reserve among the EU (European Union) countries through the co-ordination of relevant markets; and the removal of the present regulatory barriers affecting TSO operation and non-harmonized aspects that impact on real-time markets functioning.
- The presence of a strong transmission network is an important prerequisite for the efficient functioning of a cross-border balancing market.
- Achieving higher economic efficiency by means of a cross-border management of balancing is possible, but some country can see an increase in dispatching cost (this scenario is true where exports from one TSO area to another significantly increase because of the availability of cheaper generation).
- Unshared bids should also be retained in each TSO control zone, primarily for security reasons. However, the eBADGE project demonstrated that a two-level clearing mechanism (within the TSO area and on a trans-national basis) can result in market distortions if not properly managed.
- Harmonization of the national balancing markets is a pre-requisite for efficient market coupling.
- Ancillary services can also be bought from virtual power plants and distributed generation located in the distribution segment; but this requires that a robust TSO/DSO interaction is put in place with respect to market participation, system regulation and ICT deployment. Further, the trans-national balancing market would require better TSOs/DSOs communication platforms to support the cross-border markets of ancillary services.
- The GridTech project focused on conducting a fully integrated assessment of new grid-impacting technologies and their implementation into the European electricity system; this has targeted the exploitation of the full RES potential, with the lowest possible total electricity system cost. The project has shown that grid constraint analysis needs to be included in the evaluation of more accurate storage benefit quantification. However, the benefits provided by storage in a pan-European context can be evaluated and result to be potentially significant, especially with respect to RES exploitation.

Table of Contents

1 Introduction

This discussion paper is part of task 2 within the International Smart Grid Action Network (ISGAN) Annex 6 on Power Transmission & Distribution. ISGAN is one of International Energy Agency's (IEA) Implementing Agreement.

ISGAN creates a mechanism for multilateral government-to-government collaboration to advance the development and deployment of smarter electric grid technologies, practices, and systems. It aims to improve the understanding of smart grid technologies, practices, and systems and to promote adoption of related enabling government policies.[1] Annex 6 was launched in the framework of ISGAN with the aim of establishing a long term vision for the development of "Smarter" total electricity systems. Power transmission and distribution provides the enabling infrastructure for integration of distributed and large-scale renewable energy and has to be recognized as such. In the framework of ISGAN, goal of Task 2 ("Expansion Planning and Market analysis") is to assess available methods and tools for transmission expansion planning, possible technologies to make efficient use of existing infrastructure and to identify the need for new tools that integrate market modelling, network analysis and security assessment, also including the possible contribution of promising transmission technologies.

The main objective of this report is to analyze some flexibility elements, namely:

- bulk storage or aggregated distributed storage that can participate in energy markets,
- trans-national coupling of balancing markets, widening the basis for the acquisition of the resources needed for the balancing of the electric system.

Balancing can also be managed at a distribution level, and from renewable energy sources themselves when actively controlled. Although this topic is not explored in this discussion paper, we incidentally note that NREL has produced a report on balancing that can be provided from variable renewable systems[2].

One of the distinctive characteristics of the electric power sector is that the amount of electricity that can be generated is relatively fixed over short periods of time, although demand for electricity fluctuates throughout the day. Developing technology to store electrical energy so it can be available to meet daily demand fluctuations would represent a major breakthrough in electricity distribution[3]. Helping to try and meet this goal, electricity storage devices can manage the amount of power required to supply customers at times when need is greatest, which is during peak load.

These devices can also help provide additional flexibility required for the integration of intermittent renewable energy[4]. They can also balance microgrids to achieve a good match

[1] www.iea-isgan.org
[2] Such report is available on: http://www.nrel.gov/docs/fy13osti/57820.pdf
[3] KIC InnoEnergy has published a report called „How can batteries support the EU electricity network?" http://www.insightenergy.org/ckeditor_assets/attachments/48/pr1.pdf
[4] In many European countries RES generators have still the right to inject in the grid whatever they produce.

between generation and load. Storage devices can provide frequency regulation to maintain the balance between the network's load and power generated, and they can achieve a more reliable power supply for high tech industrial facilities. Thus, energy storage holds substantial promise for transforming the electric power industry[5]. In this paper, energy storage and balancing activities in Europe and North America are discussed.

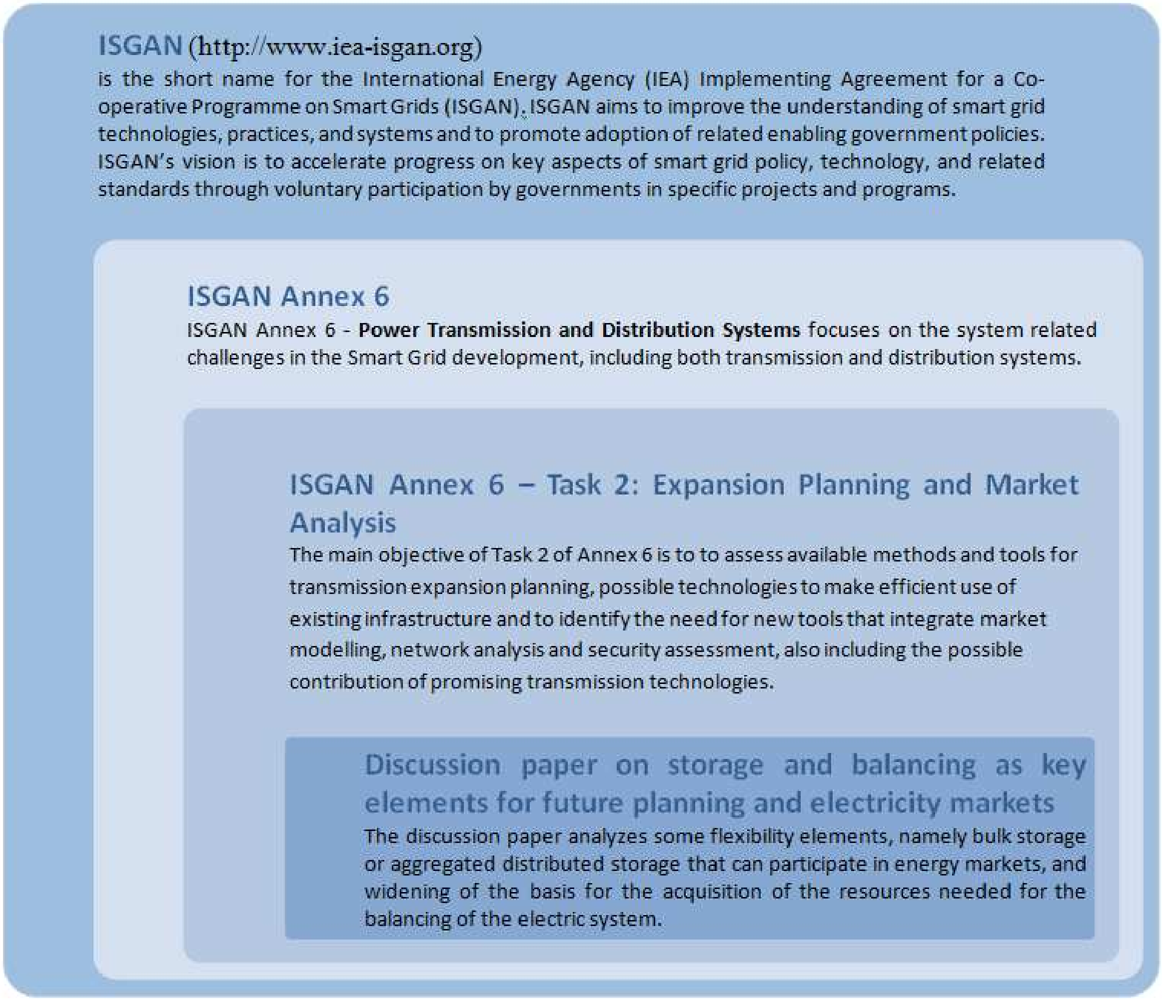

Figure 1 - This discussion paper in the ISGAN framework

Chapter 3 describes the challenges brought by increasing Renewable Energy Source (RES) generation and its variability in Europe. Energy storage is an important flexibility option to locally compensate for RES generation swings. Two on-going European research projects are described in detail: e-BADGE aims at designing the optimal pan-European Intelligent Balancing

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However, there is in most countries an on-going gradual changing process in the direction of making this kind of generation „dispatchable“, i.e. subject to dispatching orders from the TSO. In Canada, the IESO has fully dispatchable wind on the transmission system and is developing the same capability for all solar above 5 MW, see: http://www.ieso.ca/Pages/Ontario's-Power-System/Supply-Mix/Managing-a-Diverse-Supply-of-Energy.aspx

[5] http://energy.gov/oe/services/technology-development/energy-storage

mechanism that is also able to integrate Virtual Power Plant Systems; GridTech conducts a fully integrated assessment of new grid-impacting technologies and their implementation into the European electricity system. Finally, a case study in Italy is presented, evaluating the impact on the Italian national electric system of two new upgrades that could affect the island of Sardinia starting from the year 2020.

In Chapter 4, the current market situations for energy storage in North America are introduced along with a list of recent proposed and implemented policies both at the national and state or provincial level. Then a variety of energy storage technologies in various maturity stages are presented, followed by a summary of grid applications provided by different technologies, and a project on flywheel technology as an example. Also included is an assessment to evaluate the outlook of energy storage systems in 2020 under a scenario of meeting the United States 20 percent Renewable Portfolio Standard (RPS). In addition, a number of barriers that prevent utilities, developers and regulators from capitalizing on the deployment of energy storage resources are also highlighted.

Chapter 5 summarizes storage and balancing as key elements for future planning and electricity markets.

This report is based on facts, technical and economical. It also refers to existing or planned projects that will improve power balancing opportunities in a cost effective way. Investments on the electricity market are done, however, only if a calculable money flow is secured between producers, TSOs, DSOs, networks, customer installations, etc. The study group is aware of the necessity to align the conclusive facts drawn from this report with real markets conditions before drawing decisive conclusions. Nevertheless, they believe that this discussion paper may be useful to stimulate discussions about new alternative routes forward that could turn out to be decisive for integrating a steadily growing amount of renewables and ensure a role to play for flexibility resources located in the distribution segment.

2 Overview of European Energy Storage and Balancing Activities

One of the "hottest" themes of the last years is the need to integrate a steadily increasing amount of electric generation from Renewable Energy Sources (RES), whose generation pattern is inherently variable and can only be controlled in reduction at the price of wasting part of the potential generation. Lacking still nowadays a technology fit for bulk storage[6], any generation surplus produced when primary energy sources (wind, sun) are peaking cannot be stored in significant quantities (apart the contribution pumping hydro power plants can provide). This means that demand and generation must match exactly in real time and some conventional generators have to stay available as reserve ready to intervene in order to compensate "gaps" in the forecast of RES generation. However, reserve generation is usually very expensive. In Europe, every country purchases reserve on its own with a waste of resources (available reserve that could otherwise be offered on the energy markets) with respect to an optimized case in which reserve resources are shared among several countries. However, sharing reserves at trans-national level requires a constant check of the state of the network in order to be sure that the energy produced by the most economically convenient generation resource can also be transported up to where it is needed. Finally, widening the basis for the provision of reserve to entities located on distribution networks could also contribute to achieve a real-time dispatching efficiency. This could be made possible whenever distributed RES generation is matched with local storage in order to guarantee a reliable and predictable network injection. Thus, storage and flexible balancing mechanisms are key elements for the system.

However, treating these two aspects in depth would require dealing with a lot of aspects: generation technologies, system analysis, real-time markets architectures, regulation, etc. In this chapter, we restrict focus on storage and flexible balancing mechanisms in order to answer to the following questions:

- How much bulk storage would be needed in the system in order to achieve an optimal dispatching efficiency?
- What amount of costs can be spared by resorting to trans-national balancing mechanisms instead of retrieving reserve country by country?
- What kind of barriers should be removed in order to make it possible to implement trans-national balancing mechanisms.

2.1 Renewable Energy Sources Variability and Possible Remedies

According to ENTSO-E (European Network of Transmission System Operators for Electricity) sources[7], in 2014, the total ENTSO-E Net Generating Capacity (NGC) is 1024 GW. While NGC

[6] In this report, for "bulk storage" we mean all devices that are connected to the transmission grid and are characterized by a maximum capacity in the order 100 MW or more.

[7] ENTSO-E – Electricity in Europe 2014 – synthetic overview of electric system consumption, generation and exchanges in the ENTSO-E area

is stable when it comes to nuclear, hydraulic and fossil fuel energy, non-hydro renewable energy sources increased by 11 GW (+ 4.9 % compared to 2013) and represented 22% of the total NGC of ENTSO-E (see Figure 2).

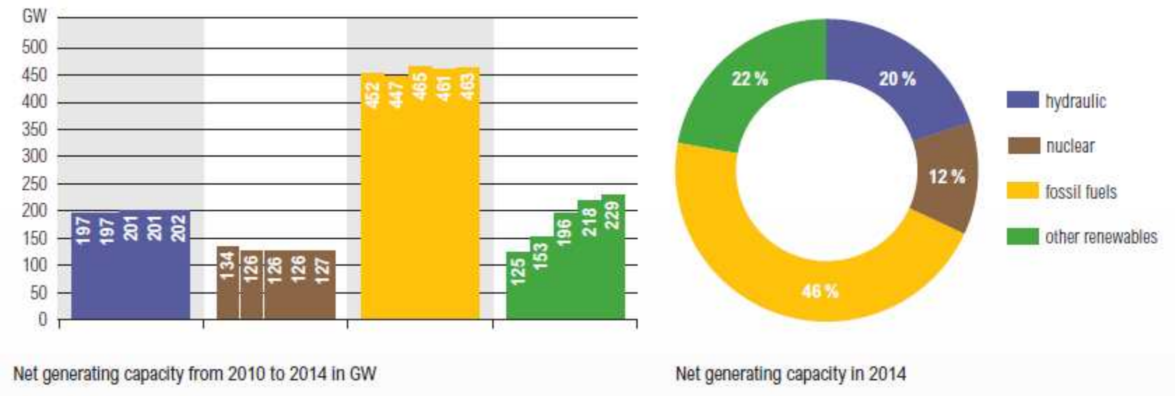

Figure 2 - Energy Net Generation in 2014 (ENTSO-E Area)

Within this amount, an important position is held by RES having a marked intermittent behaviour, solar but most notably wind generation (see Figure 3).

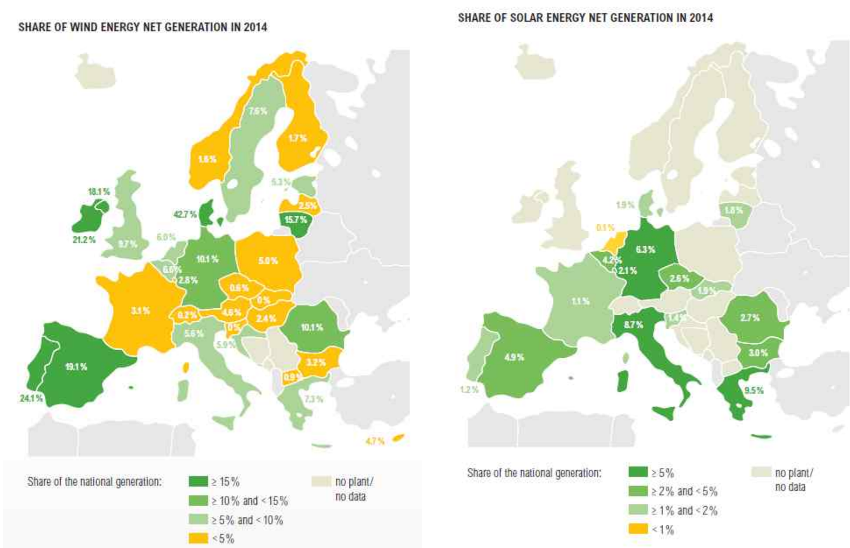

Figure 3 – Share of Intermittent RES Generation in 2014 (ENTSO-E Area)

A marked intermittency in the generation pattern constitutes a challenge both for network planning and for network operation. Constantly changing generation patterns affect flows within the grid making it difficult to ensure security of supply, to guarantee the availability of an adequate reserve margin to cope with unforeseeable events and to ensure that electricity markets (especially those close to real time) function in a proper way.

There is a limited capacity to predict generation patterns for intermittent RES especially when the prediction horizon overcomes a couple of hours: prediction algorithms are still a subject for research.

In this frame, storage could be an important flexibility option allowing to locally compensate for RES generation swings:

- accumulating power when there is a generation peak that can neither be absorbed by the load nor is possible to export the exceeding power to other areas
- releasing power when there is a RES generation shortage.

In this way, the combined action of storage and RES generation could bring to a steady power injection into the grid, comparable with the controllable generation of conventional power plants.

However (see Figure 4) there is still a lack of commercially available storage technologies to be employed in transmission networks for accumulating big quantities of energy ("bulk storage"): hydro pumping is the only mature technology [8] but this technology needs opportune environmental conditions (plenty of water, possibility to develop two reservoirs at different heights) and cannot be implemented everywhere, in particular not necessarily close to the big RES generation locations.

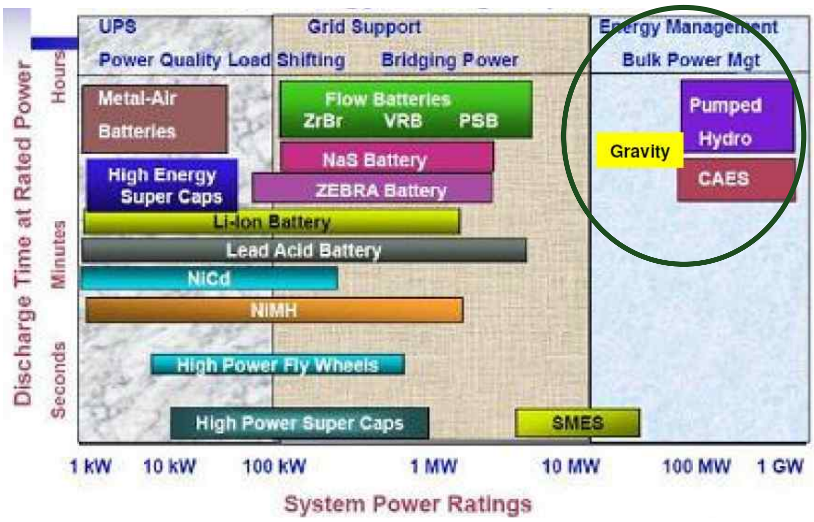

Figure 4 – Present Storage Technologies Options

Therefore, energy has to be consumed as soon as it is produced: power demand and supply have to remain balanced in real time in order to maintain frequency stable. In order to maintain real time balancing, Transmission System Operators (TSOs) have to compensate imbalances with respect to real time injection/withdrawal programs declared in the electricity markets by resorting to the usage of reserve. Thus, an amount of reserve generation has to stay available to move its program for compensating real time deviations from the scheduled generation and load programs.

[8] Compressed air systems (CAES) could become mature in a few years.

Directive 96/92/EC produced the unbundling of generation and retail from the transmission system operation. Generation companies (GenCos) need economic signals to provide reserve services in an economic way: balancing market was created with this aim.

However, the important increase of variable RES foreseen for the next years will put more and more the network under stress (the EC 2050 Roadmap[9] indicates that between 31.6% and 48.7% of electricity production will come from wind by 2050[10]). There is a need to compensate variability (real time balancing) while maintaining an adequate reserve level from conventional (dispatchable) generation.

According to ENTSO-E definitions, reserve can be classified into three categories[11]:

- **Frequency containment reserves** – operating reserves for constant containment of frequency deviations from nominal value in the whole synchronously interconnected system. Activation of these reserves results in a restored power balance at a frequency deviating from nominal value. Operating reserves have activation time up to 30 seconds and are activated automatically and locally.
- **Frequency restoration reserves** – operating reserves to restore frequency to nominal value after system imbalance. Activation up to 15 minutes, typically managed by an automatic controller.
- **Replacement Reserves** – operating reserves used to restore the required level of operating reserves to be prepared for a further system imbalance. This category includes operating reserves with activation time from 15 minutes up to hours. They may be contracted or subject to market.

Apart frequency containment reserves, that are retrieved by utilizing automatic mechanisms, the other two kinds of reserves are activated with market mechanisms in many countries. Such markets, aiming at removing congestion and load-generation imbalance, are located very close to real time (see Figure 5), and are typically affected by high prices.

[9] Communication from the Commission to the European Parliament, the council, the European Economic and Social Committee and the Committee of the Regions - Energy Roadmap 2050 - COM(2011) 885/2

[10] By comparison, in a normal wind year the wind power capacity installed by early 2014 would produce 257 TWh of electricity, enough to supply 8% of the EU's electricity consumption (from EWEA, "Wind in power: 2013 European statistics, February 2014*)*.

[11] ENTSO-E network code on load frequency control and reserves

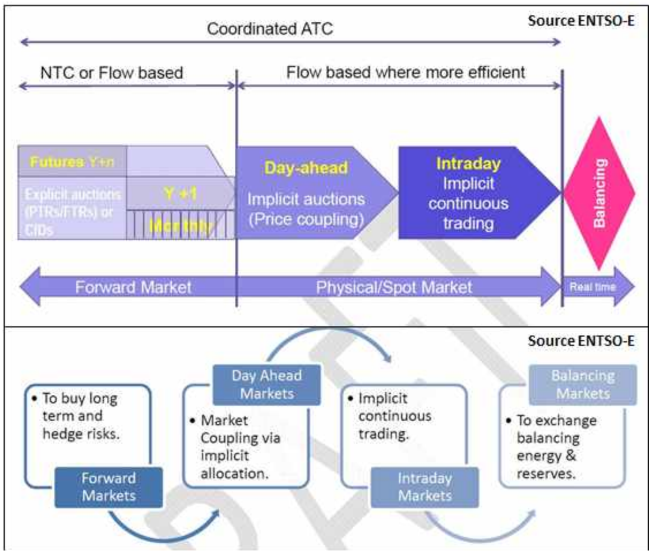

Figure 5 – Temporal Collocation of Balancing Markets[12]

There is a clear necessity to reduce real-time markets costs, that are often much higher than day-ahead market costs. This can be achieved by sharing reserve among the EU Countries. This could be achieved by coordinating relevant markets, removing the present regulatory barriers affecting TSO (Transmission System Operator) operation and non-harmonized aspects on real-time markets functioning, thus creating the basis for a pan-European balancing market. This operation is however very complicated because dispatchability of non-local reserve depends on the real-time flows in the network, that must be known to the TSO and used as an additional information for clearing the real-time balancing markets. There is also a clear competition between the amount of interconnectors capacity that can be put available for commercial cross-border flows and the portion that has to stay available for allowing reserve dispatching in real time. As shown in Figure 6, theoretically speaking there should be an optimal compromise at the point where the marginal value of one extra interconnector MW put available for day-ahead commercial trade equals the marginal value of putting the same amount of interconnection capacity available for ancillary services (reserve provision).

[12] The scheme in figure reflects the so-called European Target Model for congestion management. In December 2009 the Electricity Regulatory Forum ("Florence Forum"), chaired by the European Commission and composed of all member states and relevant stakeholders, endorsed the establishment of the European Target Model for congestion management in the electricity market. This work, continued in 2010 through the Ad-Hoc Advisory Group to ERGEG, has constituted one the main basis for ENTSO-E’s Framework Guidelines on Capacity Calculation and Congestion Management.

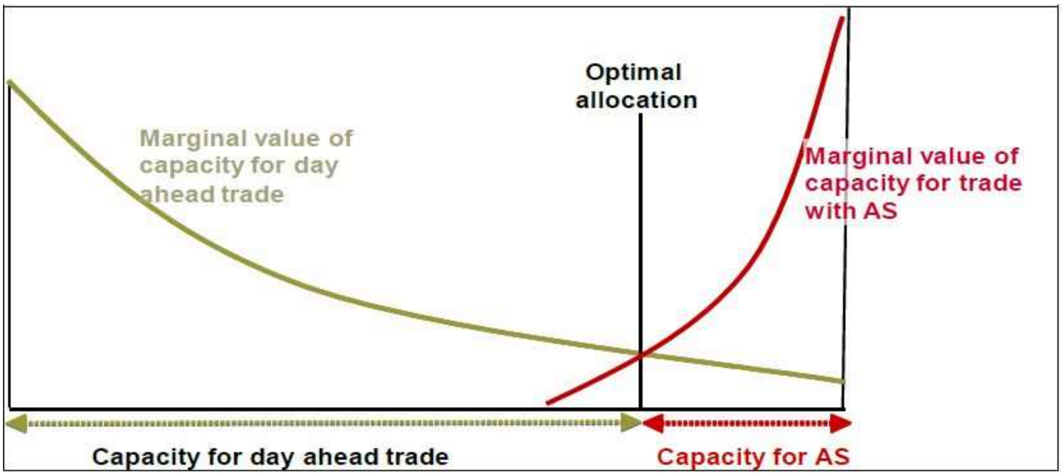

Figure 6 – Trade-Off Between Cross-Border Capacity to be Used For Commercial Day-Ahead Trade and for Ancillary Services (Source ENTSO-E)

Within the ENTSO-E code Network Code on Electricity Balance (NCEB), currently submitted for final approval of ACER (Agency for the Cooperation of Energy Regulators) and the European Commission[13], an extension of the concept of market coupling now extensively applied in Europe to day-ahead markets towards real time markets and balancing markets is theorized and a phased approach is proposed to foster cooperation amongst TSOs in various areas of Balancing. The key concept of Coordinated Balancing Areas: as time passes, the level of cooperation within a Coordinated Balancing Area and between neighboring ones will increase; neighboring Coordinated Balancing Areas will merge; and finally all Coordinated Balancing Areas will merge to reach the final target of a single pan-European Common Merit Order list.

The NCEB is aimed at creating a level playing field for all potential providers of Balancing Services, including demand side response, energy storage and intermittent sources. The harmonized processes and the use of Standard Products form a framework for providers to offer Balancing Services to regional or pan-European Balancing Markets based on TSO-TSO cooperation.

As shown in Figure 7, all this has to be seen as an important tile towards the creation of a pan-European Internal Energy Market, thus increasing markets liquidity and optimizing the usage of complementary generation resources in different Countries (gas, wind, PV, nuclear…).

It is worth noting that ENTSO-E has set up some ongoing pilot projects on cross-border balancing with the aim to test the feasibility of the European (target) model and intermediate steps established in the ACER Framework Guidelines on Electricity Balancing (FG EB), evaluate the associated implementation impact, report on the experience gained[14].

[13] Available on: https://www.entsoe.eu/Documents/Network%20codes%20documents/NC%20EB/140806_NCEB_Resubmission_to_ACER_v.03.PDF

[14] https://www.entsoe.eu/major-projects/network-code-implementation/cross-border-electricity-balancing-pilot-projects/Pages/default.aspx

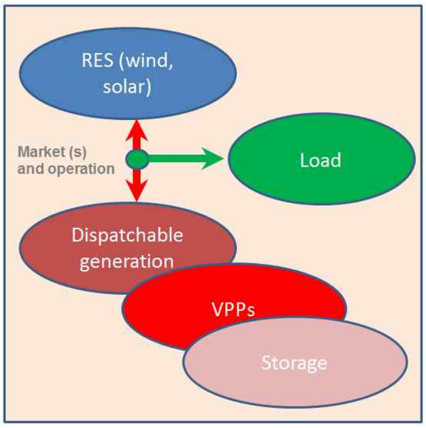

Figure 7 – Interaction between system and flexibility elements

At the same time, while bulk storage is still (at least for the short time) not to be seen as something to be massively deployed, distributed RES generation can be matched with local storage located in distribution networks close to the RES generator in order to guarantee a reliable and predictable network injection (so called: Virtual Power Plants). Such elements could be also enabled to present bids for balancing provision, thus contribution to further enlarge the offer basis and to make real time markets more liquid.

Bulk storage could, by contrast, be a strategic element for the mid-long term, supposing new technologies can become mature as a result of R&D activities. Whereas, as already explained, pumping hydro power plants are nowadays nearly the only available technology allowing storage of big quantities of energy ("bulk storage"), it is important to understand the needs for storage within the future European System.

2.2 Ongoing European Research Projects

On the background of what explained above, the following section contains some results coming from two EU Research Projects both ending in 2015:

- **e-BADGE** (http://www.ebadge-fp7.eu) – the overall objective of the eBadge project is to propose an optimal pan-European Intelligent Balancing mechanism also able to integrate Virtual Power Plant Systems by means of an integrated communication infrastructure that can assist in the management of the electricity Transmission and Distribution grids in an optimized, controlled and secure manner. The project eBADGE sees the participation of 13 European partners, including the Slovenian ELES network operator, the network operator APG Austrian and Slovenian electricity market operator Borzen. There are major industrial partners such as Telekom Slovenje (coordinating the project) and SAP and leading research centers including RSE.
- **GridTech** (http://www.gridtech.eu) – this project conducts a fully integrated assessment of new grid-impacting technologies and their implementation into the European electricity system. This will allow comparing different technological options towards the exploitation of the full potential of future electricity production

from RES, with the lowest possible total electricity system cost. Within the 2020, 2030 and 2050 time horizons and in various scenarios, the goal is to assess, among different innovative technologies, which ones and where, when, and to which extent could effectively contribute to the further development of the European transmission grid, fostering the integration of an ever-increasing penetration of RES generation and boosting the creation of a pan-European electricity market, while maintaining secure, competitive and sustainable electricity supply. The technology categories taken into account within the project to foster RES integration include transmission, storage and demand technologies. In order to assess the impact of the innovative technologies and carry out techno-economic analyses, the project methodology is based on the integration of two types of analyses, that are strictly correlated: a pan-European one (top-down approach) and a regional one (bottom-up approach). The pan-European study is carried out by modeling the whole European power system (EU30+ region) for the 2020, 2030 and 2050 time horizons, by a zonal approach. For the bottom-up level, for 2020, 2030 and 2050 scenario timeframes, GridTech focuses on 7 target countries: Austria, Bulgaria, Germany, Ireland, Italy, Netherlands, Spain. The analyses on these countries are based on market and/or grid detailed approaches.

eBadge: Transnational Balancing Study and Recommendations

As previously described, the eBADGE project[15] aims at defining the optimal pan-European Intelligent Balancing mechanism also able to integrate Virtual Power Plant Systems by means of an integrated communication infrastructure. In this optic, the research of the optimal algorithm for the best allocation of balancing resources is really important in order to be able to exploit at the best all the bids and offers available in different nations.

Part of the project was devoted to creating a new simulation environment for a hypothetic trans-national balancing market between Austria, Italy and Slovenia allowing to give a gross estimation of the economic benefits that balancing markets coupling could bring to the system[16]. In parallel, the regulatory context was investigated[17] and an investigation on barriers and criticalities[18] was carried out. In the following, some important results are summarized.

The creation of a truly integrated Internal Electricity Market (IEM) is clearly a benefit for the entire European power system from the point of view of the social welfare and the competition,

[15] http://www.ebadge-fp7.eu/

[16] See the following report: R. Calisti, F. Careri, M. V. Cazzol, A. Zani - Scenario analyses on a future trans-national balancing/reserve market among Austria, Italy and Slovenia, results of further inclusion of Germany - Deliverable D2.4 of the project eBADGE

[17] See the following two reports:

1. H. Auer, R. Rezania, G. Lettner - Market Architectures for Cross-Border Procurement and Activation of Balancing Capacity and Balancing Energy in Europe – Deliverable D2.1 of the project eBADGE;
2. G. Migliavacca, A. Zani, T. Esterl, H. Auer, P. Nemček, M. Kolenc, A. Andolšek, M. Šterk - Guidelines for the creation of a trans-national reserve/balancing market between AT, IT and SI – Deliverable D2.5 of the project eBADGE

[18] See the following report: D. Burnier de Castro, T. Esterl - Analysis of changes, risk and possibilities for cross border market opening between Austria, Italy and Slovenia – Deliverable D2.2 of the project eBADGE

provided it is accompanied by a gradual regulatory harmonization of the national markets. Up to now, the focus of the integration has been given to day ahead markets, but it is important to notice that also the integration of electricity markets closer to real time, the most critical for a proper functioning of the system, is an important goal to achieve at a pan-European level. The third energy package push in this direction by creating the Agency for the Cooperation of Energy Regulators (ACER) and the European Network of Transmission System Operators (ENTSO-E) with the obligation of the latter to elaborate network codes on the basis of framework guidelines formulated by the former.

According to the last draft text of the ENTSO-E grid code on electricity balancing, a phased approach will be promoted to foster cooperation amongst TSOs in various balancing areas. As time passes, the level of cooperation within a Coordinated Balancing Area (CoBA) and between neighboring ones will increase; neighboring Coordinated Balancing Areas will merge, and finally all Coordinated Balancing Areas will merge to reach the final target of a single pan-European Common Merit Order list. [19]

A new set of ACER's recommendations were issued on 20 July 2015, which suggest further modifications of the NCEB text in order to stress the need of harmonization of the markets and of standardization of the products so as to facilitate the progressive integration of the Coordinated Balancing Areas. We limit ourselves to providing a partial view of the comments, that highlights points we deem of particular relevance concerning the coordination model to be adopted among the CoBAs:

- the definition of CoBA is amended stressing this is a region where TSOs are exchanging balancing capacity, sharing reserves, exchanging balancing energy or operating the imbalance netting process;
- The number of CoBAs should not be higher than five and each TSO should be attributed to only one of them. CoBAs should not be designed in a way that prevents their future merge.
- ENTSO-E is prompted to explore to exchange balancing services or to share reserves also between CoBAs. All standard products and all specific products for a specific balancing process should be shared among all CoBAS. A harmonized balancing energy gate closure should be adopted and this should be as close as possible to real time. Imbalance netting should be carried out within a single CoBA covering whole Continental Europe;
- Unshared balancing energy bids should be reduced to the minimum and should only consist of bids with the highest prices which cannot be activated by other TSOs. The volume of unshared bids should not exceed the amount of balancing capacity. TSOs should limit their use as much as possible.

[19] Framework Guidelines on Electricity Balancing, ACER, FG- 2012-E-009, September 2012. Available at: http://www.acer.europa.eu/Official_documents/Acts_of_the_Agency/Framework_Guidelines/Framework%20Guidelines/Framework%20Guidelines%20on%20Electricity%20Balancing.pdf

- Demand-side response could face important entry barriers into balancing services: Member States and National Regulatory Authorities should implement adequate mitigation measures.

An important activity related to the ebadge project has been the study of different market models able to describe the target model and also the intermediate model that allows a progressive and gradual passage from the present un-harmonized situation up to the final one with the internal market in which all the different power systems are perfectly integrated and all the resources are optimized at the best.

The bilateral/multilateral market-based TSO-TSO balancing model with common merit-order lists with unshared bids can be interpreted as an intermediate step next to the so-called ‘target model’. [20]

It is important to underline the fact that the exchange of bids among different TSOs is related only to balancing energy bids. The procurement of balancing capacity is performed internally each nation/zone with rules that can be different zone by zone.

In general, the bilateral/multilateral market-based TSO-TSO balancing market model with common merit order list and unshared bids relies on the following major points:

- Determination of those bids need not to be shared by each of the involved TSOs (i.e. amount of unshared bids, starting from the most expensive one);
- After the clearing of the bilateral/multilateral common merit order, there is a balancing energy flow between the offering TSOs and the requesting TSOs. However, there is no direct connection/link between a single Balancing Service Provider (BSP) and a TSO other the incumbent TSO or a single BSP and the common function;
- The bilateral/multilateral market-based TSO-TSO balancing model with common merit-order and shared bids expects a tight harmonization of the different national approaches in terms of procurement of balancing energy bids to enable smooth system operation and improvement of total system efficiency.

After this national procurement process the separation of bids into ‘shared’ and ‘unshared’ balancing energy bids is implemented. Afterwards, those balancing energy bids dedicated to be shared are forwarded immediately to a common market operator where the multilateral/international common merit-order list is built.

For this approach two independent merit-order lists for upward and downward regulation are needed both on national TSO level and on the common function. A detailed definition of standard products not only for the national procurement of balancing energy bids but also for exchanging shared balancing energy is a necessary precondition for the proper functioning of the

[20] For a deeper description of this model see: [H. Auer, R. Rezania, G. Lettner, "Market Architectures for Cross-Border Procurement and Activation of Balancing Capacity and Balancing Energy in Europe" Deliverable D2.1, FP7 Project eBadge, Dec. 2013.]

market. In case of activation of shared balancing energy bids, an exchange of balancing energy takes place after the execution of the cross-border intraday electricity markets. For this aim, only residual cross-border transmission capacity must be used. There is no reservation of cross-border transmission capacity foreseen for balancing energy exchange based on the concept of shared bids on the common function.

A further development of the previous bilateral/multilateral market-based TSO-TSO model with common merit-order lists with unshared bids finally results in a system where all bids of the Balancing Service Providers (BSPs) are shared on common function. As described in the previous model the procurement of balancing capacity bids and balancing energy bids is conducted by the incumbent TSO. Then, each TSO will forward the procured balancing energy bids to the common function, the procured balancing capacity bids remain on national TSO level. This means that the cross-border exchange among the TSOs balancing capacity is only optional. Therefore, a reservation of cross-border transmission capacity is not obligatory. However, a cross-border exchange of balancing energy is feasible only if – in case of activation of balancing energy bids – sufficient cross-border transmission capacity is available.

Moreover, in case of activation of balancing energy there is a balancing energy flow between the offering BSPs (physically connected to an associated TSO) and a requesting TSO other than the TSO where the BSP is physically connected. Eventually, it is important to note that this final model – the target model – expects an entire harmonization and standardization in terms of different national parameters and products in the context of balancing energy service provision.

This model expects besides the same national platform in each of the TSOs' control zones a common function, enabling the different TSOs to forward their balancing energy bids. There is no additional communication necessary between the involved TSOs (compared to the above mentioned, previous bilateral/multilateral market-based TSO-TSO balancing model with common merit-order lists with unshared bids). There is also no need of extension of communication between a BSPs and its incumbent TSO (i.e. TSO where the BSP is physically allocated) in comparison to the above mentioned, previous model. Again all balancing energy bids are forwarded by the incumbent TSOs to the common function and not by the BSPs.

Barriers and criticalities to a pan-European Balancing Market

Nowadays, the great diversity of ancillary market designs among its Member States represents an important barrier to the set-up of a cross-border trade of ancillary services and to the development of a fully integrated IEM. The diversity of procurement schemes for ancillary services across Europe has to be taken into account when developing cross-border balancing schemes. According to selected design parameters, balancing markets can be analyzed as shown in Figure 8. While the multinational design variables have yet to be designed, the national balancing market parameters need to be harmonized for successful implementation of cross border balancing in a way to ensure secure balancing and to enhance global welfare. The challenge of defining these parameters and of defining the degree of harmonization is to specify them in an intelligible way, but to let room for national technical requirements and specifications.

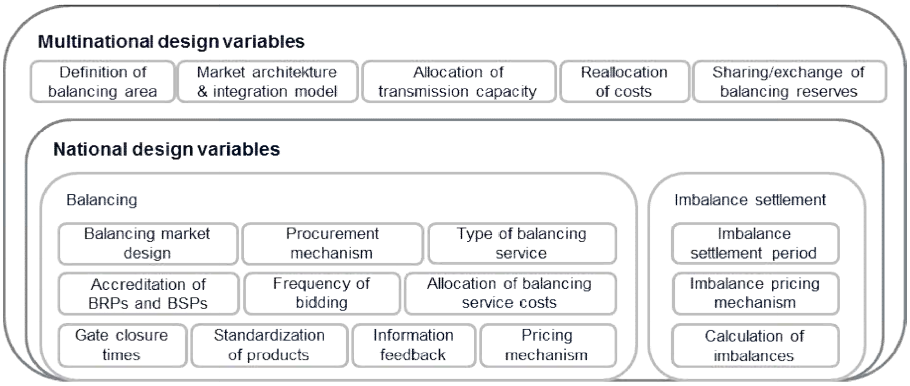

Figure 8 **- Selected design variables for analysis of national balancing markets**

One parameter is the selected market architecture. There are different market architectures for the integration of European balancing market and thus, for cross-border procurement of balancing energy and, as seen in Table 2, they have different pros (+/++) and cons (-/--). The starting point is a national balancing market without any exchange of balancing energy bids.

The cross-border BSP-TSO concept is followed by two gradually enhanced cross-border TSO-TSO balancing market architectures (considering different principles of bid exchange). The most advanced market architecture coincides with the so called 'Target Model' being consistent with the overall framework defined in the ACER and ENTSO-E documents.

The balancing market within the control zone of a single TSO (national model) is organized based on the following subsequent steps for procuring and – in case of activation – balancing services from different Balancing Service Providers (BSPs) fulfilling the prequalification criteria:

(i) Procurement of balancing capacity;
(ii) Procurement of balancing energy;
(iii) Activation of balancing energy of selected BSPs.

For the first two mentioned steps above ((i) & (ii)) separate tenders exist and the corresponding bids are split for upward and downward regulation. Well defined standard products can be offered by BSPs to the TSO that clears the market in the corresponding national market place for procurement of balancing energy.

Table 2 - Comparison of the Different Cross-Border Balancing Market Concepts

	Cross-border BSP-TSO model	**Bilateral / multilateral TSO-TSO model without common merit order**	**Multilateral TSO-TSO model with common merit order – lower degree of harmonization**	**Multilateral TSO-TSO model with common merit order – high degree of harmonization**

Economic allocation efficiency	--	-	+	++
Short/medium term applicabi lity in practise	++	+	-	--
Support of VPPs as BSPs	--	--	-	+
Harmonisation needs of neigh bouring balancing markets	--	-	+	++
Market compatibility / compe tition / transparency	--	-	+	+
Social welfare / system cost (global optimum)	--	-	+	++

In the cross-border BSP-TSO concept it is foreseen that Balancing Service Providers (BSPs) can offer balancing energy bids not only to the Transmission System Operator (TSO) in their own control area, but also to other TSOs in neighboring control areas. This offer of balancing energy bids by a BSP to a TSO has to be accepted by the 'own' TSO in the control area where the BSP is located. In case of activation of these kinds of balancing energy bids a cross-border balancing energy exchange takes place as long as there is sufficient cross border transmission capacity available at the point in time when it is actually needed.

The bilateral/multilateral market-based TSO-TSO balancing model with surplus exchange is a further development of the previously described national approach. The aim of such a balancing market model is that the involved TSOs exchange some surplus balancing energy bids based on predefined criteria. It is important to note that the exchange is restricted to surplus balancing energy bids only. The determination and procurement of balancing capacity is carried out separately by each of the TSOs. Hence, no exchange of balancing capacity among the TSOs exists and also no reservation of cross-border transfer capacity is needed to enable the exchange of balancing capacity. However, a cross-border exchange of surplus balancing energy bids is only feasible if sufficient cross-border transfer capacity is available in case of activation.

The balancing markets in Austria, Slovenia and Italy (AIS) and the need for harmonization between them were analyzed, within the project eBADGE, according to the design variables in Figure 8. The first dissimilarity between the three countries is the balancing market design. The dispatching system is the same in Austria and Slovenia (self-dispatch system on portfolio basis), but different in Italy (central dispatch system). Many details in the Network Code on Electricity Balancing implicitly assume a self-dispatch balancing market design. For central dispatch markets an exceptional regulation is in place. The optimization algorithm of the central dispatch model takes simultaneously the balancing requirement as well as the internal congestions into account. The balancing resources have to be mandatorily offered in Italy, whereas in Slovenia the balancing capacity is procured by bilateral contracts. In Austria the market-based mechanism of a tendering process is used. The manual Frequency Restoration Reserve (mFRR) balancing service of the three countries is indeed according to the operation handbook of the ENTSO-E, but the mFRR differs in some parameters as for instance regarding the time to full activation (10 minutes in Austria, 15 minutes in Slovenia and Italy). At least some of these differences have to be harmonized for the cross-border market opening of balancing energy. A first step for the harmonization would be an adaptation of the gate closure times (day-ahead, intraday, balancing energy, capacity allocation and favorable the imbalance settlement time unit) as different gate closure times make the cross-border provision of balancing energy nearly impossible.

Scenario

In order to carry out a quantitative assessment of the benefits that could be extracted from an integrated balancing market, models of both the present mechanism and the "target" model were developed and run, with a particular focus on a region encompassing Austria, Italy and Slovenia.

As shown in Figure 9, the eBADGE simulator represents both Austria and Slovenia with one only equivalent zone, while Italy is split into six zones (corresponding to the Italian day-ahead market zones). As anticipated in previous sections, settlement and clearing approach of these three nations are really different: in Austria and Slovenia the clearing of balancing energy market is mainly done without network constraints; different approach is taken in Italy, where the network has to be taken into account because its characteristics limit the field of action of real time markets. This is the reason why Italy is modeled through a zonal representation, while Austria and Slovenia are seen as single zones.

The studied scenarios refer to a period between the 1st March 2012 and the 31st July 2013. This timeframe was chosen on the basis of TSO's input, that affirms that in this period the regulatory context has been quite stable in all the involved nations.

Analyzing the rules for switching from secondary to tertiary bids in each nation, a great complexity and inhomogeneity has been observed. For our modeling purpose, simplifying assumptions have been adopted in order to keep the complexity within a range that can be dealt with in our model: in Austria and Slovenia secondary reserve is called for activation if the actual imbalance is lower than a given threshold, otherwise tertiary bids are used, for Italy a similar rule has been adopted, the only difference being that the threshold is not fixed a priori, but it is a function of the daily peak load (typically 2% of it).

Figure 9– Power System Model

In order to assess which benefits could subsist for the Italian power system in case of a common balancing market with Austria and Slovenia, two different scenarios have been defined: a **Base Case scenario** (**BC**), simulating a situation in which each nation has to solve internal imbalances only with local resources (in order to implement this scenario NTC values have been imposed equal to zero), and a **Common Balancing Market scenario** (**CBM**), simulating a situation in which balancing resources may be exchanged.

A comparison between the results of the BC and CBM scenarios was performed in terms of costs and energy flows. Costs results are presented in Table 3 and in Figure 10.

Table 3 - Balancing Costs [M€] for Each Nation

Scenarios	Nation			Total
	Austria	Slovenia	Italy	
BC	3.5	37.3	137	177.8
CBM	5.2	20.2	54.2	79.7

It can be observed that if a common balancing market is created total dispatching costs decrease for both Slovenia and Italy. Different results for Austria – most likely because the cheapest Austrian generators are used to cope with imbalances in Italy and Slovenia, while more expensive generators are used in order to face Austrian imbalances – imply higher costs for this country.

In any case, costs increases in Austria are lower than the savings that can be achieved in Slovenia and in Italy; in particular, in Italy, costs for secondary and tertiary activation amount to 137 M€ if imbalances are solved only with local generators and this value decreases to 54.2 M€ in case a common balancing market is implemented, with a saving level up to 60%. It has to be noticed that this estimation corresponds to an optimistic case in which no internal network constraint is violated. The presence of internal constraints could make it necessary to resort to less optimal solutions and reduce this saving level. So, the presence of a strong transmission network is an important prerequisite for allowing a cross-border balancing market to function efficiently.

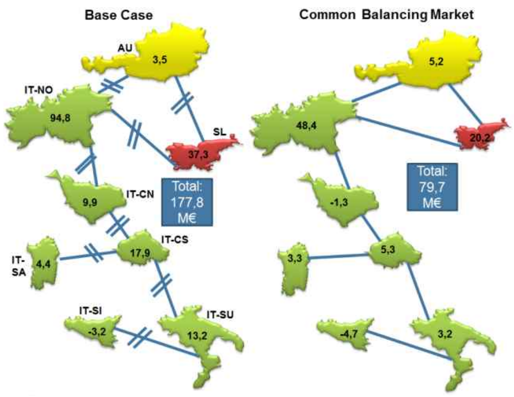

Figure 10 – Comparison of Costs-savings for the Two Scenarios (M€)

Another important result to analyze is the level of energy exchanges between the modeled macro-zones: reports the results for the CBM scenario.

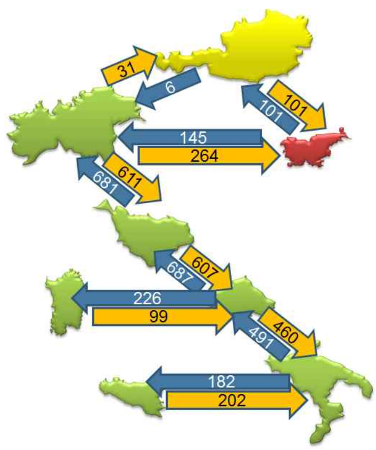

Figure 11 – Energy Exchanges [GWh] Between Zones in CBM Scenario

Considering that, in the studied period, the total imbalances that occur in all the Italian zones amount to 6286 GWh, if we compare this figure with the resulting exchanged energy, equal to 3894 GWh, we conclude that volume of exchanges between macro-zones amounts to 77.8 % of the total imbalances that occur in the system. This result highlights the benefits in terms of integration of balancing system. It can be seen that the exchanges between north Italy and Austria stay quite low: this apparently unexpected result can be justified with the weak interconnection level between the two countries.

Moreover, the level of exchanges between continental Italy and Sardinia or Sicily could be overestimated in our scenarios. In fact, in order to maintain a sufficient level of security of supply in a weakly interconnected system as well as for reasons related to reactive management, some local units are called to operate also if their costs are higher than those of other units. For these reasons, both in the day-ahead markets and in the balancing markets, weakly interconnected macro-zones tend to exploit local resources. The solution of our model does not take into account all these characteristics and thus we think that the import figures for Sardinia and Sicily could be overestimated.

GridTech: Storage Applications in a Pan-European Context and Recommendations

The development of adequate transmission infrastructures and grid-impacting technologies plays more and more a crucial role to foster the integration of RES[21]. In this framework, the main objective of the European project named GridTech (*Innovative grid-impacting technologies enabling a clean, efficient and secure electricity system in Europe*, http://www.gridtech.eu) is to conduct a fully integrated assessment of new grid-impacting technologies and their implementation into the European electricity system. This will allow comparing different technological options towards the exploitation of the full potential of future production from RES, with the lowest possible total electricity system cost.

The approach of the project entails the analysis of the 2020, 2030 and 2050 time horizons, to assess which innovative technologies and where, when, and to which extent they could effectively contribute to the further development of the European transmission grid, also towards potential supergrid (“transmission highways”) architectures. This aims at fostering the integration of an ever-increasing penetration of RES generation and boosting the creation of a pan-European electricity market, while maintaining secure, competitive and sustainable electricity supply. For each target year and scenario, the methodology is based on the evaluation of the different benefits to the European power system provided by the innovative technologies comparing the case implementing the assessed technology with respect to a base case without it. This is carried out at two levels by a pan-European approach analysis (top-down) and by regional case studies (bottom-up)[22].

In the present section, different results of the GridTech pan-European study are presented, with reference to the 2020 and 2030 time horizons.

For the purpose of GridTech project, two general categories of technologies to be investigated can be distinguished[23]:

[21] European Commission, "Long term infrastructure vision for Europe and beyond", COM(2013) 711 final, Oct. 2013.

[22] A. L’Abbate, R. Calisti, A. Zani, H. Auer, G. Koerbler, G. Lettner, P. Frias, L. Olmos, C. Fernandes, T. Maidonis, S. Vitiello, G. Fulli, G. Schauer, S. Sulakov, A. Andreev, M. Ivanov, A. Mansoldo, C. Vergine, P. Tisti, O. D’Addese, A. Sallati, K. Jansen, R. van Houtert, J. Bos, B. Heyder, L. Radulov, "The role of innovative grid-impacting technologies towards the development of the future pan-European system: the GridTech project", Proc. of CIGRE Session 2014, Paris, France, Aug. 25-29, 2014.

[23] A. L'Abbate, H. Auer, G. Koerbler, C. Fernandes, P. Frias, L. Olmos, T. Maidonis, C.F. Covrig, S. Lazarou, S. Vitiello, G. Schauer, "Promising new innovative technologies to foster RES-Electricity and storage integration into

1[st] category -> technologies directly impacting on the transmission system

2[nd] category -> technologies indirectly impacting on the transmission system

The 1st category includes technologies which are generally planned/operated by TSOs: the use of these technologies is then generally in the hands of TSOs. Transmission grid technologies (TGT) belong to the 1st category.

The 2nd category includes technologies which are generally not planned/operated by TSOs: the use of these technologies is in general not in the hands of TSOs. Electricity generation technologies (including variable RES) (EGT), energy storage technologies (EST), electricity demand technologies (EDT) (including demand side technologies and electric mobility vehicles) belong to the 2nd category.

There exist different possible classifications of EST in available literature. As the focus in GridTech is on storage of energy for electricity scopes, thermal storage has been not considered. The EST for electricity have been classified in GridTech D3.1 report[23]: focus has been especially on the EST potentially capable to effectively support the European power transmission system expansion and operation.

Attention has been then particularly paid to bulk EST such as PHES (Pumped Hydroelectric Energy Storage) and CAES (Compressed Air Energy Storage) technologies, which are more suitable for transmission side applications nowadays. In this sense, several PHES projects (including European PCIs[24]) across North-West Europe (Ireland, UK), North-East Europe (Estonia, Lithuania, Poland), Central Europe (Austria, Germany, Switzerland), South-West Europe (France, Portugal, Spain) and South-East Europe (Bulgaria, Greece) have been recorded for the short-to-mid term, while further potential PHES projects in other countries (e.g. Cyprus, Norway, Turkey) are also taken into account in a mid-to-long term; furthermore, it has to be highlighted that for some of PHES projects (like the MAREX plant in Ireland) seawater will be used. Concerning CAES, different projects (including European PCIs) are ongoing at various development stages in some countries like Germany, UK (Northern Ireland), Norway, Spain[25]. All these developments and evolutions related to PHES and CAES in the different European countries are duly taken into account in the set-up of GridTech scenarios. On the other hand, also other EST types, currently under development/use for small-scale applications, have been investigated within GridTech, as they are emerging as promising technologies, potentially useful for future transmission side applications in Europe. In particular, in several European countries (especially in Southern Europe, but not only) pilot projects based on batteries storage are more and more taken in consideration at transmission level: in this sense, the case of Italy has to be

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the European transmission system within the time frame 2020-2030-2050", GridTech Deliverable D3.1, Dec. 2013. http://www.gridtech.eu

[24] European Commission, Projects of Common Interest, 2013-2015. http://ec.europa.eu/energy/en/topics/infrastructure/projects-common-interest

[25] P. Verboven, L. Sigrist, J. Kathan, F. Geth, "Map and analysis of European Storage Projects", GRID+ Deliverable D1.3, Jan. 2014. http://www.gridplus.eu/

highlighted, given its large programmes for installing batteries for RES integration (250 MW in total) and for security enhancement (40 MW in total) on different critical sections of the 150 kV grid.

Energy storage technologies can be used for a number of applications on different time scales, which are not all directly related to the support of variable / intermittent RES generation. The main relevant clusters for TSO applications would be: RES management, area control & frequency, commodity storage, reserve provision, transmission system stability, voltage regulation, and reliability support.

The implementation of the different innovative technologies within the devised scenarios for the pan-European zonal study is carried out by the use of MTSIM (Medium Term SIMulator) tool, as it is able to take into account not only HVDC links, but also PSTs (Phase Shifting Transformers), DSM/DR (Demand Side Management/Demand Response) and energy storage systems[26]. MTSIM, developed by RSE, is a zonal electricity market tool able to simulate the behavior of the modeled European electricity system by a DC optimal power flow: the objective function consists in the minimization of the total system costs (that correspond to the costs for dispatching, emission, load shedding and excess energy) to determine the hourly clearing of the market over an annual time horizon. The model takes into account the variable costs of thermal power plants (fuel, operation and maintenance, and CO_2 emission allowances), as well as the bidding strategies put in practice by producers, in terms of mark-ups over generation costs[27]. The reservoir hydro power plants are also implicitly optimized during the annual time horizon, taking into account the annual inflows available in each zone. RES generation can be modeled by an hourly profile in each zone.

The equivalent network among zones can include both HVAC (High Voltage Alternating Current) corridors, where the physical constraints are represented through a PTDF (Power Transfer Distribution Factors) matrix, and HVDC interconnectors, that can be operated independently of the HVAC network: each inter-zonal HVAC and HVDC transit is constrained by the respective NTC (Net Transfer Capacity) value. A fully “commercial flow” optimization can be performed as well, that is optimizing the capacity values of NTC between zones, neglecting PTDF constraints. By modeling active power flows, MTSIM can detect transmission congestion and the needs for network reinforcement can be quantified.

The main results provided by the simulator are: hourly marginal price for each market zone, hourly dispatch of all power plants (hydro and thermal), hourly inter-zonal power flows, fuel consumption and cost for each thermal power plant, as well as CO_2 emissions and related costs for emission allowances. An important feature of the simulator is the corridor expansion planning modality: it can increase inter-zonal (HVAC and HVDC) transmission capacities in case the annualized costs of such expansions are lower than the consequent reduction of costs

[26] A. Zani, G. Migliavacca, A. Grassi, "A scenario analysis for an optimal RES integration into the European transmission grid up to 2050", Proc. of EEM 2011 Conference, Zagreb, Croatia, May 25-27, 2011.
[27] However, within GridTech, no market power exercise will be simulated, given the different uncertainties, while focusing on the “natural” best response of the system.

due to a more efficient generation dispatch. This feature can support the determination of the optimal expansion of the European cross-border transmission system, especially in the long-term.

For GridTech zonal study by MTSIM, the pan-European (EU30+) power system has been modeled with an equivalent representation where each country is taken into account by a node (i.e. market zone), interconnected with the other zones/countries via corridors characterized by an equivalent inter-zonal transmission capacity. In the pan-European study, the modeled EU30+[28] system takes fully into account endogenous countries such as the today's 28 Member States of the EU (EU28), the EU current and potential candidates – Albania, Bosnia-Herzegovina, FYR Macedonia, Iceland, Montenegro, Serbia, Turkey – and EFTA (European Free Trade Association) countries such Switzerland and Norway. Then, the pan-European model of the EU30+ power system includes 37 countries, as depicted by Figure 12 in light blue.

Figure 12 – The EU30+ geographical perimeter of the GridTech pan-European study

[28] AL: Albania, AT: Austria, BA: Bosnia-Herzegovina, BE: Belgium, BG: Bulgaria, CH: Switzerland, CY: Cyprus, CZ: Czech Republic, DE: Germany, DK: Denmark, EE: Estonia, FI: Finland, FR: France, GB: Great Britain, GR: Greece, HR: Croatia, HU: Hungary, IE: Ireland, IS: Iceland, IT: Italy, LT: Lithuania, LU: Luxembourg, LV: Latvia, ME: Montenegro, MK: FYR Macedonia, MT: Malta, NI: Northern Ireland, NL: Netherlands, NO: Norway, PL: Poland, PT: Portugal, RO: Romania, RS: Serbia, SE: Sweden, SI: Slovenia, SK: Slovakia, TR: Turkey. The system of Serbia also includes Kosovo.

Figure 13 and Figure 14 show the zonal scheme for the EU30+ system in GridTech 2020 and 2030 scenarios studies, respectively. In Figure 13 and Figure 14 the endogenous zones, mostly interconnected via HVAC (in black) and/or HVDC (in blue) corridors, are represented in light grey, whereas the exogenous zones (external regions), with which the EU30+ system exchanges imports/exports (blue arrows), are highlighted in orange. The system in Figure 14, which refers to the only onshore pan-European scheme, takes also into account some of the further potential inter-zonal corridors, based on HVAC (dashed black) and/or on HVDC (dashed blue), that may be techno-economically convenient and deployed at 2030 or afterwards.

From Figure 13 and Figure 14 it can be seen that the actual number of endogenous zones totally amounts to 39, as Northern Ireland is treated separately with respect to Great Britain and Germany has been split in two zones with the purpose to also highlight some of the internal north-south HVDC corridors planned within German grid[29] [30]. On the contrary, Denmark is considered as a single zone, though Figure 13 and Figure 14 show both the western Denmark zone (DK_W) and the eastern Denmark zone (DK_E), interconnected through HVDC link, to highlight the respective inter-zonal (HVAC and HVDC) corridors with the neighboring countries. Endogenous countries like Cyprus (all island system) and Iceland are isolated zones at 2020, but they may be potentially connected, via HVDC cable(s), to the rest of the pan-European system at 2030. In the pan-European study, Turkey is considered as endogenous country, also given the synchronisation of the Turkish system with the one of ENTSO-E Continental Europe. In the long-term (after 2030 to 2050), in order to take into account the developments related to the potential realisation of an offshore grid in the North Seas, additional endogenous offshore zones are also considered in the GridTech EU30+ system; however, focus of the present section is on the onshore system developments up to 2030.

As the framework of GridTech has to be seen towards the exploitation of RES in Europe, the scenarios considered in the GridTech studies are rather optimistic (yet not unrealistic) in terms of RES penetration in the different EU30+ countries, while also taking into account local specificities and national energy mix evolutions. For each target year, four main scenarios are generally considered and named S0, S1, S2, S3. Each of the four scenarios is characterized by a mix of RES and innovative grid-impacting technologies from the TGT, EST, and EDT categories, respectively. Among these scenarios, S0 represents the reference baseline to which compare the technological development, while S1, S2, S3 are respectively characterized by an higher penetration of TGT (especially HVDC), EST (especially PHES and also CAES), EDT (DR), with respect to S0. S1 is then labeled as TGT-oriented scenario, S2 is the EST-oriented scenario and S3 is the EDT-oriented scenario. For 2020, GridTech scenarios are based on the general fulfillment of 2020 RES (EU or national, where present) targets in the European countries, taking into due account elements from different sources, including NREAPs[31] and ENTSO-E SO&AF

[29] DE2 represents the south-western part of the German system, operated by TransnetBW, whereas DE1 takes account of the rest of German system, operated by the other three German TSOs.
[30] ENTSO-E, "Ten-Year Network Development Plan 2014", Oct. 2014. https://www.entsoe.eu
[31] NREAPs (National Renewable Energy Action Plans). http://ec.europa.eu/energy/en/topics/renewable-energy/national-action-plans

(Scenario Outlook and Adequacy Forecast) 2013[32] (EU2020 scenario). Following the trend, the scenario for 2030 considers a higher RES penetration, also to achieve the overall 2030 RES targets[33]: the main reference data are based on multiple sources, starting from ENTSO-E SO&AF 2013 and 2014 (Vision V3)[34].

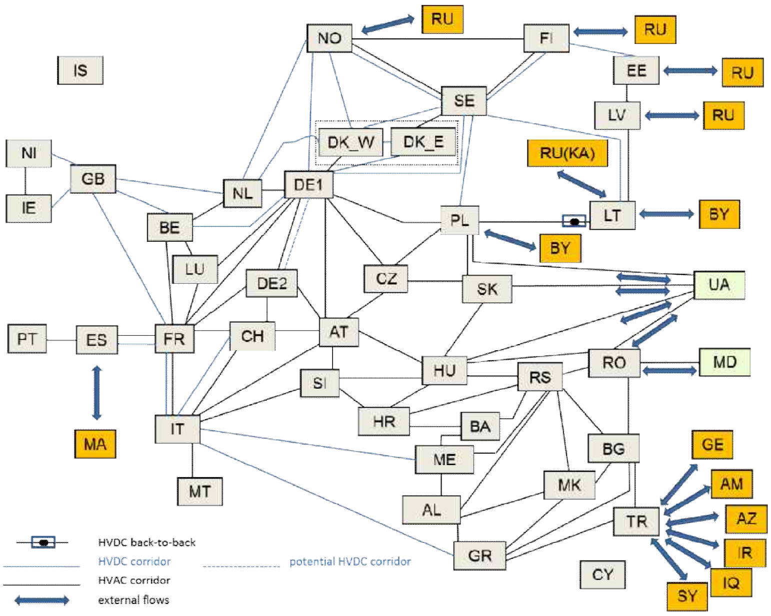

Figure 13 – Zonal Scheme of the Pan-European (EU30+) System at 2020

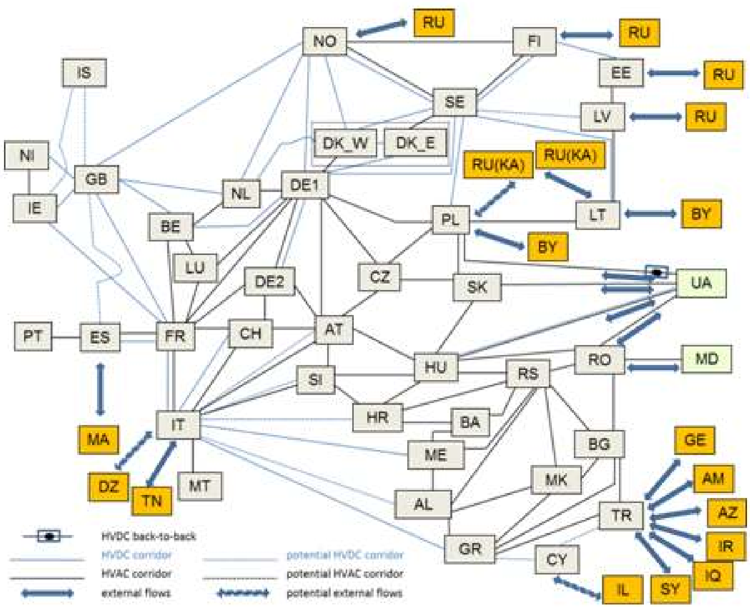

Figure 14 – Zonal Scheme of the Pan-European (EU30+) System at 2030

32 ENTSO-E, "Scenario Outlook and Adequacy Forecast (SO&AF) 2013-2030", Apr. 2013. https://www.entsoe.eu
33 European Union Council, "Conclusions on 2030 Climate and Energy Policy Framework", 23-24 Oct. 2014.
34 ENTSO-E, "Scenario Outlook and Adequacy Forecast (SO&AF) 2014-2030", Oct. 2014. https://www.entsoe.eu

Table 4 reports the overall generation capacity values, aggregated per fuel/type, for 2020, 2030 GridTech baseline scenarios related to the whole EU30+ system. From Table 4 the increasingly higher RES and gas-fired generation penetration and the relevant decrease of thermal capacity based on hard coal, lignite and oil over the years can be noticed. In terms of electricity demand, the GridTech scenarios consider a generally high level of total electricity consumption at 2020 and 2030 (starting from ENTSO-E SO&AF 2013 and 2014): this is also due to the developments related to the use of electricity for transport and heating/cooling.

By considering different sources, including ENTSO-E SO&AF 2013 and ENTSO-E TYNDP 2014 for fuel costs and SUSPLAN report[35] for generation plants availability factors, for the 2020 baseline scenario a CO_2 penalty tax of 10 €/tCO_2[36] has been adopted. The PTDF matrix calculation has been performed starting from the 2020 ENTSO-E Continental Europe Study Model (2020 STUM)[37]. Maximum inter-zonal transmission capacities (for winter/summer) have been assumed in the 2020 study for both HVAC and HVDC corridors based on TSOs' expansion plans by ENTSO-E (TYNDP 2012[38] and TYNDP 2014) and on other sources[39]. The total estimated values for the inter-zonal HVAC and HVDC capacity levels are reported in Table 5 together with the 2020 storage capacity values assumed based on different sources, including ENTSO-E, European Commission and Energy Community documents[40]. In Table 5 the PHES values also include the ones related to seawater PHES (SPHES).

Table 4 – EU30+ 2020, 2030 Scenarios: Generation Capacity

EU30+ S0 scenario	2020 (GW)	2030 (GW)
Nuclear	126.9	108.6
Hard coal	105.5	76.5
Lignite	65.6	56.6
Gas	245.1	311.2
Oil / oil shale	20.4	16.6
Other non RES	57.3	53
Total Hydro	260.7	297
Wind (onshore)	179.9	276.8

[35] J. Joode, O. Ozdemir, K. Veum, A. van der Welle, G. Migliavacca, A. Zani, A. L'Abbate, "Report on transnational infrastructure developments on the electricity and gas market", SUSPLAN Deliverable D3.1, Feb. 2011. http://www.susplan.eu
[36] European Commission, "Trends to 2050 - Reference scenario 2013", Dec. 2013.
[37] ENTSO-E, 2020 Continental Europe Study Model (STUM). https://www.entsoe.eu
[38] ENTSO-E, "Ten-Year Network Development Plan 2012", Jul. 2012. https://www.entsoe.eu
[39] Energy Community, Projects of Energy Community Interest, Nov. 2013. http://www.energy-community.org/portal/page/portal/ENC_HOME/AREAS_OF_WORK/Investments/PECIs
[40] A. L'Abbate, R. Calisti, "Description of four scenarios for the development of the European electricity system up to 2050 (with special consideration of the target years 2020, 2030 and 2050) incorporating new innovative technologies fostering RES-Electricity and storage integration", GridTech Deliverable D4.1, 2015. http://www.gridtech.eu

Wind (offshore)	37.9	96.9
Solar	126.7	243.2
RES Biomass	38.8	69.6
Other RES	2.5	8.5

By the application of the MTSIM tool to the EU30+ model, assuming a value of VOLL (Value Of Lost Load) amounting to 5000 €/MWh, several results can be obtained and related considerations can be derived.

Table 5 – EU30+ 2020, 2030 Scenarios: TGT and EST Capacities

year/scenario	Inter-zonal HVAC capacity	Inter-zonal HVDC capacity	PHES capacity	CAES capacity
2020 S0/S1/S2	100.3 GW	24.9 GW	59.9 GW	0 GW
2030 S0	131.0 GW	32.7 GW	71.5 GW	0 GW
2030 S1	131.0 GW	40.2 GW	71.5 GW	0 GW
2030 S2	131.0 GW	32.7 GW	83.3 GW	2.2 GW

The analysis of the 2020 S0 (baseline) scenario results provides that the EU30+ zonal system is enough robust, as load shedding is null. RES curtailment (2.67 TWh) is mostly concentrated in isolated (Iceland) or loosely interconnected (Ireland) systems, whereas it is very limited in Germany (DE1), Spain, Northern Ireland, Portugal. Zonal marginal costs are changing depending on countries, RES penetration, energy mix: the peripheral zones, especially located in southern Europe, present the highest average zonal marginal costs for generation, as the highest values concern Cyprus (above 70 €/MWh), Malta and Turkey (about 60 €/MWh). Also, HVDC corridors across the European system result to be rather fully utilized.

By considering different sources for 2030 study data including ENTSO-E SO&AF 2013 and ENTSO-E TYNDP 2014 for fuel costs and SUSPLAN report for generation plants availability factors, a CO_2 penalty tax of 35 €/tCO_2 has been adopted for 2030 baseline scenario[36]. By accounting for the new cross-border ties, also in accordance with network development plans, the estimation of the maximum inter-zonal transport capacities (for winter and summer) for both HVAC and HVDC corridors as well as the update of the PTDF matrix (by assuming the 2020 internal HVAC grids structure) have been carried out for the 2030 S0 scenario. The total estimated values for the inter-zonal HVAC and HVDC capacity levels at 2030 are reported in Table 5 together with the 2030 storage capacity values assumed based on different sources such as ENTSO-E, European Commission and Energy Community documents[40].

Concerning the 2030 S0 (baseline) scenario, the analysis of main outcomes provides that the EU30+ zonal system is quite robust as load shedding is null. However, RES curtailment (9.4 TWh) is rather higher than in 2020 S0 and mostly concerns Cyprus, Germany (DE1), Denmark, Spain, Great Britain, Ireland and Iceland (while it is very limited in Malta, Northern Ireland, Netherlands, and Portugal). The zonal marginal costs result to be higher than in 2020, also due to a higher value of the CO_2 penalty tax. As for 2020, HVDC corridors across the European system are fully used. It is important to highlight that the EU30+ zonal system needs first reinforcements across British islands, in Balkan, Iberian and Baltic regions, on north-south Central Europe axis and around isolated zones.

The application of additional bulk storage (mostly PHES, but also SPHES and CAES) capacity, as reported in Table 3.4, has been taken into consideration for the build-up of 2030 S2 scenario. The implementation of S2 has then led to benefits by EST over S0 scenario in terms of dispatch cost drop (800 M€) and RES curtailment decrease (1444 GWh) and also CO_2 emissions reduction (412 ktCO_2) (see Table 6).

Table 6 – EU30+ 2030 Study Results: Effects of TGT (HVDC), EST (PHES, CAES) and EDT (DR)

2030	TGT benefits	EST benefits	EDT benefits
Dispatch cost reduction	4562 M€	800 M€	1342 M€
RES curtailment reduction	7456 GWh	1444 GWh	1392 GWh
CO_2 emissions reduction	277 ktCO_2	412 ktCO_2	-7437 ktCO_2
Load shedding reduction	0 GWh	0 GWh	0 GWh

The present section, reporting some key results of the GridTech pan-European study in 2020 and 2030 scenarios, contributes to investigate the effects that innovative grid-impacting technologies, especially HVDC, bulk storage and DR, may have on the future EU30+ system. Some benefits that those grid-impacting technologies may provide to the European system as a whole are included in the results. The outcomes of the study prove the very effective performances of HVDC and the important role that bulk storage and DR may play in the evolutions of the European system. On the other hand, storage technologies may have a limited impact, concentrated in some zones of the European system, especially where an increasing penetration of variable RES is not followed by an expansion of transport capacity: regional case studies with internal grid constraints and local sensitivities are further needed. Including internal zones and grid constraints in the analysis may then represent a step further to compare the effects of bulk storage with respect to TGT (HVDC) and EDT (DR). Additional analyses towards a full quantitative techno-economic assessment of the impact of innovative technologies are being carried out within GridTech[41].

[41] A. L'Abbate, R. Calisti, F. Careri, S. Rossi, "Analysis and discussion of the results of the four pan-European scenarios on the implementation of new innovative technologies fostering RES-Electricity and storage integration", GridTech Deliverable D4.2, 2015. http://www.gridtech.eu

2.3 Two National Grid Application Studies in Italy: the Sardinian Case

This section describes a study[42] aimed at evaluating the impact on the Italian national electric system of two new upgrades that could affect the Sardinia island starting from the year 2020:

- A new sea-water pumping power plant located in Foxi Murdegu;
- An upgrade of the submarine Direct Current (DC) link SA.CO.I.

These upgrades are capable, as shown, to foster more renewable energy resources production and integration, which ultimately could increase the need for storage.

At the same time, a study case related to a new sea-water hydro pumping power plant that could be located in Foxi Murdegu (Sardinia) is presented in order to show what consequences the deployment of additional storage capacities could have on the Sardinian system that, being an insular one connected to the main grid only by mean of DC links, has strong peculiarities and constraints.

Sardinia constitutes a very interesting study case because of its peculiar geographic position with respect to the continent and for a massive amount of electric generation from Renewable Energy Sources (RES).

The approach adopted in the described study, whose perimeter is constituted by the Italian Extra High Voltage (EHV) system plus the generation park subject to the electricity market, consists of a simplified probabilistic simulation of the functioning of the electric system. The simulations have assumed 2020 as target year, aiming at evaluating system reliability as well as the impact of economic and environmental factors in the system dispatch. The impact of the two mentioned upgrades is evaluated by comparing the simulation in the case "without" (in absence of the upgrade) and "with" (including the new infrastructure).

Scenario hypotheses for the year 2020 are mainly based on those adopted by the Italian TSO TERNA in the national development plan published in 2013 and in the forecast of electric demand for the period 2013-2023:

- According to the assumptions of the "baseline scenario", only a moderate increase is assumed for the Italian electric demand;
- Electricity imports in Italy remain significant also in conjunction with the development of new HVDC submarine links along the Adriatic Sea (Montenegro, Albania e Greece) and of new overhead links along the northern border, both in HVDC (Switzerland, France) and in HVAC (Slovenia, Austria);
- An export towards Malta is also represented by means of a new submarine HVAC cable;

[42] The work here described was financed by the Italian Electricity System Research Fund (Fondo per la Ricerca di Sistema) of the Italian Economic Development Ministry.

- Reinforcements have been taken into account in the connections between Italian market areas
- South↔Sicily (new line Sorgente-Rizziconi), Center-South↔South (doubling of the Adriatic backbone and new PST devices) and North↔Center-North (upgrade of the line Colunga-Calenzano);
- Sardinia is represented as radially connected to the continent through the SA.PE.I. system (see Figure 15). The older HVDC link SA.CO.I. is supposed temporarily out-of-service in sight of programmed refurbishment and upgrading works;
- RES generation is supposed massively represented in Italy, with 13.6 GW of eolic generation and 24.6 GW of solar photovoltaic generation;
- Concerning coal power plants, an optimistic view was maintained, by hypothesizing those located in Vado Ligure and Porto Tolle still in service and supposing the repowering of the Fiumesanto as accomplished;
- ETS certificates are supposed exchanged at the price of 8 €/ton.

The scenario hypotheses depicted above are such to create south-to-north electric flows along the whole Italian peninsula.

The former of the two described studies produced a contribution to the technical-economic evaluation of a new sea-water hydro pumping power plant that could be located in Foxi Murdegu (Sardinia).

In the wave of the growing interest for the Italian national system to increase its electric storage capabilities, some researches developed by RSE[43] in the previous years had already allowed to locate the most promising potential locations for sea-water hydro pumping power plants in the southern part of Italy and on the biggest islands.

So, a new research activity was initiated with the aim to concretely evaluate the potential economic rentability of such generation/storage facilities, foreseeing to draw a technical-economic assessment of costs and rentability on the basis of a conceptual design. The site of Foxi Murdegu in Sardinia was selected for such pilot analysis, where it was conceived to build up a new hydro storage system endowed with an upper artificial reservoir having the capacity of 1.2 million of m^3 and exploiting the sea itself as the lower reservoir, with an overall head of 360 m. The overall storage capacity can be evaluated around 1000 MWh. The hydro power plant, located in a cavern, is endowed of one only turbo-pump machine having a power of 173 MW in pumping modality and 130 MW in generation.

[43] Alterach J., Bruno G., Danelli A., Marazzi R., Meghella M., Sperati S., Calisti R., Careri F., Davò F., Gatti A., L'Abbate A., Pitto A., "Progetto di massima e valutazione tecnico economica di un impianto di pompaggio e generazione marino, mediante l'utilizzo di macchine reversibili a giri variabili", RSE Ricerca di Sistema Report prot. 14000684, 28/02/2014

The same scenario at the target year 2020 was subsequently re-used for evaluating the impact of the future remake of the DC link SA.CO.I., presently connecting Sardinia, Corsica and Centre-North zone of the Italian electricity market, characterized by a maximum capacity of 150 MW. A new project foresees its repowering that may bring its overall transport capacity up to 600 MW (project "SA.CO.I.3")[44]. On this background, the latter of the studies here described concentrates its interest on the ongoing congestion between the market zones Center-North↔Center-South already verified by the former study and analyzes how the new repowered link SA.CO.I.3, beyond constituting a strengthening of the interconnection between Sardinia and continent, could also be seen as an alternative path – through Sardinia – for dispatching the electric flows from south to north along the Italian peninsula.

The two study activities depicted above have seen a first benchmark testing of the new advanced probabilistic tool REMARK+ by RSE, based on a sequential Monte Carlo method (replacing the non-sequential approach of the former tool). The new algorithm is particularly fit for studies on storage systems because it allows to take correctly into account inter-temporal constraints typical of hydro reservoirs while allowing to model the significant variability pattern introduced by the big amount of RES generation represented in the 2020 reference scenario (modeled by means of a probabilistic model). REMARK+ calculates an *Optimal Power Flow* over a yearly time horizon and with a hourly detail on load and generation dispatch.

[44] Actually, the new upgraded link configuration should be operative only starting from the year 2022. However, in consideration of the very small growing rate of the demand and to a likely slowdown in the increase of new installations of RES generation, it was deemed that a likely scenario at 2022 should resemble the one at 2020 assumed as basis for the simulations.

Figure 15 - Italian Electric Transmission Network with Evidence of Sardinian Interconnection (SA.PE.I. and SA.CO.I. Systems) Respect to the Continental Most Congested Section. Position of Foxi Murdegu Hydro Power Plant
(Graphical Elaboration of the Original Map, ENTSO-E Properties)

Foxi Murdegu case results

Given the outcomes of the simulation analyses, the effects provided by the Foxi Murdegu power plant on the 2020 Italian power system can be summarized as in the following:

- a "substitution effect" among the different thermal generation technologies can be highlighted. The production provided by the generation units based on CCGT (Combined Cycle Gas Turbine) technology results to be decreased for a yearly amount of 143 GWh whereas coal-fired plants increase their output for a total 128 GWh; the RES production injected into the system results to be increased by **46 GWh**;
- the substitution effect leads to a reduction of the yearly production costs of thermal generation for a total amount of 3 370 k€; the benefits by pumping and turbining cycles provided by Foxi Murdegu power plant can be translated in a yearly gain of 2 888 k€; the difference between the two above factors represents the increase of Social Welfare – that is the total benefit for the system – that results to amount to **482 k€/year**;
- in spite of the RES injection increase, the total yearly level of CO_2 emissions has risen for **61 000 tons**; this depends on the higher utilization of coal-based plants (+ 104 000 CO_2 tons) replacing the production by gas-based units (-43 000 CO_2 tons).

A sensitivity analysis has been then conducted to evaluate and compare the techno-economic outcomes by the variation of the CO_2 emission prices. The results of the sensitivity cases for different CO_2 emission prices[45] are in line with the expectations. The variants in presence of higher CO_2 prices have in fact provided a reduction of the Social Welfare benefit that results to amount to 242 k€/year and 178 k€/year for the respective cases with a CO_2 price of 16.5 €/ton and 21 €/ton, while in the base case, as seen above, the benefit is higher (482 k€/year). As a lower CO_2 price favors in terms of variable production costs the utilization of coal-fired plants over the CCGT units, a conclusion that can be drawn is that the storage installations provide an higher economic gain in presence of low CO_2 prices (at today's levels).

Globally, the results may appear not very brilliant in quantitative terms for the use of the pumping storage plant: this however follows the trend of lower utilization of pumping stations in Italy occurred in the latest years. It is evident that the 2020 market prices, following the trend of current ones, do not effectively foster the use of storage plants.

It is worth mentioning that, in addition to the analysis with the methodology above described, the activities related to the techno-economic assessment of the Foxi Murdegu pumping plant have been focusing also on:

- analyzing the impact of the plant on the different markets (day-ahead, balancing and ancillary services markets) through some ex-post simulations;
- evaluating the other indirect benefits provided by the plant to the system (in terms of stability enhancement and further increase of RES units installation).

Given the outcomes of such analyses and considering the high financial risk of the investment, but at the same time the significant value of the indirect benefits to the electrical system, a package of incentive mechanisms through "certificates for pumping" has been proposed, with the partial redistribution of such welfares. The certification resulted less than 2.6 €cents per kWh exchanged with the network, for the financial risk zero. The value is acceptable, whereas it is also lower than the indirect benefit produced to the entire Italian electricity system.

SA.CO.I.3 case results

Considering the analysis of the impact of the new SA.CO.I.3 HVDC link, the increase of Social Welfare assuming the rebuilding and the repowering to 600 MW of current SA.CO.I. compared with its dismantling has resulted to be rather significant.

The substitution effect among the different thermal generation technologies provides in total a CCGT production reduction of 1 352 GWh balanced by a coal-based generation increase of 1 009 GWh and a RES grid injection rise by 314 GWh. Also the import from neighboring countries increases by 29 GWh.

[45] Concerning CO_2 prices, a level of 8 €/ton has been used for this study, in line with the national development plans of the Italian TSO. The variants have been carried out for CO_2 prices of 16.5 €/ton (in line with European Regulation EC 244/2012) and 21 €/ton (in line with the IEA's World Energy Outlook 2012).

In economic terms the different dispatch has led to production costs savings (and Social Welfare increase) that amount to 40 177 k€/year corresponding to a higher level of coal-based production costs of 31 335 k€/year and a lower value of CCGT generation costs of 71 531 k€/year.

Comparing the results of the two cases, with and without the SA.CO.I.3 HVDC link, makes it possible to determine the impact on production also in geographic terms: the thermal power annual production in the Italian market zones of North and Center-North, mainly by CCGT, has decreased by 2.97 TWh in favour of the one, mainly based on coal, spread on the other Italian market zones, such as South (+1.42 TWh), Center-South (+0.82 TWh) and Sardinia (+0.42 TWh).

Also the impact on the Italian grid in terms of congestion relief proves to be an interesting outcome: in fact, a reduction of the amount of the tie congestion hours across the mostly congested inter-zonal corridor between the Italian market zones of Center-South and Center-North (upnorth) can be highlighted – from 5553 hours/year to 4225 hours/year.

Looking at the environmental effects deriving from the impact of the HVDC link, on one hand, a RES grid injection increase of 314 GWh is a positive outcome, but on the other hand the higher coal-based production over the CCGT one has resulted in a total increase of CO_2 emissions for an amount of 378 000 ton yearly.

The power flows across the Italian market zones result to be impacted by the HVDC link as illustrated in Figure 16 (case "without" SA.CO.I.3) and in Figure 17 (case "with" SA.CO.I.3).

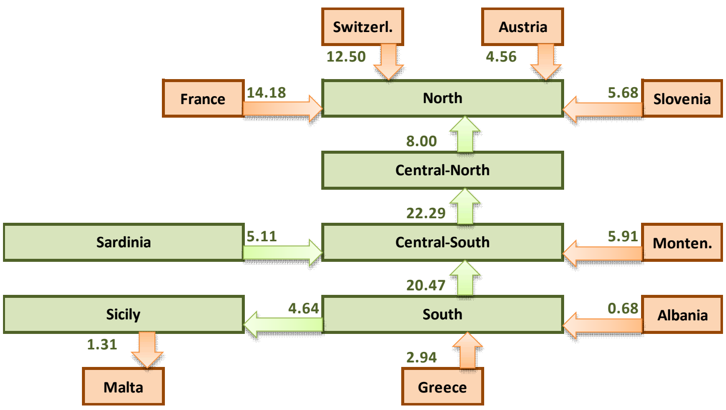

Figure 16 – Yearly Inter-zonal Power Flows in the Italian System "without" the 600 MW SA.CO.I.3 HVDC link (TWh)

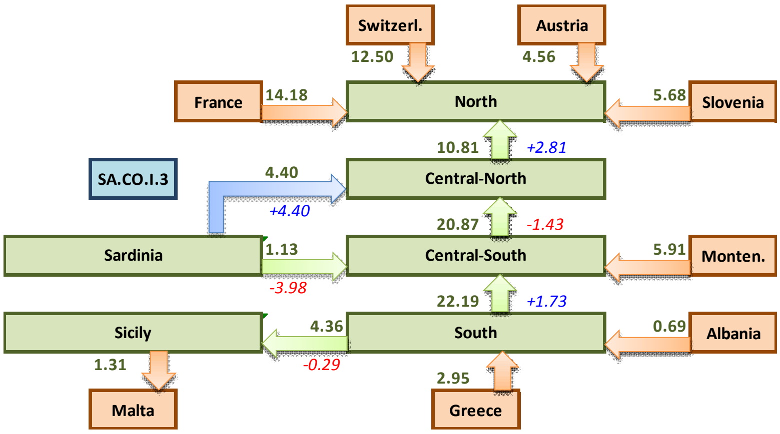

Figure 17 – Yearly Inter-Zonal Power Flows in the Italian System "with" the 600 MW SA.CO.I.3 HVDC Link (TWh)

The most important outcome of the two studies above described consists in the evidence that the two investments provide an higher RES production and integration, but on the other side, in a market situation similar to the today's one, new system elements or reinforcements may result to foster coal-based production (cheaper but also more pollutant) over gas-based generation (less cheap but also less pollutant).

The studies applied to the Italian power system have confirmed the feasibility and the usefulness of the methodological approach based on the modeling features of the REMARK+ tool with the goal to evaluate the impact of new investments in both transmission and generation. Moreover, the sequential probabilistic method applied has proved to be effective, especially in presence of storage technologies, such as the systems based on hydropumping, and with a large penetration of variable and not programmable RES.

3 Overview of North American Energy Storage and Balancing Activities

Modernizing the electric grid will help North America to meet the challenge of handling projected energy needs—including addressing climate change by relying on more energy from renewable sources—in the coming decades, while maintaining a robust and resilient electricity delivery system. By some estimates, the United States will need somewhere between 4 and 5 tera watt-hours of additional electricity annually by 2050[46]. Those planning and implementing grid expansion to meet this increased electric load face growing challenges in balancing economic and commercial viability, resiliency, cyber-security, and impacts to carbon emissions and environmental sustainability.

Electricity production from wind and other renewables technology has increased significantly to meet the renewable portfolio standards (RPS) targets imposed by 29 U.S. states, the District of

[46] Hostick, D.; Belzer, D.B.; Hadley, S.W.; Markel, T.; Marnay, C.; KintnerMeyer, M. (2012). End-Use Electricity Demand. Vol. 3 of Renewable Electricity Futures Study. NREL/TP-6A20- 52409-3. Golden, CO: National Renewable Energy Laboratory

Columbia, and 2 U.S. territories. Energy storage is attracting greater interest as an enabling technology for integrating variable renewable power into the electric grid, addressing grid reliability challenges and resiliency challenges following major storms and outages, and increasing overall infrastructure utilization. The integration of renewable energy technology into the U.S. and Canadian grids is one of the key drivers for the growing interest in stationary energy storage systems.

Energy storage systems (ESS) will play a significant role in meeting these challenges by improving the operating capabilities of the grid as well as mitigating infrastructure investments. ESS can address issues with the timing, transmission, and dispatch of electricity, while also regulating the quality and reliability of the power generated by traditional and variable sources of power. ESS can also contribute to emergency preparedness. Modernizing the grid will require a substantial deployment of energy storage and Load as a Resource (LaaR). In this chapter, we first introduce the current market situations for energy storage with recent implemented policies both at the national and state level, followed by energy storage technologies in various maturity stage and applications of those technology, and then end with the outlook and barriers for energy storage resources.

Market Situation and Policies on Energy Storage as of August 2013, there are more than 200 storage system deployments in the United States with a cumulative operational capability of 24.6 GW, with a mix of storage technologies including pumped hydro, various types of batteries, and flywheels[47]. The contribution of each technology to the overall operational capability is shown in Figure 18. At 95%, pumped hydro clearly dominates due to its larger unit sizes and longer history as the technology of choice for energy storage by the electric utility sector. Grid-scale pumped storage can provide load-balancing benefit from time spans ranging from seconds to hours with digitally controlled turbine governors and large water reservoirs for bulk energy storage[48]. Other technologies such as compressed air energy storage (CAES), thermal energy storage, batteries, and flywheels constitute the remaining 5% of overall storage capability.

[47] Note that the database has only verified the details of 121 of these deployments, with the details on the remaining projects in various stages of verification

[48] http://energystorage.org/energy-storage/technologies/pumped-hydroelectric-storage

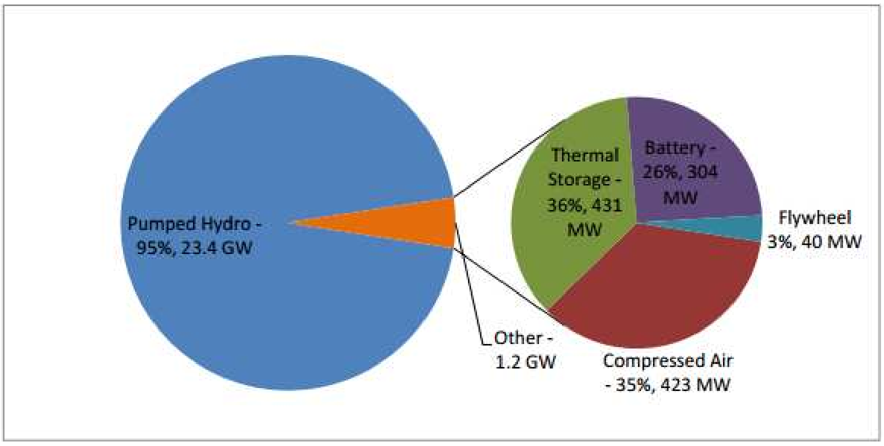

Figure 18 – Rated Power of US Grid Storage Installations[49] (including anticipated installations)

Similarly, Figure 19 shows the wide range of system sizes that have been deployed. The rated power of the various installations ranges from small, residential scale to large, utility scale systems of 1 MW or more[50]. The database is voluntary and there are many small systems most likely not in the database.

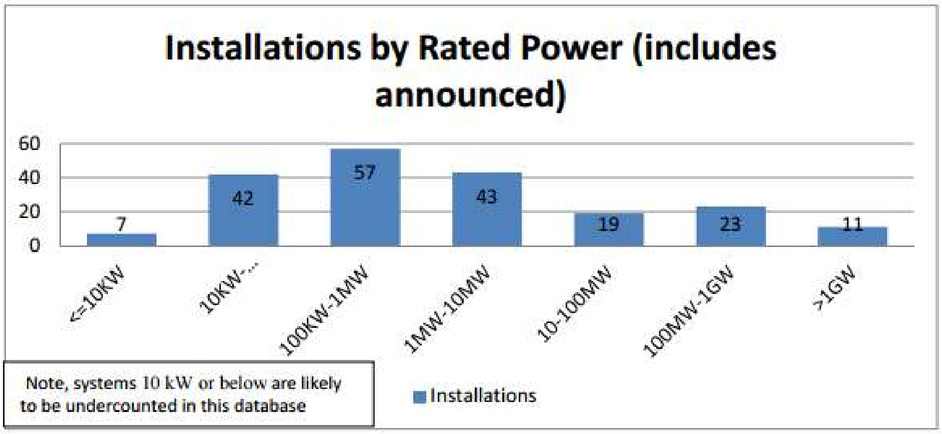

Figure 19 – Number of US Installations, Grouped by Capacity

Canada's hydro power reserves have offered the ability to provide energy that can be called upon to respond to forecasted shifts in demand from season to season and night to day in the bulk power system. There is only one pumped hydro facility in Canada, the Sir Adam Beck Pump Generating Station with 174 MW of capacity and a 300 hectare reservoir for storing pumped water. In most other cases, Canada's hydro reserves can provide electricity on-demand from reservoirs that are filled naturally and can store energy for short periods of time or over multiple years depending on the site. Approximately 87% of Canada's total 75.2 GW of hydro power

[49] Grid Energy Storage, U.S. Department of Energy, December 2013
[50] This information was accessed in August 2013, and can be found at: http://www.energystorageexchange.org/

capacity are controlled by advanced electronic control systems that could provide various levels of balancing service—subject to transmission and regulatory constraints over changes to river flow rates. In that sense much of the flexibility of hydro in Canada is not absorptive in that the hydro sites themselves cannot consume power, however the markets they supply can and ramping down their supply can in effect provide absorptive services to interconnected markets. This services agreement is contracted between Canada's Manitoba hydro system to provide balancing for wind in the US North Dakota and Minnesota markets for example. Either way, much of Canada's hydro does provide the flexibility to respond to large changes in load or supply mix on the bulk system by moderating the power output or by providing spinning reserve. While this may preclude the need for storage resources at the bulk level in these systems, there remains a role for them closer to load centres where certain losses and stability issues which are often associated with transmitting power over distances from Canada's large hydro reservoirs can be avoided.

With the advance of smart grids, Canada is seeing storage technologies integrated into the electricity system for reasons other than providing bulk power shifting. Providing the capability to respond over a range of time, power and energy ratings, and both *supply* and *absorb* power, distributed energy storage systems in Canada are being integrated into electricity distribution systems to provide a variety of different services. Since 2010, Canada has publicly funded over 60 MW of distributed energy demonstration or pilot projects.

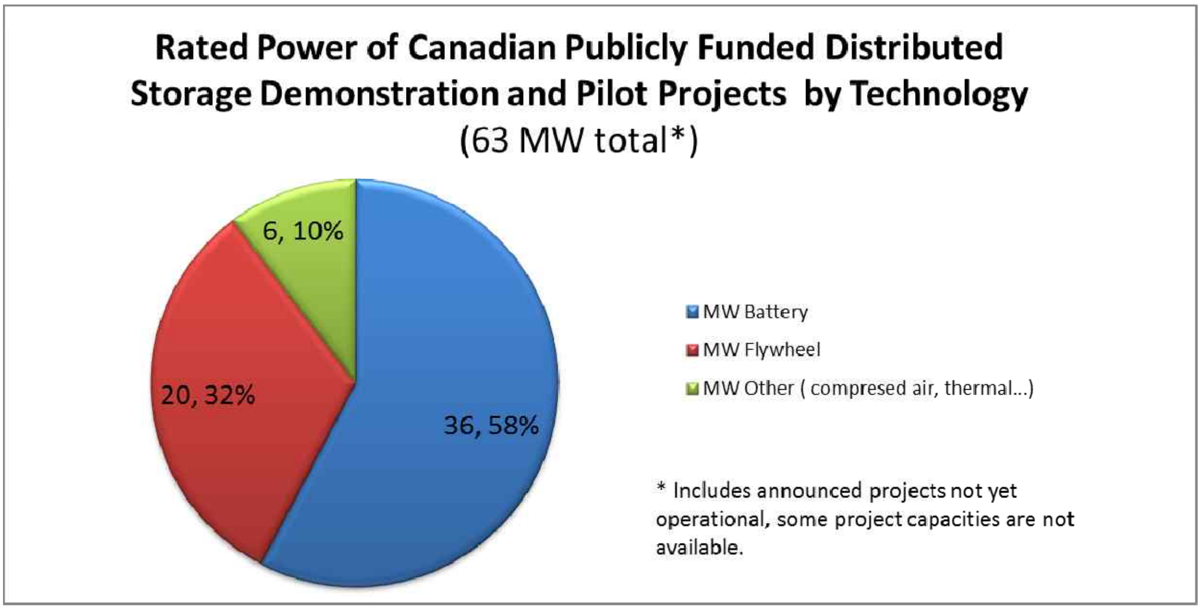

Figure 20 - As of 2015, Natural Resources Canada has calculated over 60 MW of distributed storage pilot and demonstration projects since 2010.

Energy storage systems and the services they provide can be used in regulated and deregulated markets. However, for energy storage technologies used on the grid, regulatory policies and rules provide the framework for the business case and economics of storage systems. Other incentives, such as tax structures and asset depreciation rates significantly affect the economics for storage projects. All the electrically grid-connected storage services, market opportunities, cost-recovery methods, cost-effectiveness criteria, incentives, and rebates are governed by a well-established regulatory oversight. The Federal Energy Regulatory Commission (FERC) regulates interstate transactions, while State entities such as Public Utility Commissions (PUCs) regulate utility management, operations, electricity rate structures, and capacity acquisition within their State's jurisdiction. Additionally, in some regions Independent System Operators (ISOs) provide oversight of transmission and generation. This multi-level oversight impacts the growth of the storage industry because policies can create or inhibit market opportunities for electricity storage and may determine how, and if, they will be compensated.

At the distribution level, Canadian Independent System Operators in the provinces of Alberta and Ontario are investigating the role of ESS in providing ancillary services. There are pilot projects contracted for a wide range of ESS technologies to provide ancillary services and added capacity to the Alberta and Ontario grids. Following Ontario's Long-Term Energy Plan commitment to include 50 MW of energy storage resources into procurement processes, the IESO has competitively procured 33.54 MW for frequency and voltage regulation. The Alberta Electric System Operator (AESO) released an Energy Storage Integration Recommendation Paper[51] in 2015 outlining licensing systems to operate on the market and appropriate tariff structures for various services.

New policies are being implemented at the State level, being discussed and rolled out at the national level, and previous investments are coming to fruition and can shape future investment[52]. As an example of the influence of policy structure on the adoption of storage, FERC Order 755 Pay for Performance helps structure payments and set contracts for frequency regulation, and is changing the market for frequency-regulation applications. In Order 755, the Commission is revising its regulations to remedy undue discrimination in the procurement of frequency regulation in the organized wholesale electric markets and ensure that providers of frequency regulation receive just and reasonable and not unduly discriminatory or preferential rates. Specifically, this final rule requires Regional Transmission Operators (RTOs) and Independent System Operators (ISOs) to compensate frequency regulation resources based on the actual service provided, including a capacity payment that includes the marginal unit's opportunity costs and a payment for performance that reflects the quantity of frequency regulation service provided by a resource when the resource is accurately following the dispatch signal[53].

Order 755 does not mandate a compensation methodology for capacity or performance payments, and the specific process for determining these payments and specifying resources is dependent on each individual market operator (RTO or ISO). Additionally, the U.S. Congress continues to

[51] Alberta Electric System Operator Energy Storage Integration Recommendation Paper: http://www.aeso.ca/downloads/Energy_Storage_Integration_Recommendation_Paper.pdf
[52] Policy information come from the Bloomberg New Energy Finance report on storage dated June, 2013 and the Sandia National Laboratories database: http://www.energystorageexchange.org/
[53] United States of America Federal Energy Regulatory Commission, Docket Nos. RM11-7-000 and AD10-11-000; Order No. 755, Frequency Regulation Compensation in the Organized Wholesale Power Markets, Issued October 20, 2011.

debate two bills that would help codify the cost structure for storage-related subsidies and partnership taxation structures for investment in storage and storage-related activities[54].

In addition to national developments, California, Texas, New York, Hawaii, and Washington have all proposed significant policies on storage. California has enacted laws that make energy storage more viable from a cost and regulatory perspective and give the California Public Utilities Commission (CPUC) the power to mandate certain regional penetration levels of storage. The CPUC recently mandated that 50 MW of storage be installed in the Los Angeles Basin by 2020, as well as a top-line mandate of 1.3 GW of storage for the entire state[55]. The Texas legislature has enacted SB 943 that classifies energy storage technologies alongside generation equipment, and the Public Utility Commission of Texas adopted key aspects of the bill as well as clarified rules, requirements, and definitions for energy storage[56]. In 2010, New York State established NY Battery and Energy Storage Technology Consortium (NY-BEST), a public-private partnership that researches storage technology and manufacturing, aids energy storage organizations as well as potential stakeholders, and advocates for policies and programs that could improve energy storage[57]. Additionally, Washington State enacted two laws related to energy storage: the first enables qualifying utilities to credit energy storage output of renewable sourced energy at 2.5 times the normal value; the second requires electric utilities to include energy storage in all integrated resource plans[58].

Regions of Canada that are most active in deploying smart grid technologies and developing innovative solutions are supported by provincial and territorial policy and programs. Each province's and territory's approach to smart grids differs according to its assets and needs, but the more active regions are responding to economic drivers coupled with quality of service or environmental drivers. Complementing the Alberta Electric System Operator (AESO) Recommendation paper on the integration of storage, Alberta funded six different energy storage projects through Alberta Innovates – Energy and Environment Solutions [59] division which is the lead government agency for advancing environmental technology innovation in Alberta. It granted $250,000 CAD to each project, three of which are demonstration

- PJM was the first Regional Transmission Organization (RTO) to adopt Order 755 in 2012
- Midcontinent Independent System Operator (MISO) also adopted the order at the end of 2012
- California and New York Independent System Operators (CAISO & NYISO) adopted the mandate in mid-2013
- Independent System Operator- New England (ISONE) began following the Order in January 2014.

[54] S. 795 and S. 1845
[55] Note that this number includes some of the projects funded by the 2009 ARRA that have yet to come online; these projects total 334 MW, or roughly 1/4th of the total target.
[56] http://www.capitol.state.tx.us/billlookup/history.aspx?legsess=82r&bill=sb943
[57] http://www.ny-best.org/
[58] HB 1289 and HB1296
[59] Alberta Innovates – Energy and Environment Solutions funding announcement: http://albertainnovates.ca/media/23990/energy_storage_announcement_june_2015_final.pdf

projects for smoothing wind production, reducing building level demand charges and providing grid services.

On the national level in the US, several projects that were funded under ARRA through the SmartGrid Demonstration Grant program are coming online in 2013, and their performance has the potential to guide future investment decisions and policy initiatives. In total, an estimated 59 MW of storage capacity came online in 2013, accounting for 7 of the 16 ARRA-funded projects[60]. In addition, hydrogen fuel cells for backup power are being used in more than 800 units associated with telecom towers in the U.S., as a result of ARRA funding[61].

Most of the investment in distributed energy storage technologies in Canada has occurred since 2010. In that time, NRCan's CanmetENERGY has tracked 27 demonstration and pilot projects across the country supported by various federal and provincial funds in addition to the 8 pilot projects under the Ontario IESO. These projects are complemented by research from universities, the National Research Council and CanmetENERGY into the next generation of energy storage design, manufacturing and controls that will integrate storage technologies into more efficient, reliable and resilient grids.

3.1 Energy Storage Technology and Their Applications

Storage systems can be designed with a broad portfolio of technologies such as pumped hydro, reservoir hydro, compressed air energy storage (CAES), a large family of batteries, flywheels, and superconducting magnetic energy storage (SMES). Each technology has its own performance characteristics that makes it optimally suited for certain grid services and less so for other grid applications. This ability of a storage system to match performance to different grid requirements also allows the same storage system to provide multiple services. This gives storage systems a greater degree of operational flexibility that cannot be matched by other grid resources, such as combustion turbines or a diesel generator. The ability of a single storage system to meet multiple requirements also makes it feasible to capture more than one value stream, when possible, to justify its investment. While the categorization of "deployed," "demonstrated," and "early stage," is often blurred, and changes over time, Figure 21 groups technologies studied for the US market based on their present degree of maturity[62].

[60] http://www.smartgrid.gov/recovery_act/program_impacts/energy_storage_technology_performance_reports.html
[61] http://www.nrel.gov/hydrogen/cfm/pdfs/arra_deployment_cdps_q12013_4web.pdf
[62] Several technologies that are still in the early stages of research have been omitted, as they are unlikely to be commercially viable within the next 3-5 years.

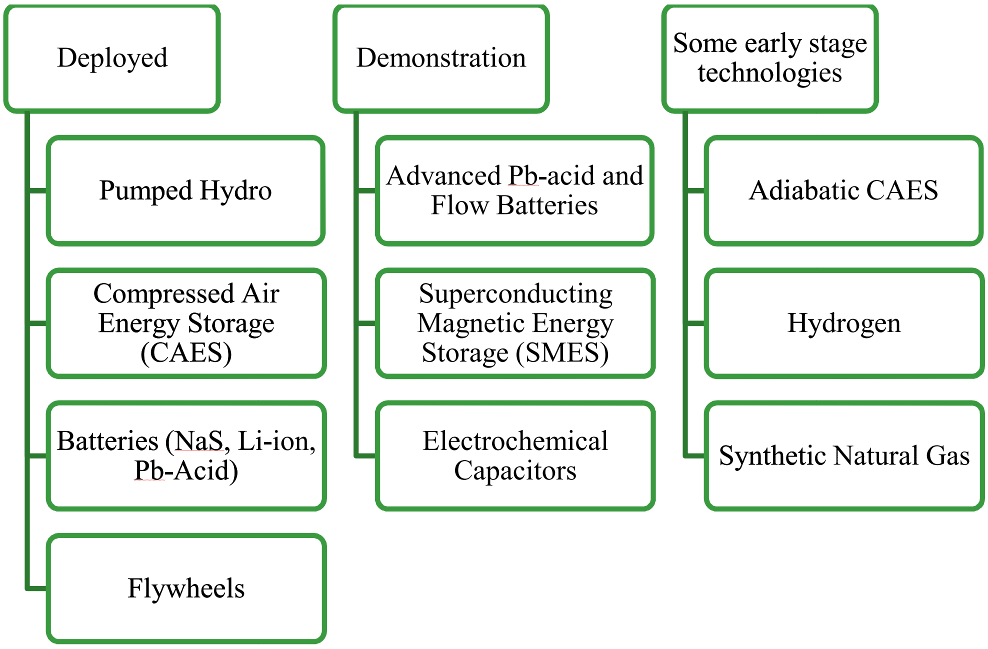

Figure 21 - Maturity of Electricity Storage Technologies[63]

Until the mid-1980s energy storage was viewed by the electric utilities as a means to time shift energy produced by coal and nuclear units during off-peak hours to displace energy that would be produced from other more expensive fuels during on-peak periods. Several factors, including environmental concerns in building large pumped hydro plants and the emergence of other storage technologies using batteries and flywheels, introduced the viability of using storage to provide other grid services[64]. The 2015 edition of the DOE/EPRI Electricity Storage Handbook describes eighteen services and applications in five umbrella groups, as listed in Table 7[65]. The services and applications identified in this table show that energy storage can be used to support generation, transmission, and distribution, as well as customer-side-of-the-meter needs of the grid. A comprehensive discussion of energy storage applications at all levels can be found in two documents referenced elsewhere in this report: Eyer (2010) and Chapter 1 of the DOE/EPRI 2015 Handbook.

[63] Grid Energy Storage, U.S. Department of Energy, December 2013
[64] A grid service, or application, is a use whereas a benefit connotes a value. A benefit is generally quantified in terms of a monetary or financial value
[65] DOE/EPRI Electricity Storage Handbook in Collaboration with NRECA, Sandia National Laboratories, February 2015. http://www.sandia.gov/ess/download/1375/

Table 7 – Electric Grid Energy Storage Services

Service Category	Service
Bulk Energy Services	
	Electric Energy Time-Shift (Arbitrage)
	Electric Supply Capacity
Ancillary Services	
	Regulation
	Spinning, Non-Spinning and Supplemental Reserves
	Voltage Support
	Black Start
	Other Related Uses
Transmission Infrastructure Services	
	Transmission Upgrade Deferral
	Transmission Congestion Relief
Distribution Infrastructure Services	
	Distribution Upgrade Deferral
	Voltage Support
Customer Energy Management Services	
	Power Quality
	Power Reliability
	Retail Electric Energy Time-Shift
	Demand Charge Management

Recognizing energy storage can have multiple services within the grid allows it to capture multiple benefit streams to offset system costs. The flexibility of storage can be leveraged to provide multiple or stacked services, or use cases, with a single storage system that captures several revenue streams to achieve economic viability. How these services are stacked depends on the location of the system within the grid and the storage technology used. However, due to regulatory and operating constraints, stacking services is a process that requires careful planning and should be considered on a case-by-case basis. Table 8 summarizes many of these key applications and challenges by energy storage technology[66].

Table 8 – Key Applications and Challenges

Technology	Primary Application	What we know currently	Challenges
Pumped Hydro	• Energy management • Backup and seasonal reserves • Regulation service also available through variable speed pumps • Time shifting • Energy arbitrage	• Developed and mature technology • Very high ramp rate • Currently most cost effective form of storage	• Geographically limited • Plant site • Environmental impacts • High overall project cost
Compressed Air Energy Storage	• Energy management • Backup and seasonal reserves • Renewable integration • Time shifting • Energy arbitrage	• Better ramp rates than gas turbine plants • Established technology in operation since the 1970's	• Geographically limited • Lower efficiency due to roundtrip conversion • Slower response time than flywheels or batteries • Environmental impact
Flywheels	• Load leveling • Frequency regulation	• Modular technology • Proven growth potential to	• Rotor tensile strength limitations

[66] Grid Energy Storage, U.S. Department of Energy, December 2013

Technology	Primary Application	What we know currently	Challenges
	• Peak shaving and off peak storage • Transient stability	utility scale • Long cycle life • High peak power without overheating concerns • Rapid response • High round trip efficiency	• Limited energy storage time due to high frictional losses
Advanced Lead-Acid Batteries	• Load leveling and regulation • Grid stabilization	• Mature battery technology • Low cost • High recycled content • Good battery life	• Limited depth of discharge • Low energy density • Large footprint • Electrode corrosion limits useful life
Sodium Sulfur Batteries	• Power quality • Congestion relief • Renewable source integration	• High energy density • Long discharge cycles • Fast response • Long life • Good scaling potential	• Operating Temperature required between 250° and 300°C • Liquid containment issues (corrosion and brittle glass seals)
Lithium Ion Batteries	• Power quality • Frequency regulation	• High energy densities • Good cycle life • High charge/discharge efficiency	• High production cost - scalability • Extremely sensitive to over temperature, overcharge and internal pressure buildup • Intolerance to deep discharges
Flow Batteries	• Ramping • Peak Shaving • Time Shifting • Frequency regulation • Power quality	• Ability to perform high number of discharge cycles • Lower charge/discharge efficiencies • Very long life	• Developing technology, not mature for commercial scale development • Complicated design • Lower energy density
Superconducting Magnetic Energy Storage	• Power quality • Frequency regulation	• Highest round-trip efficiency from discharge	• Low energy density • Material and manufacturing cost prohibitive
Electrochemical Capacitors	• Power quality • Frequency regulation	• Very long life • Highly reversible and fast discharge	• Currently cost prohibitive
Thermochemical Energy Storage	• Load leveling and regulation • Grid stabilization	• Extremely high energy densities	• Currently cost prohibitive

US Case Example

Beacon Power will design, build, and operate a utility-scale 20 MW flywheel plant at the Humboldt Industrial Park in Hazle Township, Pennsylvania for the plant owner/operator, Hazle Spindle LLC. The Beacon Power technology uses flywheels to recycle energy from the grid in response to changes in demand and grid frequency. When generated power exceeds load, the flywheels are speeded up to absorb and store the excess energy as kinetic energy. When load increases, the flywheels are slowed down, and the kinetic energy is converted back to electrical energy.

The flywheel system can respond nearly instantaneously to an independent system operator's control signal at a rate 100 times faster than traditional generation resources. The system does not burn fuel, has zero direct emissions, can last 20 years or more and requires virtually no maintenance in the mechanical portion of the system. Two hundred Beacon Gen4 flywheels will be connected to provide 20 MW in capacity and can fully respond in less than 4 seconds.

Flywheel technology has been successfully tested on live grids at utility scale in New York and California. The technology achieved system availability of over 97 percent, higher than the average for conventional generators performing frequency regulation. It is currently deployed at a megawatt scale under New England's Alterative Technologies pilot program, and a 20 MW plant in New York Independent System Operator (ISO) territory in Stephentown NY[67]. However, flywheel technology is still relatively new for utility scale storage and the up-front costs are high.

Canadian Case Examples

A number of new storage projects have recently come online and been contracted for grid balancing applications, creating a diverse energy storage technology portfolio in Canada. In December 2012 the Independent Electricity System Operator (IESO) of Ontario procured 10 MW of regulation capacity in a pilot to test the ability of alternative sources of stored energy to provide regulation and other services to the grid. Through a competitive process, three vendors were selected to provide regulation services from lithium-ion batteries (RES Canada), fly wheels (NRStor, Temporal Power) and commercial load management (ENBALA). The pilot represents an important step in leveling the playing field for grid services.

3.2 Market Outlook and Barriers

A balancing market is a niche market within a competitive electricity market for last-minute, just-in-time, rapid-response electricity. This market may demand either increases or decreases in a quantity of electric power supplies, and electricity generators are paid to quickly ramp up or ramp down to meet this demand. This market results from discrepancies between scheduled electric power generation and actual real-time electric demand and generation, and is often served by fast-ramping electric power plants like gas turbines and by demand response.

The IESO in Ontario has evolved its demand response programs into a competitive market process – the demand response auction. Occurring once a year, through this process the IESO will seek out 350 MW of capacity for each of the summer and winter periods. This can provide an additional income stream for the wide variety of participants who can provide 1 MW or greater of flexibility to the grid.

[67] Beacon Power 20 MW Flywheel Frequency Regulation Plant, Hazle Spindle, LLC.

Pacific Northwest National Laboratory (PNNL) analyzed a hypothetical 2020 grid scenario in which additional wind power is assumed to be built to meet the United States' 20 percent RPS target[68]. The assessment addresses the following questions:

- What are the future balancing requirements necessary to accommodate enhanced wind generation capacity, so as to meet RPS targets of about 20 percent of the generation for each interconnection individually in 2020?
- What are the most cost-effective technology options for providing additional balancing requirements today and in 2020 assuming technological progress?
- What is the market size (quantified in MW and MWh) for energy storage and its respective cost targets (expressed in $/kWh) for balancing and energy arbitrage applications by regions?

Several models were used to address the three questions. The outcomes are listed below.

- Total intra-hour balancing market for the U.S. is estimated to be 37.67 GW assuming about 223 GW of installed wind capacity in 2020.
- Each technology option requires its own size to meet the future balancing needs.
- A number of energy storage technologies are currently cost competitive in certain applications. Some of these technologies include NaS batteries, flywheels, pumped storage, and demand response. Other storage technologies, which are currently cost-prohibitive, are expected to become cost competitive by 2020. These technologies include: Li-Ion and redox flow batteries.
- Given the rate at which the market values arbitrage services, energy storage devices are not expected to achieve cost recovery when deployed in this application.
- Energy storage systems employing differing storage technologies in a hybrid configuration did not demonstrate any technical performance advantage over single-technology solutions. Therefore, hybrid systems must differentiate themselves from competing technologies by offering a cost savings.

There are still a number of barriers prevent utilities, developers and regulators from capitalizing on the deployment of energy storage resources, as evidenced by there being only a handful of new energy storage deployments beyond existing pumped storage hydropower.

- Technology costs are identified as the primary barrier. In many instances, energy storage does not offer an effective value proposition as a technical solution.
- Another major barrier is outdated regulations.
- Revenue compensation mechanisms in the different market environments present a barrier.

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[68] National Assessment of Energy Storage for Grid Balancing and Arbitrage, Pacific Northwest National Laboratory, Prepared for the U.S. Department of Energy, Office of Electricity Delivery and Energy Reliability. September, 2013.

- Limited knowledge amongst stakeholders and the lack of modeling capabilities prevent many stakeholders from thoroughly evaluating energy storage technologies for deployment.
- In addition, common test methodologies must be established to ensure that comparisons amongst differing technologies are fact-based and accurate.
- Utility and developer risk and uncertainty is a barrier that follows from the others.

One of the key ways in which some of the above barriers are being addressed is through the development of protocols and best practices for evaluating storage systems both technologically and economically. One such effort has been underway since 2012 and has already addressed four ESS applications (with four more upcoming in early 2016). This is the ESS Protocol for measuring performance of storage systems. This is sponsored by The Department of Energy's Office of Electricity Delivery and Energy Reliability (OE), Energy Storage Systems (ESS) Program with two national labs (Pacific Northwest National Laboratory and Sandia National Laboratory) serving as facilitators and writers. The protocol is primarily the product of the ESS stakeholders (nearly 100 entities consisting of industry, state commissions, regulatory agencies, utilities, and universities) who have participated in the creation of the protocol and are now adopting its use[69].

A number of different organizations are working to address these barriers and clear the way for energy storage resources to compete in the marketplace. In the end, energy storage resources have the technical capabilities to be a vital power system resource but there are a number of other technologies that provide similar services. The key is ensuring that all of these technologies have equal market access based on their capabilities and costs, to be a part of the portfolio of resources that will power the nation's future electricity system[70].

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[69] Summer Ferreira, David Rose, and David Schoenwald, Kathy Bray, David Conover, Michael Kintner-Meyer, and Vilayanur Viswanathan, Protocol for Uniformly Measuring and Expressing the Performance of Energy Storage Systems, http://www.sandia.gov/ess/publications/SAND2013-7084.pdf

[70] Dhruv Bhatnagar, Aileen Currier, Jacquelynne Hernandez, Ookie Ma and Brendan Kirby, Market And Policy Barriers To Energy Storage Deployment.

4 Conclusions

The present discussion paper highlights how two different provisions (activating transnational balancing markets in order to allow sharing balancing reserves and deploying bulk storage) can be positively impact on the possibility to integrate massive amounts of RES generation, that will be one of the most important challenges to be tackled in the next years within the electric system all over the world.

Transnational balancing markets could allow to achieve a greater dispatching efficiency in the balancing markets, by integrating more reserve resources and better exploiting the complementary characteristics of the generation set in the different interconnected countries. These factors would bring to costs reduction and less generators in stand-by.

By contrast, implementing transnational markets would be more complicated, since ensuring cross-border dispatchability of balancing orders requires constant availability of the network state parameters (node by node and link by link) for all the interconnected countries and to take into account all this information into the clearing algorithm. This is a huge amount of data to be acquired in real time and put available for the clearing. More in general, a better synchronization of the markets would be required as well as a harmonization of a lot of details in the set-up of the markets (e.g. gate closure, products offered in the market).

In the following, we report some important considerations on the implementation of trans-national balancing markets:

- Achieving higher economic efficiency by means of a cross-border management of balancing is possible but some country can see dispatching cost increase (this is true where exports from one TSO area to another significantly increase because of the availability of cheaper generation)
- Unshared bids should also be maintained for security reasons in each TSO control zone. However, as it was experimented in the eBADGE project, a two-level clearing mechanism (within the TSO area and on a trans-national basis) can easily bring to distortions if not properly managed
- Harmonization of the national balancing markets is a pre-requisite for efficiently coupling them
- Ancillary services can also be bought from virtual power plants and distributed generation located in the distribution segment, but this requires that a robust TSO/DSO interaction[71] is put in place what concerns market participation, system regulation and ICT deployment: as said above, trans-national balancing market would need better TSOs/DSOs communication platforms to support cross-border markets of ancillary services.

[71] This important analysis is not within the scope of the eBADGE project but will constitute the central investigation subject of a new European research project named SmartNet that will start in January 2016 and last three years.

A further point: the implementation of trans-national balancing markets would also imply higher ICT costs. In the e-BADGE project a rough screening has been carried of the most important requirement on ICT. As a matter of fact, ICT technology has to be:

- **integrated among all the actors** participating in the trans-national market (TSOs, DSOs, market operators, aggregators, retailers, final users), each with his role. **Interoperability** is key, since the HW stretches from large central servers up to smart meters of residential users.
- Able to ensure **computability** in a limited amount of time. This may put strong limitations both to algorithms and to the SW/HW requirements
- Conceived in a **modular** way that ensures **scalability** with a ever-increasing huge number of connected players, asynchronous distributed transactions, etc (relatively low performance requirements but with high distributed data storage capability)
- Able to **reconfigure** themselves fast to respond to requests in real time
- Algorithms **robust** whatever are the market conditions; **reliability** of components, also by means of components redundancy
- **Secure** and protected against cyber-attacks (use of dedicated network, firewalls allowing only communications between enabled subjects).

On the other side, more bulk storage deployment would be very beneficial, especially allowing a better flexibility in the network dispatch and for reducing the prices on real time markets. In some pan-European case applications of the GridTech project, as highlighted in this report, the main benefits provided by bulk storage to the system may be especially significant in presence of high RES penetration and with a lack of transmission capacity. However, still nowadays apart from hydro pumping (that is however not feasible everywhere), no other mature technology is fit for storing big quantities of energy. Research is ongoing and some technologies (like CAES) seem they could become mature in the next years.

In any case, as also the Foxi Murdegu case explained in this report shows, in order to push private investors to look at storage facilities, a clear business case should be available clarifying in how many years they could get back the invested money and start getting a profit. In a system that is more and more penetrated by RES generation, in particular PV generation, peaks of the daily consumption curve are more and more flattened and price differences between day-ahead prices in day and night hours blur out. This justifies less and less an investment on devices that take profit from arbitraging between high and low cost hours. Again, profit lays more and more in the real time markets but developing a business case based on studies of these markets is by far more difficult and risky.

All in all, the issue is still open. For sure, regulation will have a big role in the next years in order to push towards one or the other direction.