Facilitating energy storage
to allow high penetration of intermittent
renewable energy

stoRE
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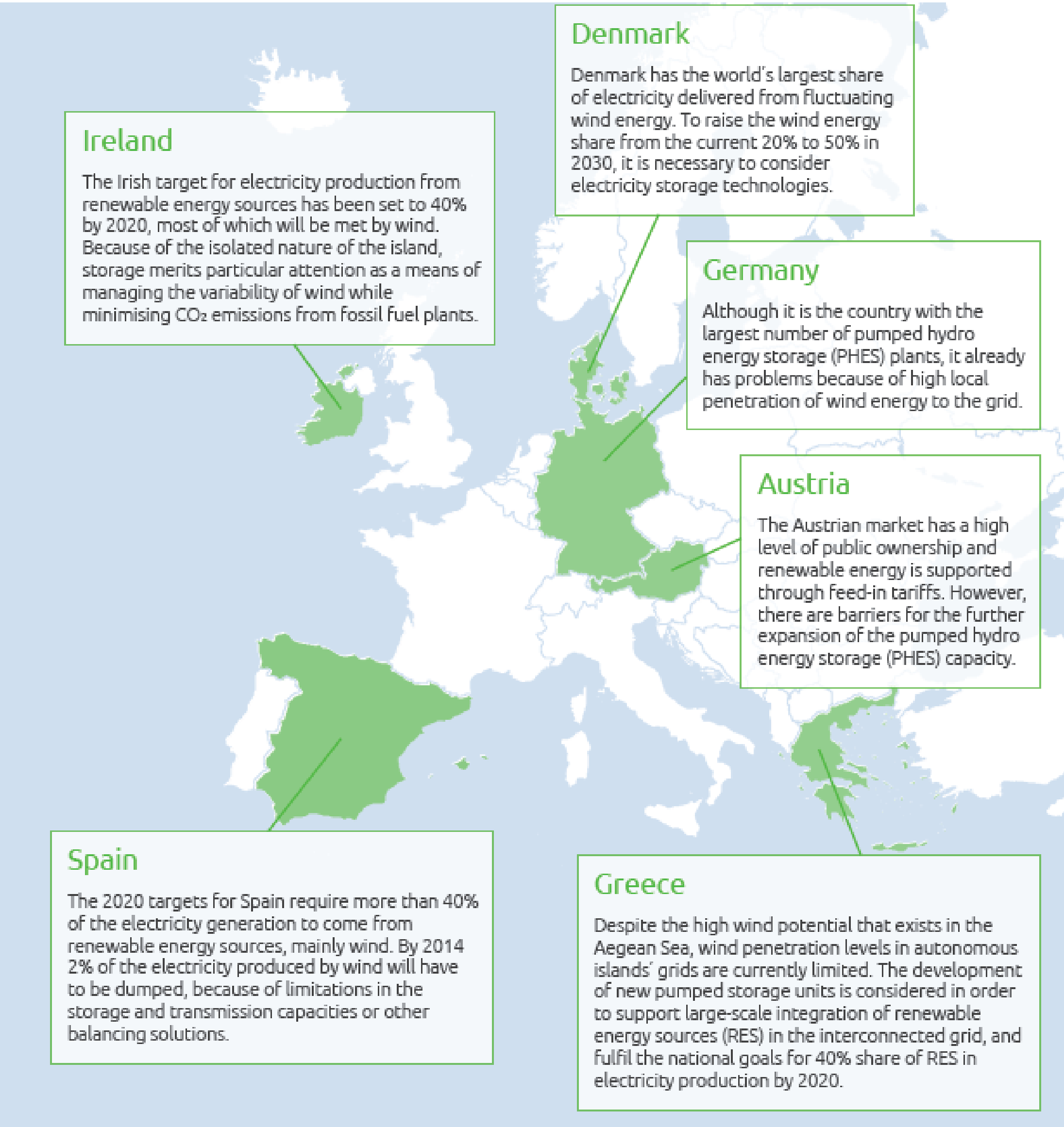
List of Abbreviations

ACER	…	Agency for the Cooperation of Energy Regulators
BSP	…	Balance Service Provider
CAES	…	Compressed Air Energy Storage
CBA	…	Cost Benefit Analysis
CCS	…	Carbon Capture and Storage
CEF	…	Connecting Europe Facility
CSP	…	Concentrated Solar thermal Power
DSO	…	Distribution System Operator
EC	…	European Commission
EIA	…	Environmental Impact Assessment
ENTSO-E	…	European Network of Transmission System Operators for Electricity
ES	…	Electricity Storage
ESF	…	Electricity Storage Facilities
EST	…	Electricity Storage Technologies
ESS	…	Electricity Storage System
EU	…	European Union
FG	…	Framework Guidelines
GW	…	Giga Watt
GWh	…	Giga Watt hour
IEM	…	Internal Energy Market
MS	…	Member States
MW	…	Mega Watt
MWe	…	Mega Watt electric
MWh	…	Mega Watt hour
NC	…	Network Codes
NRA	…	National Regulatory Authority
PCI	…	Projects of Common Interest
PHES	…	Pumped Hydro Energy Storage
PV	…	Photovoltaics
RES-E	…	Electricity from Renewable Energy Sources
SEA	…	Strategic Energy Assessment
SET-Plan	…	European Strategic Energy Technology Plan
TSO	…	Transmission System Operator
TYNDP	…	Ten Year Network Development Plan

Introduction

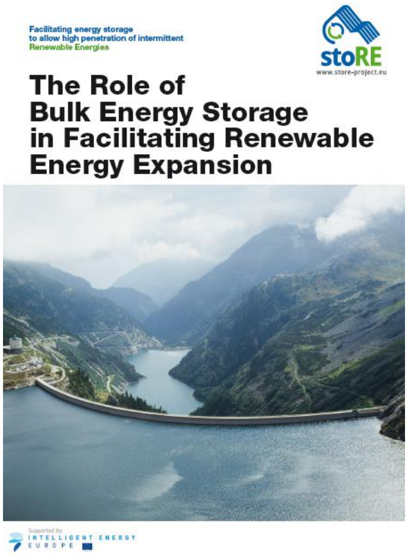
The stoRE project aimed to facilitate the realisation of the ambitious renewable energy targets for 2020 and beyond by unblocking the potential for energy storage infrastructure. The work focused on large-scale energy storage facilities like pumped hydro energy storage (PHES) and compressed air energy storage (CAES) plants. The issues we addressed were addressing the environmental, regulatory and market both on the European level and for six target countries. The target countries are briefly presented in the map below:



Recommendations for improving the regulatory and market framework were developed, taking into account the input from a wide consultation processes with all relevant actors. These recommendations have been discussed with decision makers helping to advance the on-going debate in Europe and the targeted Member States about the future of the energy policy. This report gives a snapshot of the main outcomes. All full reports are available for downloading in the project website: www.store-project.eu

The Role of Bulk Energy Storage

Economics



PHES plants are characterised by a long asset life (typically 50 – 100 years), high capital costs and low operation and maintenance costs. Project costs for PHES systems are very site specific, with some quoted costs varying in the range of 450 – 2500 €/kW. Additionally, capital costs depend not only on the installed power, but also on the energy storage (reservoirs) and power rating at any given site. Since PHES is a mature technology, its capital cost is not expected to change substantially in the future. Figure 4 details the specific investment cost (based on the published capital costs) and installed capacities (indicated by the diameter of the corresponding circle) for some existing and proposed PHES plants in Europe until 2020. The capital costs per kW for proposed PHES are between 470 €/kW and 2170 €/kW, whereas the majority are either extensions to existing projects, repowering of projects or pump-back PHES. However, it can be seen that most of the projects are between 500 €/kW and 1500 €/kW.

A great number of existing PHES plants were built before liberalized markets by state owned utilities. Now, as the latest deployments of new PHES plants in Europe show, developers operating in liberalized markets tend to repower, enhance projects or build “pump-back” PHES rather than conventional “pure” pumped storage. This trend is partly driven by a lack of economically attractive new sites. Furthermore, repowering or enhancing existing infrastructure is less capital intensive and reduces environmental and planning issues. Repowered plants benefit from improvements in technology and design and usually use more efficient and larger turbines / pumps. “Pump-back” facilities have the advantage that their energy storage capacity is generally much greater.

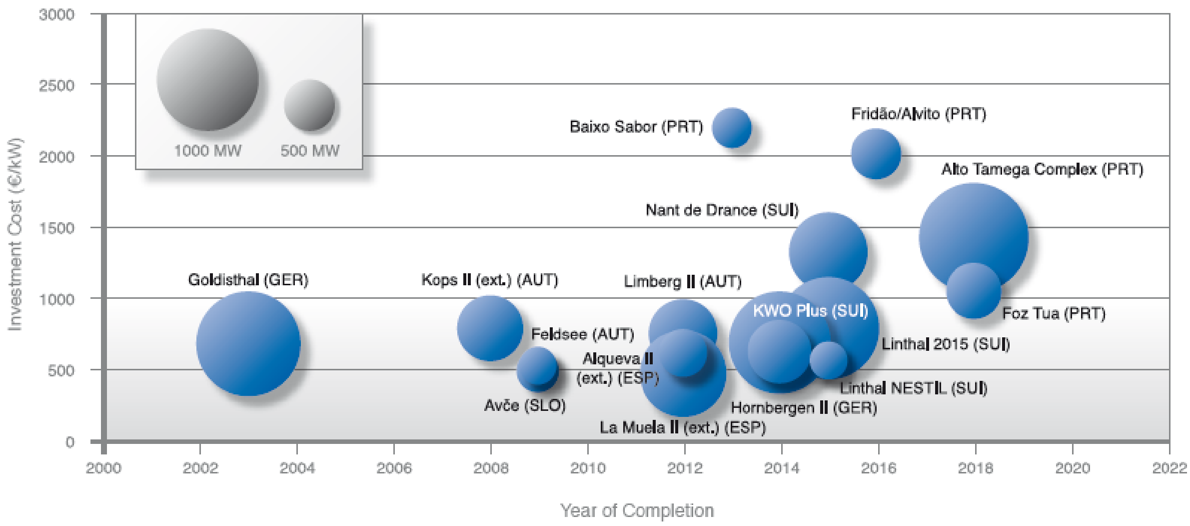


Figure 1: Comparison of the specific investment cost of some existing and proposed PHES plants in Europe up to 2020 (Source: Deane et al, 2010)

Nowadays, in liberalized electricity markets, bulk energy storage projects may be remunerated through ancillary services payments, capacity payments and electricity trading. Electricity trading is usually the major source of revenue for bulk EST systems since operators may take advantage of price arbitrage opportunities. For arbitrage, the electricity price during pumping mode has to be at least 20 – 30% lower than the selling price during generating mode, in order to compensate for energy losses. This implies that significant volatility (not necessarily high energy prices) must be present in the wholesale price of electricity to generate revenue (Dena, 2010).

However, due to long construction times and high uncertainty of future electricity prices (and therefore of arbitrage opportunities) PHES systems are risky investments. On the one hand, the ongoing integration of large amounts of very variable and less predictable wind and solar power into the European electricity system induces more frequent and uncertain price fluctuations at the competitive spot market due to changing in-feed. On the other hand, increasing RES-E generation can also have a negative economic effect for bulk EST. The so-called "merit order effect" (cf. Sensfuß et al, 2008) has the potential to lower the arbitrage between peak and off-peak prices in the long-term. Especially PV can lead to a price damping effect in the midday peak, therefore lowering of the available price margin – as it was already observable in the German electricity market in the years 2010 and 2011 (Steffen, 2012).

Applications

As mentioned in the previous section, the potential for revenue from price arbitrage alone is not sufficient to attract investments in bulk EST, both because of the low profit margins compared to high investment costs and because of the dependence of the price difference on energy policy and regulations. However, other applications and possible revenue streams exist for bulk EST, which are briefly described in this section.

Primary, Secondary and Tertiary Control

Any imbalance between electric power generation and consumption results (in real-time) in a frequency change within the entire network of the synchronous area – i.e. a frequency deviation occurs. If the system frequency declines below 50 Hz, the total demand has been larger than the total generation. If the frequency rises above 50 Hz, the total demand has been less than the total generation. To stabilise the system frequency to 50 Hz after a sudden imbalance, the primary control reserves (also called rapid or spinning reserve) are activated, which allow a balance to be re-established at a system frequency other than the frequency set-point (see Figure 2). Primary control reserves are provided by all transmission system operators (TSO) connected to the synchronous area and have to be fully activated within max. 30 seconds after a deviation occurs (ENTSO-E, 2011).

Secondary control reserve (or standing / energy imbalance reserve) is activated after 30 seconds to restore system frequency to 50 Hz within the synchronous area and to rebalance generation and consumption within each control area / block. Whereas all control areas have to provide mutual support to primary control reserve, only the control area / block affected by a power imbalance is required to undertake secondary control action for correction. Since, in practise, electricity demand varies continuously (even without forecast errors), secondary reserve is required on a continuous basis. Further on, its activation makes primary control reserve available again (ENTSO-E, 2011).

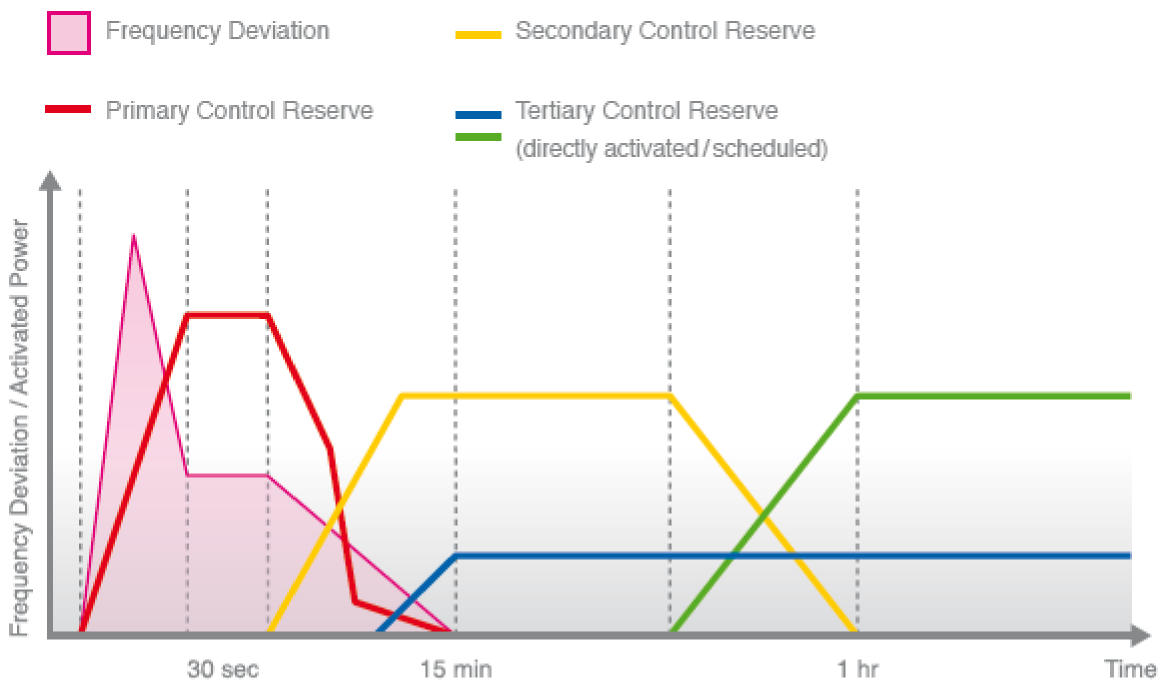


Figure 2: Principal of frequency deviation and subsequent activation of reserves (Source: ENTSO-E, 2011)

Tertiary control reserve (also called minute reserve) is typically operated in succession or, in case of larger incidents, as a supplement to secondary control reserve. Its function is to free up secondary control reserve and any primary control reserve still in use (cf. Figure 2). Total tertiary control reserve of a control area / block has to be larger than the largest expected loss of power (generation unit, power feed-in etc.) of the control block / area (ENTSO-E, 2011).

Since primary control reserve has to be capable of being activated within seconds, normally bulk EST (PHES & CAES) cannot be applied unless they are specifically designed for fast activation times (e.g. Dinorwig PHES in the United Kingdom, cf. Edison Mission Energy, 1999). Otherwise, bulk EST fit perfectly for secondary and tertiary control reserves and their provision is of great importance to bulk EST for generating additional revenues. Due to increasing shares of RES-E generation, the prices for control reserves, especially the energy prices for negative tertiary control, have been increasing in recent years (Ehlers, 2011). Nevertheless, todays volumes of needed control power are rather small and their market is highly competitive.

Blackstart Capability

Blackstart is the ability of a power plant / electricity system to start-up and provide necessary power to re-energise the grid and start other power generating systems without the use of an external power resource after a complete power outage or islanding situation. Only power plants with no or very low start-up energy needs (e.g. provided by diesel engine / generator etc.) have the ability of a blackstart. Another important feature of a blackstart compatible power plant is its flexible controllability, which allows it to cope with demand variations when new loads are connected. Bulk EST are well-suited technologies for this kind of services, they can be designed to perfectly incorporate the functionality of blackstart capability. However, no market exists for blackstart capability, but in some countries there is a remuneration scheme for this service (Ruester et al, 2012).

Transmission and Distribution Investment Deferral

The avoidance of the use of transmission and generation resources during peak-load hours contributes to transmission investment deferral – e.g. delay of new constructions and upgrades of connection lines, transformers, stations, etc. This can be achieved by installing EST units (bulk EST in particular) near load. This reduces losses and increases efficiency, lowering the need for bulk transfers and peak outtakes and finally reducing the use of transmission lines (cf. Denholm et al, 2009). However, this service is not remunerated but it represents an additional benefit for the electricity system.

Management of RES-E

Bulk EST can enable firming up and backup of variable / intermittent RES-E generation to allow for extended periods of low electricity generation which typically characterises patterns of wind and / or PV generation. This also allows RES-E generation to take advantage of daily load patterns, enabling them to shift generation in time (cf. Figure 3) and, furthermore, to capitalise higher peak load prices. Unlike thermal power plants, bulk EST systems can help fully utilising future RES-E generation by storing excess RES-E generation (e.g. this electricity might be available at low cost for pumping purposes in a PHES system) and "restoring" it when needed.

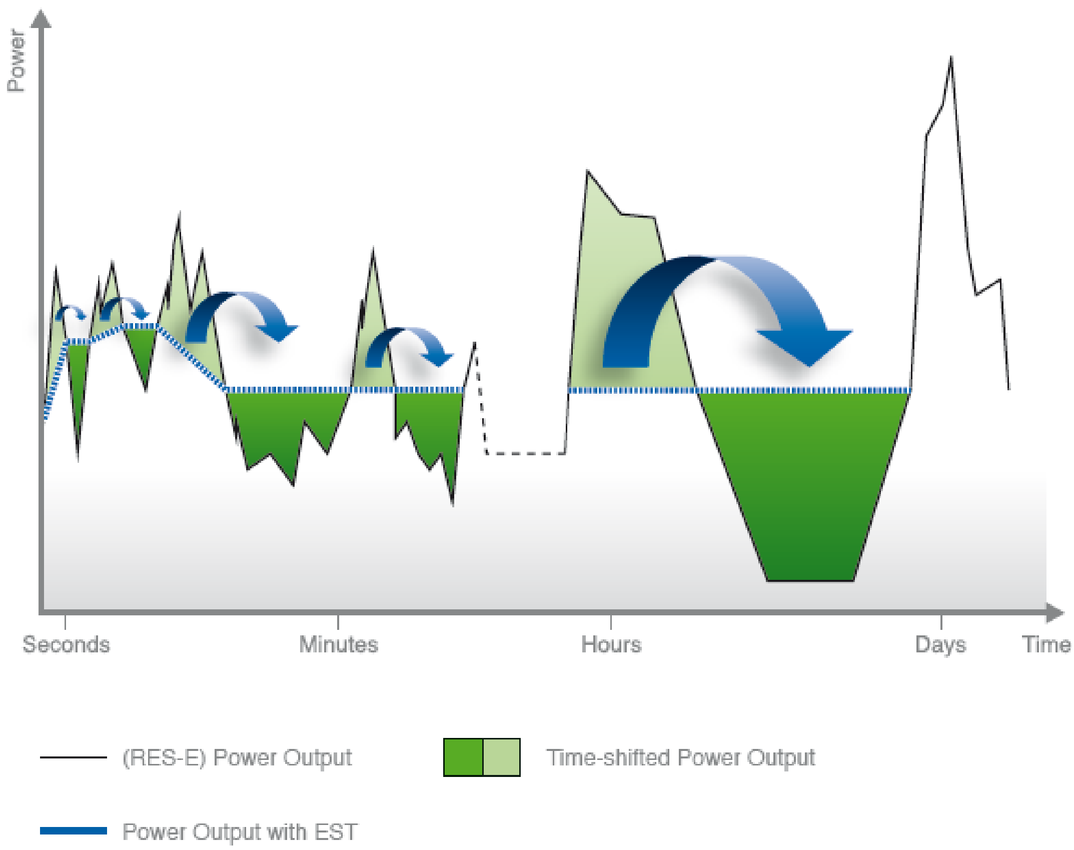


Figure 3: Basic principles of output smoothing of EST on different time scales (i.e. storage capacities and response times)

Moreover, the high flexibility of bulk EST, i.e. fast ramping rates and the ability to switch from electricity consumption to electricity generation (and vice versa) within a very short time period, make them highly suitable for balancing short term fluctuations of intermittent RES-E generation (e.g. wind and PV). Therefore, especially intraday markets (e.g. trading hourly- and 15-minutescontracts) could be very profitable in case of forecast errors / high drop-off rates of RES-E generation (or electricity demand).

Bulk EST have been used to provide balancing services in the electricity systems already for a long time. However, storage capacities of bulk EST are limited and by no means sufficient to balance power fluctuations caused by variable / intermittent RES-E generation over long periods of time. Well-balanced charging / discharging cycles are always needed to maximise the benefits of bulk EST in an electricity system on different scales in time.

Contribution in Future European Electricity Systems

This chapter provides an overview on the possible contribution of bulk EST in future European electricity systems. For this, the geographic allocation of future potentials of bulk EST are identified and are matched with the spatial dispersion of future RES-E deployment and the existing thermal power plant-portfolio on regional level in Europe. Selected results for the years 2030 and 2050 for two different RES-E deployment scenarios are also shown.

Pumped Hydro Energy Storage in European Context

First, the geographical allocation of future potentials of bulk EST across Europe is identified. The estimation of the future potential of bulk EST implementation is based on a summary and synthesis of the most relevant existing work, studies and modelling results on this topic (on country level as well as on European level).

Figure 4 shows that the highest total potentials for (P)HES are located in parts of Scandinavia, Central and Western Europe. Besides Norway and Sweden, European countries in mountainous areas, such as the Alps and the Pyrenees, have significant potential for deployment of PHES systems. Particularly Luxembourg, Switzerland and Austria have a very high PHES potential in relation to their land area. On the contrary, countries with a rather flat landscape like Denmark, Finland, Latvia and the Netherlands have no existing (P)HES power plants and also no development plans for new PHES systems at the moment.

For the purpose of our analyses, two different future RES-E deployment scenarios in European countries for the years 2030 and 2050 have been developed based on modelling results derived from the Green-X RES-Electricity deployment simulation tool (Huber et al, 2004). Green-X provides future scenarios on annual RES-E capacities installations and electricity generation per country under a variety of different possible policy settings and constraints. The two generated scenarios are: a business-as-usual scenario (BAU) with moderate increase of RES-E deployment and an environmentally friendly scenario (GREEN) with high increase of RES-E deployment in Europe.

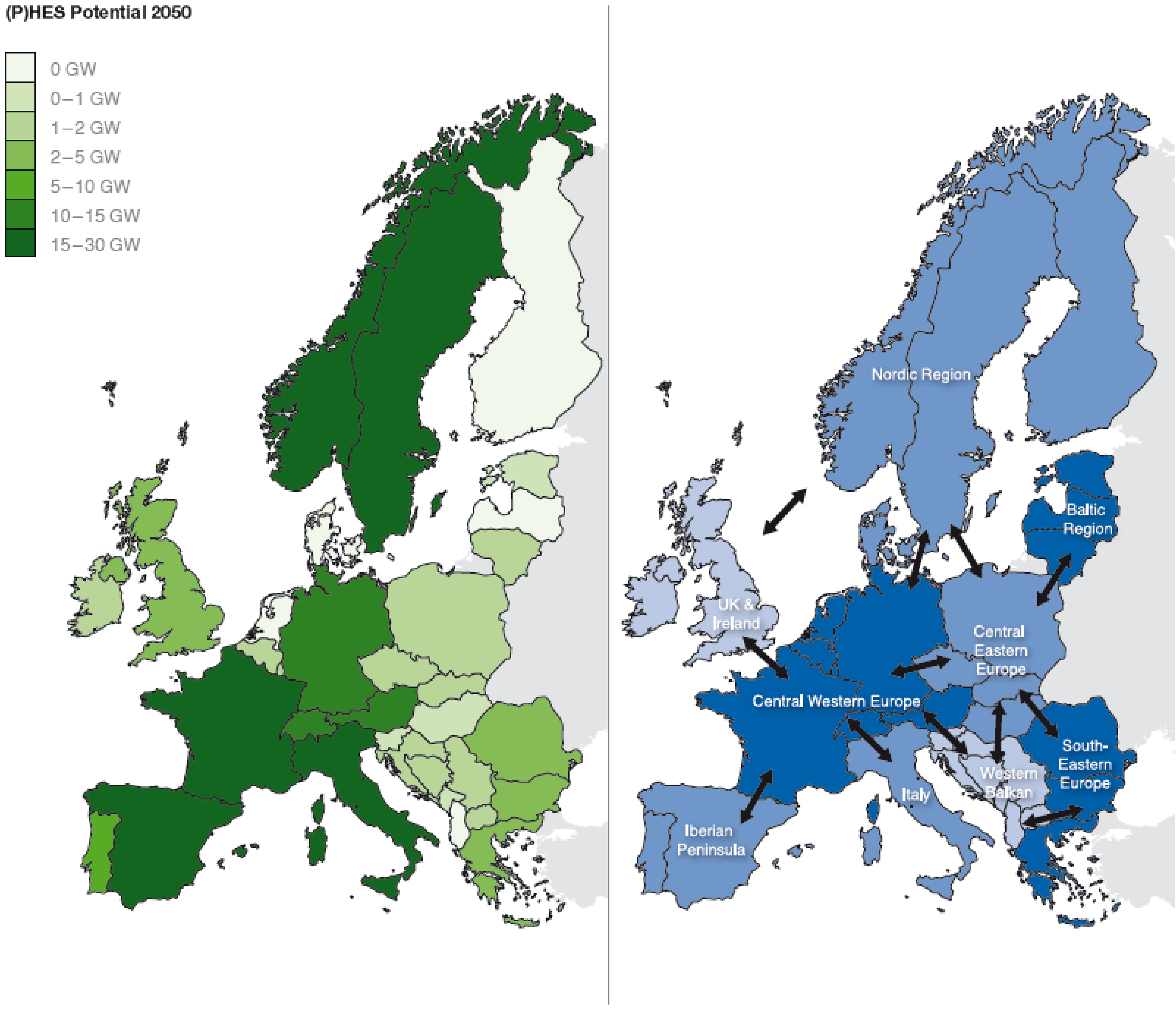


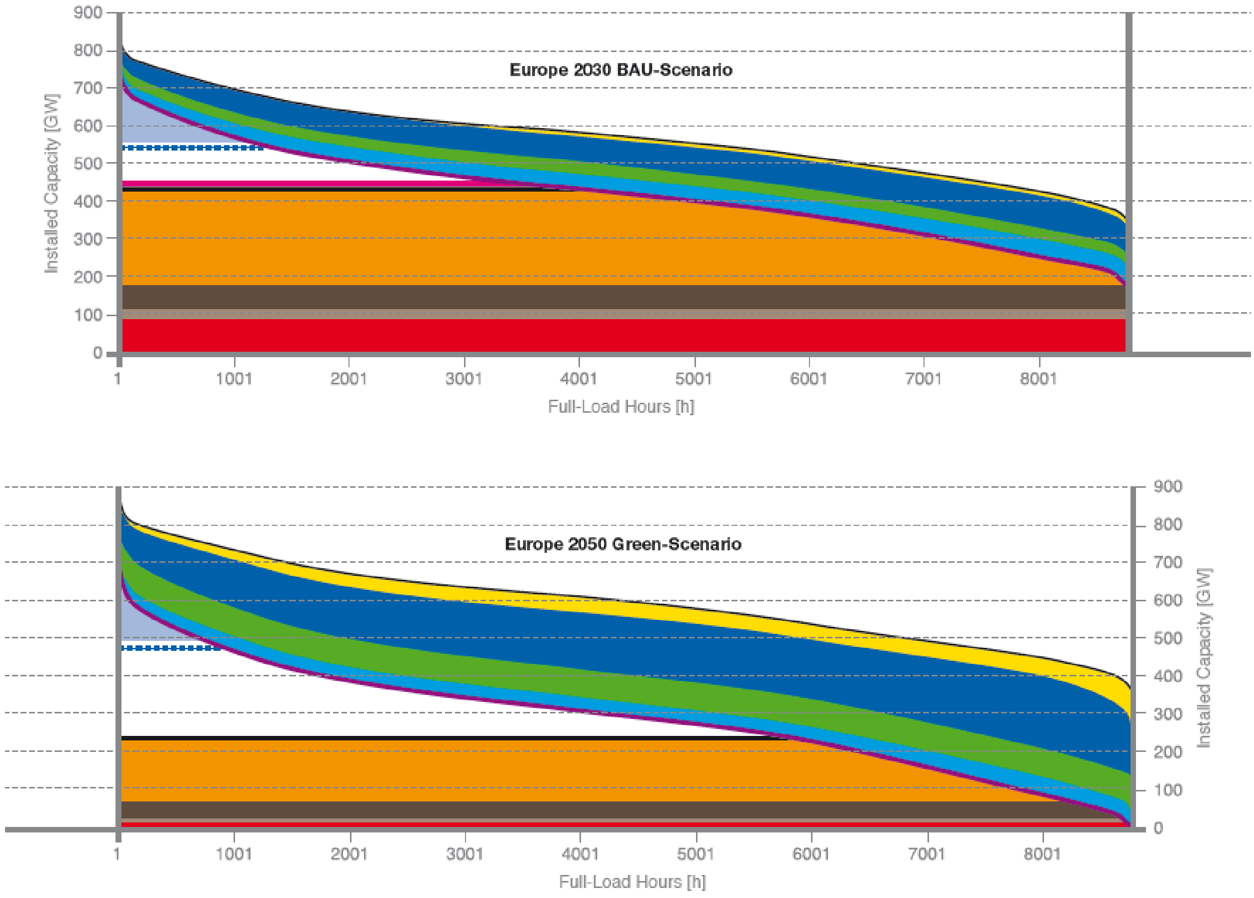
Figure 4: (P)HES potential in Europe until the year 2050 in power capacity per country (left) and clustering of countries to nine different European electricity market regions (right)

Taking into account the physical constraints in the European (cross-border) transmission grid in the analysis, European countries were clustered into nine different electricity market regions according to the different wholesale electricity market places / prices (as a consequence of physical constraints in the transmission grid). This clustering coincides with relevant EC documents and the ENTSO-E's "Ten Year Network Development Plan (TYNDP)".

Comparison of Selected Results

In order to be able to estimate the possible direct benefits and future contribution of bulk EST implementation to balance an incumbent regional electricity system, the identified bulk EST potentials are matched with the spatial dispersion of future RES-E deployment and the existing thermal power plant-portfolio on regional level in Europe. Doing this, the residual load curves of the nine different regions for the years 2030 and 2050 and for two different scenarios (BAU and GREEN) were derived and the possible coverage of the residual load curves with existing thermal power plants and bulk EST was analysed.

The results of the BAU scenario in the year 2030 and of the GREEN scenario in the year 2050 are shown below for the Europe region, combining the results of all nine analysed regions.



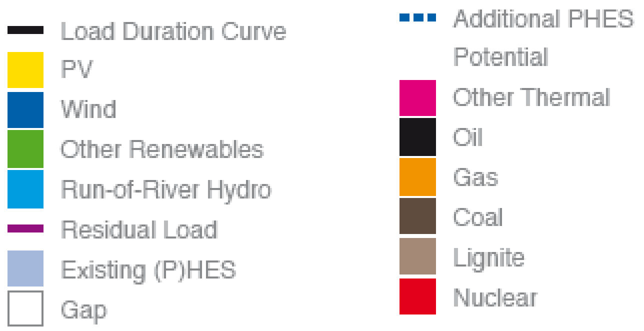


Figure 5: Load duration, residual load curve and coverage of the residual load of the Europe region with existing thermal power plants and PHES in the BAU scenario in the year 2030 and in the GREEN scenario in the year 2050

The top of figure 5 shows the load duration, residual load curve and coverage of the residual load of the Europe region with existing thermal power plants and PHES in the BAU scenario in the year 2030. In general, the residual load curves (purple line in Figure 9) were generated by subtracting hourly PV (yellow area), wind (dark blue area), other renewables (green area) and run-of-river hydro (light blue area) electricity generation from the load duration curve (black line). Note, that after every subtraction of respective RES-E feed-in from the load, the residual load curve is sorted again from highest to lowest residual load values. Therefore, a vertical cross-section from the load curve to the residual load curve does not determine RES-E feed-in at a certain point in time simply because it represents RES-E feed-in data from different points in time.

After their establishment, the residual load curves for the years 2020, 2030 and 2050 were "filled-up" with the still existing[14] thermal power plant capacities (cf. Figure 5). The thermal power plant capacities are drawn as constant bands, starting with the base-load and least-costly power plants (i.e. nuclear, lignite and coal) followed by gas and oil power plant capacities.

Additionally, existing installed capacities of (P)HES systems in the respective region are depicted as constant bands indicated downward from the top of the residual load curves in order to show their potential for providing peak-load power. Any available additional PHES potentials (currently not implemented) within the region are indicated by a blue dotted line (cf. Figure 9). The electricity consumption of existing and future PHES systems in pumping mode is not incorporated in the residual load curves. However, in general this additional demand would only alter the residual load values in times of high RES-E feed-in / low residual load (i.e. right side of the residual load curve).

In many analysed regions and time horizons a gap (indicated in white colour) remains between the PHES band and the upper band of the thermal power plants, meaning that there is not enough installed power plant capacity available within the region to meet regional electricity demand.

It can be seen that in the Europe region a capacity gap of about 100 GW remains in the year 2030 in the BAU scenario, meaning that new thermal and / or PHES power plants will be needed to cover electricity demand in this scenario. The blue dotted line indicates that only a minor part of this missing capacity could be provided by new, currently not utilized PHES systems in the European region. Yet, in some of the nine analysed regions (e.g. Baltic region, Central Western and South Eastern Europe) new PHES systems could have major contributions in filling this gap.

Furthermore, in some regions (e.g. Iberian Peninsula and Italy) sufficient (thermal) power plant capacity is available in the region (i.e. no capacity gap between supply and demand). This fact has two reasons: On the one hand, high RES-E deployment in the regions (especially wind, but also PV) and, on the other hand, large amounts of still existing thermal power plants in the year 2030 (due to high investments in gas-fired thermal power plants in the last ten years in the regions).

Due to age-related phase-out of the majority of nuclear and thermal power plants in the Europe region in the GREEN scenario in the year 2050, large amounts of integrated RES-E cannot hamper the growth of the gap of missing generation capacity in comparison to the BAU 2030 scenario. As already seen in the BAU scenario, new PHES schemes could only slightly contribute to minimise this gap.

However, in several regions (e.g. Central Western and South Eastern Europe, the Iberian Peninsula etc.) RES-E feed-in exceeds electricity load occasionally in the year 2050 in the GREEN scenario. This RES-E excess generation can be used for (large-scale) electricity storage (e.g. this electricity might be available at low cost for pumping purposes in a PHES system) and / or for exports to neighbouring regions. Unlike thermal power plants, PHES systems can help fully utilising future RES-E generation by storing excess RES-E generation and "restoring" it when needed.

Environmental Issues

Environmental performance of existing energy storage installations

This section describes a key task which aims to determine the environmental performance of existing energy storage facilities. The knowledge gained from the experiences highlighted in six case studies will form the foundation for determining international best practice and to lower environmental barriers to implementing new energy storage schemes.

The main benefit of PHES and CAES from an environmental perspective is that storing electricity from renewable energy sources will result in a reduction of its curtailment with consequent reduction in carbon dioxide emissions. The following sections highlight the main conclusions of the environmental performance during operation as determined by the case studies and literature review.

CAES

- The case study on the Huntorf CAES facility has highlighted very few environmental impacts during operation. This is partly because the CAES was constructed into a previously modified environment. It is important to note however that there may be further impacts during construction, the analysis of which is beyond the scope of this report.

- The main drawback of the existing CAES is that it is a hybrid system. This means that it is dependent on an external heat source (i.e. natural gas) to replace the heat lost during the compression stage. The required amount is however, one third what conventional gas turbines require. Using biofuel instead may be a way of making CAES carbon neutral, provided that the biofuel is itself carbon neutral. Advanced Adiabatic CAES systems, which are currently under research, would eliminate the required external heat source.

Open-system (pump-back) PHES

- Thissavros pump-back PHES has several environmental impacts associated with it, mainly because the dam and PHES facility were constructed simultaneously into a relatively unmodified environment. Since most of the long-term impacts are associated with the initial construction of the dam, a more benign solution would be to retrofit an already existing hydropower scheme with pumps. The receiving environment in such a case would already be heavily modified, resulting in a significantly lower environmental impact of the PHES. Although retrofitting has a lower environmental impact, it is not always an option as some countries or regions may require new developments.

- The construction of a dam for hydro generation results in alteration of the natural flow regime of the river. The flow is controlled primarily to meet electricity demands with little consideration for the environmental needs of the downstream river system. This regulation ultimately reduces or eliminates natural peak flood events and low flow events. While minimum flows are normally maintained, this does not guarantee that the environmental needs are met. The operating regime of the facility could be managed, by means of environmental flow, so as to simulate natural flow conditions. In this way the environmental impact could be mitigated but it should be noted that environmental flow is not a perfect substitute for natural flow. Changing operating regimes may also incur a trade-off in reduced operational flexibility and ability to provide fast reserve to accommodate variable renewable energy sources.

- Rivers transport a vast amount of sediment and nutrients to their lower reaches and coastal areas. The presence of a dam on a river will hinder this process by allowing sediment to accumulate behind it instead. Reduced sediment transport to the downstream environment causes a reduced accretion rate that may be detrimental to the coastal and delta areas and ultimately to the flora and fauna that inhabit these.

- Changing a river environment into a lake environment will likely result in thermal stratification. As extraction of water from the lower thermal layers is the norm when operating the turbines the downstream river is affected by colder water and higher salt concentrations from the discharge. A direct result of changing water temperature, velocity and nutrient levels is that the species abundance and diversity can change. Native species may be outcompeted by non-native species that are more adapted to the new conditions.

- Fluctuating water levels, resulting from the operating regime, will cause frequent inundation and draw down of shoreline, isolation of spawning areas, loss of habitat and limited regeneration both upstream and downstream. Natural fluctuations vary in magnitude on a seasonal basis whereas operational fluctuations vary on a daily basis at a relatively constant magnitude.

- The presence of a dam hinders both upstream and downstream fish migration. This can be detrimental to fish populations as it can prevent movement between spawning and feeding areas. For upstream migration fish passes may be an option for smaller dams, but for larger dams such as Thissavros the only feasible option is to transport them by trucks or fish lifts. Downstream migration will generally occur via turbines or spillways. Both upstream and downstream migration by artificial means is not fully effective and will result in some fish mortality.

Semi-open PHES

- Kopswerk II and Bolarque II were constructed in heavily modified environments resulting in low environmental impact during operation. Goldisthal on the other hand was constructed in a less modified environment which has resulted in a greater environmental impact. Therefore potential PHES sites in already modified environments should be considered where available.

- As with the pump-back PHES fluctuating water levels, resulting from the operating regime, will cause frequent inundation and draw down of shoreline, isolation of spawning areas, loss of habitat and limited regeneration both upstream and downstream.

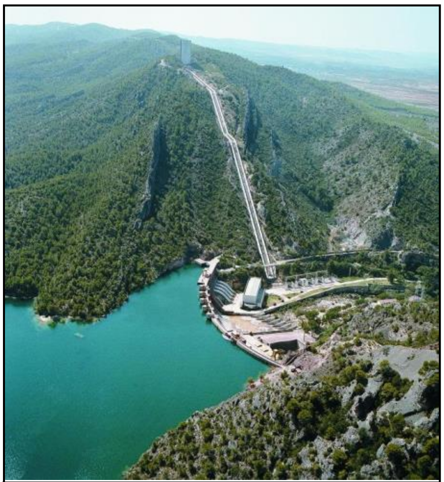


Figure 6: Bolarque II ; Source: CEDEX/Ministerio de Formento

Closed-loop PHES

- Turlough Hill was specifically designed for peak operation which means that the water level fluctuates through its full active range on a daily basis. This regular mass movement of water inhibits the natural lake processes within the lower lake.

- The shoreline vegetation communities associated with oligotrophic lakes, which are listed on Annex I of the Habitats Directive, is an important characteristic. The artificial modification of the natural water level can reduce the diversity of typical soft water species present. It is unlikely that the natural vegetation of the Lough Nahanagan shoreline can tolerate the artificial lowering of the lake levels and the regular lowering and raising of lake levels associated with the daily operation of the plant.

Recommendations for furthering the Sustainable Development of Bulk Energy Storage Facilities

The following key electricity and environmental legislation that affects new PHES and CAES projects has been reviewed by the project team:

- Renewable Energy Directive (Directive 2009/28/EC)
- Water Framework Directive (Directive 2000/60/EC)
- Directives Relating to Biodiversity and Natura 2000 Network
    - Habitat Directive (Directive 92/43/EEC)
    - Birds Directive (Directive 2009/147/EC)
- Directives Relating to Environmental Assessment
- SEA Directive (Directive 2001/42/EC)
- EIA Directive (Directive 2011/92/EEC)

The main conclusion has been that without clear EST policy, no strategic plans or programmes can be adopted increasing the difficultly associated with project development. Currently, project development is a lengthy and costly process as it is generally developer driven. In order to facilitate the further and sustainable development of electricity storage projects, appropriate policy and strategic plans and programmes need to be in place.

Based on that conclusion the following recommendations were formulated:

Establish a Need: Once the need for bulk EST has been identified, it is essential that energy storage policy and clearly discernible objectives are developed at EU and MS level.

Develop Plans and Programmes: Where MS acknowledge the need for energy storage in their NREAP they should consider this technology at a strategic planning level, the early stage of the decision-making cycle, and develop sustainable plans and programmes to facilitate the national and regional deployment of bulk EST as appropriate.

Identify Viable Sites at Strategic Level: It is recommended that physically viable sites be identified and tested (subject to environmental assessment) at a strategic level during the development of PHES plans and programmes.

Develop Clear Guidelines and Document Best Practice: Clear MS guidelines for sustainable project development, best practice guidelines and guidelines for planning are required to further the sustainable development of bulk EST.

Facilitate Planning and Approval Procedures: It is recommended that the efficiency and speed with which bulk EST projects are considered during the planning approval stage be improved with the establishment of appropriate mechanisms.

Development of Bulk Energy Storage & Natura 2000

The Birds and Habitats Directives can have a significant bearing on the success or otherwise of a new Pumped Hydro Energy Storage (PHES) and Compressed Air Energy Storage (CAES) development. The purpose of this section is to provide sector specific guidance on how best to ensure that PHES and CAES developments are compatible with the provisions of the Birds and Habitats Directive with particular focus on Article 6 procedures. The guidance is designed for use by competent authorities, developers and consultants and will be of interest to Non-Governmental Organisations and other stakeholders.

The main bulk Energy Storage Technologies (EST) plants available are PHES and CAES. PHES can be categorised further according to water management as closed loop, semi-open or open systems. PHES is currently the only commercially proven large scale (5 MW – 2 GW) EST with over 300 plants installed worldwide with a total installed capacity of over 95 GW.

The main elements of a PHES scheme include two water reservoirs, a power house and a penstock and tailrace connecting the power house to the upper and lower reservoirs respectively. When energy production exceeds demand, the excess energy is used to pump water from the lower to the upper reservoir and during times of peak demand, water is released from the upper reservoir to flow through turbines, into the lower reservoir, producing hydroelectric power.

The Birds and Habitats Directives form the cornerstone of the EU's nature conservation policy that is built on two pillars: (1) the Natura 2000 (N2K) network of protected sites and (2) the system of species protection. The Habitats Directive requires the appropriate assessment of the implications of plans or projects for N2K site/s. The appropriate assessment process 'tests' whether the plan or project will have 'an adverse effect on the integrity of the site'.

PHES developments are large infrastructural projects involving major civil, mechanical and electrical engineering works and by their nature, size and scale they have the potential to have significant environmental effects. PHES developments are inextricably linked to water resources and watercourses (e.g. rivers, lakes and artificial reservoirs). Depending on the quality and the level of human interference, water environments can support important and threatened habitats and species. This potential interaction between ecological resources and PHES can result in potentially significant ecological impacts.

An appropriate assessment is undertaken subsequent to a plan or project being subjected to the screening exercise. Due to the size, scale and nature of PHES and CAES developments, there will be a requirement for them to be screened for appropriate assessment in nearly all cases. An appropriate assessment is an impact assessment tool to determine the implication of a plan or project on the integrity of the N2K site, either alone or in combination with other plans and projects, with respect to the site's ecological health (structure and function) and its conservation objectives.

Importantly, the outcome of the assessment informs decision-making, that is, it is legally binding. If the outcome of the assessment is positive and no reasonable scientific doubt remains regarding the absence of negative effects to the site, then the competent authority can grant consent and authorise the plan or project. **The competent authority shall only approve or authorise a PHES or CAES project having ascertained that it will not adversely affect the integrity of the site concerned.**

Where adverse impacts cannot be ruled out, the assessment must proceed to Stage 3 where alternative solutions are examined. Alternative design, sites and technologies need to be examined to determine if they can feasibly achieve the objective of the plan or project. Where a feasible alternative is identified, then it must be subject to a screening exercise and process repeated as necessary.

Where no alternatives exist, the plan or project must proceed to Stage 4. A decision must be taken on whether it is considered to qualify as a plan or project of 'imperative reasons of overriding public interest' (IROPI). If it qualifies, adequate compensatory measures must be designed to ensure the coherence of the N2K network.

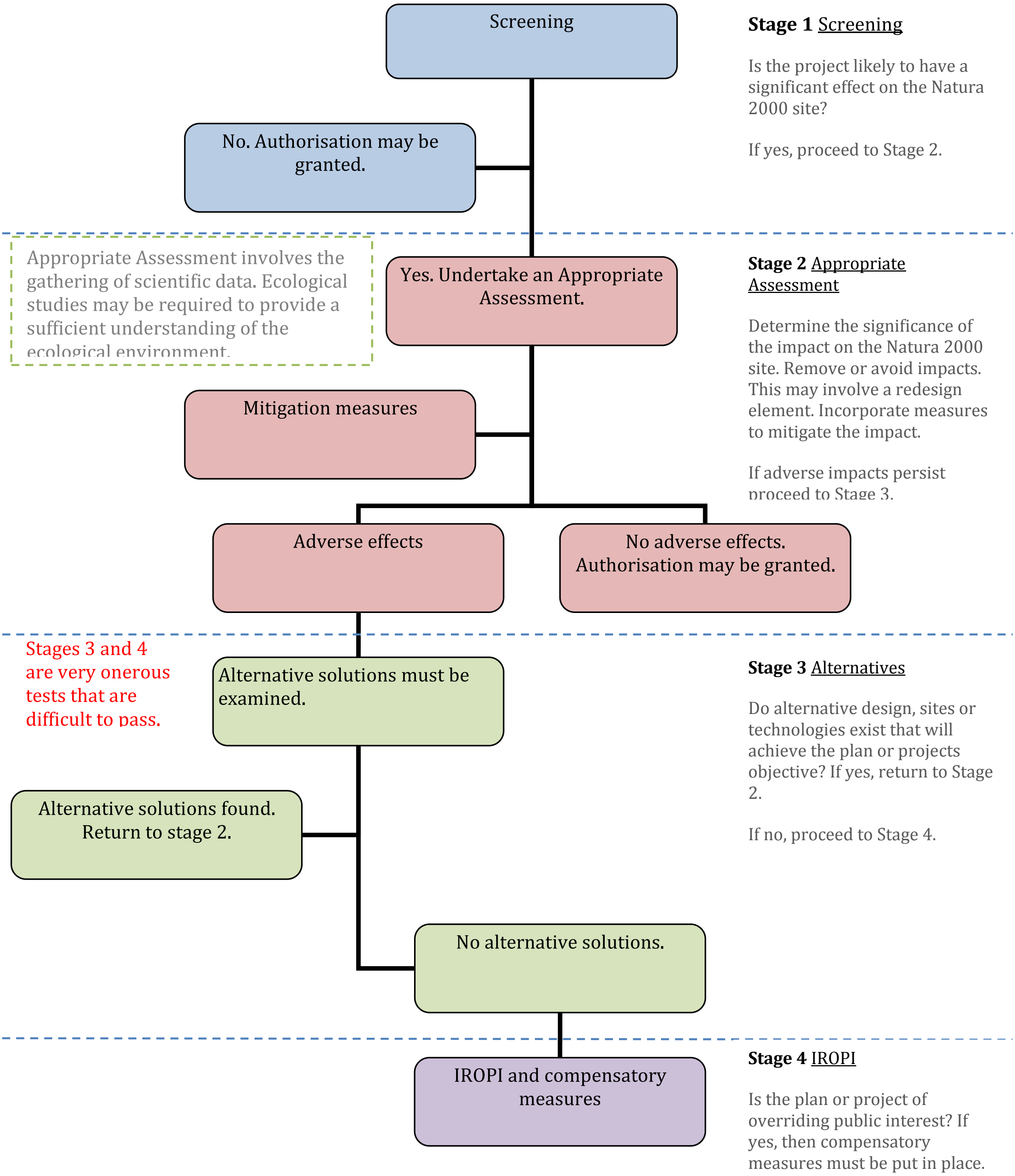


Figure 7: Flowchart summarising stages of Appropriate Assessment

European Regulatory and Market Analysis

This section identifies the key elements of the European market framework that potentially create unfavourable conditions for the development and operation of electricity storage infrastructure and provides policy makers with recommendations for possible improvements. The project mainly focuses on bulk storage technologies, however the framework conditions are very similar for storage technologies of smaller scale and therefore the recommendations in this document cover a wider spectrum of electricity storage technologies.

The main directives, policies, funding instruments and other relevant European initiatives were reviewed, highlighting the parts relevant to electricity storage. Overall, most of the policies and Directives contain direct references to electricity storage, recognising its importance and potential role in the future electricity system. However, there is no concrete support foreseen for electricity storage projects, and no concrete framework for their operation. For example there is no definition for electricity storage, resulting in their treatment as normal generation systems in most cases.

The on-going efforts and processes for the completion of a Single Energy Market for Europe were examined first, including the following documents:

- The Electricity Directive - Directive 2009/72/EC
- Framework Guidelines on Capacity Allocation and Congestion Management for Electricity
  - Network Code on Capacity Allocation and Congestion Management
- Framework Guidelines on Electricity Balancing
  - Network Code on Balancing
- Framework Guidelines on Electricity Grid Connections
  - Network Code on Requirements for Grid Connection
  - Network Code on Demand Connection
- Framework Guidelines on Electricity System Operation
  - Network Code for Operational Security
  - Network Code on Operational Planning and Scheduling
  - Draft Network Code for Load-Frequency Control & Reserves Network
- Better Governance for the Single Market - COM(2012) 259
- Making the Internal Energy Market Work - COM(2012) 663

Then the energy infrastructure package was examined as an enabler for the development of the Single Energy Market for Europe. The following documents have been reviewed:

- Blueprint for an integrated European energy network - COM(2010) 677
- Guidelines for trans-European energy infrastructure - COM(2011) 658
- Establishing the Connecting Europe Facility - COM(2011) 665
- The Ten Year Network Development Plan (TYNDP)
- The list of “Projects of Common Interest” (PCIs)

Finally, the main policies, directives and other initiatives directly related to renewable energy were studied, as expressed in the following documents:

- The Renewable Energy Directive - Directive 2009/28/EC
- Energy 2020 - COM(2010) 639
- The European Strategic Energy Technology Plan's (SET-Plan) as expressed in COM(2009) 519
- The Energy Roadmap 2050 - COM(2011) 885
- Renewable Energy: a major player in the European energy market - COM(2012) 271

The next step of the work discussed the views of all stakeholder groups as expressed during a wide consultation process, which comprises:

- Development of a questionnaire and supporting document after a thorough review of the European Directives and Policies
- Distribution of documents to selected experts and feedback for improvements
- Distribution of final documents to stakeholders (including the industry, utilities, civil and environmental NGOs, governmental organisations and EC officials) by e-mail
- Contact by telephone with selected experts
- Four round tables where the main concerns regarding regulatory aspects at a European level as well as the first draft results were discussed
- Experts input during the project's 2nd advisory board meeting
- Collection and analysis of feedback from overall 55 experts

The collected feedback was grouped into four sub-sections: Current business model, regulatory framework, market design and other regulatory and market issues. The relevant report discusses the different viewpoints, presenting the arguments supporting each position. Regarding the business model and marginal viability of electricity storage systems in the current framework, the report discusses whether the marginal viability reflects that there are more efficient solutions for balancing. Also the following issues are examined: the market distortions that could affect the price signals, the applicability of the unbundling principle on electricity storage, the energy infrastructure package and the role that storage projects should have and other issues such as grid fees, network codes, etc.

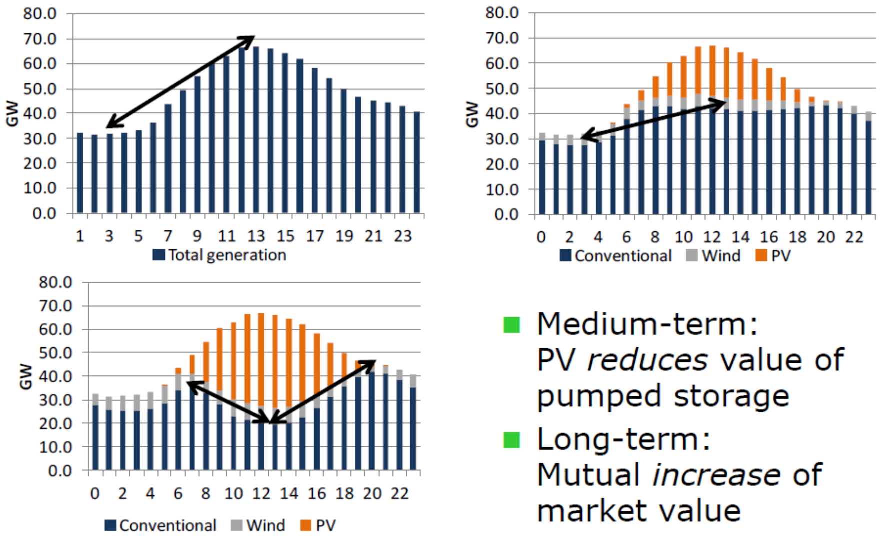


Figure 8: How solar energy might affect the storage requirements. Source: Simon Mueller, IEA

Finally, the following recommendations were formulated for adapting the market design in order to facilitate the development of the electricity storage infrastructure, to the extent necessary for accommodating the future development of variable renewable energy.

Recommendations to the European Commission:

1. Re-evaluate the exemption of the PHES from the financing provision of the infrastructure package, restricting only financing to plants that could be profitable without support.

2. Officially clarify the applicability of the unbundling principle to electricity storage (Article 9(1) of the Electricity Directive), by including a clear definition of electricity storage in the Directive and involving all stakeholders in a dialogue to propose an approach that fulfils the following conditions:

- Ensure the functioning of an open, fair and transparent market, by introducing clear restrictions to the use of electricity storage facilities by system operators if and when they are allowed some kind of control over them.
- Facilitate the market selection of the most efficient solution when a decision has to be taken for transmission vs. storage.

3. Maintain the possibility to include in the PCI also projects not foreseen in the TYNDP. This provision should be made as long as TSOs are not allowed to control electricity storage as such projects do not feature in the TYNDP.

4. Introduce targeted regulatory interventions and initiatives in order to deal with the cause or the effects of market distortions and to ensure the timely development of storage infrastructure to the extent necessary to facilitate the continuous growth of renewable energy. Here are listed some ideas proposed in this direction that could form a basis for further consideration:

- In future revisions of renewable energy support mechanisms elements could be introduced that reward flexibility.
- Provide some kind of support for renewable electricity storage, for example granting priority dispatch to the stored electricity stemming from RES and exempting this electricity from any grid fees and taxes.

5. Monitor the transposition to national legislation of Electricity Directive Article 15 (7) for transparent and market based mechanisms for balancing and encourage the integration of mechanisms on the national level that will ensure adequate market liquidity for providing the necessary services to balance the grid.

Recommendations to ACER and ENTSO-E:

1. Include definitions of electricity storage in the network codes, also taking into account small scale systems with the potential to become elements of the smart grid developments, in order to facilitate the development of similar administrative procedures in the Member States for their connection to the grid.

2. Develop a method to calculate grid fees that will take the real impact of the electricity storage system on the grid into account, as in most cases storage systems are not contributing to congestion problems, but are actually relieving them.

3. Apply common rules across Europe regarding grid fees in order to avoid deployment of a project in one country and provision of services in another, due to different framework conditions.

4. Critically review the Cost Benefit Analysis methodology developed for the evaluation of the proposed Projects of Common Interest to ensure that it is fair and treats electricity storage projects in equal terms with transmission and generation projects.

<u>Recommendations to project developers and other stakeholders involved with electricity storage:</u>

1. Closely monitor the on-going development of the network code on balancing in order to ensure that electricity storage facilities will gain full access to cross border markets.

2. Monitor the transposition to national legislation of Electricity Directive Article 15 (7) for transparent and market based mechanisms for balancing and to encourage the integration of mechanisms at national level that will ensure adequate market liquidity for providing the necessary services to balance the grid.

3. Critically review the Cost Benefit Analysis methodology developed for the evaluation of the proposed Projects of Common Interest to ensure that it is fair and treats electricity storage projects in equal terms with transmission and generation projects.

Target Countries Analysis

Energy Storage Needs

This part of the work provides an estimation of the additional energy storage needs in the electricity supply systems of the target countries. The existing power generation mix and transmission system, and the planned development and reinforcements are considered, along with the national plans for renewable energy development and alternative scenarios in the next decades up to 2050. The necessity of new energy storage facilities and their feasibility from the energy point of view is investigated with the aid of simulations of mainland electricity system operation characteristics, using specially developed software.

The computation methodology follows two steps. First the residual load for the scenario under investigation is calculated. Therefore hourly load and production data of different years per primary energy carrier are used. The second step is the calculation of the overall storage needs. For this purpose an algorithm was developed at the Helmut-Schmidt-University to estimate the energy storage needs just from a system point of view.

The aim of the energy storage facilities in this approach is to integrate the maximum renewable energies possible without any focus on the electricity spot market price. The residual load is here defined as the load demand minus the non-controllable production from renewable sources. When the residual load is negative this means that there is a surplus of energy from renewable sources that exceeds the load demand. This surplus can either be rejected by down regulating renewable production units, exported to neighboring countries or stored. Down regulation or energy export is not an option within the computation algorithm. The aim is to use as little power and capacity of the storage system to fully integrate all the surpluses due to renewable energies. In principle the algorithm follows a peak shaving valley filling strategy.

To minimize the energy storage needs, an intelligent operation strategy was implemented. If it can be expected that there will be a high surplus of renewable energies on the electricity system, the energy storage system (ESS) plans its operation in a way to be able to fully integrate this surplus. If the surplus of renewable energy is expected to exceed the capacity of the ESS, it tries to plan the operation in a way to empty the reservoirs completely before to integrate as much renewable energy as possible. To estimate the additionally needed storage capacity a further technology, in addition to the already existing ESS, is introduced. This technology has an unlimited capacity and power. This technology can take the surplus of renewable energy that cannot be stored by the existing system. Due to the unlimited power and capacity this technology enables the full integration of all renewable energies. The actual used power and capacity of this second technology is an indicator of the additionally needed energy storage system.

In this section we will present the qualitative and quantitative results highlight the need and benefits of energy storage in future electricity systems.

Austria

The first scenario for 2020 (scenario A) is the scenario with the installed capacities of RES-e foreseen in the Austrian National Renewable Energy Action Plan. Scenarios B and C are the Business as Usual and the Green scenarios developed by EEG. The 2020 scenarios do not differ much in their installed wind power. What can be observed is that there is a strong raise in PV installations in the GREEN scenario C. Furthermore, scenarios B and C foresee a higher installed power of PHES systems than the NREAP. For 2050 the GREEN and the BAU scenarios are investigated further, having a significant variance between them regarding the amount of installed PV. Because of the high potential for PHES in the Austrian Alps, two further 2050 scenarios have been investigated. For these scenarios the two electricity systems of Austria and Germany have been combined.

Austria has theoretically enough storage capacity in the big reservoirs in the Alps (~2 TWh) to store all the surplus of renewable energy produced within the country. Only in the 80% RE scenario an additional installed pump power of 3 GW would be needed. Practically though, the model foresees that the reservoirs will fluctuate by up to 80%, which cannot be accepted from an environmental point of view.

It has been shown that the connection of the Austrian and the German electricity systems gathers a very high potential. Especially the better exploitation of the Austrian PHES system is a big advantage for both countries. The capacity of the existing reservoirs is big enough to cover even the total storage needs of Germany. The transmission capacity required for that will most probably be very high, but even with lower capacities a very high surplus of RES-e can be stored. When building new transmission lines also the Austrian energy system becomes more flexible and the total energy storage needs in both countries decrease. Just an expansion from the current capacity of 2.2 GW to 9.2 GW would allow to curtail as little as 2% of the energy from variable renewable sources. Furthermore, in that case the reservoirs would fluctuate only up to up an acceptable range of 14%.

Denmark

6 scenarios have been investigated for the Danish system. In the lowest wind scenario the needed power and capacity are still in a low range and can be handled with import/export from/to neighboring countries like Norway, Sweden and Germany or with the heating sector. After 2020 the energy storage needs will rise rapidly and reach 660 GWh at an 80% share of RES which is expected to happen between 2030 and 2035. The high energy storage requirements are due to the fact that Denmark doesn’t have a large enough solar potential to use the balancing effects of PV with Wind. On the other side Denmark has a high share of CHP plants where excess wind energy can be used to produce heat. This way the additional energy storage needs can be reduced to 600 GWh. In a scenario with 80% renewables the export of excess energy to Germany will be difficult because wind speeds (especially offshore) in Denmark and Germany correlate strongly especially during strong wind when export would be needed. However, with a transmission capacity of 3 GW the additional storage needs could be further reduced to 442 GWh.

Scenario	Additionally needed power in GW		Additionally needed capacity in GWh	
	Charging	Discharging		
2020	2.19 – 2.36	2.18 – 2.36	38.68 – 55.22	
80 %	4.85	3.25	660.75	
80 % incl. heating	3.90	3.12	600.00	
Transmission capacity				
	None	1500 MW	3000 MW	Unlimited
Rejected Energy	4928 GWh	2928 GWh	2318 GWh	2280 GWh
Transmittable Energy	0	2000 GWh	2609 GWh	2648 GWh

Germany

In the case of Germany, 7 scenarios have been investigated, one reference scenario with actual data from 2011 and 6 development scenarios for renewable energy sources. The results show that up to the year 2020, the existing and planned energy storage facilities have enough capacity to integrate the renewable energy generation. After the year 2020 the need for new energy storage installations will increase rapidly. In the following Table the results for an 80% share of renewable energy sources are highlighted. The additionally needed capacity varies between 950 GWh and 1534 GWh, which is 20 to 40 times the current capacity. The additionally needed installed power is 3 to 7 times higher than the one currently installed. It can be seen that with a stronger development of wind power the additionally needed power is lower but the needed capacity is higher than with a stronger development of PV.

Scenario 80% RE	Additionally needed power in GW		Additionally needed capacity in GWh
	Charging	Discharging	
Equal	38.79	25.17	1,308
Wind	31.85	25.74	1,534
PV	55.16	29.04	950

Greece

In the case of Greece, 6 scenarios have been investigated similar to the scenarios in the other target countries. However, for each scenario a scenario with a higher penetration limit was added to take into account possible new installations of fossil fired power plants and the resulting technical minimum for RE integration. The results for an 80% share of RES are summarized in Table 3.

Scenario 80% RE	Additionally needed power in GW		Additionally needed capacity in GWh
	Charging	Discharging	
Equal	11.9	8.2	375
Wind	10.6	8.3	430
PV	13.5	8.2	340
Higher penetration limit (2 GW)			
Equal	13.5	8.0	1440
Wind	12.2	8.0	1550
PV	15.1	8.1	1320

Ireland

6 scenarios have been investigated for Ireland, one reference scenario with actual data from 2011, 4 development scenarios for renewable energy sources and one scenario with import/export investigations. The results show that the Irish system will need energy storage facilities already in the year 2020. In the lowest wind scenario the needed power and capacity are still in a low range but will rise very fast with additional installed wind power. In an 80% RE scenario the total needed storage capacity reaches 2.7 TWh. This is due to the fact that Ireland doesn't have a large enough solar potential to use the balancing effects of PV with Wind. Alternatives to storage are the rejection of wind energy or the export/import to/from the UK. However, as the UK is also planning to increase the installed amount of wind power, import/export of energy will not always be possible. When assuming a share of 80% renewables in Ireland and UK, the results from Table 4 show that an interconnection capacity of more than 2 GW cannot be used to a high extend and will therefore not be economically feasible. This is due to the very high time correlation of wind speeds in both countries.

Scenario	Additionally needed power in GW		Additionally needed capacity in GWh	
	Charging	Discharging		
2020	1.73 – 1.86	1.60 – 1.79	14.32 - 70.00	
80 %	6.8	4.3	2,700	
Interconnection capacity				
	None	1 GW	2 GW	Unlimited
Rejected Energy	7,729 GWh	6,695 GWh	6,122 GWh	5,744 GWh
Transmittable Energy	0 GWh	1,029 GWh	1,603 GWh	1,981 GWh

Spain

Similar to the scenarios in the other target countries 6 scenarios have been investigated for Spain as well. In addition to those a nuclear scenario was added to take into account possible new installations of nuclear power plants and the resulting technical minimum for RE integration for each scenario. The results show that up to the year 2020, the existing and planned energy storage facilities in Spain have adequate capacity. When taking a technical minimum into account because of nuclear power plants that cannot be switched off, the existing storage facilities are not sufficient. After the year 2020 the need for new energy storage installations will increase rapidly. As can be seen in Table 5, the additionally needed storage capacity in the 80% scenarios lies between 640 and 2240 GWh in the basic scenarios and between 4300 GWh and 6340 GWh in the nuclear scenarios. Energy storage needs are lowest in the PV scenarios.

Scenario 80% RE	Additionally needed power in GW		Additionally needed capacity in GWh
	Charging	Discharging	
Equal	35.3	36.5	2240
Wind	34.2	36.8	1290
PV	36.8	30.4	640
Nuclear scenarios			
Equal-n	45.3	33.6	6340
Wind-n	44.2	33.6	5000
PV-n	46.8	34.9	4300

Target Countries Action Lists

The energy storage requirements assessments in each of the target countries have been used as a basis in a wide consultation process with key actors, where it was discussed how the regulatory and market conditions affect the development of energy storage infrastructure. This resulted in a list of actions for every country, which can help to bridge the gap between the energy storage capacity and the future energy storage needs. The actions proposed vary between the countries but they follow a similar pattern. In this section are presented the type of actions that have been suggested and discussed with key decision makers in the six countries:

Giving a **regulatory status** to energy storage that clearly differentiates it from energy generators and energy users is a common issue. This would be the first step in clarifying all legal uncertainties that have been created by treating energy storage facilities as generators or as consumers depending on the mode they were operating. This "definition" of storage should not be given in a general manner as there are different technologies with different sizes, characteristics and applications in different parts of the value chain (generation, transmission, distribution, end-users). One possibility would be to identify specific applications or services that some technologies can provide and incorporate these new options in the regulation. Establishing a **stakeholder platform** that brings all energy storage actors together and maintains an open communication line with the decision makers can be useful for clarifying the regulatory issues but also providing input to all other actions discussed here. This would allow consensus building in controversial issues and widely acceptable solutions to be implemented.

In order to reduce public opposition to large energy storage projects, especially pumped hydro, campaigns for the **information of the public** about the role of bulk energy storage should be developed, while the local population should be involved at an early stage before the development of new projects.

Regarding the **economic feasibility of energy storage plants**, various possible actions are proposed like: Harmonise the European balancing energy markets in order to create new trans-border means of income for energy storage facilities. Investigate best practices in grid access fees for energy storage with the aim to exempt indefinitely the energy storage facilities from the obligation to pay grid fees. Develop innovative support mechanisms for energy storage facilities that help them to contribute in the power system infrastructure without distorting the energy market.

In terms of the role of **policy**, it has been recommended that renewable energy forecasts and comprehensive modelling tools will be used in order to define **national energy storage targets starting for 2025 and beyond**, which will provide certain security for the long term investments. Based on the results of the forecasts and models, also priority should be given to increasing the transmission capacity to neighbouring countries in order to more efficiently use the full potential of energy storage infrastructure.

Finally, there is room to improve the authorization of bulk energy storage projects. Development of a strategic environmental plan for large PHES units on a national level would be very useful. Central identification and classification of sites based on capital cost, environmental effects, grid or other constraints, and possible benefits to local communities would lead to reduced costs and reduced delays in the construction of new infrastructure.

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The logos of the partners cooperating in this project are shown above and more information about them and the project is available on www.store-project.eu