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ENTEC

Energy Transition Expertise Centre

Study on
Energy Storage

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Acronyms

AC	Active Consumers
ACER	Agency for the Cooperation of Energy Regulators
AEMO	Australian energy market operator
aFRR	Automatic frequency restoration reserve
AIB	Association of Issuing Bodies
BEV	Battery electric vehicle
BMBF	Federal Ministry of Education and Research
BTES	Borehole thermal energy storage
BTM	Behind the meter
C&I	Commercial and industrial
CAES	Compressed air energy storage
CAPEX	Capital expenditure
CEEAG	Guidelines on State Aid for Climate, Environmental Protection and Energy
CEER	Council of European Energy Regulators
CEF	Connecting Europe Facility
CERA	Cyprus Energy Regulatory Authority
CESA	Continental Europe Synchronous Area
CfD	Contracts for Difference
CHP	Combined heat and power
COP	Coefficient of performance
CSP	Concentrated solar power
DA	Day-ahead
DR	Demand-response
DSM	Demand-side management
DSO	Distribution System Operator
EASE	European Association for Storage of Energy
EEA	European Environment Agency
EECS	European Energy Certificate System
EFR	Enhanced Frequency Response
EGEC	European Geothermal Energy Council
ENTSO-E	European Network of Transmission System Operators for Electricity
ERAA	European resource adequacy assessment
ERCOT	Electric Reliability Council of Texas
ESGC	Energy Storage Global Conference
ESIF	European Structural and Investment Funds
ESIF	European Structural and Investment Funds
ETM	Electricity Target Model
EU	European Union

EV	Electric vehicle
FCR	Frequency Containment Reserve
FERC	US Federal Energy Regulation Commission
FFR	Fast Frequency Response
FRR	Frequency Restoration Reserve
FTM	Front of meter
GIE	Gas Infrastructure Europe
GO	Guarantee of Origin
HEMS	Home Energy Management Systems
HP	Heat Pump
IC	Information and Communication
ICT	Information and communication technology
ID	Intra-day
IGCC	International Grid Control Cooperation
INTER	International Thermonuclear Experimental Reactor
IRENA	International Renewable Energy Agency
ISEA	Institute for Power Electronics and Electrical Drives (German: Institut für Stromrichtertechnik und Elektrische Antriebe)
ISO	Independent system operator
ISP	Imbalance settlement period
IVPEE	Impuesto sobre el valor de la producción de la energía eléctrica
KPI	Key performance indicator
kWh	Kilo watt hours
LAES	Liquid air energy storage
LDES	Long-duration energy storage
LIB	Lithium-Ion Battery
LOLE	Loss of load expectation
MEC	Maximum Export Capacity
mFRR	manual Frequency Restoration Reserve
MIC	Maximum Import Capacity
MS	Member State
MWh	Mega watt hours
NDP	National Development Plan
NECPs	National Energy and Climate Plans
NER	Nordic Energy Research
NERC	North-American Electric Reliability Corporation
NRA	National Regulatory Agency
NRAA	National resource adequacy assessment
OPEX	Operational expenditure
PCI	Project of Common Interest
PEM	Polymer Electrolyte Membrane

PHS	Pumped hydro storage
POD	Power Oscillation Damping
PPA	Power Purchase Agreement
PPE	Programmation pluriannuelle de l'énergie
PV	Photovoltaics
RAA	Resource adequacy assessment
RAB	Regulated asset base
RE	Renewable Energy
RED	Renewable Energy Directive
REP	REPowerEU
RES	Renewable Energy Sources
RFB	Redox Flow Battery
RM	Ramping Margin
RoCoF	Rate of Change of Frequency
RR	Replacement Reserve
RTO	Regional Transmission Organisation
SCR	Storage Charge Record
SDR	Storage Discharge Record
SEM	Single Electricity Market
TCO	Total Cost of Ownership
TEN-E	Trans-European Networks for Energy
TERRE	Trans-European Replacement Reserves Exchange
TES	Thermal Energy Storage
TRL	Technology readiness level
TSO	Transmission System Operator
TTES	Tank Thermal Energy Storage
TWh	Terra watt hours
TYNDP	Ten-Year Network Development Plan
UPS	Uninterrupted power supply
UTES	Underground Thermal Energy Storages
V2G	Vehicle to grid
VAT	Value Added Tax
VPP	Virtual Power Plants

Executive Summary

Flexibility of energy supply and demand becomes increasingly important with increasing shares of intermittent renewable electricity generation. Energy storage is one of the candidates to provide the required flexibility to the electricity system. Against this background, the Energy Transition Expertise Centre was asked to deliver a study on energy storage to improve the understanding of energy storage technologies, their business case, and best practices for enabling the development of energy storage capacities.

Current situation and potential development of energy storage technologies until 2030

A large number of energy storage technologies are described in this report. They comprise mechanical, electrochemical, electrical, chemical and thermal energy storage technologies and are at different levels of development. The technical parameters and costs of these technologies are still expected to develop further until 2030, showing that there is still a lot of research and development in the field of energy storage.

The annual European energy storage market for stationary batteries in the electricity system has seen an increase in installed capacity from 0.6 GWh in 2015 to about 9.4 GWh in 2022. Between 2021 and 2022 the market has doubled. About 30% of the 2022 market was residential storage, roughly 2% were Commercial and Industrial (C&I) storage and about 70% front-of-meter installations. Many new projects are announced, already under construction or submitted. The projects are concentrated on four countries: Spain, Germany, Ireland and Greece. In Germany, the three largest chemical storage plants are announced with 100 / 50 MW each. However, pumped hydro storage (PHS) plants still have a much larger capacity at about 44 GW (power) and more than 200 GWh (energy). Further PHS plants are under development to provide large-scale flexibility to absorb growing intermittent renewable electricity production.

There exists also a wide variety of thermal energy storage (TES) technologies and applications, varying in temperature levels, possible sectors and technological maturity. TES forms therefore a diverse field present throughout the EU energy system, including (domestic) hot water tanks/installations, a growing front- and behind-the-meter electricity storage energy capacity reaching almost 14 GWh in 2022, almost 190 GWh of solar thermal-related TES in 2020, and 6.8 GWh of concentrated solar power-related TES.

The applications in which energy storage can play a role cover a wide range from bulk storage services to services supporting behind the meter customer energy management. Energy storage has seen a strong market growth in the last years and the market is expected to grow further at a high pace. Next to energy storage, other flexibility solutions are supply-side flexibilities, interconnectors and demand side management. Supply-side flexibilities, which will in the future be provided by renewable energy technologies, partly mean that renewable energy is not used to its full potential. Electricity storage on the other hand comes with a need for additional resources for the production of assets, and energy storage also implies losses. Interconnectors can reduce the demand for storage but have long permit and construction times. Demand side management can support the system and save costs for the user, but is also dependent on communication infrastructure and user needs. All flexibility options will be important to level supply and demand. Balancing and deploying them is one of the key challenges for the future energy system.

Market value of stored electricity and cost gaps

Power market arbitrage becomes profitable in 2021 and 2022, further cost reduction would substantially improve profitability. If we look only into arbitrage, cost gaps for storage technologies did exist in power markets before 2021, as price levels and price spreads have been too low for most storage technologies. The price developments since 2021 however show a strong increase of average electricity power market prices and price spreads, which make many storage technologies profitable in 2021 and 2022. Calculations with expected electricity price levels in 2030 still show cost gaps for storage technologies participating only in arbitrage, if today's technology costs are considered. High uncertainties are connected to future price level expectations, as expected price spreads most probably are falling to a lower level compared to 2021. Cost reduction due to further storage technology development would substantially improve profitability even with lower market prices and price spreads.

Ancillary service markets most beneficial today. Highest revenues can be realised on balancing markets. Earnings on frequency containment markets (FCR) reaches e.g. in Austria 76,000 Euro/MW in 2020 and 190,000 Euro/MW in 2021. Such earnings make battery storage investments beneficial, but overall market size and tendered volumes are limited. Other balancing markets as automatic and manual frequency restauration reserve (aFRR and mFRR) generate lower revenues, but could generate additional earnings from activated balancing energy. Trading strategies become more complex as participants must make estimates for balancing capacity and energy payments and bid accordingly.

Other storage applications are paid on a project basis. Storage technologies to support transmission/distribution infrastructure receive typically individual payments per project. The level of payments is similar to FCR payments, e.g. 26,000 Euro/MW per year in Australia. Storage operators stack revenues and combine different use cases and revenue streams.

Storage technologies contribute in capacity provision mechanisms and capacity markets or capacity auctions. In this case storage technologies typically receive a capacity payment for the provision of firm capacity. The clearing price for capacity provision in UK's capacity market for delivery in 2025 - 2026 was GBP 18 per kW and year (ca. 20,000 Euro/MW per year). Another revenue stream can be generated with reduction of peak capacity and related grid connection fees. Storage technologies are often combined with PV generation and benefit from reduced payments related to local grid fees and grid capacity prices.

Future revenue expectations for storage technologies. Overall, profitability of storage technologies is already present in some markets and for some applications, whereas for others, such as power market arbitrage only, profitability is limited. Some factors that could decrease the attractiveness of investments in storage technologies are potentially increasing interest rates (making CAPEX-intensive investments comparably less attractive) and disincentives stemming from the regulatory design (e.g., introducing net metering). In addition, other flexibility resources from the demand-side (e.g., load shifting of heat pumps or electric vehicles, potentially bidirectional charging of electric vehicles) complement and compete with storage technologies in some services.

Several important factors will increase the attractiveness of using energy storage as a flexibility option in the future: Firstly, technology costs for different storage options will decrease in the future. Secondly, technological improvements like longer lifetimes or an increased maximum number of cycles will make individual business cases more profitable and relevant for certain specific services. Thirdly, the phase-out of conventional flexibility options and simultaneously an increasing need for flexibility due to larger shares of renewables in all Member States are likely to lead to favourable market conditions for energy storage technologies. In addition, multi-use concepts such as combining peak shaving with a market-driven use of a storage, can ensure that investments in energy storage pay off, as savings from one use case and revenues from another are stacked.

Survey approach. As part of this study an online survey was conducted on behalf of the EnTEC consortium. The aim of this survey was to provide complementary input on:

- Current and future uses of energy storage;
- Current and future revenue streams for energy storage;
- Barriers, opportunities and drivers for energy storage.

Invitations to complete the survey were sent out by the European Association for Storage of Energy (EASE) to all of their members (including various associations) and the survey was shared with EGEC, GIE, Euroheat & Power and Solar Heat Europe. Overall, 93 respondents filled out the survey. They provide a good cover of technologies and locations; there are higher concentrations of respondents in particular countries, which may be a result of the survey dissemination method, but since these countries are also the locations where energy storage investors are most active, the sample is still representative of the current state of the energy storage community.

Current roles and revenues of energy storage. The results show that energy storage currently supplies a very wide range of services across all categories. Storage is already playing a role in a lot of different markets. In those markets already a wide range of business models for energy storage exist. These differ across technologies, projects and storage project portfolios. Although each technology group has a dominant income stream, revenue stacking is important, as most respondents indicate a number of revenue streams. Arbitrage is currently the dominant revenue stream overall, followed by the provision of ancillary services. Interestingly, services to transmission and distribution network operators are a relatively small component of reported revenues. Behind the meter storage services and revenue streams are relatively low compared to the other categories of products/services.

Future services and revenues of energy storage. Respondents are highly optimistic about the future business case and growth potential for energy storage. They do not expect their business models to change significantly towards 2030, but some outliers exist where respondents expect a shift in their dominant service provided and associated revenue. The results suggest that a more diverse business model with more value stacking is likely in the future for all technologies.

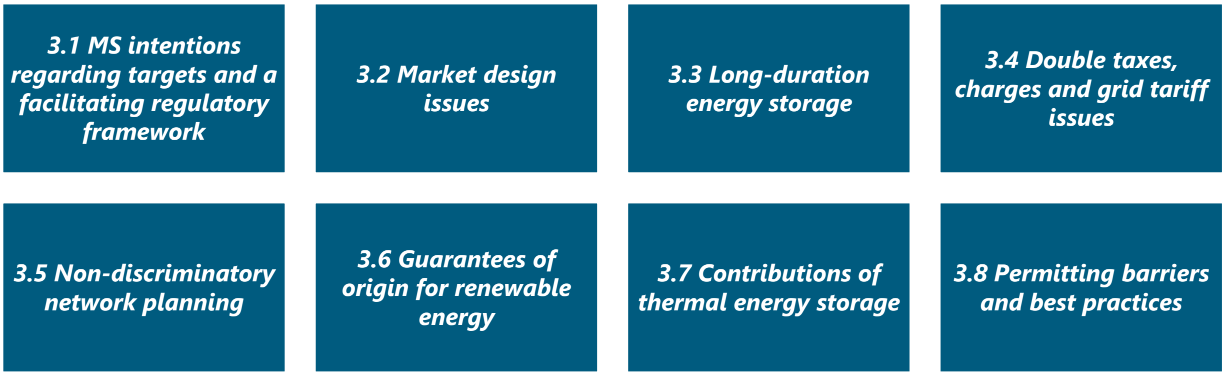
Perceived opportunities, barriers and desired actions. The perceived barriers that are ranked as most important by the respondents, are related to regulation and market access. This is followed by financial barriers and by the absence of long-term policy signals in general, the issue of double taxation and grid charging, and the lack of a regulatory framework for local flexibility markets. Technological barriers are considered least important by most respondents.

Most respondents indicate that fair access to technology-neutral competitive markets across the whole EU, including remuneration of energy system services that are currently not valued, would be the most desired way to support energy storage. There seems to be significant divergence between Member States in terms of market access and level playing field. No Member State is perceived to offer both perfect market access and sufficient policy guidance.

Policy and regulatory frameworks for energy storage

Chapter 4 complements the technology and market analyses of the study by focusing on selected policy and regulatory issues. The analysis is structured according to 8 different topics, shown in the figure below. The analysis has been developed based on literature review and interviews together with a validation round by Member State experts who were asked to check and update national fiches that summarised the situation in their country. The main findings for each topic analysed in chapter 4 are presented next, while the updated national fiches of the 2020 study on energy storage for the EU27 are presented in Annex 4.

Figure 1 Storage topics analysed in chapter 4



MS intentions regarding targets and a regulatory framework facilitating the deployment of storage

Several Member States have now a legislative definition of storage. National goals for energy storage can provide a positive environment for energy storage, and are effective if supported by financing and regulative programs. Goals for energy storage capacity to be installed have been announced by some Member States. Tenders for energy storage or renewables combined with energy storage are an effective means to support investments in energy storage, and have also been adopted so far by a handful of Member States.

Market design issues

Significant progress has been made in the removal of entry barriers for storage and other flexibility sources with the adoption and implementation so far of the Clean Energy Package. Some remaining national barriers to entry are related to the access to spot and balancing markets and should be further addressed with on-going measures. More progress is needed on other areas, such as on regulatory frameworks for the procurement of flexibility by DSOs, contracts for services procured by system operators to allow further value stacking by storage operators, and the representation of locational aspects and provision of locational information to market parties

The provision of 'conventional' non-frequency ancillary services such as voltage control and black start is often still not remunerated. The need for new ancillary services in the Continental Europe Synchronous Area and Nordics is currently small, and thus procurement is mainly limited to the Irish SEM and the Baltic countries. Nonetheless, the need for remunerating these new ancillary services should increase in all synchronous systems as the penetration of variable renewable energy sources grows.

Long-duration energy storage

Long-duration storage can be understood that long-duration storage should be able to discharge continuously for multiple hours (more than 4, or even 10) up to even weeks. For long-duration storage in the weekly to seasonal timeframe, technologies are either still in development or the potential left in the EU is limited/located in some MSs only. Policy discussions are strongly related to need for further development of long-duration energy storage technologies' technical performance and costs.

The needs for weekly and seasonal flexibility will increase in the future. Nevertheless, it is unclear how much new long-duration energy storage will be necessary in the future EU electricity system to meet long-term flexibility needs, given competition with other flexibility sources. Further research is needed on how much long-duration flexibility the increased renewable energy targets and reduced gas consumption could require, among which from storage. The justification for specific support schemes for large-scale long-duration energy storage deployment should be driven by flexibility needs.

Other issues for long-duration storage could be addressed. This includes increasing the liquidity and products in forward markets, improving capacity mechanism design, and the market for hybrid RES-storage.

Double taxes, charges and grid tariffs

Cases where taxes, surcharges and/or grid tariffs are imposed fully twice on electricity that is stored and fed back into the grid constitute a penalty for the business case of energy storage solutions. The issue affects many of the potential applications including arbitrage, all ancillary services and various services to support transmission and distribution infrastructure. A provision in a revised Energy Taxation Directive is being considered to address double taxation. Also, while it is too early to assess the transposition of the Clean Energy Package, recent progress in some Member States has been identified to ensure that grid tariffs are cost-reflective and non-discriminatory.

Non-discriminatory network planning

The role of storage assets should be properly reflected by network operators in their network planning, in order to evaluate correctly their potential to contribute to network development and system operation. Similarly, network operators should take fully into account the potential of storage when conducting the resource adequacy assessment.

The EU legislative framework for inclusion of storage in network planning is largely set in place, but there are some lags in implementation on national level, especially concerning the consideration of storage projects in national and distribution development plans. Moreover, the incentives for network operators to consider alternative measures to investing in new power lines (such as electricity storage) are used only scarcely in MSs.

When storage is considered, generally only large-scale storage assets are considered by network operators, in particular in the resource adequacy assessments – this means the potential contribution of storage is not fully analysed and it puts smaller storage assets in disadvantage.

Guarantees of origin for renewable energy

The current EU legislation for guarantees of origin (GOs) does not foresee a role for energy storage, since GOs can only be issued to producers of energy. There is only limited experience with GOs with a high temporal granularity and inclusion of storage. The current draft European GO standard foresees higher time granularity as an option, but there is no legal basis for (standalone) storage issuing GOs. However, the proprietary EnergyTag GO standard was developed with the aim of introducing granular GOs and also covers energy storage use cases. There could be a potential value in extending the GO system that could do a closer tracking renewable energy flows from production to consumption. This would include introducing GOs with a more detailed time granularity. Energy storage could then offer a "time shifting" service to allow conserving GOs in time. Although a potential value exists, the scope of demand for the GO "time shifting" service is not known and probably limited at the moment. Moreover, the cost of introducing such system is probably higher than the expected benefits, in particular due to the current low price of GOs.

Contributions of thermal energy storage

Thermal energy storage (TES) needs are expected to grow significantly in order to allow for the increased deployment of renewable energy. TES can contribute to the EU energy system in multiple ways, including facilitating the integration of renewable electricity and renewable thermal energy, moderating the need for increase in electricity generation capacity, and providing ancillary services to the electricity system. Through these contributions, TES can lead to significant investment savings, help replace fossil fuel use, especially gas and coal, increase the energy system flexibility and reduce greenhouse gas emissions throughout the EU27.

Recent best practices with TES in the EU and abroad are presented in this study.

Permitting barriers and best practices

Complex and lengthy permitting procedures are considered an important barrier for large-scale energy storage projects. The consulted experts indicated that streamlining and digitalisation of permitting procedures while setting clear time limits would be helpful in addressing the barrier. For pumped hydro storage, better knowledge and application of the ecological points system in the Water Framework Directive by regional authorities would be useful. Moreover, the adjustments to the Renewable Energy Directive to accelerate permitting for renewables that are proposed in the context of REPowerEU address the issues of permitting, in part also for storage projects.

1 Introduction

Flexibility of energy supply and demand becomes increasingly important with increasing shares of intermittent renewable electricity generation (i.e. solar PV and wind power). Energy storage is one of the candidates to provide flexibility to the electricity system, facilitating the integration of renewables, lowering electricity prices during peak times, facilitating the electrification of the economy and increasing the security of supply of the electricity system. Against this background, the Energy Transition Expertise Centre (ENTEC) was asked to deliver a study on energy storage to improve the understanding of energy storage technologies, their business case, and best practices for enabling the development of energy storage capacities. The study was delivered in the first semester of 2022.

The specific objectives of the study are to:

- Update the information on the costs and performance of the different storage technologies, their trends for the coming years and a comparison against other flexibility sources (covered in chapter 2);
- Assess the market opportunities for energy storage (covered in chapter 3). In particular:
    - the market value of energy storage in different MSs through their possible revenue streams (i.e. from the day-ahead and intraday markets, ancillary services markets, etc) and the approaches towards stacking revenues from different markets;
    - the existence and magnitude of cost gaps for energy storage technologies by comparing the expected revenues with the costs.
- Analyse the policy and regulatory issues for the development of energy storage (covered in chapter 4), focusing on the discussion and identification of best practices for a selection of topics, including:
    - Member State intentions (incl. targets) facilitating the deployment of storage;
    - Market design issues;
    - Barriers to long-duration energy storage;
    - Double taxes and charges;
    - Non-discriminatory network planning;
    - Guarantees of origin;
    - Contributions of thermal energy storage;
    - Permitting barriers and best practices.

The report is structured around these objectives (one chapter each). Additionally, several deliverables are made available as annexes that can be accessed online and can be used for further research and policy development.

2 Current situation and potential development until 2030

Energy storage, as defined by the EU in the Clean Energy Package, is a means of "deferring the final use of electricity to a moment later than when it was generated, or the conversion of electrical energy into a form of energy which can be stored, the storing of such energy, and the subsequent reconversion of such energy into electrical energy or use as another energy carrier"[1]. Energy storage is one of the key elements of the future flexibility system. In this chapter, the database of energy storage technologies delivered with this report will be described in detail in Section 2.1. It also includes information on EU energy storage facilities and analysis of both data sets. In Section 2.2, energy storage will be compared to other flexibility solutions such as supply-side flexibility, interconnections, and demand-side management.

2.1 Database of storage technologies

The information on energy storage technologies prepared in this task consists of several parts:

- A techno-economic dataset with detailed information on five groups of energy storage technologies regarding their technical and cost characteristics as well as the services these technologies can provide,
- Data analysis and use case descriptions for the identified energy storage technologies
- Global figures on energy storage for the EU
- A dataset of storage facilities in the EU, including operational, announced as well as de-commissioned projects of all storage technologies and
- Behind the meter data on electricity storage technologies per country.

The excel document delivered with this report contains a large set of techno-economic data, the facilities data base and behind the meter data. The content will be described together with the analysis of the data in the following. The link to the excel download can be found in Annex 2.1 Energy Storage Database.

2.1.1 Techno-economic dataset

The techno-economic data is provided in the excel document delivered with this report, in the sheet "Energy Storage Technologies". The five groups of energy storage are analysed in detail here: mechanical, electrochemical, electrical, chemical and thermal energy storage. These five groups are again subdivided into a total of 50 individual storage technologies (see excel document for details). For each of these technologies, technical, economic and other key performance indicators (KPIs) are described:

- **Level of maturity (technology readiness level, TRL)**. For the TRL, the definition by the Horizon 2020 2014-2015 Work Programme was used:
    - TRL 1 – basic principles observed
    - TRL 2 – technology concept formulated
    - TRL 3 – experimental proof of concept
    - TRL 4 – technology validated in lab
    - TRL 5 – technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)

[1] EU (2019) Directive 2019/944 of the EU parliament and the council on common rules for the internal market for electricity. Article 2, Paragraph (59)

    - TRL 6 – technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)
    - TRL 7 – system prototype demonstration in operational environment
    - TRL 8 – system complete and qualified
    - TRL 9 – actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)
- **Energy carrier in** and **Energy carrier out** describe the type of energy input and output of the technology.
- **Energy Capacity, Power installed capacity** and **Storage duration at full power** describe the size of the system regarding capacity, power and the ratio of both.
- **Round-trip efficiency (%)** refers to the efficiency of electricity output to electricity input, while the **Conversion efficiency (%)** is described for technologies which only convert electricity to another type of energy and not back to electricity (e.g. several chemical technologies).
- **Response time** is the time that the technology needs to provide its full power after standstill.
- The **Availability factor** is defined as the time that the technology is able to produce or store electricity throughout a certain time period. The availability factor describes if a technology needs much time for maintenance or not. A high availability factor is favorable, ideal would be an availability factor of 100.
- The **Lifetime (years)** is the time that the storage technology can operate without exchange of the major components. The lifetime in years may define the end of operation of a storage technology even though the maximum possible number of cycles is not reached yet.
- The **Number of cycles** defines how many full load cycles the system can be operated before the end of life is reached. This metric is commonly used for battery technologies, but can be used for other storage technologies as well. For batteries, the end of life is commonly defined as having left 80% of the original storage capacity.
- Regarding economic KPIs, first the **CAPEX (€/kW)** and the **CAPEX (€/kWh)** are described. For electrochemical technologies, the CAPEX is the total CAPEX of the system, once described per power and once per capacity. For all other technologies, the CAPEX is additional. That means that the power specific CAPEX needs to be added to the capacity specific CAPEX to get the total system CAPEX. The CAPEX values are described as ranges. These ranges are due to several cost differences for the systems: Larger storage systems have lower specific cost, smaller systems have higher specific cost. Also, storage cost may differ in different countries of the EU, e.g., labour intensive technologies may have higher cost in countries with higher labour cost. In addition, cost may vary due to geological differences (as for pumped hydro storage) or different types of storage within one technology (such as tank storage or underground storage for hydrogen).
- The **Typical CAPEX (€/kW)** and **Typical CAPEX (€/kWh)** are meant to provide a mean or average value for a certain technology. In many cases it is not easy to define this value as it depends e.g. on the size of the system.
- The **OPEX (€/kW / €/kWh / % of CAPEX)** describes the per power or per electricity stored or annual cost of the technology. This typically includes operation and maintenance such as labour cost, exchange of components and fuels.
- **Critical raw materials** used for each technology were listed. The definition of critical raw materials is used as defined by the European Commission[2].

[2] European Commission (2020) Critical Raw Materials Resilience: Charting a Path towards greater Security and Sustainability. https://ec.europa.eu/transparency/documents-register/detail?ref=COM(2020)474&lang=en. p. 3

- Regarding the use, it was distinguished between **front of meter (FTM)** and **Behind the meter (BTM)** storage. Some technologies may be used for both applications.
- The storage services as described by EASE[3] were listed in the data sheet and for each technology it was indicated whether the service can be provided by this technology (marked with an *X*) or not, or if the technology could provide parts of the described service, it was marked with an *(X)*.
- At the end of the excel table, **major technological issues** of each technology are indicated, such as maturity of the technology or geographical constraints.

Excurse: Total Cost of Ownership – TCO

In this work, the basic cost components of energy storage technologies are described. For investment decisions, methods for profitability analyses are necessary. A distinction can be made between static and dynamic methods. Static methods are used when small investment amounts or investments with a short useful life are involved. Static means that the timing of cash flows is not accounted for in the profitability analysis. Costs and revenues are either considered for one year or average values are calculated for the entire period. This makes calculation simple and gives quick results. Static methods include comparative cost accounting, comparative profit accounting, comparative profitability accounting and static amortisation accounting.

When making investment decisions, companies often use the "total cost of ownership (TCO)" as part of the comparative cost comparison to support the decision. The TCO refers to the lifetime cost associated with an asset. This means that the total cost of an asset is summed up over the lifetime of the asset. The TCO may comprise:

- Initial investment (CAPEX) including the main system, balance of system, cost, of land use, financing cost etc.
- Cost of installation
- Cost of operation, e.g., fuel cost, cost of labour
- Cost of maintenance, e.g., technical checks
- Component replacement cost, e.g., battery replacement or engine refurbishment
- Cost of disposal / savings by residual value of asset after time of use

Companies may apply more or less detail in the analysis, e.g., cost of disposal or residual value are often not applied or irrelevant for certain assets. The TCO may differ extensively depending on the location, type of investor and other project-specific factors. The TCO can be used as a static or a dynamic method.

The advantage of the TCO analysis is that it is a simple and easily understandable way to compare different solutions. It is more comprehensive than only looking at the investment cost, as also costs during operation are considered, and can therefore give more insights into the profitability of an energy storage technology. The TCO can be used to compare different storage options in the same application. A TCO is necessary for investment decisions, as all costs need to be taken into account. Also, the dynamic method should then be considered to account for changing prices and the time value of money. To evaluate the profitability of a concrete project, the revenues also need to be taken into account, i.e., the TCO needs to be complemented with an analysis of the market and achievable revenues.

3 EASE (2022) https://ease-storage.eu/energy-storage/applications/

2.1.2 Data analysis

2.1.2.1 High level grouping of energy storage technologies

For the simulation of energy storage technologies with the EC's tool METIS[4], a high-level grouping of the energy storage technologies was requested, reducing the amount of detail of the techno-economic dataset. For this purpose, Table 2 shows a condensed version of energy storage technologies and their key indicators.

Only technologies which are expected to be significant, i.e. adopted on a TWh-scale, up to 2050 are included. The focus is on electricity storage; thermal storage is not regarded. Very short-term storage (e.g. flywheels) is not included as this time scale is not modelled in METIS. For home-storage systems and electromobility, the potential can be used to mandatory include these technologies in the model. Short-term is defined as duration of hours to a few days, medium-term as a few days to a week, and long-term as a few weeks to months.

CAPEX, OPEX, efficiency and lifetime are defined as in Section 2.1.1. The loss rate is given in % loss per day or per month, depending on the technology. Potential is defined as the economic potential for each technology. More detailed data can be found in the excel documentation delivered with this report.

Table 1 High level grouping of energy storage technologies with data of end 2021

	CAPEX [€/kW]	CAPEX [€/kWh]	OPEX [% of CAPEX]	round trip efficiency [%]
long-term storage, large scale (hydrogen)	2979	10	30 €/MWh	30
medium-term storage, large scale (PHS)	1880	470	28 €/kW-year	80
short-term storage, large scale (LIB)	1350	345	0.5-1	88-95
short-term/long-term storage, large scale (Lead-acid batteries)	1000	400	1-2.5	85
Short-/medium-term storage, large scale (Redox-flow batteries)	1500	400	1	70
short-term storage, large scale (Sodium-based batteries)	595	675	1.5	85
PV-home storage systems (LIB)	1200	1000	1-2	88
Electromobility (LIB)	75 pack cost,	160 pack cost,	2	90

Source: data collected by Fraunhofer ISE

[4] European Commission (2022) METIS. https://energy.ec.europa.eu/data-and-analysis/energy-modelling/metis_en

Table 2 High level grouping of energy storage technologies with data of end 2021

	loss rate [% loss per day or per month]	lifetime [years]	lifetime [cycles]	potential up to 2050 [TWh]
Long-term storage, large scale (hydrogen)	negligible	25[5]	n.a.	130 TWh[6]
Medium-term storage, large scale (PHS)	0.005-0.02% p.d.[7]	40	14,000	4 TWh[8]
Short-term storage, large scale (LIB)	1% p.m.	15	3000	min: 1.9 TWh max: 5.3 TWh[9]
Short-term storage, large scale (Lead-acid batteries)	0.1-0.4% p.d.	10	1500	10-100 GWh[10]
Short-/medium-term storage, large scale (Redox-flow batteries)	0.4% p.a.	20	7000	will be a share of the ESS LIB market
Short-term / medium-term storage, large scale (Sodium-based batteries)	0.34% p.a.	15	4500	will be a share of the ESS LIB market
PV-home storage systems (LIB)	1% p.m.	15	3000	included in short-term storage LIB potential
Electromobility (LIB)	1% p.m.	8-15	3000	min: 27.3 TWh max: 39.7 TWh[11]

Source: data collected by Fraunhofer ISE

5 Kharel, Subodh; Shabani, Bahman (2018) Hydrogen as a Long-Term Large-Scale Energy Storage Solution to Support Renewables. Energies 2018, 11(10), 2825.

6 Fuel Cells and Hydrogen Joint Undertaking (2019), Hydrogen Roadmap Europe. A Sustainable Pathway for the European Energy Transition. p. 22. Source states 140 TWh for Europe – 90% is assumed to be on EU-grounds

7 Fuchs, Georg; Lunz, Benedikt; Leuthold, Matthias; Sauer, Dirk Uwe (2015) Chapter 7 - Overview of Nonelectrochemical Storage Technologies. In: Electrochemical Energy Storage for Renewable Sources and Grid Balancing, 2015; Pages 89-102

8 Gimeno-Gutiérrez, Marcos; Lacal-Arántegui, Roberto (2015) Assessment of the European potential for pumped hydropower energy storage based on two existing reservoirs. Renewable Energy Volume 75, March 2015, Pages 856-868

9 Fraunhofer ISI, Internal database + forecast model, status May 2022. *Potential = Cumulated annual LIB demand from 2010-2030 (2010-2050

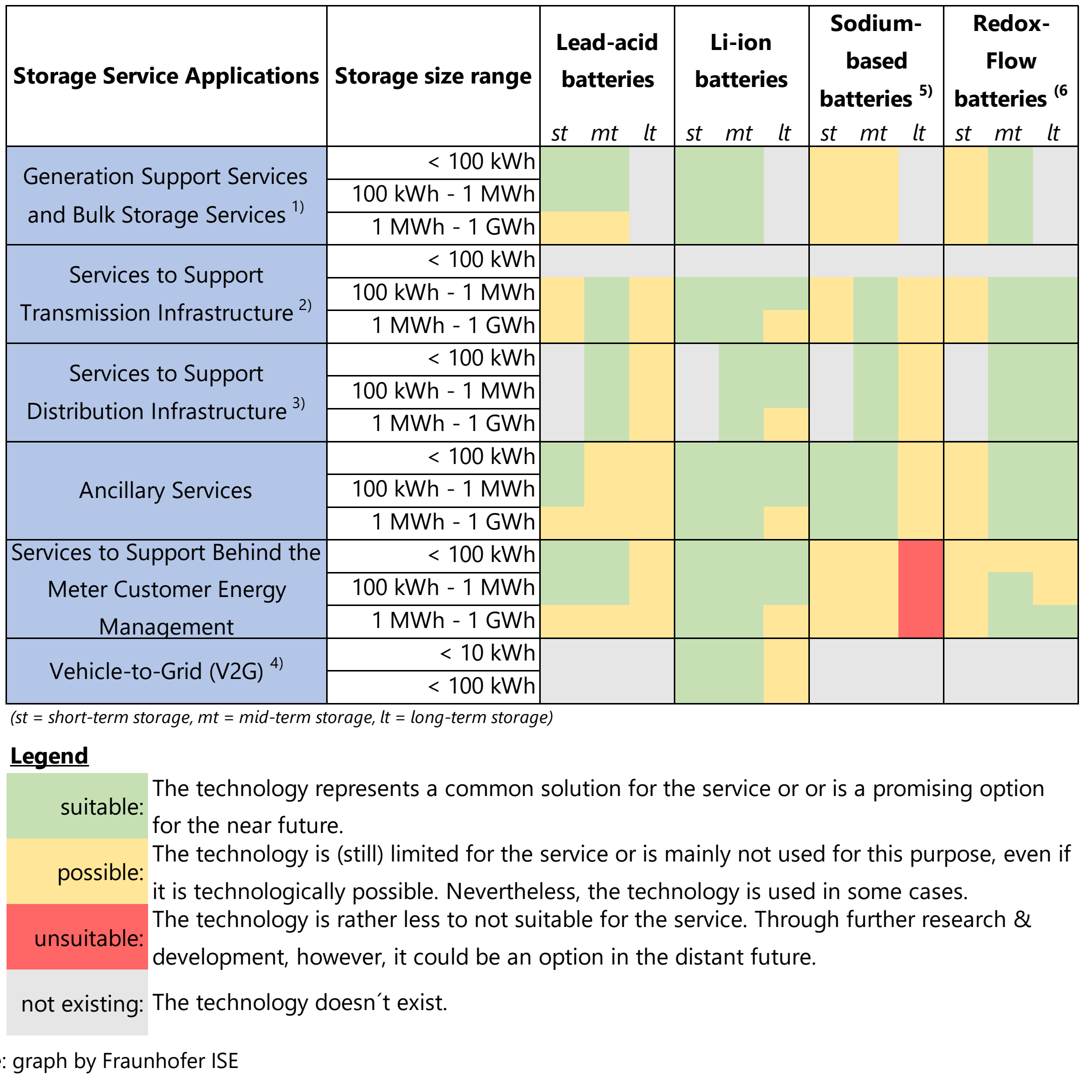
10 Assumption by Fraunhofer ISI

11 Fuchs, Georg; Lunz, Benedikt; Leuthold, Matthias; Sauer, Dirk Uwe (2015), Chapter 7 - Overview of Nonelectrochemical Storage Technologies. In: Electrochemical Energy Storage for Renewable Sources and Grid Balancing, 2015; Pages 89-102

2.1.2.2 Batteries

In addition to the *high-level grouping*, a grouping of battery technologies in relation to storage services was prepared. The in-depth assessment is integrated into the use case matrix excel file as a worksheet and shown in Figure 2 The table illustrates which battery technology is suitable for the respective storage service application according to EASE classification. For this purpose, the energy storage duration from a short- (st) to long-term (lt) perspective for relevant battery technologies was set in relation to different storage size ranges. It can be seen that the **Li-Ion battery** is primarily suitable for short -term storage. In the case of the **lead-acid battery**, UPS and telecommunication were not taken into account (as these are auxiliary systems for emergency power), and can therefore be allocated to short- to medium-term storage services with a storage size range up to 1 MWh. The **sodium-based batteries**, operating at high temperature, are mainly suitable for medium-term storage services. If the technology develops further towards operation at room temperature, long-term storage tasks will also become attractive for the technology. **Redox flow batteries** are particularly suitable for large-scale systems that want to store energy in the medium to long term duration. Small-scale short-term storage is technologically possible, but not economically competitive with Li-ion batteries.

Figure 2 In-depth assessment of battery technologies for storage service applications

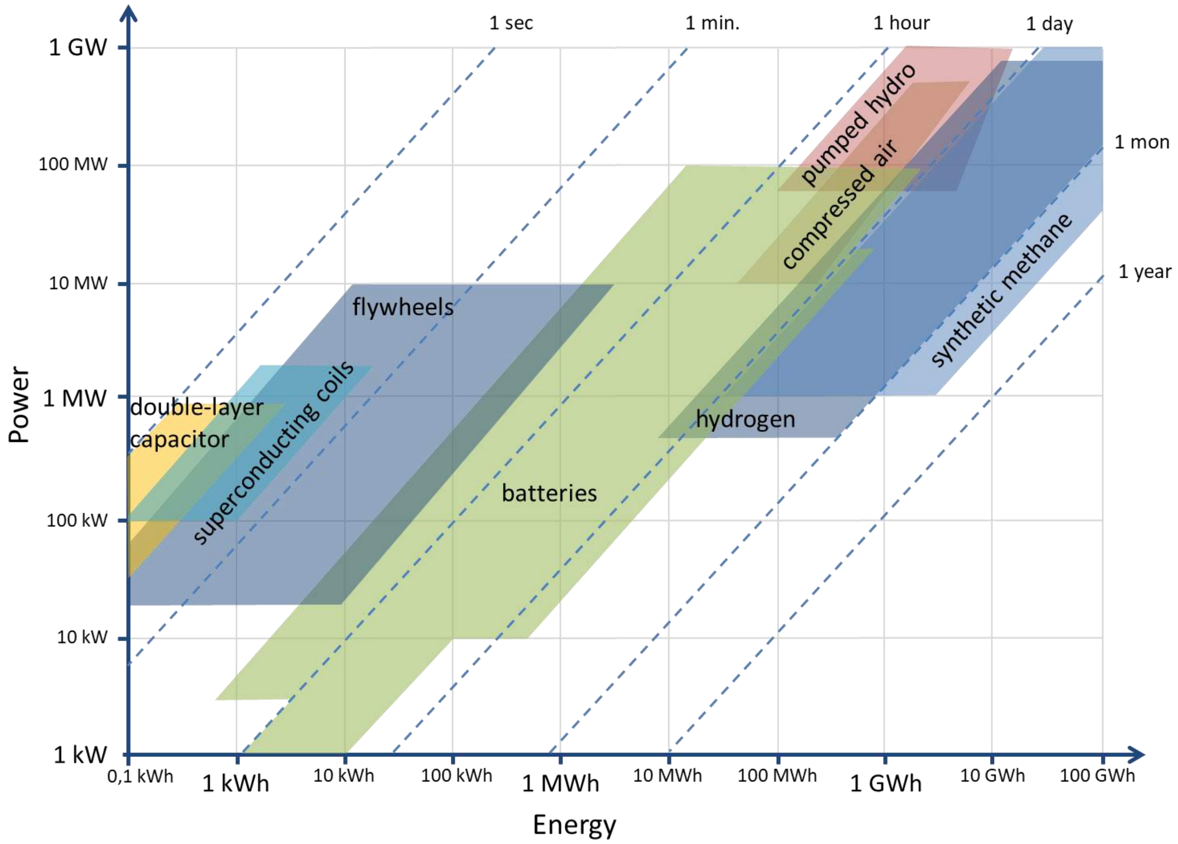


Source: graph by Fraunhofer ISE

2.1.2.3 Power and energy ranges of different storage technologies

Figure 3 shows the energy and power ranges of different storage technologies. Technologies with high power and smaller capacity can be considered short-term storages such as capacitors, flywheels and to some extent batteries. Batteries can also range in the higher power and higher capacity area to compete with pumped hydro and compressed air. Hydrogen and synthetic methane can be considered long-term energy storage technologies with high energy capacities.

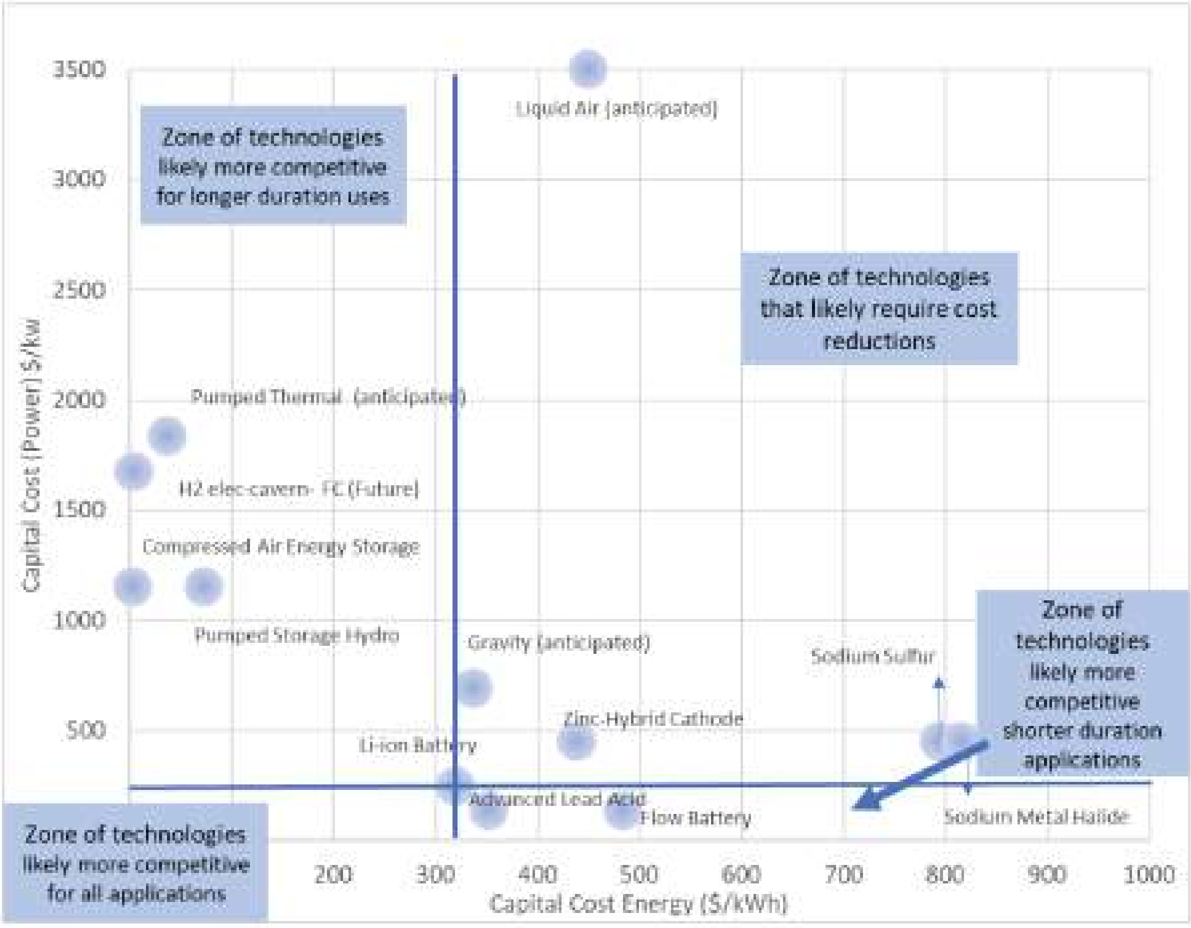
Figure 3 Power and energy ranges of different storage technologies



2.1.2.4 Long-term and short-term energy storage technologies

Figure 4 shows the capital cost of power and cost of energy for different storage technologies. The graph shows that the cost of each technology can give an indication of the competitiveness of the technology in a certain application, e.g. longer duration use and shorter duration use. If a technology has a high cost per unit of power but a low cost per unit of energy, it is more likely to be competitive in long-term energy storage applications. Pumped hydro, Compressed Air Energy Storage, Pumped Thermal Energy storage and Compressed Hydrogen Storage fall into this category. Technologies which have a low cost of energy but higher cost per power are more likely to be competitive for short-term energy storage. Advanced lead acid batteries, flow batteries and Sodium fall into this category. Lithium Ion Batteries with relatively low cost for energy and power may fall into both of these categories in some applications, depending on the future cost development. Technologies with higher cost for power and energy will need to reduce cost to be able to be competitive in either of the two applications.

Figure 4 Capital cost of power and energy for different technologies[12]

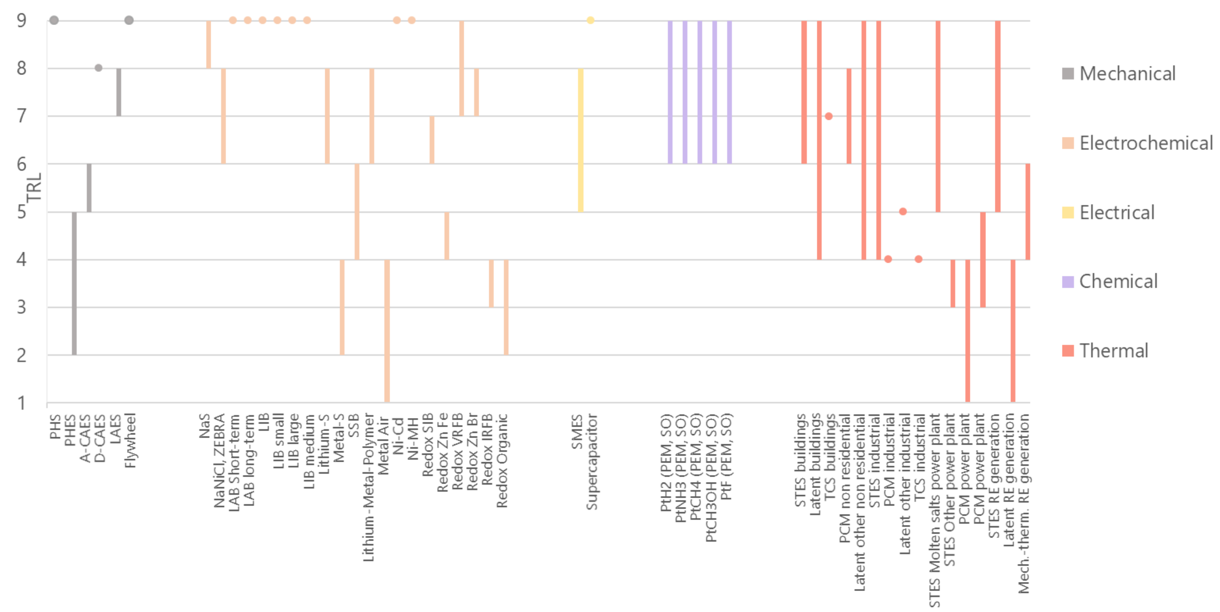


12 NREL (2022) Storage Futures Study - Key Learnings for the Coming Decades, p. 6

2.1.2.5 Technology readiness level

Figure 5 shows the TRL of the analysed energy storage technologies, grouped by technology type. It can be seen that in every type of technology, there are sub-technologies which reach a TRL of 9, a system proven in operational environment. Also in every group, there is still research and development of new technologies. Further development is therefore to be expected.

Figure 5 TRL of energy storage technologies



Source: graph by Fraunhofer ISE

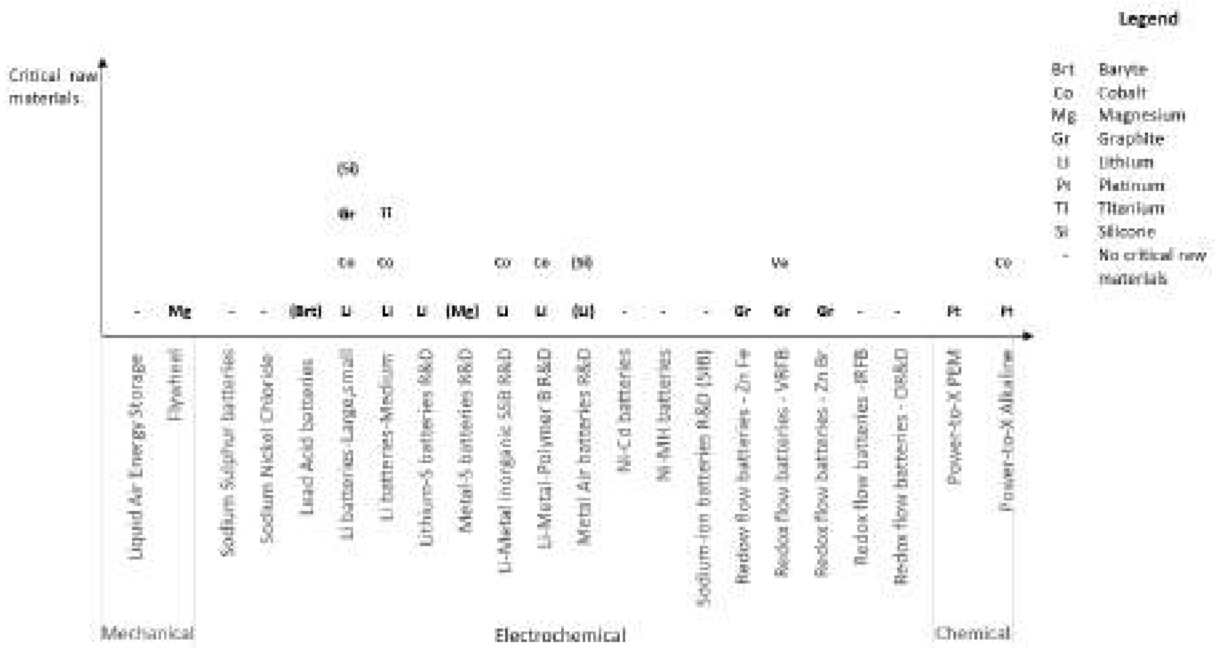
Abbreviations: Pumped Hydro Storage (PHS), Pumped Heat Electrical Storage (PHES), Adiabatic Compressed Air Energy Storage (A-CAES), Diabatic Compressed Air Energy Storage (D-CAES), Liquid Air Energy Storage (LAES), Sodium Sulphur batteries (NaS) Sodium Nickel Chloride batteries (NaNiCl, ZEBRA), Lead Acid batteries (LAB), Lithium-ion batteries (LIB), Lithium-Metal inorganic (SSB), Sodium-ion (SIB), Redox flow - Vanadium (VRFB), Redox flow - Iron (IRFB), Superconducting Magnetic Energy Storage (SMES), Power to Hydrogen with polymer electrolyte membrane electrolysis or solid oxide electrolysis (PtH2 (PEMFC, SOFC)), Power to Ammonia with polymer electrolyte membrane electrolysis or solid oxide electrolysis (PtNH3 (PEM, SO)), Power to Methane with polymer electrolyte membrane electrolysis or solid oxide electrolysis (PtCH4 (PEM, SO)), Power to Methanol with polymer electrolyte membrane electrolysis or solid oxide electrolysis (PtCH3OH (PEM, SO)), Power to Methanol to Gasoline with polymer electrolyte membrane electrolysis or solid oxide electrolysis (PtF (PEM, SO)), Sensible Thermal Energy Storage (STES), Thermo Chemical Storage (TCS), Phase Change Material (PCM)

2.1.2.6 Dependency on critical raw materials

Figure 6 shows the need for critical raw materials as defined by the European Commission[13] for different energy storage technologies. For electrical and thermal energy storage, no critical raw materials are needed. Mainly electrochemical technologies depend on critical raw materials, even though there are some technologies such as sodium sulphur batteries, sodium nickel chloride batteries and other, which do not depend on critical raw materials. Lithium Ion batteries have the largest need for critical raw materials. Regarding chemical energy storage, the need for critical raw materials is by the electrolyser, in the graph the materials for Alkaline and PEM electrolysis are given.

[13] European Commission (2020) Critical Raw Materials Resilience: Charting a Path towards greater Security and Sustainability. https://ec.europa.eu/transparency/documents-register/detail?ref=COM(2020)474&lang=en. p. 3

Figure 6 Need for critical raw materials by technology (graph by Fraunhofer ISE)



2.1.3 Use cases for energy storage

In this section use cases for energy storage will be described. Use cases are defined as the combination of selected technologies, the potential services where they could be used and the different actors which can offer the service. Thus, one technology can be used in different services, or in one service but by different actors.

Table 3 gives an overview on the analysed services, taken from the EASE characterisation of storage applications[14], and the minimum technical characteristics which a technology needs to have in order to provide a certain service. Some requirements exclude some technologies from the participation in a certain service, such as the fact that services to support distribution infrastructure require a storage duration of one or more hours, excluding e.g. flywheels from that service.

Table 3 Key technical characteristics for services provided by energy storage technologies

Service	Minimum technical requirements
Generation Support Services and Bulk Storage Services	storage duration of minutes to several hours
Services to Support Transmission Infrastructure	ramp-up within milliseconds or minutes
Services to Support Distribution Infrastructure	storage duration of one or more hours
Ancillary Services	no special requirements
Services to Support Behind the Meter Customer Energy Management	power installed capacity starting from 100 kW

Source: (EASE, 2022)

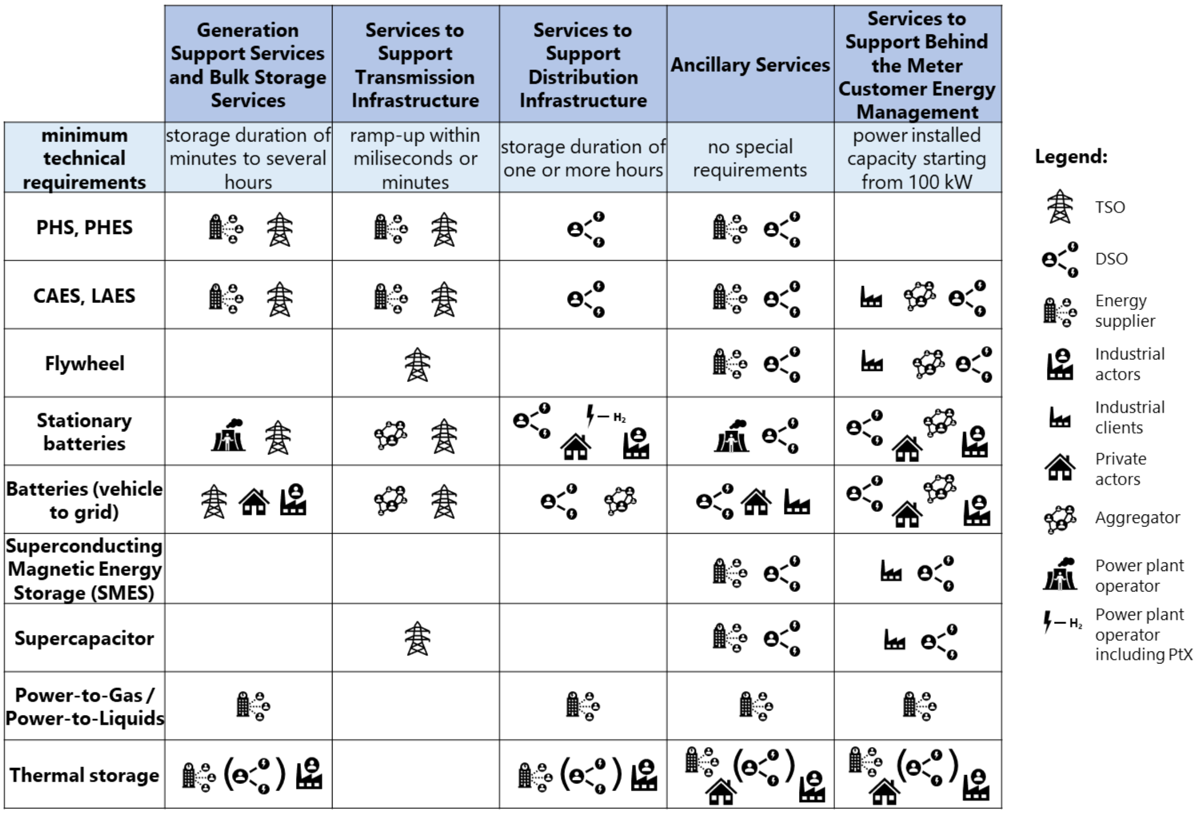
[14] EASE (2021) European Energy Storage Market Report. https://ease-storage.eu/publication/emmes-5-0-march-2021/

Figure 7 shows the matrix of use cases. This matrix gives an overview on the use cases and possible actors. For more detail on the services each technology can provide, please refer to the techno-economic information described in Section 2.1.

Actors are described with a focus on those providing the service. Actors profiting from the services, such as e.g., energy producers, Transmission System Operators (TSOs), industry and prosumers, do so independent from the type of storage providing the services, therefore they are not included in the analysis.

In general, most technologies can provide most services. Actors offering these services are mainly bound to the service; for example, services to support behind the meter customer energy management are more likely provided by industrial clients, aggregators and Distribution System Operators (DSOs), independent from the type of technology which can provide the service. On the other hand, energy suppliers and TSOs are more present in the services to support transmission infrastructure and DSOs more present in the services to support distribution infrastructure.

Figure 7 Use cases and actors for high-level grouping of storage technologies



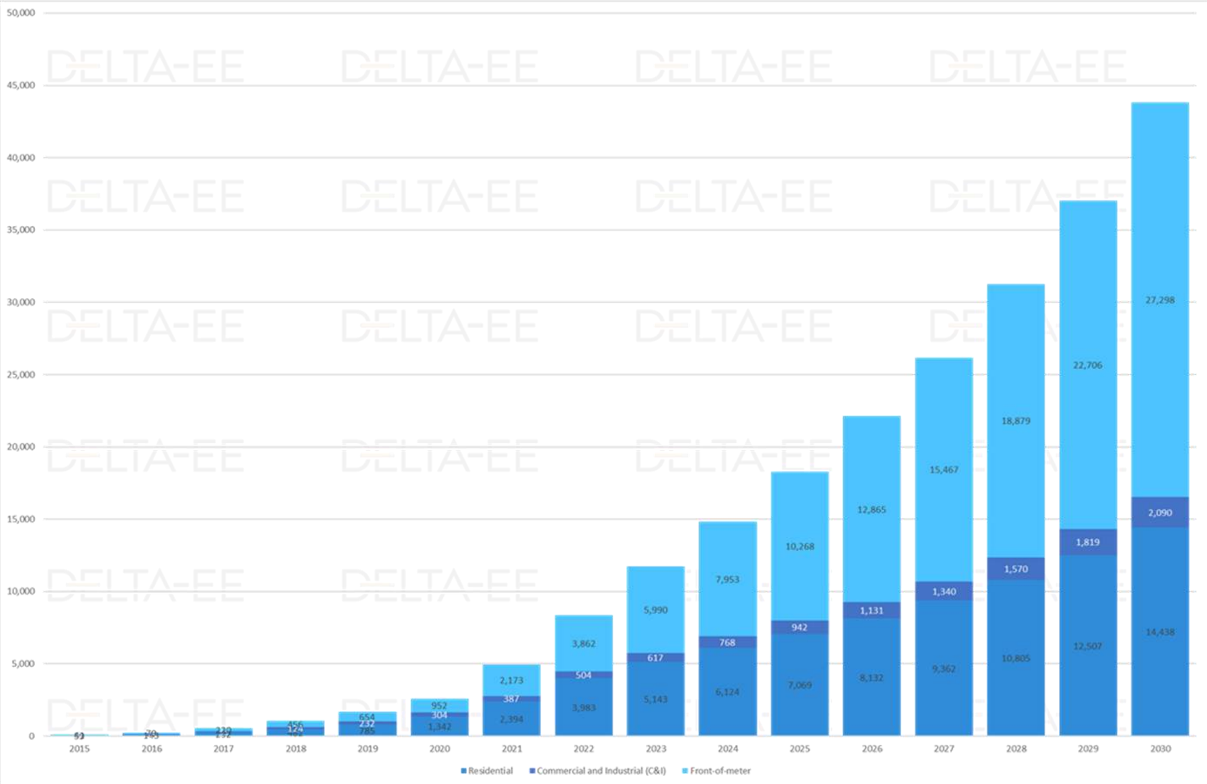
Source: graph by Fraunhofer ISE

2.1.4 Global figures (Europe)

Electricity storage

The annual European energy storage market has seen an increase in installed capacity from 0.6 GWh in 2015 to about 9.4 GWh in 2022. The EU countries encompass roughly 80% of this market. Between 2021 and 2022 the market has doubled. About 30% of the 2022 market was residential storage, roughly 2% were Commercial and Industrial (C&I) storage and about 70% front-of-meter installations. The European Energy Storage Market Report by EASE provides EU data on the development of energy storage technologies in the EU countries. Therefore, this report does not focus on this topic in much detail.[15] In year 2021, about 3 GW of new battery storage was installed and in 2022 it is expected to reach about 5 GW (see also Figure 8). Additionally, there is about 40 to 44 GW of installed pump hydro power installed in Europe. Also thermal energy storage, mainly molten salt storage in concentrated solar power plants (CSP) in Spain, contributes with a capacity of about 6.8 TWh to the electricity system in Europe.[16]

Figure 8 Annual European energy storage market forecast (MWh)[17]



Source: 6th edition of the EASE/Delta-EE European Market Monitor on Energy Storage (EMMES), updated for 2022

Thermal energy storage

Summary overviews and outlooks on the limited data available for thermal energy storage have been published, notably by IEA ECES in 2018[18] and IRENA in 2020[19]. Central differentiation of thermal storage is the technical dimension into: Sensible heat storage, latent heat storage, thermochemical heat storage.

Regardless of this, no valid data on overall installed thermal energy storage systems in the EU area could be collected during the analysis. Taking district heating applications as an example, this could

15 EASE (2021) *European Energy Storage Market Report*. https://ease-storage.eu/publication/emmes-5-0-march-2021/

16 IRENA (2020), Innovation Outlook: Thermal Energy Storage.

17 EASE (2021) *European Energy Storage Market Report*. https://ease-storage.eu/publication/emmes-5-0-march-2021/

18 IEA-ECES (2018), Applications of Thermal Energy Storage in the Energy Transition – Benchmarks and Developments

19 IRENA (2020), Innovation Outlook: Thermal Energy Storage.

be due to the locally organised and little regulated heating market. In this area, thermal energy storage systems are not subject to mandatory registration and therefore do not have to be reported to any authority or other organisation. As a consequence, little valid data is available and no concrete statement, e.g. on the market situation, can be made within the scope of the study. Conclusions for further developments can only be drawn to a limited extent from existing data on thermal storage products sold[20], without knowing the concrete need in various sectors. In view of the need for further research on thermal energy storage systems, the collection of this data could be the focus of a EU-wide study.

Although data is scarce, it is clear that storage capacities involved are huge. Just looking at solar thermal-related TES, Europe had 189 GWh stock in 2020 in Europe according to Solar Heat Europe (+/-10 millions of 200-300l storage)[21]. This is followed by quick increase in deployment of heat pumps coupled with storage. The biggest TES stock is still related to e-boilers: there are tens of millions of storage of at least 100l each in France, given nuclear electricity legacy. And the use of e-boilers is by far not limited to France. This all is supplemented by district heating and industry-scale storages, which should at least to some extent be reflected in the Thermal energy storage map referred to in the Celsius project. In the electricity sector, the EU has at least 6.8 GWh of thermal storage related to CSP plants in Spain and the used molten salt technology is being gradually adjusted for the wider needs of RES-E storage (also PV and wind).[22]

Electric boilers, together with thermal storage, start being used to integrate excess renewable electricity, e.g. in Germany.

Some publications include global figures on thermal energy storage. In part, these are based on estimates and do not cover an important segment: domestic hot water tanks. For example, in an IRENA study from 2020[23], current global TES storage capacities for heating applications are assumed as follows:

- Buildings (excluding domestic hot water tanks) = 91 GWh
- District heating = 105 GWh
- Industry = 2 GWh

In addition, storage capacity for space cooling is assumed to increase from 14 GWh in 2030 to 26 GWh in 2030.

According to the study, the required storage capacities for Molten Salt's storage for the power sector will increase from 21 GWh to 491-631 GWh in the same period in order to meet the amount of storage capacity IRENA assumes to be able to comply with the Paris Agreement.

Based on a data collection of publicly available projects, the IRENA study assumes over 234 GWh of thermal energy storage across the globe in 2019 (not counting domestic hot water tanks). For IRENA's Paris Agreement-aligned Transforming Energy Scenario, an increase to 800 GWh is required by 2030.

[20] Grand View Research (2020), Thermal Energy Storage Market Size, Share & Trends Analysis Report, https://www.grandviewresearch.com/industry-analysis/thermal-energy-storage-market

[21] Solar Heat Europe (2021), Thermal Energy Storage: A game changer for heat decarbonisation.

[22] IRENA (2020), Innovation Outlook: Thermal Energy Storage.

[23] IRENA (2020), Innovation Outlook: Thermal Energy Storage.

At the Energy Storage Global Conference (ESGC) organised by EASE, Solar Heat Europe made a presentation[24] in which a conservative estimate of the domestic solar heat systems with TES units installed in Europe was summarised to a total storage capacity of over 180 GWh in 2020.

In view of the decarbonisation of the energy system, underground thermal energy storages (UTES) in connection with district heating could play a special role, especially against the background of flexibilisation.

A potential long-term scenario described by Victoria et al[25], a total storage capacity of 224 TWh is derived for large-scale thermal storages in the European area in a long-term. This concerns in particular the member states where district heating plays a key role. The assumptions include an increasing supply of renewable energy and assume an increase from 602 TWh/year to 1096 TWh/year in an ambitious scenario in which 50% of the heat demand is to be covered by district heating by 2050.[26]

While hot-water based technologies are broadly used, they don’t and can’t satisfy all needs for TES, especially the need for compact long-term storage as well as high temperature storage needs for industry and power sector. Conventional solar thermal and heat pump systems coupled to water tanks have high land/space footprint. Therefore, research should continue on TES, as recently highlighted by IRENA and EU’s Renewable heating and cooling platform.

2.1.5 Facilities data

The “facilities data” sheet in the corresponding excel document to this text (see Annex 2.1 Energy Storage Database) contains a non-exclusive list of current electricity storage facilities in the EU countries (data for Latvia and Malta missing). The former list was updated by using the DOE Global Energy Storage Database[27] and checking for updates to the old version. 179 datasets were added or updated.

Figure 9 shows the distribution of technologies in the collected data set. Mechanical storage systems make up the main share of installed power, energy capacity and number of projects. As mechanical storage systems often have large power and energy capacity, the share in the number of projects is lower; here large numbers of electrochemical projects can be seen. Among the other technologies, electrochemical and thermal energy storage systems make up large shares. Also hybrid projects make up a large share.

However, it is to be noted that the data set is not complete. In some cases, only the installed power is named but no energy capacity, in other cases only the energy capacity is named while the installed power is lacking. This may lead to distortions in the results shown.

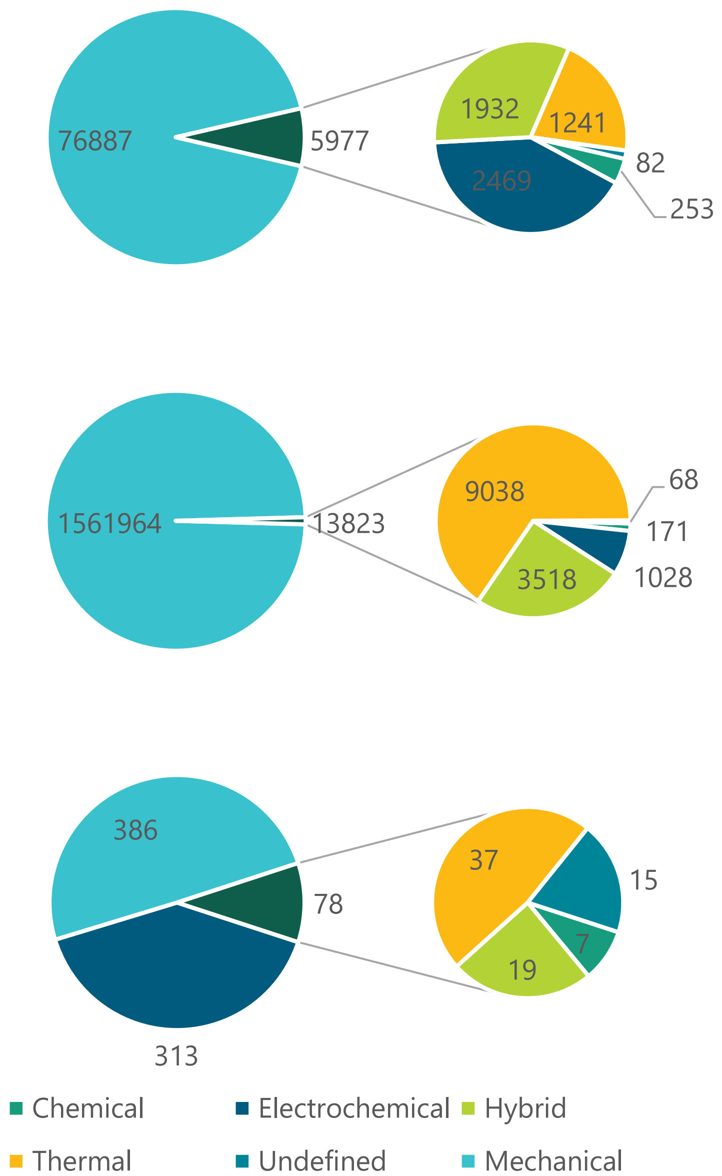
[24] Solar Heat Europe (2021), Thermal Energy Storage: A game changer for heat decarbonisation.

[25] Victoria et al. (2019), The role of storage technologies throughout the sector-coupled European energy system.

[26] Heatstore (2021), Roadmap for flexible energy systems with underground thermal energy storage towards 2050.

[27] DOE (2022) Global Energy Storage Database. https://sandia.gov/ess-ssl/gesdb/public/

Figure 9 **Distribution of a) power [MW], b) energy capacity [MWh] and c) number of projects by storage technology [-]**



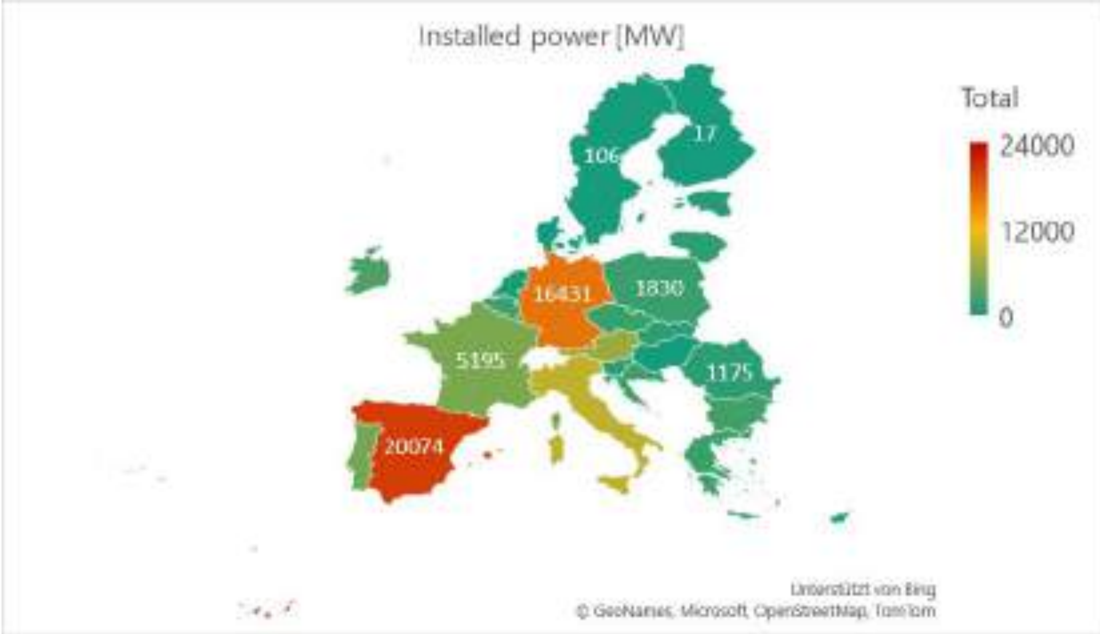
a)

b)

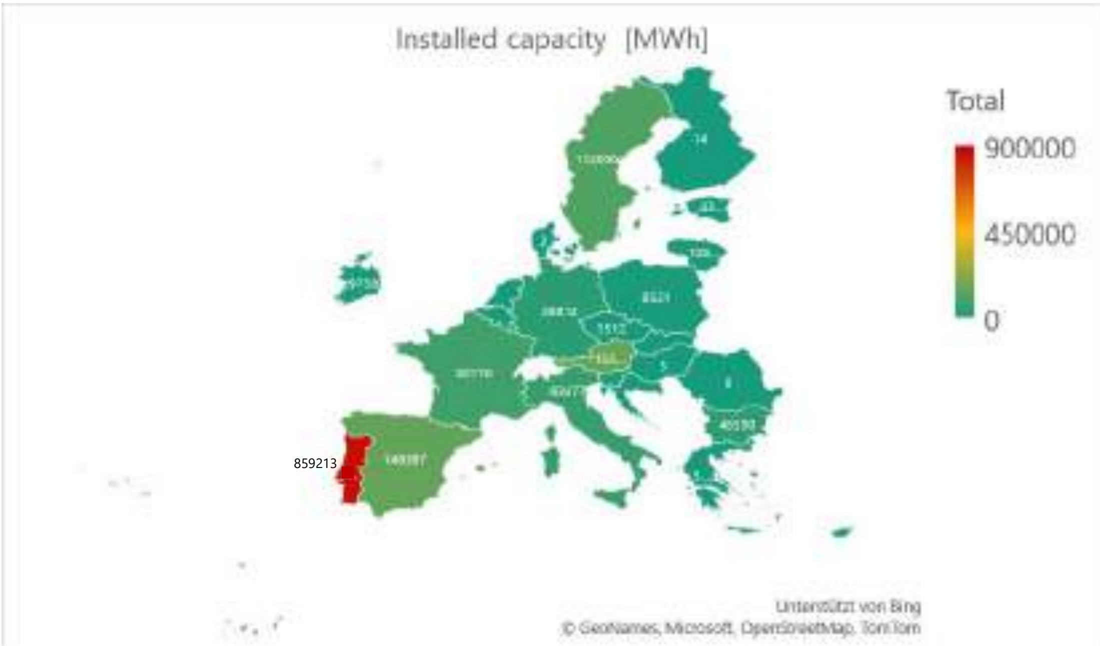
c)

Figure 10 shows the distribution of energy storage by country. Depending on if the differentiation is done by power, by energy capacity or by number of projects, a different picture can be seen: Power-wise, Spain and Germany have the largest amount of storage systems; if differentiated by energy capacity, Portugal is the leader. Regarding the number of projects, Germany and Spain have the largest values. However, this is also largely due to lack of data in the database: for electrochemical projects in Ireland for example, power installed energy capacity is well documented while the energy capacity value is only available for three projects. The Irish share is therefore underestimated in the energy capacity related graph.

Figure 10 Distribution of energy storage a) power [MW], b) energy capacity [MWh] and c) number of projects by countries [-] (May 2022)



a)

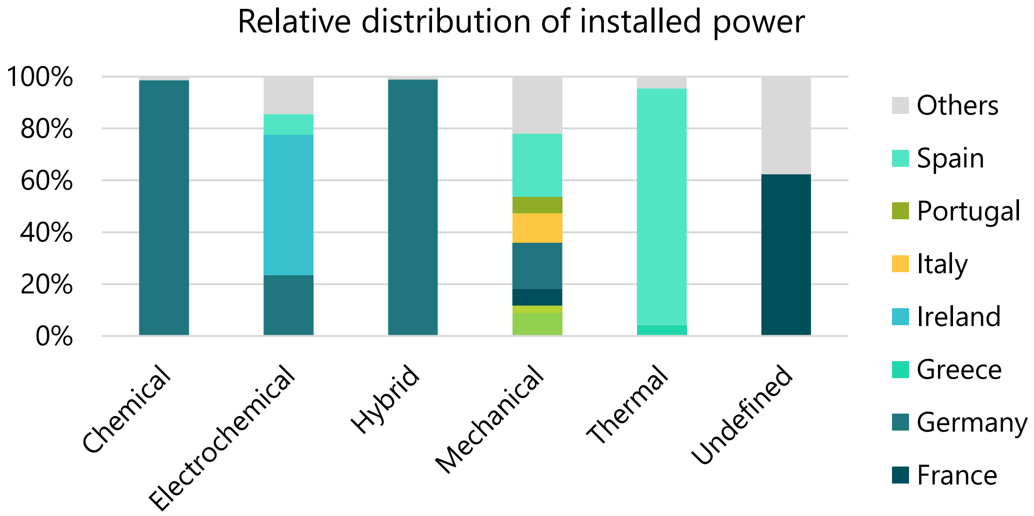


b)

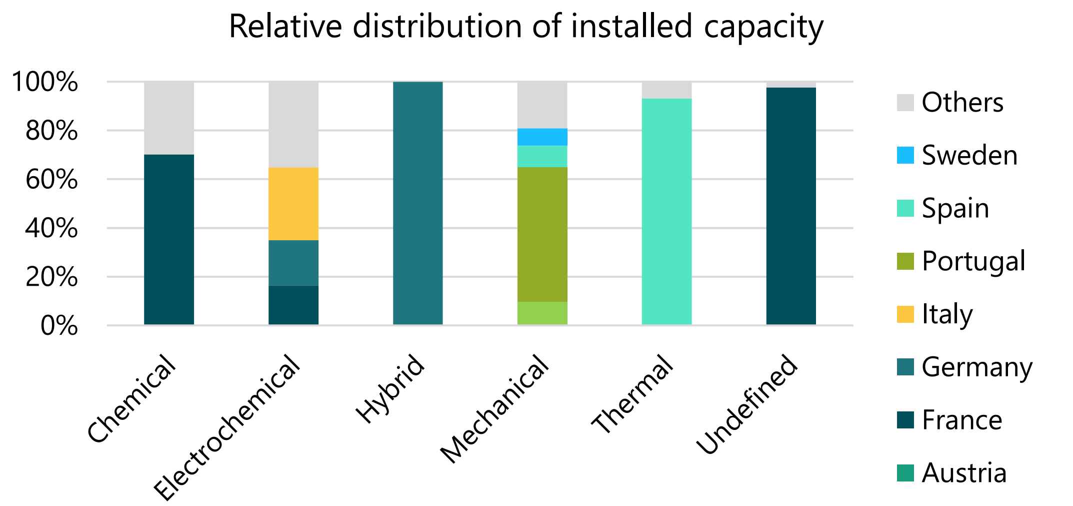
c)

Figure 11 gives a more detailed picture for the special distribution of the single technologies. Depending on if power, energy capacity, or number of projects are looked, at, the picture changes. This again is due to partial lack of data. However, it can be seen that a larger variety of countries is given in the case of mechanical storage systems: Many countries have mechanical energy storage systems, while e.g. chemical energy storage is concentrated in France and Germany.

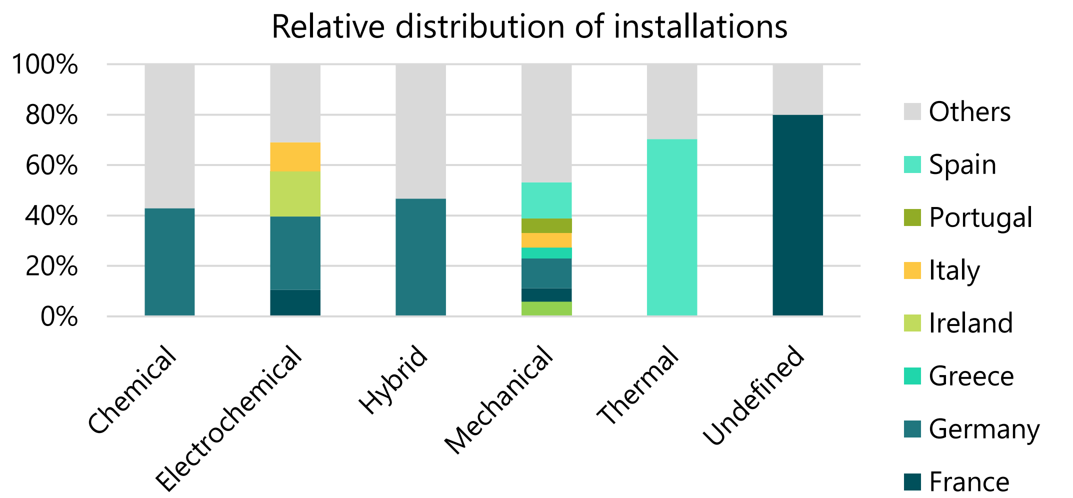
Figure 11 **Distribution of energy storage a) power, b) energy capacity and c) number of projects by country**



a)



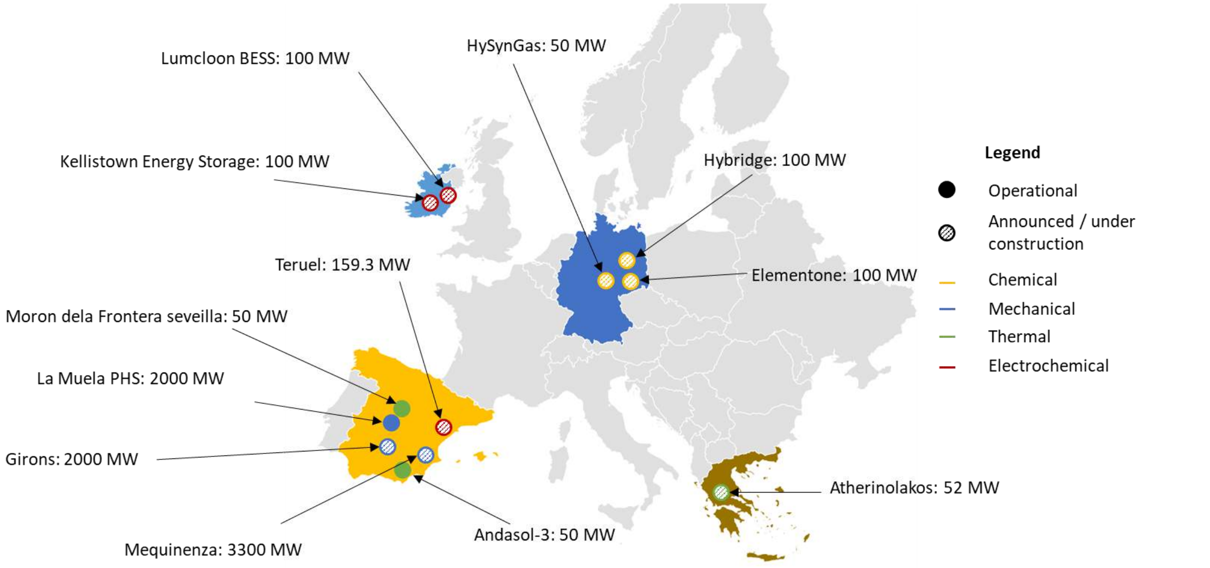
b)



c)

Figure 12 shows the three largest projects per technology in terms of power. Many of these projects are only announced some under construction, submitted or operational. The projects are concentrated on four countries: Spain, Germany, Ireland and Greece. In Germany, the three largest chemical storage plants are announced with 100 / 50 MW each. Large thermal projects are operational or planned in Spain and Greece. Large mechanical projects (all pumped hydro storage) are in operation or announced in Spain.

Figure 12 Three largest projects per technology



Source: graph by Fraunhofer ISE

Table 4 Three largest projects per power per technology

Country	City/location	Facility Name	Technology	Power (MW)	Energy capacity (MWh)	Date of commis-sioning
Germany	Lower Saxony	Hybridge	Chemical - P2G	100		2023
Germany	Diele	Element One	Chemical - P2G	100		2022
Germany	Brunsbüttel	HySynGas	Chemical - P2G	50		
Spain	Teruel	Teruel	Electrochemical - Battery	159.3		
Ireland	Kellis	Kellistown Energy Storage	Electrochemical - Battery	100		
Ireland	Derrycarney	Lumcloon BESS	Electrochemical - Battery	100		2020
Spain	Mont-Negre	Mequinenza	Mechanical - PHS	3300	75110	2020
Spain	Cortes-La Muela	La Muela	Mechanical - PHS	2000		2013
Spain	Girones	Girones	Mechanical - PHS	2000		2027
Greece	Atherinolakos	MINOS	Thermal - Molten salts	52	260	2020
Spain	Aldeire Granada	Andasol-3	Thermal - Molten salts	50	375	2011
Spain	Morón de la Frontera Sevilla	Arenales	Thermal - Molten salts	50	350	2013

2.1.6 Behind-the-meter data

For all EU-27 countries, the former list of current installed "behind-the-meter storage" was updated. It is striking that current and accurate data could only be found for individual countries. One of the most accurate data sets is available for Germany. The ISEA of the RWTH Aachen University is investigating the BTM capacities installed annually in Germany.[28] It is advantageous that in Germany (almost) all behind-the-meter storage installations must be entered in a market register of the German Federal Network Agency and the Federal Motor Transport Authority. Germany has the largest installed BTM capacity in Europe with 4.4 GWh (April 2022). For other countries, the best data could be obtained partly from the storage association (EASE), market research institutes or national energy authorities. With the expected increase in BTM storage, it should be considered for future data collection to set up a European register and also to conduct interviews with relevant institutions.

2.2 Alternative flexibility solutions

Flexibility in the electricity sector is usually referred to as "the possibility to adjust the electrical consumption or the electrical production of an installation or process"[29]. Energy storage is only one of several flexibility solutions. This section gives a broader view on flexibility and puts storage into perspective. There are four main types of flexibility in energy systems[30]:

- Flexible generation
- Demand side management
- Energy storage
- Interconnections

Today, flexibility is mainly provided by the supply side, namely thermal power plants. Due to the goal of decarbonisation, flexibility will need to be mainly provided by renewable energy technologies, demand side management, energy storage and interconnectors in the future.

All four flexibility options will interact in the future to balance supply and demand in the European energy system. This section will focus on the three options apart from storage: the flexible generation, looking at the supply-side in Section 2.2.1, interconnectors in Section 2.2.2 as well as demand side management in Section 2.2.3. For each flexibility option, cost, potential as well as barriers and enablers will be explained. Section 2.2.4 will then give an overview and comparison of the discussed topics.

2.2.1 Supply-side

Supply-side flexibility refers to the flexibility of energy generation technologies. In literature, also the term "dispatchable power plants" is used. As demand has always been variable, generation technologies have always been providing flexibility to balance supply and demand[31]. However, with more volatile renewable energy technologies in the system and a reduction of flexible generation technologies such as thermal power plants driven by fossil fuels, the demand for flexibility rises.

Flexible generation technologies are typically fossil fuel driven thermal power stations, such as coal fired steam turbines, gas turbines, nuclear power plants and waste incineration. Renewable thermal

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[28] Figgener, Jan, et al. "The development of battery storage systems in Germany: A market review (status 2022)." arXiv preprint arXiv:2203.06762 (2022).

[29] Next Kraftwerke (2022): What is Flexibility in the Electricity Sector? https://www.next-kraftwerke.be/en/knowledge-hub/flexibility-electricity-sector/

[30] EnTEC (2022) Digitalisation of Energy Flexibility, p. 16

[31] IRENA (2019) Flexibility in conventional power plants – Innovation landscape brief

technologies include biogas, geothermal power, concentrating solar power and hydrogen burnt in gas turbines. Reservoir hydropower can also provide substantial amounts of flexibility. To some extent, also volatile renewable energy technologies such as photovoltaics and wind energy can provide flexibility, by throttling the power output. This can be done by either switching off single power plants or by reducing the amount of grid feed-in partly. Usually, the grid operator has access to larger plants and can regulate them down by radio ripple control signal. Ripple control signals can be transferred directly via the electricity grid and do not need an additional communication network. In many cases curtailment of renewable energy is necessary to avoid grid congestion, which is also a form of flexibility. This however should be one of the last options as this means that low-cost and low-emission energy is dumped. Therefore, flexibility of volatile renewable energy technologies is not discussed as flexible generation in this section.

To provide flexibility, power stations need to run in part load to be able to react quickly to needed load changes[32]. Ramp rates and start-up times of thermal power plants may be long (several minutes for a state-of-the-art open cycle gas turbine but up to two hours for a state-of-the-art hard coal-fired power plant[33]). However, by retrofitting conventional power plants can be made more flexible[34]. On the path to decarbonisation, hydropower plants, gas turbines and biomass electricity plants will provide important amounts of supply-side flexibility in Europe[35]. Volatile renewable plants can contribute to short-term flexibility.

Cost

The cost of supply-side flexibility depends strongly on the technology and the business model that the operator uses. Thermal power plants usually operate as generation technology and provide flexibility as an additional asset, so the cost for the flexibility is hard to determine. A look at the markets in which these technologies can participate can be useful. Flexibility is offered at the spot market as well as the reserve markets. However, it is to be noticed that the prices on spot market and reserve markets are driven not only by supply-side flexibility but also by electricity storage taking part in these markets. In addition, the market values reflect the prices, not the cost. This means that effects of supply and demand shortages, hedging and other effects influence the price while the cost may not vary. E.g. for frequency response reserve, the 52-week-average price between 2014 and 2022 ranged between about 1,500 and about 4,000 €/MW/week for bids from the German market[36]. Prices for positive automatic frequency restoration reserve (aFRR) power have been varying between 100 and 3000 €/MW/week for power[37]. Prices have been varying strongly especially in the year 2020. Volatility has since then decreased only slightly. For further detail on the market options see Chapter 2 of this report.

[32] Grunewald, Philipp (2016) Flexibility in supply and demand. Paper prepared for DEMAND Centre Conferences, Lancaster, 13-15 April 2016

[33] Agora Energiewende (2017) Flexibility in thermal power plants – With a focus on existing coal-fired power plants

[34] IRENA (2019) Flexibility in conventional power plants – Innovation landscape brief

[35] European Union (2016) EU Reference Scenario - Energy, transport and GHG emissions - Trends to 2050

[36] Regelleistung-Online (2022) Leistungspreise – PRL – Aktuelle Leistungspreise. https://www.regelleistung-online.de/prl/leistungspreise/. Checked on April 27,2022

[37] Regelleistung-Online (2022) Leistungspreise – SRL/aFRR – Aktuelle Leistungspreise. https://www.regelleistung-online.de/srl/leistungspreise/. Checked on April 27, 2022

Potential

The technical potential for flexible generation is huge, if fossil driven technologies are included. If only renewable energy technologies are included, the potential of hydroelectricity, geothermal energy and burning biogas and hydrogen in gas turbines need to be accumulated. The potential for pumped storage hydroelectricity in Europe is estimated to be about 29 to 80 TWh, of which 4 to 33 TWh lie in the EU, depending on the typology of the system[38]. The potential for geothermal energy is estimated to be 80 to 100 GW_e; however, the long term goal is to increase electricity production from geothermal energy up to 15-30 GW_e[39]. The potential for gas turbines driven by biogas and hydrogen is practically not limited (apart from resources and production capacity). This will rather be a matter of how to produce the amount of hydrogen and how to use it.

The potential for flexibility from virtual power plants in 2050 is estimated to be 180 GW (164 GW for intraday spot market, 16 GW for ancillary services (balancing reserves)). If VPPs for further uses are also counted, 184 GW for VPPs for congestion management (1 GW), for critical grid situations (39 GW) for internal balancing (80 GW) and for exploitation of limited grid capacities (64 GW) increase the total potential in 2050 to 364 GW.[40] Of course, these numbers are not to be seen as additional to the numbers above, as virtual power plants can combine volatile renewable energies with e.g. biogas power plants or hydroelectric power.

To understand the magnitudes, the EU reference scenario for 2050 is taken as an example[41]: This could include roughly 100 GW gas fired power plants, 140 GW hydro generation, 55 GW nuclear, 45 GW biomass/waste plant capacities. This means that about a quarter of the installed power capacity of 1390 GW will be somewhat flexible in its generation. These generation technologies will provide about 40% of the electricity generation. The potential is of course higher, but the scenario shows that flexible generation, mainly provided by gas power plants and biomass electricity plants, will play a major role in the future energy system. Also, newer plans by the EU include larger shares of PV[42] and wind energy[43], however, the potential of flexible generation is large.

Challenges and enablers

Barriers can be technological, technical, economic, social/behavioural as well as regulatory. There are rather few barriers for supply-side flexibility, as this has been the main solution in the past and present European energy system.

The market for supply-side flexibility, namely spot market and reserve markets, have been in place for a long time and has proven valuable to the energy system. The implementation project "International Grid Control Cooperation (IGCC)" is a Europe-wide attempt to reduce system imbalances by international cooperation. The balancing markets can be considered as enablers for the support of supply-side flexibility, as supply and demand are met and the market thus functions.

A technological challenge for supply-side flexibility provided by renewable energy is the cost: Primary energy, which comes without cost, is lost when volatile renewable energy technologies are dispatched for congestion management. Depending on the cost of renewable energy compared to

38 JRC (2013) Assessment of the European potential for pumped hydropower energy storage - A GIS-based assessment of pumped hydropower storage potential. P. 33

39 Geothermal ERA-NET (2022) Geothermal Energy. http://www.geothermaleranet.is

40 EnTEC (2022) Digitalisation of Energy Flexibility, pp. 20

41 EUROPEAN COMMISSION (2021) EU Reference Scenario 2020 - Energy, transport and GHG emissions - Trends to 2050. p. 81 ff.

42 EC (2022) REPowerEU: A plan to rapidly reduce dependence on Russian fossil fuels and fast forward the green transition. https://ec.europa.eu/commission/presscorner/detail/en/IP_22_3131

43 EC (2022) Boosting Offshore Renewable Energy for a Climate Neutral Europe. https://ec.europa.eu/commission/presscorner/detail/en/IP_20_2096

other flexibility options, this may be a costly option to avoid. Alternatives are the extension of interconnectors and the use of storage systems to prevent these losses.

A technological challenge for fossil flexibility technologies is the CO_2 emissions and decarbonisation goals. In the long run, fossil flexibility solutions will need to be replaced by renewable technologies. Challenges for renewable technologies are that providing flexibility always means that the available primary energy is not used. The loss in provided energy must therefore be rewarded by the market with an incentive for providing flexibility.

SmartGrids are an enabler for supply-side flexibility, as they facilitate information on the demand in real-time and make power generation adaptation possible. On the other hand, a barrier in that context is that real markets for regional flexibility are still missing.

2.2.2 Interconnections

An interconnector is a power line connecting the electricity grids of two countries. Interconnectors can therefore connect regions of high demand with regions of high electricity generation and balance supply and demand on a short time scale. Strictly speaking, interconnectors themselves do not provide flexibility, but are often considered as such as they connect storage systems, supply-side flexibilities and other sources of flexibility with the local demand. Interconnectors therefore connect countries with the flexibility of other countries.[44] In 2020, 80 GW of interconnectors were in operation in Europe[45].

Cost

The cost of interconnectors mainly depends on the type of interconnector, on the operating voltage level, the number of circuits and the length. Costs for overhead lines range between 150,000 and 140,000 €/km. Underground cables are more expensive with 450,000 to 590,000 €/km. Subsea cables cost ranges between 700,000 and 1,100,000 €/km.[46]

Brown et al.[47] assume values based on power and length of 445 €/MWkm for AC overhead lines, 400 €/MWkm for DC overhead lines and 1100 €/MWkm for DC submarine cables. The DC converter pair is assumed to cost about 150,000 €/MW. This data is from 2015, so today cost may be even higher.

Materials and manufacturing contribute to about half of the cost for aboveground cables and almost 60% for underground cables. Installation and civil works make up another third of the cost; the rest is engineering and commissioning, project management, regulatory consents, studies etc.[48]

The European Commission supports the expansion of the European electricity network with grants from the Connecting Europe Facility (CEF) and the European Structural and Investment Funds (ESIF).

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[44] Grunewald, Philipp (2016) Flexibility in supply and demand. Paper prepared for DEMAND Centre Conferences, Lancaster, 13-15 April 2016

[45] Entso-e (2021) Ten Year Network Development Plan – Completing the map – Power system needs in 2030 and 2040.

[46] ACER (2015) Report on unit investment cost indicators and corresponding reference values for electricity and gas infrastructure – Electricity infrastructure. Pp. 11

[47] Brown, Tom; Schierhorn, Peter-Philipp; Tröster, Eckehard; Ackermann, Thomas (2015) Optimising the European transmission system for 77% renewable electricity by 2030. IET Renewable Power Generation. doi: 10.1049/iet-rpg.2015.0135

[48] ACER (2015) Report on unit investment cost indicators and corresponding reference values for electricity and gas infrastructure – Electricity infrastructure. Pp. 12

Potential

Theoretically, the technical potential to add interconnectors is huge. The main restrictions are long lead-times of the projects and public acceptance. In the following, the focus will therefore be on the targets in the EU.

The Ten Year Network Development Plan (TYNDP), provided by ENTSOE-e in 2021, describes the future plans for interconnectors in Europe: By 2025, about 35 GW new cross-border enforcements are planned, and some are under construction already. By 2030, 50 additional GW would be cost-efficient to support the system, according the ENTSOE-e's study results. Slightly more than half of these could be covered by existing projects, the rest is conceptual. By 2040, an additional 43 GW are estimated to be necessary. 14 GW of these are already concrete TYNDP projects.[49]

The EU has set interconnection targets for its Member States. The targets are defined by the share of the electricity produced in a country's territory that can be transported across the borders to neighbouring countries. Up to 2030, the target is set to at least 15%[50]. The 2020 target was 10%. To help achieve these targets, an expert group on electricity interconnection was set up in 2016.[51]

Challenges and enablers

A technological barrier of interconnectors are their high costs and high effort for the implementation of such projects.

The main technical barrier to building new interconnectors is long lead times for installations. From planning to start of operation ten to twenty years may pass. One main obstacle is lengthy permit granting procedures. The regulation on the trans-European networks for energy (TEN-E) sets EU guidelines for new energy infrastructure. In the current process of revision of this regulation, strict time limits for permitting procedures are therefore planned[52].

Environmental issues such as air pollutant emissions, water pollution, solid waste, land-use, wildlife/biodiversity impacts and human health impacts are another obstacle for interconnectors[53]. To exclude as many of these issues as possible also contribute to the lengthy permit granting procedures.

A social barrier for the implementation of interconnectors is the low level of public acceptance for large infrastructure projects and grid projects in general. An enabler here would be to inform the public and industry about the benefits of electricity interconnectors[54]. The TEN-E regulations also contain rules on transparency to ensure involvement of citizens in the planning process.

2.2.3 Demand-Side

Demand side flexibility is commonly defined as the ability to adapt demand configurations by reducing, increasing, or shifting a portion of demand over a specified time period in response to price or activation signals in order to provide a service toward energy system stability and security while remaining cost effective[55]. In this section, demand side solutions to provide flexibility to the system

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[49] Entso-e (2021) Ten Year Network Development Plan – Completing the map – Power system needs in 2030 and 2040.

[50] EU (2018) Regulation 2018/1999. (6)

[51] European Commission (2022) Electricity interconnection targets. https://energy.ec.europa.eu/topics/infrastructure/electricity-interconnection-targets_en

[52] EU (2021) Revision of the TEN-E Regulation - EU guidelines for new energy infrastructure. Briefing – EU Legislation in Process. P. 5

[53] United Nations (2006) Multi Dimensional Issues in International Electric Power Grid Interconnections. Pp. 117

[54] ENSYSTRA (2021) Opportunities and barriers to interconnector expansion in the North Sea Region

[55] *IRENA (2019) Demand-side flexibility for power sector transformation*

will be described. The contribution of the alternative flexibility options is discussed in terms of their technical implications, type of flexibility, time scale, maturity of the technology delivering the service, and qualitatively estimated costs.

In this work, the demand-side flexibility option is categorised into DSM through sector coupling, through industry load shifting and though households with smart electricity use. Each of these categories is further subdivided into specific processes and applications suitable for DSM.

2.2.3.1 DSM through sector coupling

Sector coupling (also referred to as sector integration or Power-to-X[56]) is seen as a promising option to decarbonize sectors such as the heating or mobility sector by electrifying processes that are currently based on fossil fuels. Considered sector coupling technologies, like heat pumps and electrolysers, convert electrical energy into useful energy which also acts as an energy storage medium. Additionally, these demand side technologies can also be used as flexibility resources. Their flexibility can be enhanced by including a storage unit or by the expansion of the existing storage units. In this study e-mobility as well as other technologies are considered as a sector coupling technology that can provide flexible demand. From this perspective flexible demand can be a competitor to storage technologies, but typically the capabilities of flexible demand can be extended or facilitated by heat and gas storage technologies. In this case energy storage can be a relevant technology facilitating DSM as the DSM strategies and storage systems can enhance the penetration rate of RE generation by decreasing the short-term variability caused by the unpredictable and intermittent nature of RESs.

Cost

The primary objective of sector coupling technologies – as is also the case for all other demand-side resources – is not flexibility provision, but fulfilling end customer needs like heat, mobility, etc. Therefore, only the part of the investments that are needed to provide flexibility are considered. Relevant sector coupling technologies that can provide flexibility and represent a competitor to storage technologies are residential and commercial heat pumps, electrolysers and electric vehicles. The cost assessment for flexibility provision is based on the difference between the sector coupling technology with and without flexibility provision, so that only the additional investments and costs that are needed to run the technologies in a flexible way. The main cost components for flexibility provision with DSM, particularly for heat pumps and electrolysers, are cost for ICT and metering (upfront) as well as costs caused by operation at a lower efficiency. Both aspects have to be overcompensated by the profits from flexibility use. Table 5 gives an overview on estimated costs. For electric vehicles main costs emerge from smart charging stations or wall boxes and the related metering infrastructure.

Table 5 Cost of DSM through sector coupling technologies

Appliance	Action	Initialisation costs - Investment (EUR/kW)	Initialisation costs - Yearly Fixed cost (EUR/kW)	Activation costs (EUR/MWh)
Heat pumps	Load increase, Load decrease, Load shifting	100–200a	4–8c	3.3–82.4

[56] Wietschel et al. (2020) Energy integration across electricity, heating & cooling and the transport sector - Sectorcoupling

Appliance	Action	Initialisation costs - Investment (EUR/kW)	Initialisation costs - Yearly Fixed cost (EUR/kW)	Activation costs (EUR/MWh)
Electrolysers	Load increase, Load decrease, Load shifting	500–1000a	20–40c	16.5–44.9
Electric vehicles	Load increase, Load decrease, Load shifting	40–1200b	25–90	~ 0

[a] Investments in the system, [b] Investments for infrastructure, [c] 4% of investments are considered as fixed yearly costs e.g. communication costs. Initialisation costs consist also of upfront investments mainly for measurement infrastructure, control and communication technologies.
Sources:[57, 58, 59].

Table 6 Technical parameters of DSM through sector coupling

Appliance	Duration of intervention (h)	Shifting duration (h), recover after intervention end
Heat pumps	4	3
Electrolysers	4	6
Electric vehicles	1 (<24)	<24

Sources: [57, 58, 59]

Heat pump (Power-to-Heat). Final energy consumption for space heating in residential and commercial sector in EU makes significantly high share. Heat pumps as a centralised (district heating) as well as decentralised solution play a crucial role in meeting the heating demand. It can also significantly provide flexibility to balance the power grid by decoupling heat demand and power load supported with a thermal storage[60].

Heat pumps can be turned on and off instantly, and they fully ramp up in 30 seconds, allowing for quick response[61]. The availability of flexibility from heat pumps is determined by the end user's heat demand, and it is typically high between 4 and 22 hours per day, and especially during the winter months[61]. When energy prices are low, heat pumps may be used in conjunction with buffer heat storages to provide flexibility by storing heat during off-peak hours and using it on chilly days. Actual availability is influenced by a variety of factors, including but not limited to system size, domestic hot water supply, temperature zone, and building standards[61].

Due to their ramp rates and availability, heat pumps may contribute to system stability by offering intra- and inter-day flexibility. Thermal storage may be employed to offer positive and negative control reserve in the event of frequency variations, depending on its availability and control strategy. Especially heat pumps installed in the power intensive industries enable congestion management depending on where the industry is located.

Potential

57 Ladwig (2021) A Techno-Economic Comparison of Demand Side Management with Other Flexibility Options

58 Misconel et al. (2021) Assessing the value of demand response in a decarbonized energy system – A large-scale model application

59 DG ENERGY (2016) Impact assessment study on downstream flexibility, price flexibility, demand response & smart metering

60 Pau et al. (2018) Optimal Scheduling of Electric Heat Pumps Combined with Thermal Storage for Power Peak Shaving

61 European Commission (2022) Digitalisation of energy flexibility

In the EU, the generation of heat using heat pumps has been increasing per year, over the last six years, approaching 250 TWh in 2020[62]. The annual number of heat pumps (HP) in operation in the EU from 2013-2020 is approximately ranging from 25 to 42 million[63]. Furthermore, the heat pump sales in the EU for the building sector are expected to grow fast until 2030. Heat pumps account for 14.8 million installation in 21 EU countries in 2020 with 7.4% growth over 2020[64]. The European heat pump association estimates that 6% of residential buildings are equipped with heat pumps. Assuming an average heat pump capacity of 4 kW per installation the total installed heat pump capacity reaches 60 GW in 2020 and grows to more than 100 GW in the upcoming years.

Electromobility (Power-to-Mobility)

Electric vehicles (EVs) could be a flexible option for the power system when its demand can be shifted in time, within a very short response time i.e., through controlled charging (smart charging) or when the vehicles even feed electricity back into the grid enabled by bidirectional charging providing Vehicle-to-Grid services. EVs are loads with high level of charging behaviour uncertainty. However, if they are led to charge in a certain pattern, they can be used as a flexibility option[65]. Furthermore, depending on the type of customer, their suitability for demand side flexibility may differ[66].

While electric vehicles are well-suited to providing aggregated flexibility services to centralised markets, they are also suggested for offering local voltage regulation to the distribution grid.[67.] As EVs are mobile assets, they are located at a precise network node at a certain time accounting the voltage at that node they are plugged in. A central aggregator collects all voltage readings for all network nodes and communicates them to all EVs, which subsequently change their charging rates appropriately.

With a low response time within seconds, the vehicle batteries can provide flexibility for 30 min to one hour[68]. Since the activation time of batteries is fast, EVs comply for the provision of Frequency Containment Reserve (FCR) and automatic frequency restoration reserve (aFRR) service. The availability is expected to be accounted for throughout the year given no influence of the seasonal variation on the driving pattern.

Potential

The number of battery electric cars and plug-in hybrid cars has reached 3.8 million in 2021 with a growth of 85% compared to 2020. The market share of battery electric cars and plug-in hybrid cars on all cars in Europe is estimated to be roughly 1.1 percent in 2020 and increased to 1.6 percent in 2021[69]. At the same time the share in yearly sales already reached 18% in 2021 evenly divided between battery electric cars and plug-in hybrid electric cars. With an estimated battery capacity of 40 kWh per electric car (battery electric and plug-in hybrid cars) the overall battery capacity in 2021

62 European Commission (2021) Progress report on competitiveness of clean energy technologies

63 www.statista.com/statistics/739745/heat-pumps-in-operation-eu/

64 European heat pump association (2021) Market Report 2021

65 Kaushik et al. (2022) Comprehensive Overview of Power System Flexibility during the Scenario of High Penetration of Renewable Energy in Utility Grid

66 Earl et al. (2019) Electric vehicle manufacturers' perceptions of the market potential for demand-side flexibility using electric vehicles in the United Kingdom

67 Beaude et al. (2013) Introducing decentralized EV charging coordination for the voltage regulation

68 IRENA (2018) Power system flexibility for the energy transition

69 https://www.statista.com/statistics/955443/number-of-electric-vehicle-charging-stations-in-europe/

is in the range of 150 GWh. According to the estimation of EEA (European Environment Agency), on an average 50% of all the car fleet in the EU-28 will be electric vehicles in 2050. EV's share of overall electricity consumption in Europe will rise from 0.03% in 2014 to 4-5% by 2030 and 9.5% by 2050[70].

Electrolyser (Power-to-Gas)

Using the Power-to-Gas technologies, electricity is converted into the chemical energy carrier i.e., hydrogen by means of electrolysis of water. The hydrogen produced in this way can then be fed into the existing natural gas grid or can be temporarily stored in a local hydrogen storage facility. The technical analysis of large-scale electrolysers performed by Gusain et al. (2020) shows that the PEM cells are suitable for providing balancing services. Moreover, its fast dynamic response can provide frequency regulation services[71]. Due to its faster reaction times, electrolyser development has shifted away from alkaline electrolysers[72]. The rapid reaction time of electrolysers enables the provision of FCR services while utilising inexpensive power during off-peak hours. Asymmetric bidding would provide suppliers with even more flexibility, since the ability to bid specifically for upward or downward regulation would allow for the most efficient use of existing capacity. In terms of compensation, capacity payments are often more appealing than energy payments. Large scale electrolysers may also contribute to lower the critical peaks loads by adjusting or curtailing their electricity demand. Additionally, its bidirectional quick ramping capacity may assist minimise renewable energy source variations and reduce energy curtailments.

Electrolyser's technical property of high-speed performance indicates a significant capacity to participate in FCR, since any fluctuation in demand may be accomplished in less than one second. For load providers, the control system can be configured with an inverse droop[73] characteristic, reducing consumption during frequency drops and increasing consumption during frequency increases.

Potential

Large flexibility is also expected from electrolysers that produce green hydrogen. According to the fuel cells and hydrogen observatory the hydrogen supply capacity from water electrolysis reached 44 tons per day or 16,000 tons per year by the end of 2020, but is expected to grow substantially. Assuming a continuing production and a 60% efficiency of the electrolyser the power demand would increase from some 100 MW to several GWs in just a few years. Around 85% of the worldwide hydrogen projects are located in Europe[74)] taking a substantial share of newly installed assets. Across sectors, it is estimated that Europe has the potential to generate about 665 TWh and 2250 TWh of hydrogen in 2030 and 2050, respectively[75]. The objective of the European hydrogen strategy until 2030 is to produce up to 10 million tons of renewable hydrogen per year, related to 40 GW of electrolyser capacity. Thus, the technical DSM potential depends on the future continuation of the fast diffusion of these technologies. However, the usable potential is linked to monetary and non-monetary incentives for owners of flexibility resources. Depending on the availability of the resources for DSM, their activation is based on technical requirements such as a maximum duration

70 European Environment Agency (2016) Electric vehicles and the energy sector - impacts on Europe's future emissions

71 Gusain et al. (2020) Technical Assessment of Large Scale PEM Electrolyzers as Flexibility Service Providers

72 Eichmann et al. (2014) Novel Electrolyser Applications: Providing More Than Just Hydrogen

73 Inverse droop control is to control the active and reactive outputs by measuring grid voltage amplitude and frequency to trace the predefined droop characteristic. The droop characteristic describes the correlation between the input parameters (grid voltage amplitude or frequency) and the outputs (active or reactive power) of the controller

74 https://auroraer.com/media/companies-are-developing-over-200-gw-of-hydrogen-electrolyser-projects-globally-85-of-which-are-in-europe/

75 Fuel cells and Hydrogen (2019) Hydrogen Roadmap Europe

of an intervention as well as the shifting duration[76], i.e., the number of hours that demand can be shifted from the originally planned point in time (see Table 6).

Challenges and Enablers

Barriers can be economic, technological, technical, social/behavioural as well as regulatory. Many barriers are similar for residential heat pumps and electric vehicles.

A major obstacle hampering the activation of residential demand-side flexibility is that profitability of demand response is limited[77] while many consumers fear a loss of comfort[78] (that is, thus, not offset by a financial compensation).

Technological barriers comprise high costs for communication and metering technology[79], the lack of interoperability between several parties as well as the necessity to have functioning concepts for data sharing and suitable communication protocols in place[80],[81]. Furthermore, enhanced ICT capabilities also might go along with an increased potential of cyber-attacks[79].

Technical requirements that may act as barriers are minimum bid size, the aggregation of multiple small loads (EV participants), the minimum duration of flexibility and load frequently changing the network node for charging (EVs as non-stationary loads changing locations)[82].

While the aforementioned technical requirements can also be classified as regulatory barriers, other regulatory obstacles comprise incentives and price signals for flexibility provision, the possibility for a collective prequalification of small-scale flexibility resources and, overall, a functioning regulatory framework for flexibility provision. Social barriers include a lack of information about DSM[83], low awareness of and confidence in DSM and a lack of trust in data sharing infrastructure and utilities in general.

Enablers, on the other hand, comprise the role out of smart metering infrastructure, the creation of save and trustworthy data frameworks as well as the clarification of third-party access to data with regard to flexibility (as suggested in the proposal for RED III Art 20a). Pilot projects that test and showcase solutions can also act as enablers[84].

Electrolysers as an industrial-scale technology face barriers similar to the ones for industrial load management. We therefore refer to the following section for barriers regarding this technology.

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[76] Duration of Intervention determines how long the demand of a DSM application can be reduced or increased, whereas shifting duration presents the maximum of minutes or hours, an electricity demand can be shifted to an earlier or later point in time

[77] Globisch et al. (2020) The stranger in the German energy system? How energy system requirements misalign with household preferences for flexible heat pumps

[78] Toft et al. (2015) Exploring private consumers' willingness to adopt Smart Grid technology

[79] Gautham et al (2018) Roadmap Electric Vehicles and Grid Integration (V1G versus V2G)

[80] ElaadNL (2016) EV Related Protocol Study

[81] IRENA (2021) Innovation outlook: Smart charging for electric vehicles

[82] Wohlfarth et al. (2019) Setting course for demand response in the service sector

[83] Advanced Energy Economy Institute (2018) Cybersecurity in a distributed energy future. Addressing the challenges and protecting the grid from a cyberattack

[84] Jakeman et al. (2020) Digital technologies and use cases in the energy sector

2.2.3.2 DR through industry load management

Flexibility from industrial processes can be provided by the means of load shedding and time-variable production. There is relevant potential for demand side flexibility especially in the energy intensive as well as wood and paper industries[85].

Cost

It is more convenient to use industrial flexibility to provide services since larger loads demand less resources to attain the minimum size necessary for bidding in the market. Additionally, in the industrial sector, the information and communication (IC) infrastructure are often already in place for energy management, necessitating a lesser investment to deploy industrial assets[86]. Many industrial sectors, as shown in Table 7, can adjust their electricity consumption for short duration without having a significant impact on its overall operations. The extent timing of this frequency relies on the industrial facility's utilisation, which varies over time.

Table 7 Cost of DSM through industrial load management in the potential sectors (based on survey data from 2012/13)

Sector	Appliance	Action	Initialisation costs - Investment (EUR/kW)	Initialisation costs - Fixed cost (EUR/kWa)	Activation costs (EUR/MWh)
Non ferrous metals	Aluminium electrolysis	Load shedding	1-20[b]	0-1	225-1500
Chemical	Chlorine electrolysis	Load shedding	1-20[b]	0-1	30-310
Paper and Pulp	Paper machines	Load shifting			225
	Mechanical wood pulp production	Load shifting, delay	1-20[b]	0-1	0-10
Iron and Steel	Electric arc steel	Load shedding	1-20[b]	0-1	130-1000
Non metallic minerals	Cement mill	Load shifting	1-20b	0-1	0-6

[b] Investments in the infrastructure

Aluminium industry: The flexibility in the aluminium industry can only be seen in load shedding. The load shifting can only take place to a very limited extent, as the liquid aluminium has to be processed directly and is alloyed and rolled specifically for the customer. The capacity of downstream process steps are an impediment to load shifting in this case[87]. The duration of the load shedding is shown in Table 7.

[85] Fritz (2013) Övergripande drivkrafter för efterfrågeflexibilitet

[86] Minniti et al. (2018) Local Markets for Flexibility Trading: Key Stages and Enablers

[87] Bauknecht et al. (2016) Systematischer Vergleich von Flexibilitäts- und Speicheroptionen im deutschen Stromsystem zur Integration von erneuerbaren Energien und Analyse entsprechender Rahmenbedingungen

Chemical industry: The main potential in the chlorine industry lies in the process of chlorine electrolysis. The flexibility of chlorine electrolysis is essentially enabled by the downstream chlorine tanks. The load of this industry is already actively marketed in the reserve market[88].

Paper and Pulp industry: The paper industry's load management potential is bound to the production of wood pulp and the processing of paper products. Machineries powered by electricity can be utilised for load management in actual paper production, and for the production of wood pulp, wood is ground into fibres. Both operations need a continuous electricity supply. Additionally, wood pulp may be temporarily held in silos. This raises the potential of load shifting for this procedure, depending on the storage capacity[89].

Iron and Steel industry: The secondary steel which is basically the scrap steel which is recycled through the process of electric arc furnace. However, it may only capable of load shedding since there is no scope for load increase to catch up with production[90].

Non-metallic minerals industry: Out of four main steps of cement production, for demand side management, the cement grinding mills in particular are to be taken into account, as only here is a relevant storage facility downstream. The load profile of cement production depends on the season, the day of the week and the time of the day. The cement mills are not in operation in winter and primarily run at night and on weekends in the other seasons in order to be able to use off-peak tariffs[91]. Moreover, raw mills are classified as shiftable technologies in the literature[91].

The flexibility from the appliances such as heat pumps, circulating pumps, ventilation, air conditioning and electric pumps can be enabled during certain hours by regulating the consumption. Huge cooling systems can be found in the food industry where the cooling demand occurs in all the seasons. However, the annual profile has a clear correlation with the outdoor temperature.

Table 8 Technical requirements of DSM through industrial load management

Appliance	Action	Duration of intervention (h)	Shifting duration (h)
Aluminium electrolysis	Load shedding	4	12
Chlorine electrolysis	Load shedding	4	6
Paper machines	Load shifting	3	24
Electric arc steel	Load shedding	4	12
Cement mill	Load shifting	3	6
Mechanical wood pulp production	Load shifting, Delay	2-3	4

Sources: [92]

[88] Klobasa *et al. (2011)* Kurz- bis Mittelfristig realisierbare Marktpotenziale für die Anwendung von Demand Response im gewerblichen Sektor

[89] Hartkopf et al. (2012) Lastmanagementpotenziale der stromintensiven Industrie zur Maximierung des Anteils regenerativer Energien im bezogenen Strommix

[90] Paulus et al. (2011) The potential of demand-side management in energy-intensive industries for electricity markets in Germany

[91] Klobasa (2007) Dynamische Simulation eines Lastmanagements und Integration von Windenergie in ein Elektrizitätsnetz auf Landesebene unter regelungstechnischen und Kostengesichtspunkten

[92] Müller et al. (2018) Demand Response Potential: Available when Needed?

Challenges and Enablers

The main requirements for a successful activation of industrial load flexibility is that all relevant electricity markets are implicitly and explicitly open for DSM[93]. Correspondingly, despite explicit requirements in the Renewable Energy Directive (RED II, Art. 15.8). One crucial barrier is that in some countries, DSM is still only possible in all markets and methods for pre-qualifying, measuring, communicating, and paying of DSM are not developed in all member states[94]. Important social barriers are, firstly that there is a lack of awareness and knowledge about DSM; and secondly that in organisations where energy is not linked to the core business, energy projects are often not considered a priority[95].

As significant regulatory obstacle can be identified for industrial load management, solving these obstacles would present an important enabler. Solutions in this direction include that prequalifying can be performed at aggregated level to reduce administrative and measurement burdens. Similarly, technical modalities (which in some cases are not designed according to market needs but according to traditional market participants, i.e. large-scale conventional power plants) should be adjusted according to DSM resources' capabilities. This refers to e.g. availability of capacity, required size of bid, frequency of auctions and the option of asymmetric bidding[96].

On the technical side, according to the European Smart Grids Task Force, the smart meter roll out and the use of smart meter data to provide a proper legal basis to DSOs and TSOs could work as an enabler[96]. In this regard, the requirements for Smart Meter Systems, outlined in the Directive (EU) 2019/944[97], Art. 19, present a framework to ensure that sufficient information on energy consumption exist. The proposal for a directive amending the Renewable Energy Directive[98], Preamble 18 and Article 20a would provide for a framework ensuring that access to necessary consumption data is granted. As additional enablers, the improvement of load and generation forecasting at distribution level as well as establishing a reliable and secure communication between flexibility provider and TSO/DSO are named.

Propositions for social enablers include an information campaign on DSM for industries with a focus on "Green Image" to motivate industry to participate in DSM, seminars to overcome the lack of technical know-how in the industry and establishing a more consumer-friendly administrative process for DSM[99].

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93 Antretter et al. EnTEC (Energy Transition Expertise Centre) (2022) Digitalisation of Energy Flexibility. Report prepared for the European Commission

94 Zancanella et al. (2017) Why Demand Response is not implemented in the EU? Status of Demand Response and recommendations to allow Demand Response to be fully integrated in energy markets. Forouli, Aikaterini; Bakirtzis, Emmanouil A.; Papazoglou, Georgios; Oureilidis, Konstantinos; Gkountis, Vasileios; Candido, Luisa et al. (2021): Assessment of Demand Side Flexibility in European Electricity Markets: A Country Level Review. In: Energies 14 (8), S. 2324. DOI: 10.3390/en14082324.

95 Cardoso et al. (2020) Making demand side response happen: A review of barriers in commercial and public organisation*s*

96 European Smart Grids Task Force (2019) Final Report: Demand Side Flexibility. Perceived barriers and proposed recommendations

97 Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market for electricity and amending Directive 2012/27/EU

98 Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL amending Directive (EU) 2018/2001 of the European Parliament and of the Council, Regulation (EU) 2018/1999 of the European Parliament and of the Council and Directive 98/70/EC of the European Parliament and of the Council as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652

99 Shoreh et al. (2016) A survey of industrial applications of Demand Response

2.2.3.3 DR through households with smart electricity use

Cost

Along with the appliance associated with the domotic devices, the main costs or efforts relate to comfort losses for adapting appliance usage times and routines. If metering and control technologies are in place, related costs for demand response decrease substantially as these costs would not be additionally any more. Some activation costs would still remain, if appliances would operate less efficient.

Table 9 Cost of DSM through households with smart electricity use

	Action	Initialisation costs - Investment (EUR/kW)	Initialisation costs - Fixed cost (EUR/kWa)	Activation costs (EUR/MWh)
Air conditioner	Load shifting	40–1,200[b]	25–90	70
Washing machine	load shifting, load shedding, valley filling			10
Dryers	Load shedding, load shifting			10
Dish washers	Load shifting			10
Refrigerators/freezers	load shifting	40–1,200[b]	25–90	70
Water circulation pumps (heating system)	Load increase, decrease	100–200[a]	4–8[c]	10

[a] Investments in the system, [b] Investments for infrastructure, [c] 4% of investments

Potential

The potential for shifting electricity consumption in the households identified in the literature are primarily through air conditioners, washing machines, dryers, dishwashers as well as refrigerators[100, 101]. If the proper infrastructure is in place, such as smart meters, sensors, communications technologies, certain smart appliances may also offer demand-side flexibility.

For utilising the flexibility of the household appliances, it is necessary to ensure their save functioning as well as sufficient availability. Either the load can be shifted manually by the user, for instance, to price signals by switching or preprograming their household appliances accordingly, or can be remotely controlled and operated automatically. However, the load may only be shifted to other times for a limited period of time. The user has to use the dishwashers which may not be used

[100] Apel et al. (2012) Ein notwendiger Baustein der Energiewende: Demand Side Integration. Lastverschiebungspotenziale in Deutschland. Kurzfassung

[101] Scholz et al. (2014) Möglichkeiten und Grenzen des Lastausgleichs durch Energiespeicher, vershiebbare Lasten und stromgeführte KWK bei hohem Anteil fluktuierender erneuerbarer Stromerzeugung

immediately now, but later in the day, which means that the load is not always available for shifting[102]. At the same time, it must be guaranteed that the user can regulate the appliance, if he or she wants.

Fixed and shiftable loads are the two types of household loads. Fixed loads are appliances whose power consumption and use time cannot be modified (e.g., televisions and refrigerators), while shiftable loads are appliances whose power consumption or operating time may be pushed to a later period (e.g., air conditioner, washing machine, dishwasher)[103]. As with heat pumps, the operation times of direct electric heating systems may be shifted in consideration of the given temperature tolerance corridors of the rooms to be heated. Air conditioners are mostly operated during the summer months in Central European countries, in contrast to Southern European countries used also during other hot months of the year. The air intake and exhaust fans may be turned on or off, or flexibly adjusted if they have variable speed drives. Demand response can be done as long as the appropriate air quality is maintained. In a refrigerator the compressor is the primary component with cooling compartment temperatures range between +2°C and +7°C, while freezer compartment temperatures range between -12°C and -20°C. Both the compartments have a rated power range of 50 to 300 W, a load factor of around 33%, and a continuous runtime of several minutes to a half hour. The duration of operation for washing machines, dishwashers, and driers is typically between 15 minutes and 3 hours, and they continue once switched on, making these appliances appropriate for load shifting activation within limited time ranges related to their physical storage capacity[104].

Table 10 Technical parameters of DSM households with smart electricity use

Appliance	Action	Duration of intervention (h)	Shifting duration (h)
Air conditioner	Load shifting	1	1
Washing machine	load shifting, load shedding, valley filling	6	24
Dryers	Load shedding, load shifting	6	24
Dish washers	Load shifting	6	24
Refrigerators/freezers	load shifting	2	1
Water circulation pumps (heating system)	Load increase, decrease	12	12

Challenges and Enablers

Barriers and enablers for residential flexibility are similar to the ones for residential heat pumps and electric vehicles that are charged at home (see Section 2.2.3.1.). Typical appliances in this section

102 Bilton et al. (2014) Smart appliances for residential demand response

103 Ruzbahani et al. (2019) Smart Households Demand Response Management with Micro Grid

104 Boßmann (2015) The contribution of electricity consumers to peak shaving and the integration of renewable energy sources by means of demand response

have lower energy and power demands so that low costs for metering and controlling such appliances are even more important. Similarly, loss of comfort is a major barrier for the flexible use of some residential appliances, as the necessitate a change in the users' behaviour[105]. The diffusion of home energy management systems (HEMS) can be a strong enabler for activating small scale demand response, if the systems allow for an interoperability between different vendors.

2.2.4 Summary and Comparison

In this chapter three flexibility options were described, which are expected to play a major role in the future energy system, together with energy storage. Table 11 summarises the main elements described and compares them with energy storage.

Supply-side flexibility at low cost within a renewable based system has a medium potential for expansion. Challenges are to extend renewable driven supply side flexibility technologies such as hydropower, geothermal energy, and renewable driven gas power plants. Enablers can here be balancing markets, reasonable congestion management and the increase of SmartGrids. In comparison to energy storage, supply-side flexibility can be provided by technologies which need to be installed anyways to reach the European climate goals. However, curtailment of volatile renewable energy technologies can be avoided by using electricity storage.

Interconnections usually come with high cost and have a medium potential for expansion. Challenges are long permit times, environmental issues and public acceptance. Enablers here are the reduction of permit times as aimed at by the European Commission, and information of the public. Interconnections are a necessary part of a growing renewable driven European energy system and will be unavoidable. In comparison to storage, the main disadvantage is that interconnectors need several years until they are implemented, while most storage systems can be installed in shorter time periods. Therefore, interconnectors are part of the long-term strategy and can be accompanied by energy storage in a meaningful way.

DSM through sector coupling technologies and household appliances are comparatively costlier than the industrial load management. In the industrial sector, the IC infrastructure are often already in place for energy management, necessitating a lesser investment to deploy industrial assets, whereas, smart devices and control technologies needs to be in place otherwise it adds up to additional upfront cost. Enablers can here be the availability of a framework for data and access, communication protocols, prequalification at aggregated level and HEMS for activating small-scale demand response. In comparison to storage, DSM can be provided by the underlying technologies and optimised DSM can aid avoiding investment in small to medium side storages. Otherwise, flexibility can also be enhanced by strategically accompanied energy storages.

All flexibility options will be important for the future energy system. Balancing renewable energy curtailment, grid expansion, demand side management and energy storage in a cost-optimal way is the key challenge for the future energy system. The potential of all flexibility options needs to be exploited to ensure a safe and cost-effective energy supply.

[105] Toft et al. (2015) Exploring private consumers' willingness to adopt Smart Grid technology

Table 11 Comparison of flexibility options

	Energy Storage Systems	**Supply-side**	**Interconnections**
Cost	high	low	high
Potential for growth	high	medium	medium
Challenges	Regulatory issues, creating business opportunities	Renewable supply side	Long permit times, environmental issues, public acceptance
Enablers	Balancing markets, local flexibility markets	Balancing markets, congestion management, SmartGrids	Limit permit times, information of the public

	Electric vehicles & heat pumps	**Industrial load management**	**Household appliances**
Cost	medium	low	medium
Potential for growth	high	high	low
Challenges	Market rules need to account for small-scale flexibility resources; fear of a loss of comfort and control	Methods for pre-qualifying, measuring, communicating, and paying of DSM in all member states and for all markets	Market rules need to account for small-scale flexibility resources, Difficult to influence user behaviour
Enablers	Framework for data availability and access is available. Communication protocols enabling DSM and bidirectional charging are published	Prequalifying at aggregated level	Requirement of HEMS for activating small scale demand response

3 Market value of stored electricity and cost gaps

3.1 Introduction and approach

The diffusion of storage technologies is linked to potential market revenues in different energy markets. Within the assessment of potential revenues quantitative market indicators are used that consider bulk storage services via arbitrage, revenues for ancillary services and earnings as well as avoided costs via end customer energy management and self-production.

Next to this key use cases and revenue opportunities additional use cases are analysed in a qualitative way to assess potential earnings and cost gaps. An overview of the revenue assessment is given below:

Quantitative assessment with market data

- Bulk energy arbitrage: Day-Ahead and Intraday market
- Ancillary services frequency regulation: FCR, aFRR, mFRR, RR
- Customer energy management self-consumption: residential electricity prices

Qualitative assessment of markets

- Transmission and distribution infrastructure (Upgrade deferral, congestion relief and voltage support)
- Capacity provision, capacity markets/auction
- Black start and voltage support

The assessment of potential cost gaps for storage technologies is done by comparing revenue and costs for storage technologies. Typical use cases are defined that consider the utilisation of storage technologies and further technical parameters related to the application of the technology.

To gather input from market participants about current and expected future revenues of energy storage, barriers, and gaps between public and private values of energy storage, a survey was also conducted. The results of the survey are summarised in the later part of this chapter in the section 3.5. The full survey results are attached as an appendix to this report.

3.2 Market overview

Revenues for storage can be generated in different energy markets. Based on available data on European scale, main indicators are derived. Several indicators are calculated for arbitrage trading, ancillary service markets and for end customer energy management. Next to price indicators also the procured capacities and activated energy volumes are assessed (see Figure 13).

Figure 13 Overview of revenue indicators for number of (electricity) storage technologies

Source: own figure.

3.2.1 Day ahead market

Storage technologies can generate revenues, when they participate in day-ahead spot markets. Revenues in the spot market are an alternative option for storage technologies next to its participation in balancing markets. Typically, revenues in the balancing markets are higher compared to the day ahead spot market so that main market participation especially of storage technologies like batteries concentrate on balancing markets. However, pumped-storage hydro power participated in day ahead spot-markets for many years and benefited from daily price spreads.

Data sources and approach

Based on market data from the ENTSO-E transparency platform two types of average price spreads are calculated as indicators for potential market revenues.

- Highest daily price spread: Difference between highest and lowest hourly market price within on day (24 hours)
- Second highest price spread: Difference between second highest and second lowest hourly market price within on day (24 hours)

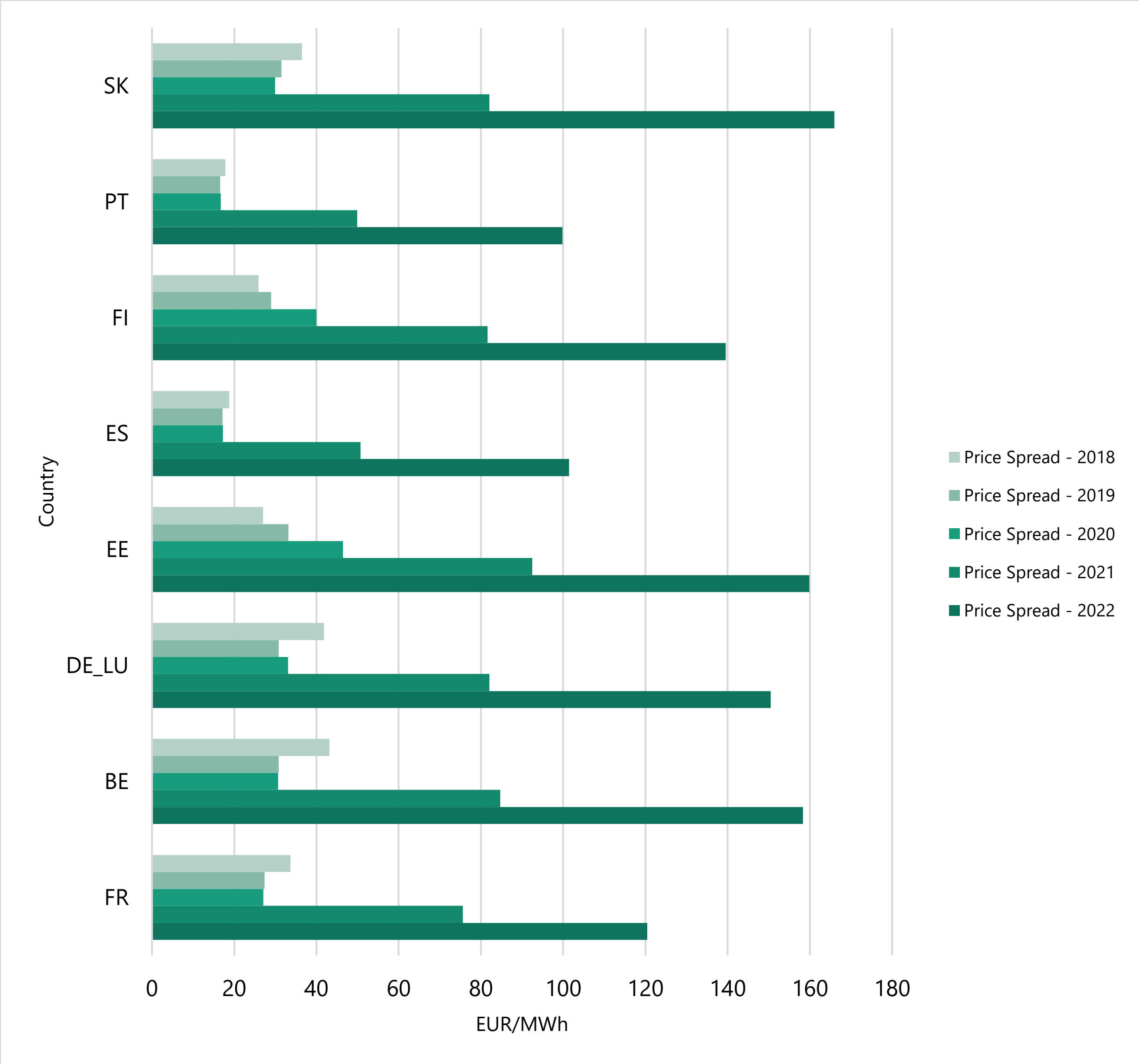
An assessment of day ahead markets is done for EU member states and some none-EU countries like Switzerland and Norway for the years 2018 until 2022.

Price spreads indicators and outcome of the analysis

Average electricity prices on whole-sale markets decreased from 2018 until 2020 and have increased substantially in 2021 and 2022. The price spread indicator (highest and lowest price per day) was in a range between 16 and 46 Euro/MWh until 2020 and increased substantially in 2021 and 2022. In Germany, France, Finland and Slovakia the price spread indicator increased to more than 75 Euro/MWh in 2021 and up to 100 Euro/MWh and beyond in 2022. Spain and Portugal had lower price spreads compared to the first mentioned countries (see Figure 14).

Therefore, price spread levels and revenue conditions for storage technologies developed in a similar range and direction in most of the analysed member states in the last years.

Figure 14 **Development of average daily price spreads in the day ahead markets from 2018 to 2022 in selected countries (EUR/MWh)**



Source: own calculation, based on ENTSO-E transparency data, price spread is the difference between highest and lowest hourly market price on a specific day.

3.2.2 Intraday market

Another option for storage technologies is the participation in intraday markets that allow trading of electricity with shorter lead time. Storage technologies can be charged day-ahead and sell energy on shorter time frames or use price spreads within the day. Intraday markets allow continuous and auction trading. For the price spread analysis the intraday market data for continuous trading is used. Benefitting from intraday arbitrage requires the definition of a trading strategy and the forecast of intraday market prices. Published market data indicates average, lowest, highest and last electricity price that were used for transactions in a specific hour. All available market data indicators are used to calculate potential market spreads in the intraday market. The market indicators and the derived market spreads therefore only give a rough estimate of potential price spread as arbitrage trading requires a good market price forecast. The price spread indicator is substantially higher compared to market data from day ahead markets. Therefore, revenues on this market could be higher compared to day ahead markets.

Data sources and approach

The Figure 15 below present time series of prices for Austria, Germany, France and Czech Republic for the time period 2017 to 2020. Data is only available for one year for the Czech Republic, for three years for Austria and France and for four years for Germany. The market data is obtained from EPEX SPOT, OTE and Nordpool data platform. Price spreads are calculated on the basis of four types of market data in a specific hour that can be used as an indicator for potential market revenues for storage technologies.

- Highest price: Indicates the highest price for a transaction within a specific hour
- Lowest price: Indicates the lowest price for a transaction within a specific hour
- Last price: Indicated the price for the last transaction that has been done for the specific hour
- Weighted average price: Indicates the average price of every transaction for a specific hour weighted by the traded energy volume.

Based on these intraday market indicators the price spread is calculated using the difference between highest and lowest hourly market price for each type of price indicator within on day (24 hours).

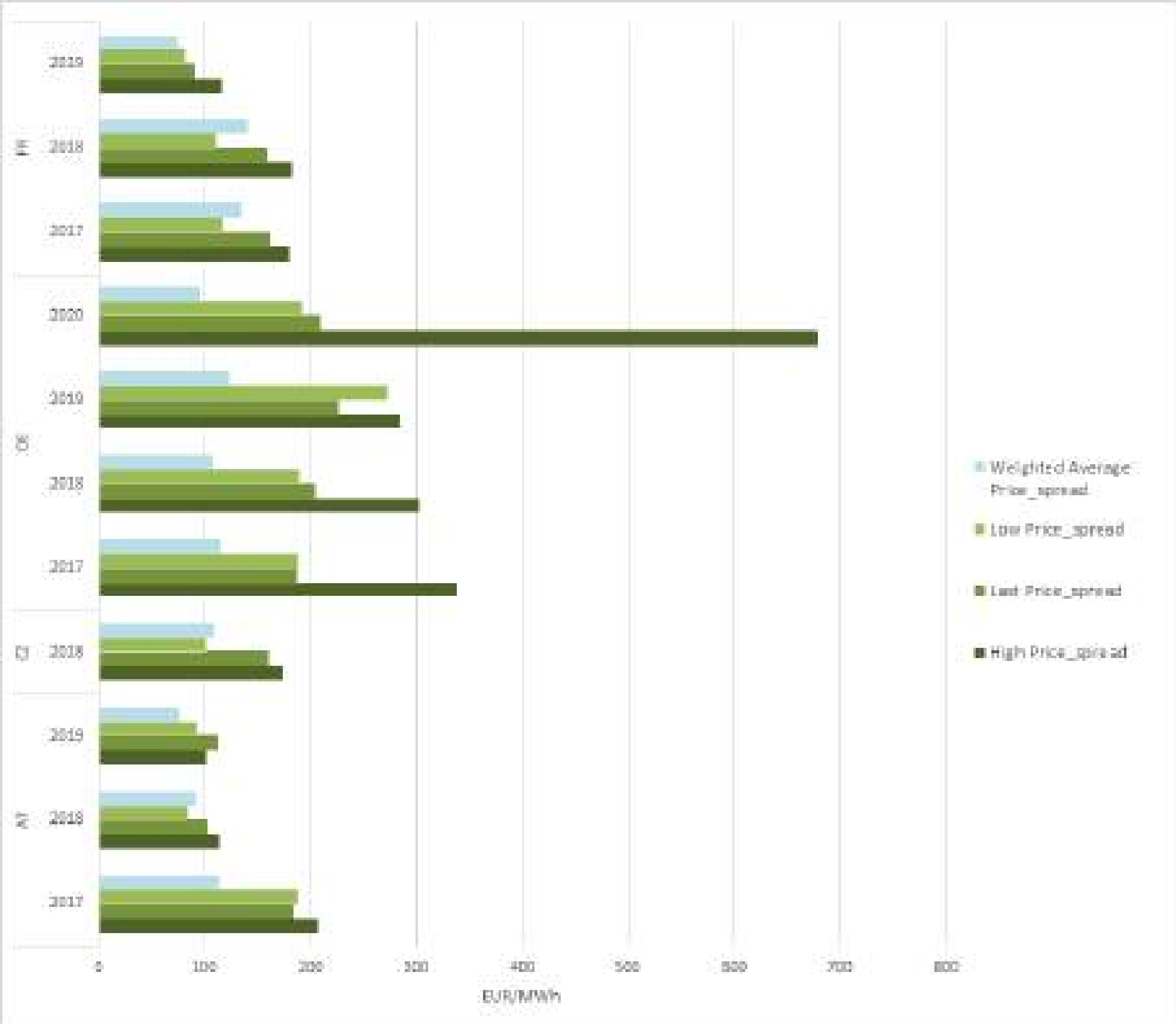
Price indicators and outcome of the analysis

Calculations are done for selected EU member states for the years 2017, 2018, 2019 and 2020. Average electricity price spreads on the analysed intraday markets are in the range between 81 and 679 EUR/MWh (see Figure 15).

The range of the weighted average price spread indicator is between 74 and 140 EUR/MWh. In 2018, the price spread based on the weighted average intraday price in France was around 140 EUR/MWh, which was the highest in the analysed markets. The lowest price spread occurred also in the French intraday market in 2019 with 74 EUR/MWh. Price spread in the German intraday market was above 100 EUR/MWh in 2019.

Price spreads on the intraday market were substantially higher compared to the day ahead average price spreads for 2018 and 2019. They were observed to be between 27 and 33 EUR/MWh in France and between 31 and 42 EUR/MWh in Germany for example on the day ahead market.

Figure 15 **Development of average daily price spread of indicators in the intraday market for selected countries and years (EUR/MWh)**



Source: own calculation, based on ENTSO-E transparency data, price spread is the difference between highest and lowest hourly market price on a specific day.

3.2.3 Ancillary service markets

Storage technologies are participating in ancillary service markets in Europe and increased its market shares substantially in the recent years due to the potential revenues that are generated here. According to the balancing guideline balancing markets distinguishes between balancing capacity and balancing energy and remunerate all participants for capacity and energy served.

Data sources and approach

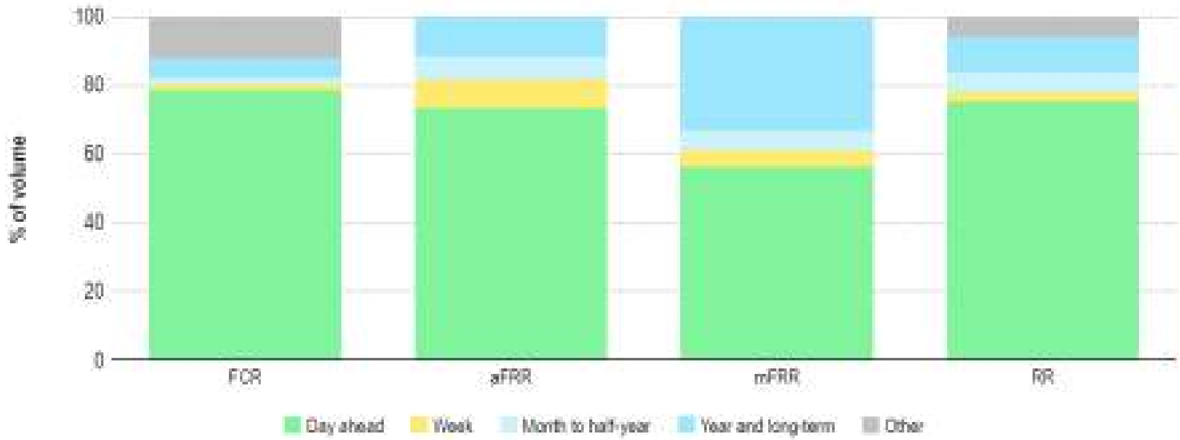
Based on market data from the ENTSO-E transparency platform, below are the indicators calculated for potential market revenues for selected EU member states and the years 2019 until 2022.

- aFRR - Automatic Frequency Restoration Reserve balancing reserves
  - Average prices over the course of the day
  - Annual average prices aFRR procured capacity
  - Monthly overview of aFRR activated Balancing Energy
  - Volume of contracted Balancing Reserves

    - Monthly overview of contracted aFRR activated Balancing Energy
- mFRR - Manual Frequency Restoration Reserve balancing reserves
    - Average prices over the course of the day
    - Annual average prices mFRR procured capacity
    - Monthly overview of mFRR activated Balancing Energy
    - Volume of contracted Balancing Reserves
    - Monthly overview of contracted mFRR activated Balancing Energy
- FCR - Frequency Containment Reserve balancing reserves
    - Average prices over the course of the day
    - Annual average prices FCR procured capacity
    - Monthly overview of FCR activated Balancing Energy

Balancing capacity is procured on a daily basis in some member states and allows the participation of small scale assets as well. In 2020 already 80% of the FCR volume procured was tendered on a day ahead basis. The lowest share of day ahead procurement could be found for mFFR with less than 60% of the volume (see Figure 16).

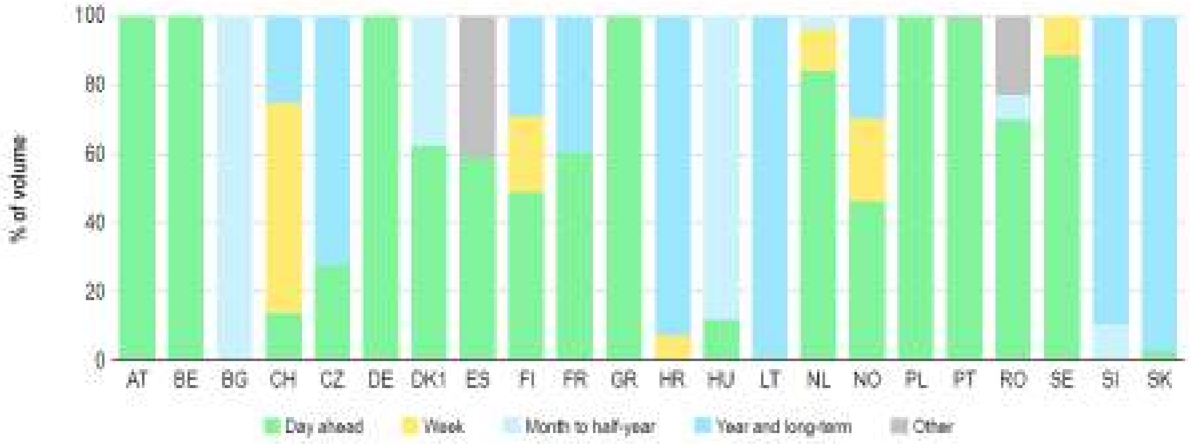
Figure 16 Repartition of the procurement lead time of each type of reserve in selected European markets - 2020 (%)



Source: ACER calculations based on NRAs data

In many member states day ahead procurement of balancing reserves is implemented for all types of reserves (see Figure 17). Only a few member states procured part of the reserves on a weekly or longer lead time in 2020.

Figure 17 Repartition of the procurement lead time of each MS, for all types of reserve (FCR, aFRR, mFRR, RR) - 2020 (%)



Source: ACER calculations based on NRAs data

3.2.3.1 FCR - Frequency Containment Reserve

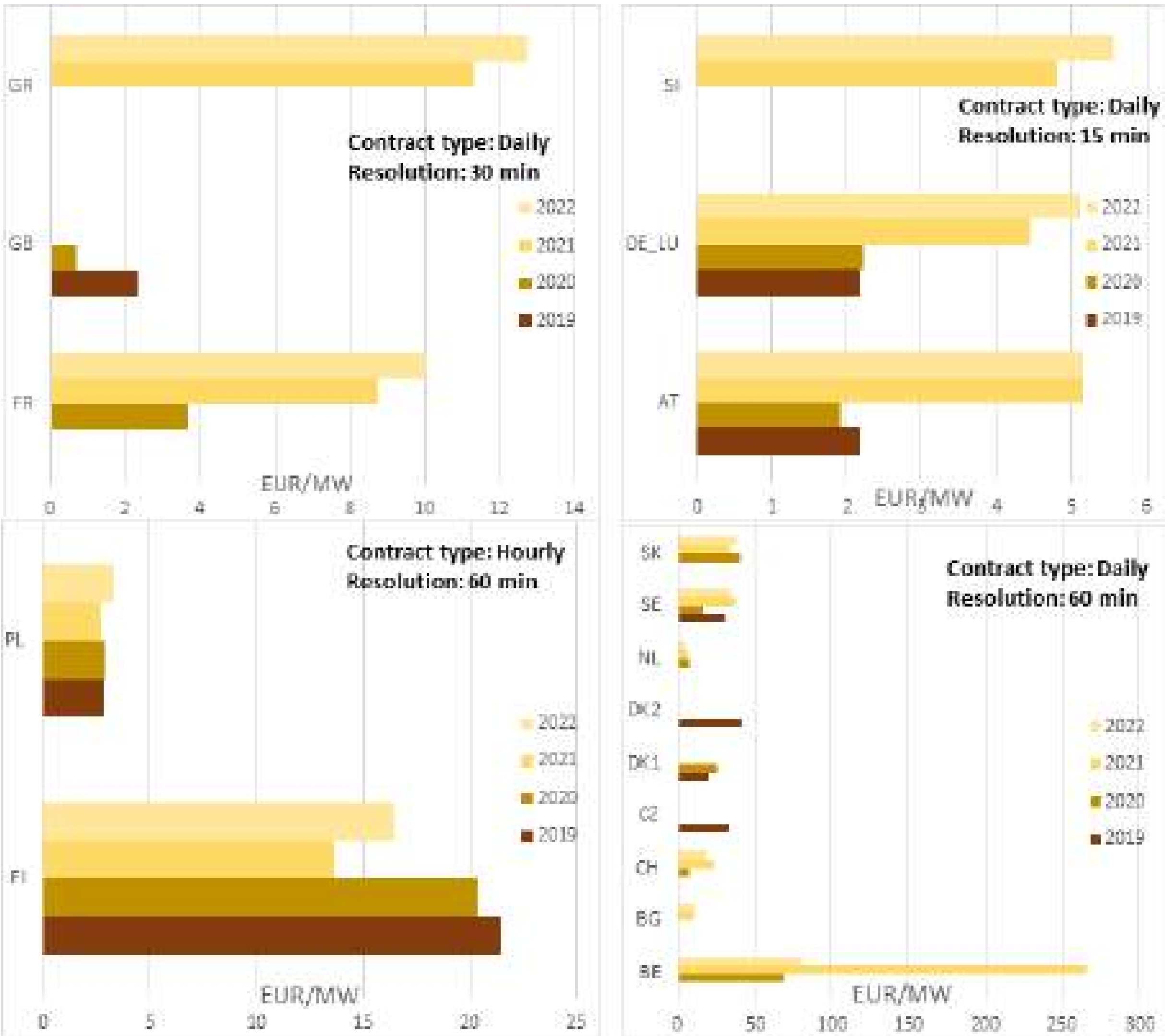
For the annual average price to procure capacity, the picture is diverse across Europe. It is categorised into distinct contract types and respective resolutions of the products. As per Article 6(9) of the Recast Electricity Regulation the contracts for balancing capacity shall not be concluded more than one day before the provision of the balancing capacity and the contracting period shall be no longer than one day across EU. The balancing markets in the analysed member states use daily and hourly contract types with 15 min, 30 min and 60 min resolution. Price indicators are calculated for each time resolution separately. A comparison between member states on a yearly basis is also given as a conclusion.

In Germany, Slovenia and Austria with 15 min product resolution, the price was almost equal at around 5 EUR/MW per 15 min in 2022 (see Figure 18). The average prices in Greece and France with 30 min product resolution reaches 8.7 EUR/MW per 30 min in France and 11.3 EUR/MW per 30 min in Greece in 2021. Capacity prices for FCR have followed similar trends in Greece and France for the year 2021 and 2022 although the prices in France are slightly lower than in Greece. Related to one MW provided for one-hour prices in these markets reaches 20 EUR/MW per 60 min in 2021 and 2022.

In contrast, the products with 60 min resolution are covering a larger range of capacity prices and are costlier in some member states compared to the previous two markets with lower product resolutions. The countries in this category see capacity prices below 20 EUR/MW per 60 minutes as in Finland in 2021, but also above 80 EUR/MW per 60 minutes as in Belgium. In some member states it can be seen that capacity prices were below 10 EUR in each year, e.g. in Sweden, the Netherlands or Denmark.

Revenues from FCR in the analysed markets and member states could reach more than 50,000 EUR/MW per year, if capacity prices are above 6 EUR/MW per 60 minutes. In some member states revenues of more than 175,000 EUR/MW per year could be realised, if capacity prices are above 20 EUR/MW per 60 minutes.

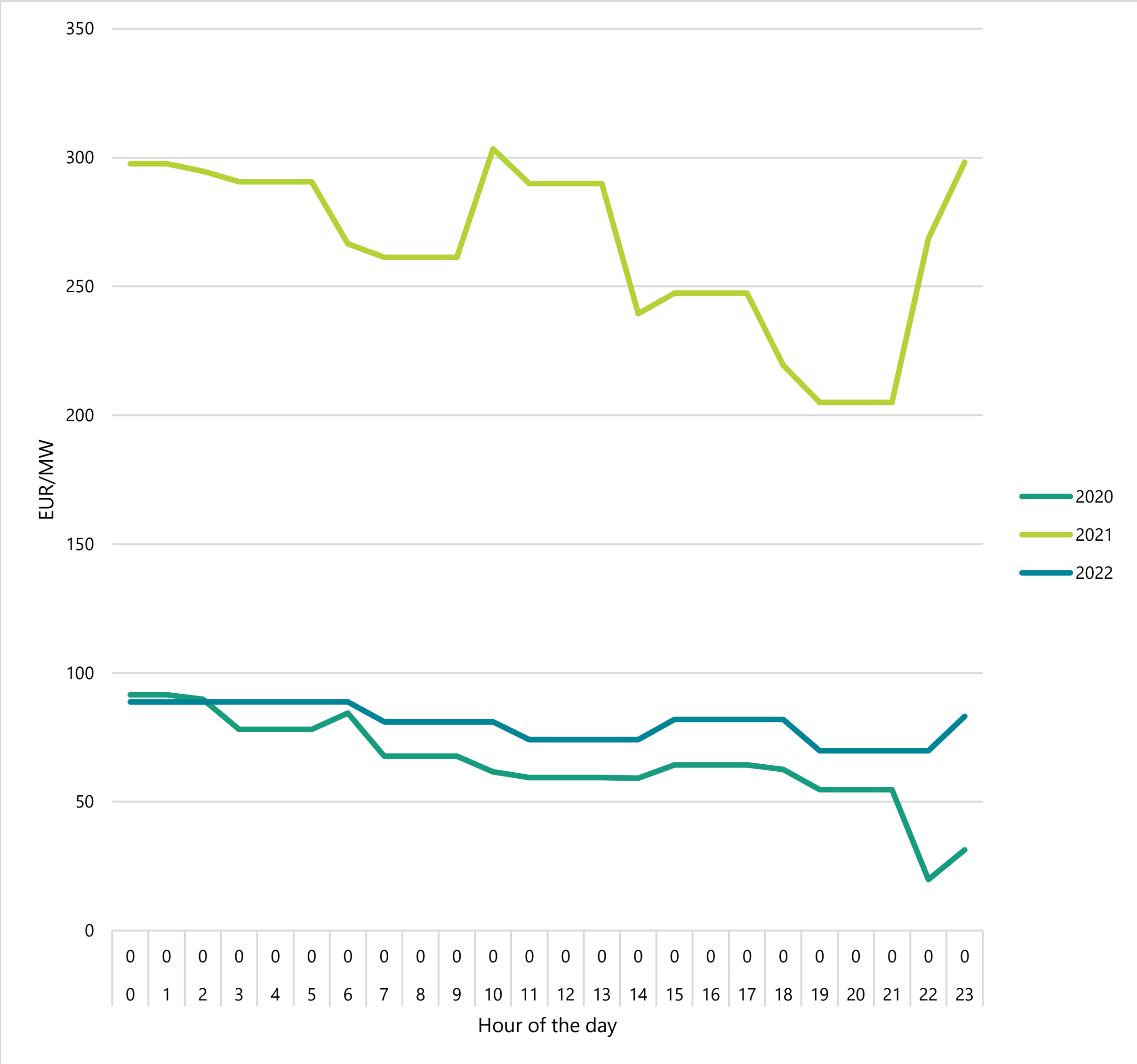
Figure 18 Annual average price for procured capacity (FCR) from 2019 to 2022 in selected countries (EUR/MW/per contract resolution)



Source: own calculation

The contracted average price for the procured FCR over the course of a day varies, which is illustrated for Belgium in the Figure 19. Average capacity price level is about 3 times higher for the year 2021 compared to 2020 and 2022. The peak capacity prices were typically reached in the night times. In the year 2021 a high-capacity price was also seen between 9:00-12:30 varying between 280 and 310 EUR/MW per one hour. Periods with lower capacity price levels were noticed around the evening times after 18:00 for all years.

Figure 19 Average prices for procured capacity (FCR) over the day from 2020 to 2022 in Belgium (EUR/MW per one hour)



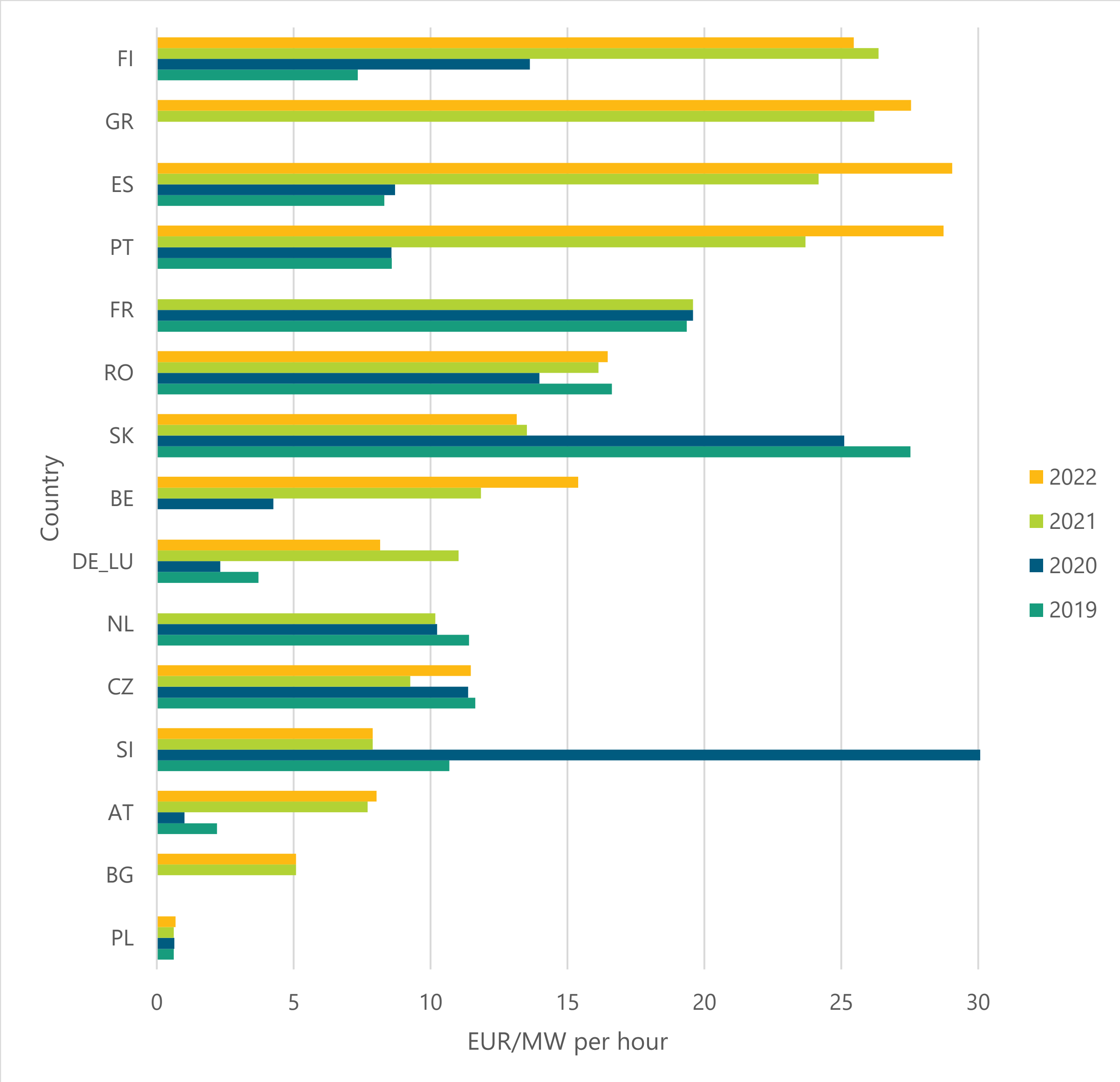
Source: own calculation

3.2.3.2 aFRR - Automatic Frequency Restoration Reserve

In the majority of countries, the average price of activated balancing capacity from aFRRs has followed a similar pattern between 2019 and 2021. Nevertheless, as illustrated in Figure 20, the growth of prices in each country continues to be significantly distinct. After 2019, the prices decreased in most countries, e.g. in Germany and Luxembourg, Romania or in Slovakia[106].

[106] ACER (2021), Market Monitoring Report 2020 – Electricity Wholesale Market Volume

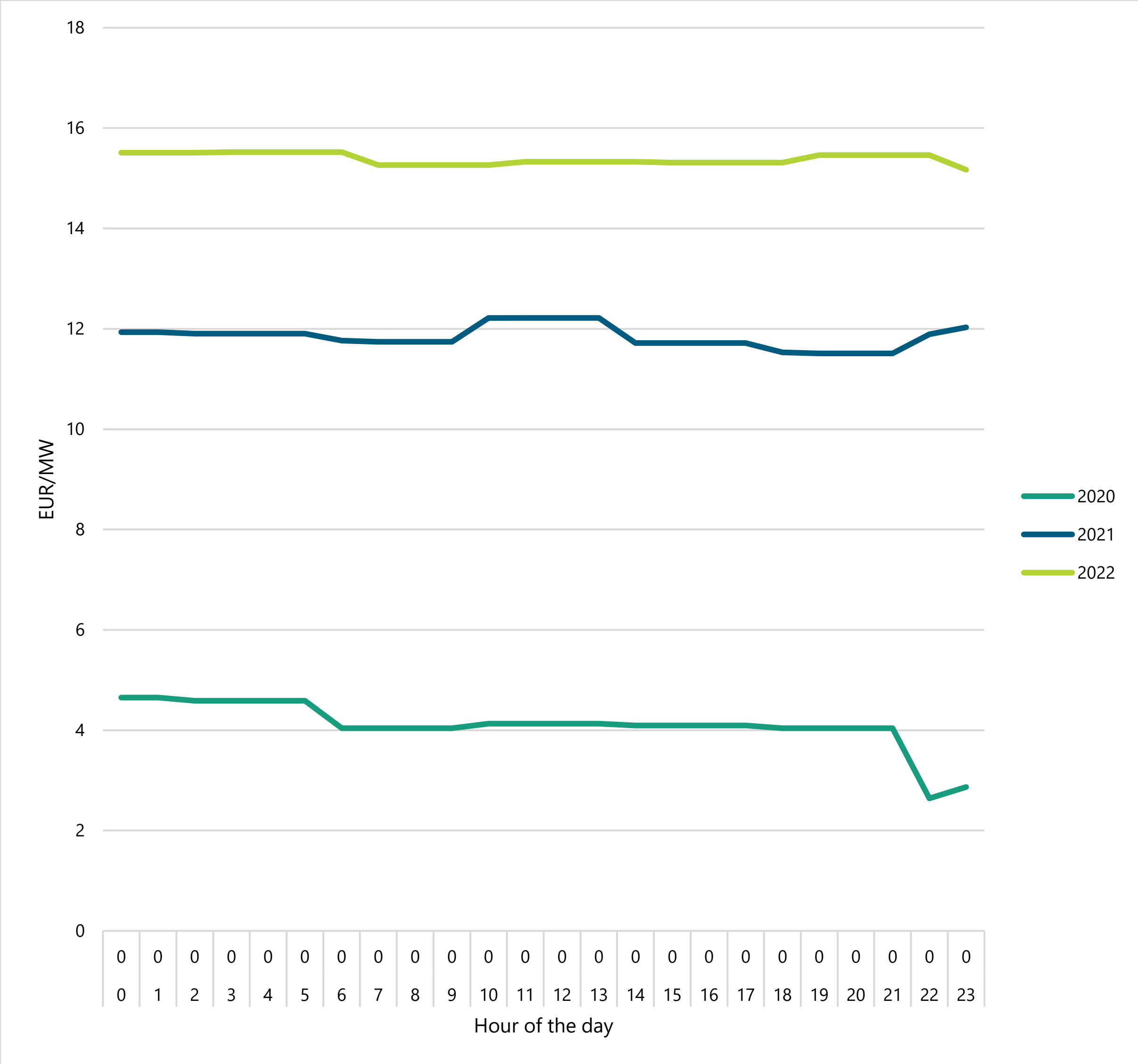
Figure 20 Annual average price for procured capacity (aFRR) from 2019 to 2022 in selected countries (EUR/MW per hour)



Source: own calculation

On closer inspection of the average costs throughout the day in Belgium as seen in Figure 21, the prices are three times higher in 2021 than in 2020. It may have been caused by the COVID-19 pandemic and related lockdown measures that had a substantial effect on energy systems in 2020. Compared to 2020, hourly pricing was mostly steady throughout the day in 2021.

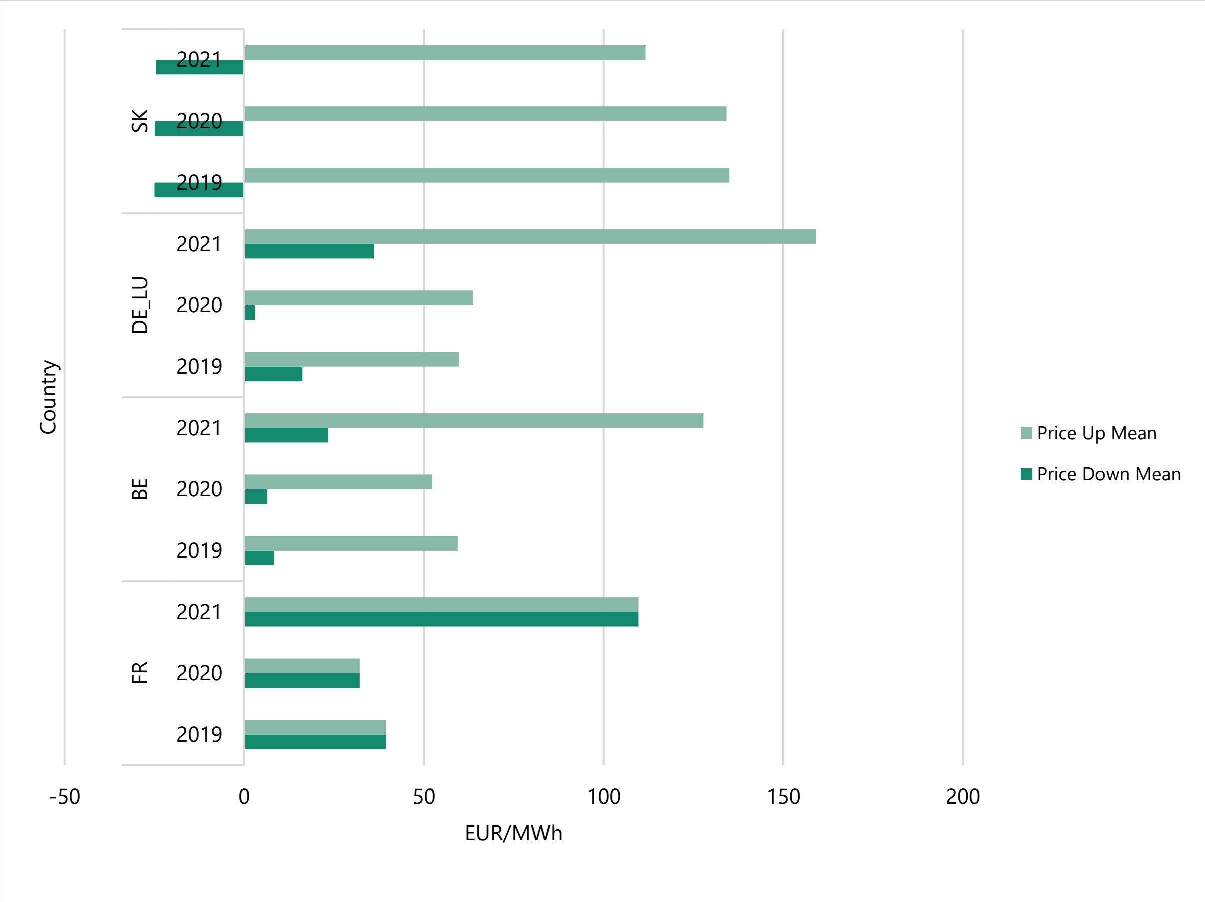
Figure 21 Average prices for procured capacity (aFRR) over the day from 2020 to 2022 in Belgium (EUR/MW)



Source: own calculation

With the exception of Germany and Luxembourg, all countries observed lower prices for upward capacity in comparison to 2019, which indicates that this service was on average less costly to TSOs. In 2021, practically all countries in the Figure 22 witnessed significant increase in the price of the service. However, the service became much more costly in 2021 for almost all countries. A similar pattern can also be seen for the downward regulation service. Figure 22 in particular clearly shows that the Slovakian downward capacity price was not only negative (providers have to pay for received energy) but also stable throughout the course of the three years. These two developments in Slovakia may be the consequence of three years of declining electricity demand. Each country's annual prices for downward and upward capacity vary, however in France, prices for both services are same.

Figure 22 Annual average price for activated balancing energy (aFRR) from 2019 to 2021 in selected countries (EUR/MWh)

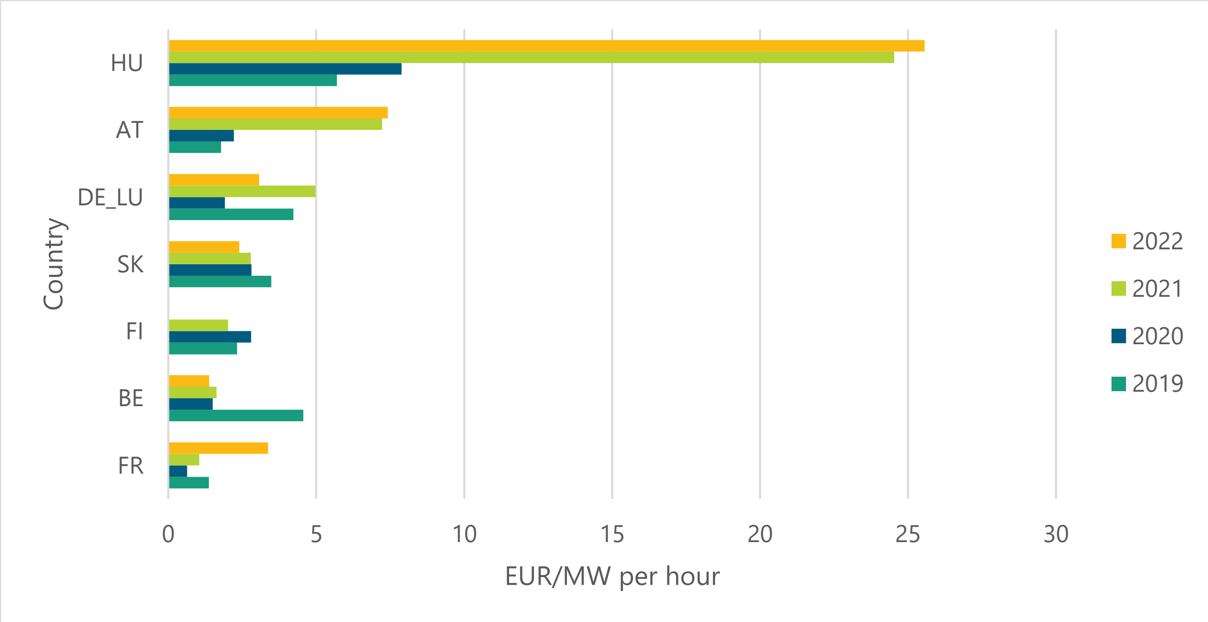


Source: own calculation, prices are weighted to time and not with regard to the activated balancing energy

3.2.3.3 mFRR - Manual Frequency Restoration Reserve

In 2019 and 2021, the average prices of manual balancing capacity, mFRRs have followed similar patterns in most of the countries, with the exception of France. As depicted in Figure 23, there is a minor decline in prices in 2022 compared to 2021, whilst prices in France almost tripled. Nevertheless, the price development in each country continues to be considerably distinct. On further analysis, the 2019 peak prices in Belgium declined by a factor of three compared to the future years. For the remaining countries, the varying pattern is apparent.

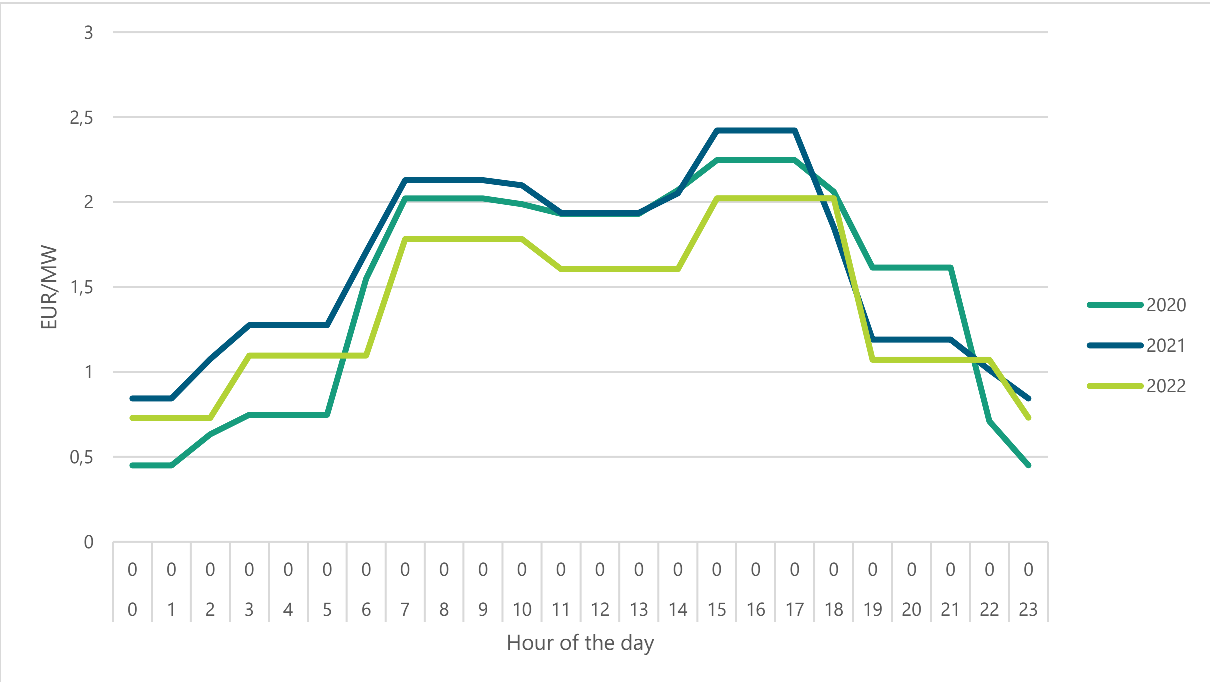
Figure 23 Annual average price for procured capacity (mFRR) from 2019 to 2022 in selected countries (EUR/MW)



Source: own calculation

Unlike aFRR, the yearly average hourly price fluctuates slightly from year to year (see Figure 24). These hourly prices exhibit a spike between 7:00 and 9:00 am and between 15:00 and 17:30 pm. In 2021, the highest peak prices between 15:00 and 17:30 were 2.5 EUR/MW, whilst the lowest prices in 2020 were below 0.5 EUR/MW.

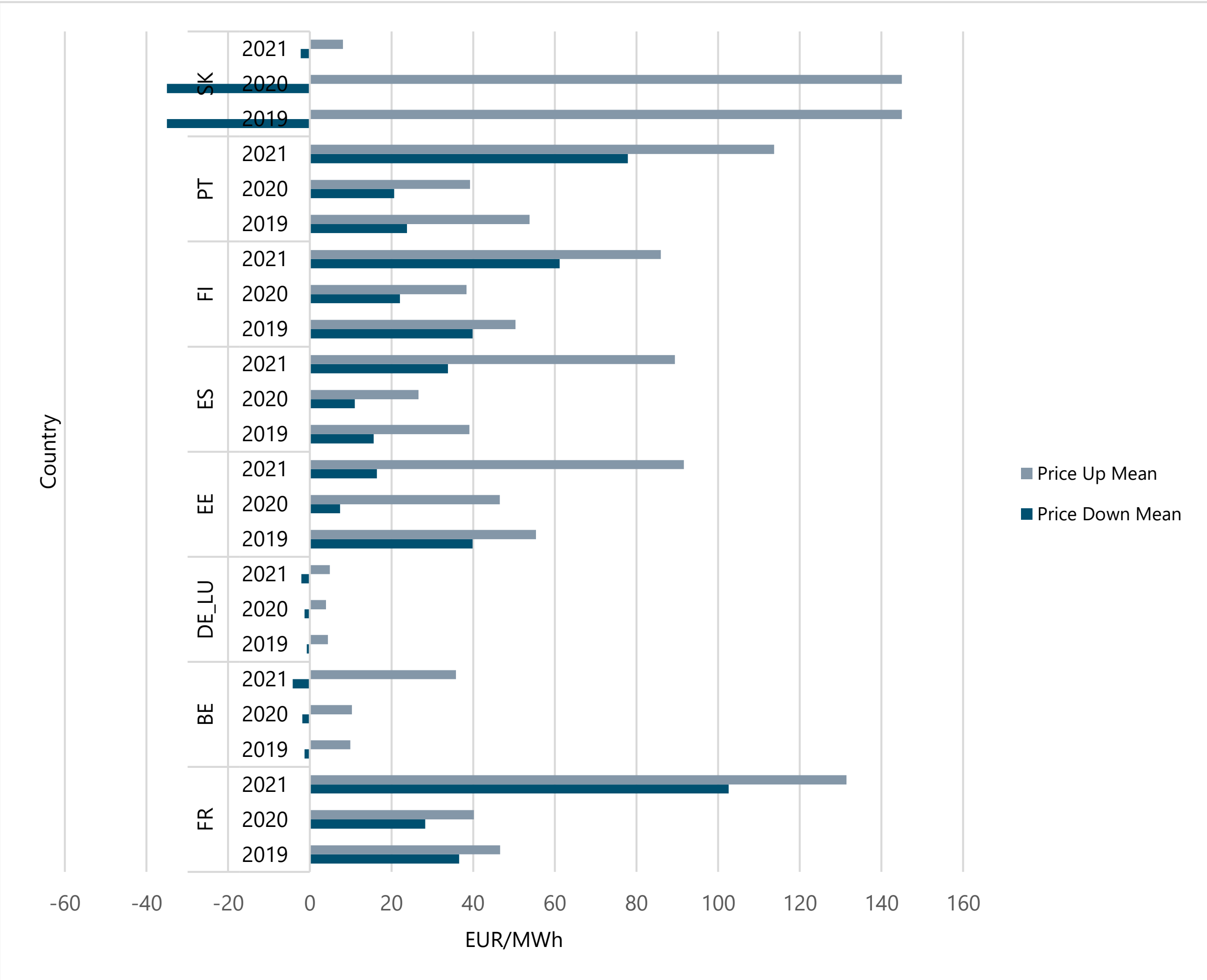
Figure 24 Average prices for procured capacity (mFRR) over the day from 2020 to 2022 in Belgium (EUR/MW per hour)



Source: own calculation

The pattern of average price development for upward energy services for mFRR remains the same for the majority of the countries, with some exceptions. Germany, Luxembourg, and Belgium observed lower prices for upward capacity for each country, which indicates that this service was on average less costly to TSOs. However, in 2021, the price was 3 times higher than in 2020 in Belgium. Estonia, Finland Portugal and Slovakia have experienced high prices in 2019 and 2020. The peak price was seen in Slovakia reaching beyond 140 EUR/MWh, which substantially dropped to 10 EUR/MWh. In Figure 25, it can be noticed that the price for upward energy spiked in the year 2021 at around 130 EUR/MWh, which is around thrice the previous years. At the same time, the price for negative energy service was the highest this year at 105 EUR/MWh. The result also shows that Slovakia had the lowest yearly average price (-35 EUR/MWh) for down energy service in the years 2019 and 2020, compared to Germany, Slovakia, and Belgium. In Slovakia participants pay for energy on average, if they provide negative mFRR balancing energy.

Figure 25 Annual average price for activated balancing energy (mFRR) from 2019 to 2021 in selected countries (EUR/MWh)



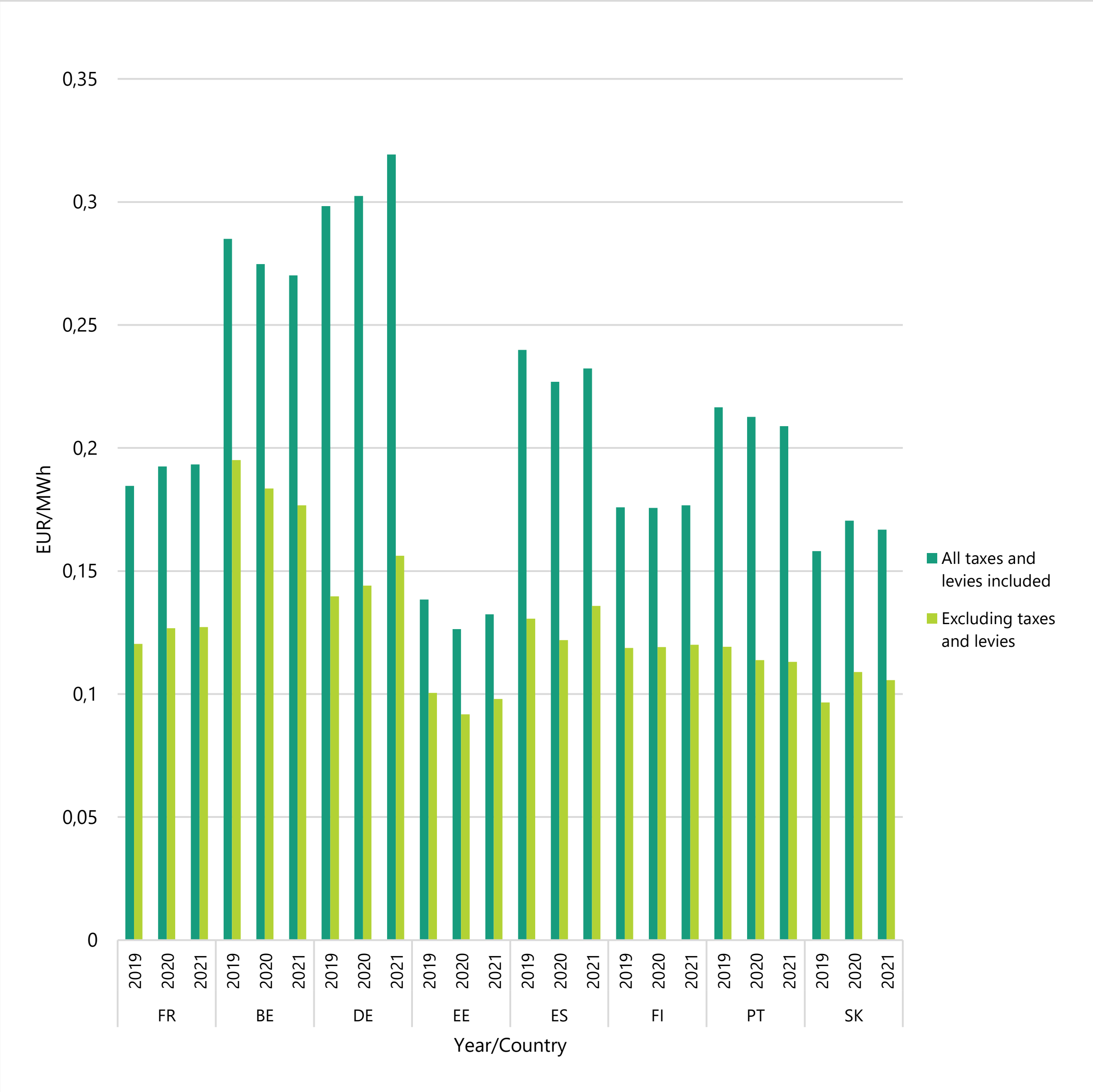
Source: own calculation

3.2.4 Residential electricity prices

This section highlights the development of electricity prices for residential consumers within the EU. Based on EUROSTAT data platform the prices presented here are with and without taxes, levies and VAT for household consumers.

For household consumers in the EU, electricity prices excluding taxes and levies were highest in Belgium in 2019, 2020 and 2021 (0.195 EUR/kWh, 0.183 EUR/kWh and 0.176 EUR/kWh, respectively); see Figure 26. The lowest electricity prices were in Estonia (0.1 EUR/kWh, 0.091 EUR/kWh and 0.098 EUR/kWh, respectively). For household consumers in the EU, electricity prices including all taxes and levies was highest in Germany in 2019, 2020 and 2021 (0.29 EUR/kWh, 0.30 EUR/kWh and 0.31 EUR/kWh, respectively). The lowest electricity prices were in Estonia (0.13 EUR/kWh, 0.12 EUR/kWh and 0.13 EUR/kWh, respectively).

Figure 26 Development of retail prices from 2019 to 2021 in selected countries (EUR/MWh)



Source: own calculation

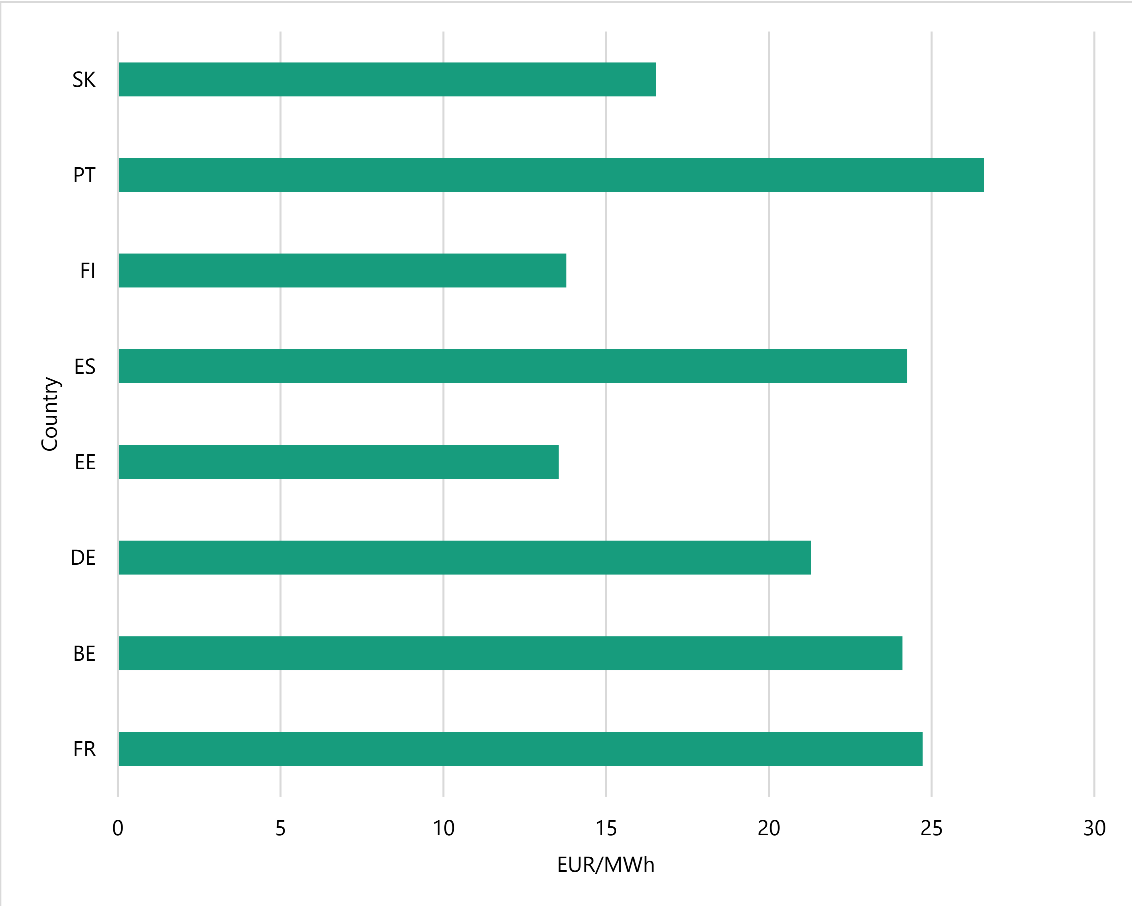
3.2.5 Future electricity market development

Based on JRC'S dataset, average daily price spreads were calculated as indicators for potential market revenues.

- Highest daily price spread: Difference between highest and lowest hourly market price within on day (24 hours)

Calculations are done for selected EU member states for the year 2030. In 2030 (Figure 27), average wholesale electricity price spreads are expected to be significantly lower than in 2021 (see Figure 14). Estonia has the lowest price in the selected countries in the range between 15 and 18 EUR/MWh and Portugal has the highest in the range between 25 and 28 EUR/MWh.

Figure 27 Average daily price spreads in the day ahead market in selected countries for 2030 (EUR/MWh)



Source: own calculation

3.3 Qualitative assessment of other applications

Next to the described market applications several other services can be provided by storage technologies. Revenues are generated via direct payments or indirectly via avoided costs for other services. As no markets for these services currently exist the assessment of potential incomes is done in a qualitative way. Typical payments resp. avoided costs are described and examples for implementations of these non-market applications are given.

3.3.1 Storage to support transmission and distribution infrastructure

Main services to support transmission and distribution infrastructure are reactive power compensation, grid upgrade deferral and contingency support.

3.3.1.1 Transmission infrastructure support

Examples for services in the transmission grid are upgrade deferral, congestion relief and contingency support.

Contingency support can play a major role in future power systems with high shares of renewable energies if spinning reserve from fossil generators are less available. "Virtual inertia" can be provided by storage technologies e.g. batteries in combination with grid-forming inverters. Grid planning and future system roadmaps e.g. in Germany, Great Britain or in Australia already indicate the need for virtual inertia especially for a save operation when parts of the power grids become separated from the main synchronous system.

In the recent scenario framework 2021 for the German grid development plan up to 100 GW of storage capacity (behind the meter and utility scale battery storage) are assumed until 2037[107]. System operation and system stability require the implementation of instant reserves substituting fossil generators. Battery storage is indicated as one possible solution next to the upgrade of wind and pv generators, phase shifter in gas power plants and controllable reactive power compensation systems[108]. Revenues for the provision of such capabilities are not defined so far, but discussions have been started to extend ancillary service markets with new system services[109].

In the German grid development plan battery storage is also foreseen to increase grid utilisation and avoid grid congestions with the so called "grid booster concept"[110]. Three projects are currently foreseen to relieve grid congestions. Investments should be covered under the grid regulation scheme within a given amortisation time frame of 15 years, but conditions are not finally decided.

In less interconnected systems with a high diffusion rate of renewable energies system splits could have a stronger impact on the system and would cause larger outage time for electricity users. For this reason, power system operators in Australia or Great Britain have worked on research projects and implemented demonstration sites that identified potential benefits of storage technologies for grid operation[111]. Potential revenues can come from market services, direct contracted services or regulated services as part of the grid regulation. Also direct funding with government support could be feasible. The discussion on market design to value the capabilities of storage technologies is ongoing[112].

Research activities of the Australian energy market operator (AEMO) identified the role that storage can play in the transition of the Australian power system[113]. Demonstration projects with battery storage have been implemented that use different revenue streams. One of the largest battery

[107] https://www.netzentwicklungsplan.de/sites/default/files/paragraphs-files/Szenariorahmenentwurf_NEP2037_2023.pdf

[108] https://www.netzentwicklungsplan.de/sites/default/files/paragraphs-files/NEP_2035_V2021_2_Entwurf_Systemstabilitaet.pdf

[109] https://www.energate-messenger.de/news/215087/uebertragungsnetzbetreiber-fordern-aenderungen-am-energiemarktdesign

[110] https://www.netzentwicklungsplan.de/sites/default/files/paragraphs-files/NEP_2035_V2021_2_Entwurf_Teil1_0.pdf

[111] https://www.esig.energy/download/survey-of-grid-forming-inverter-applications-julia-matevosyan/?wpdmdl=7869&re-fresh=60c1f40f22d5f1623323663

[112] https://esb-post2025-market-design.aemc.gov.au/

[113] https://aemo.com.au/-/media/files/initiatives/engineering-framework/2021/application-of-advanced-grid-scale-inverters-in-the-nem.pdf?la=en&hash=B4E20D68B23F66090ADA5FD47A50D904

projects in Australia is the Hornsdale power reserve project. The battery receives a government support of AUD 4 million every year over ten years to provide 90 MW of frequency reserve, which represents 3.2 Euro/MW/h. Further storage projects in Australia that provide grid services are the Dalrymple battery project (30 MW/ 8 MWh) in South Australia, which is the first project with advanced inverter technology. It receives AUD 12 million funds from Australian government[114]. The largest planned grid-forming battery in the world will be constructed by Australian utility AGL. The 250MW/250MWh Torrens Island battery will have an investment of 180 million dollars and should be operational in 2023[115]. Furthermore, the Australian renewable energy agency announced AUD 100 million as direct funding for grid-forming inverters[116] expecting to finance at least three projects.

In Europe battery storage projects have been implemented under the enhanced frequency response (EFR) regime in UK. National Grid launched a 200 MW action in 2016 on EFR and selected 8 battery storage projects that receive GBP 9.44 MW/h over 4 years (10.7 Euro/MW/h).

Scottish Green Battery Complex (Hunterston and Kincardine) will participate in National Grid's Scottish Stability Pathfinder 2 tender, which seeks to address voltage and stability issues faced by the U.K. electricity grid. The battery should provide grid stability services and power management across the central belt of Scotland[117]. Parts of the battery revenue will be provided from this tender to the projects.

3.3.1.2 Distribution infrastructure support

Energy storage systems can secure a reduced demand taken from the grid and benefit from lower network charges. Investment deferral for distribution grids have been a main use case for storage project e.g., in California. Currently discussion on flexibility markets like Equigy[118] are ongoing in Europe, in UK the Piclo Flex market started to trade energy flexibility online on an independent marketplace[119]. Storage can contribute its services via these platforms to grid operators, but distribution grid related markets and potential revenues are still under discussion. In Germany incentives should be given to flexible demand and storage technologies to support distribution grid operators. Revenues could be given as a direct payment, if storage applications become controllable by grid operators. Another discussed option is a variable grid tariff in times of higher grid congestions.

3.3.2 Capacity provision, capacity markets/auction

Capacity markets are another option for storage technologies to generate revenues. Especially in power systems, where security of supply is in a strong focus, capacity markets have been implemented in the past. Capacity markets can be set up with capacity payments or with quantity mechanisms.

[114] https://www.pv-magazine-australia.com/press-releases/grid-scale-escri-battery-charges-up-in-south-australia/

[115] https://www.pv-magazine.com/2021/11/30/work-begins-on-250-mw-250-mwh-grid-forming-battery-in-australia/

[116] https://www.pv-magazine.com/2021/12/30/australia-pours-funding-into-advanced-inverter-capability-batteries/

[117] https://www.pv-magazine.com/2022/01/26/europes-largest-battery-storage-project-leverages-grid-forming-inverter-tech/

[118] https://equigy.com/

[119] https://picloflex.com/

Under capacity payments storage technologies receive a payment for the provision of firm capacity, whereas under quantity mechanisms a specific capacity is auctioned or tendered and storage technologies receive the price bid from the auction or tender. In existing programs storage technologies have participated and won in auction to provide firm capacity.

In UK already in 2013 a capacity mechanism was proposed that has two types of auctions: T-4, which is held four years in advance (capacity is not required until four years later), and T 1, which is held one year in advance. Battery storage participated in the auctions and won 252 MW (after 150 MW and 500 MW) in recent auctions[120]. The clearing price for the T-4 auction was equal to GBP 18 per kW and year (2.3 EUR/MW per h) for delivery in 2025 to 2026.

Delivery year	2017-18	2019-20	2018-19	2019-20	2020-21	2021-22	2022-23	2023-24	2024-25	2025-26
Main auction date—years before delivery	1	1	4	4	4	4	3	4	4	4
Price (£/KW per year)	7	0.8	19	18	23	8.4	6.4	16	18	30.6
Capacity (GW)	54	4	49	46	52	50	45	44	41	42
Total cost (£m, nominal)	378	3	956	834	1180	423	290	698	734	1296

Source: EMR delivery body[121]

Another revenue stream could be established when storage is combined with renewable generation and especially with PV generation. This allows the reduction of peak capacity and reduce grid connection fees. Revenues are very location specific and related to network tariffs of the relevant grid level.

3.4 Assessment of revenue/cost gaps

In this section, the potential revenue/cost gap selected business opportunities for energy storage is assessed. The analysis is conducted based on the technology data from Task 1 and the market indicator dashboard presented in the framework of Task 2.1. To illustrate the influence of different market conditions, costs, potential revenue and resulting revenue/cost gaps are calculated on an annual basis by distributing the necessary investment (including interest) and operational costs over the lifetime of the energy storage (annuity method). The reader should keep in mind that the assessment is performed without the use of an energy system model. It thus excludes interactions with the energy system. Possibilities for revenue stacking, which improve the business case of the storage technologies, are not considered, since assessing multi-use concepts would require to calculate the flexibility potential available for different purposes dynamically while also considering risk affinity, uncertainties and other factors relevant for a functioning multi-use concept. This analysis is performed for selected Member States and years. A comprehensive analysis of the individual investment conditions in each member state and considering all possible business cases is beyond the scope of this report.

[120] Capacity Market auction results, KPMG, London https://assets.kpmg/content/dam/kpmg/uk/pdf/2021/03/kpmg-capacity-market-t-4-results.pdf.

[121] https://www.emrdeliverybody.com/CM/Capacity%20Auction%20Information.aspx

3.4.1 Arbitrage trading on the day ahead spot market

Various factors such as the expansion of renewables, the demand increase through sector integration, the phase-out of fossil power plants as well as recent political events have led to an increase of power prices as well as a general rise of the volatility of the power markets. As shown in Section 3.2.1, this is the case throughout Europe. Consequently, arbitrage trading, i.e., profiting from power markets spreads by selling during peak price hours and purchasing power during periods of low prices using energy storage can become a functioning use case.

To give an assessment of the approximate revenue/cost gap of this use case, we used the technology data from Task 1.3 for a large-scale short-term storage. Table 12 gives an overview on the parameters we assumed for this use case.

Table 12 Arbitrage trading parameter assumptions

Parameter	Description
Storage type	short-term storage, large scale (LIB)
Storage capacity [MWh]	1
C-Rate	1
Lifetime [years]	15
CAPEX [€/MWh]	345000
OPEX [% of CAPEX]	0.5%
Round trip efficiency [%]	88% (2030: 90%)
Lifetime [cycles]	3000
Interest rate [%]	3%
Annual cost of storage [EUR/a]	28899

Source: Task 1 / own assumptions

For our calculation of the use case spot market trading, we further assumed two variations:

1) The storage can make one full cycle per day. Furthermore, the average daily spread (i.e., between the highest and lowest price of the day) can be exploited.
2) The storage can make two full cycles per day exploiting both the highest and the second highest spread per day.

Our calculation is based purely on techno-economic parameters and correspondingly not a modelling task. Therefore, we do not cover any effect caused by the interaction of large-scale storage technologies with the market or cannibalisation effects. Additionally, we assume that the storage system can benefit from the full daily spread (and second largest spread). The calculation is based on the day-ahead prices (also presented in the market indicator dashboard).

Table 13 and Figure 28 refer to spot market trading in France.

Table 13 Potential income from arbitrage trading for France Average spreads and potential income from arbitrage trading using historical day-ahead market prices for France

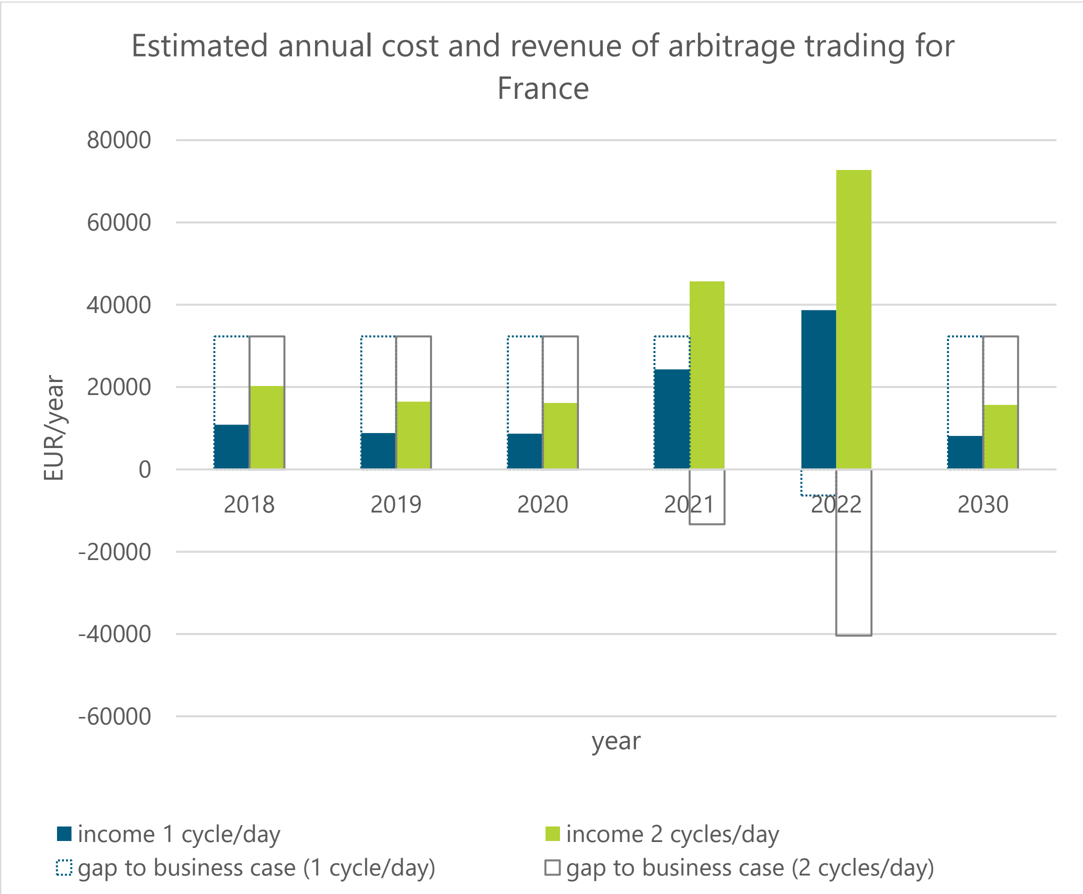
The indicator "Average daily spread second" refers to the spread between the second highest and the second lowest price per day. A negative "gap to business case" indicates positive revenue.

		2018	2019	2020	2021	2022	2030
Average daily spread (day-ahead market)	EUR/MWh	34	27	27	76	120	25
Average daily spread second (day-ahead market)	EUR/MWh	29	24	23	67	106	23
Income 1 cycle/day	EUR	10816	8797	8694	24278	38692	8121
Income 2 cycles/day	EUR	20231	16463	16121	45670	72736	15707
Number of cycles during lifetime (1 cycle/day)	cycles	5475	5475	5475	5475	5475	5475
Number of cycles during lifetime (2 cycles/day)	cycles	10950	10950	10950	10950	10950	10950
Gap to business case (1 cycle/day)	EUR	21533	23553	23656	8072	6343	24228
Gap to business case (2 cycles/day)	EUR	12119	15886	16229	-13321	-40387	16642

Source: Task 1 / own assumptions

Figure 28 Spot market trading using large-scale LIB storage, the case of France

A negative gap to business case indicates that the potential revenue is positive.



Source: own calculation

As visualised through the "gap to business case" in the figure, the earnings from arbitrage trading in the years 2018 to 2020 are not sufficient to compensate for the investment and operational costs of the storage system. The increased volatility of the day-ahead market prices in the years 2021 leads to increasing income and consequently a positive estimated net revenue, if more than one cycle per day can be performed. For the first months of 2022, the results indicate that revenue is even slightly positive for one cycle per day. For the METIS modelling results for the year 2030, the recent price and price spread increases were not taken into consideration. Consequently, 2030 aligns with the years 2018-2020. As a result, the results indicate a substantial gap to business case, i.e., the revenue from spot market trading is estimated to be negative.

It has to be noted that even for one cycle per day, the technology-specific maximum number of cycles for LIB given by Task 1 is surpassed.

The analysis for France, thus, shows that arbitrage trading under the current conditions can generate positive net revenue, as long as battery deterioration is not an issue. A return to market conditions similar to the years 2018-2020 would, however, lead to negative net revenues.

Table 14 Potential income from arbitrage trading for Germany

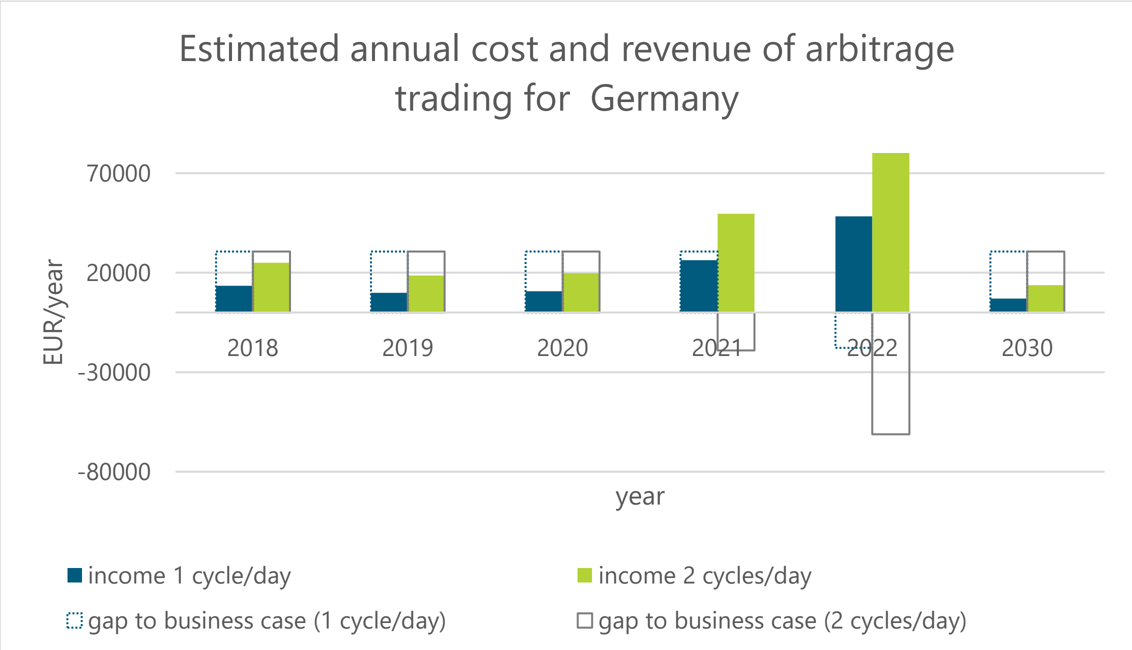
Average spreads and potential income from arbitrage trading using historical day-ahead market prices for Germany

		2018	2019	2020	2021	2022	2030
Average daily spread (day-ahead market)	EUR/MWh	42	31	33	82	150	21
Average daily spread second (day-ahead market)	EUR/MWh	36	27	28	73	136	20
Income 1 cycle/day	EUR	13439	9899	10639	26348	48333	6998
Income 2 cycles/day	EUR	24982	18534	19672	49705	91862	13711
Number of cycles during lifetime (1 cycle/day)	cycles	5475	5475	5475	5475	5475	5475
Number of cycles during lifetime (2 cycles/day)	cycles	10950	10950	10950	10950	10950	10950
Gap to business case (1 cycle/day)	EUR	17186	20726	19986	4276	-17709	23627
Gap to business case (2 cycles/day)	EUR	5642	12091	10952	-19081	-61237	16913

The indicator "Average daily spread second" refers to the spread between the second highest and the second lowest price per day. A negative "gap to business case" indicates positive revenue.

Figure 29 Spot market trading using large-scale LIB storage, the case of Germany

A negative gap to business case indicates that the potential revenue is positive.



Source: own calculation

Figure 29 visualises the revenue/cost gap for Germany. We do not assume a difference in the storage investment or operational costs for different countries. Therefore, the storage annuity costs are equal throughout all cases we present here (for spot market trading). However, as shown in Figure 29, market conditions for Germany are more positive than for France. The "gap to business case" for Germany is lower than for France. This is caused by higher price spreads in the day-ahead market, which result from a higher share of renewables in the market and thus a more volatile supply side.

In contrast, spot market trading in Spain is estimated to have a substantially large gap to business case under the market conditions of the 2018 – 2020 and to be having a negative revenue in 2021 as well if only one cycle per day is assumed.

Table 15 Potential income from arbitrage trading for Spain - Average spreads and potential income from arbitrage trading using historical day-ahead market prices for Spain

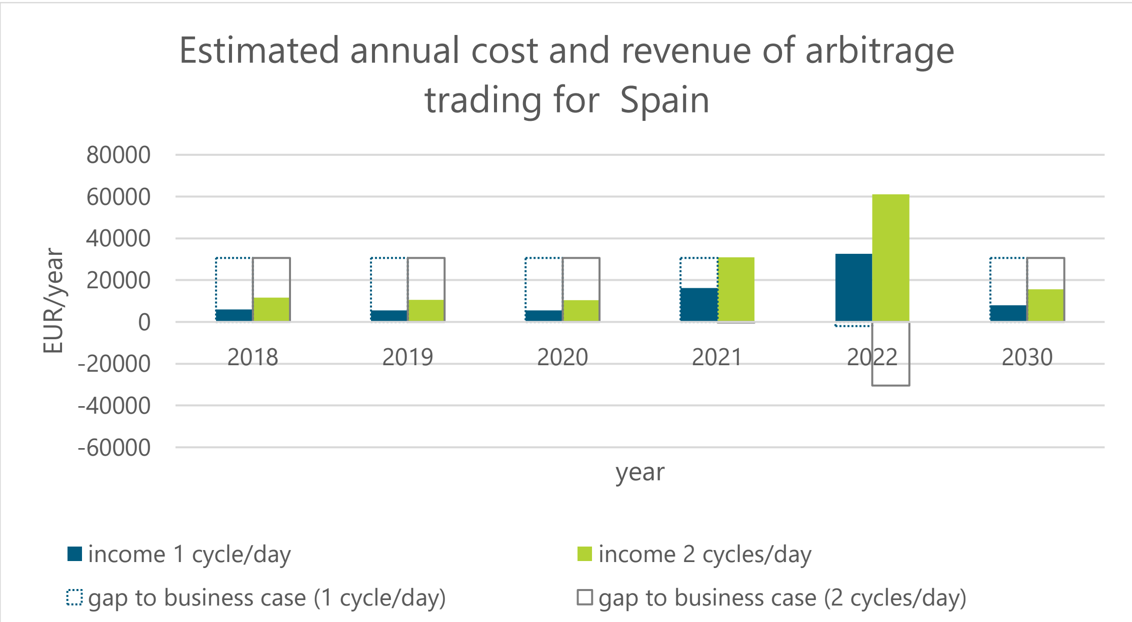
The indicator "Average daily spread second" refers to the spread between the second highest and the second lowest price per day. A negative "gap to business case" indicates positive revenue.

		2018	2019	2020	2021	2022	2030
Average daily spread (day-ahead market)	EUR/MWh	19	17	17	51	101	24
Average daily spread second (day-ahead market)	EUR/MWh	17	16	15	46	89	23
Income 1 cycle/day	EUR	6040	5521	5535	16284	32592	7965

		2018	2019	2020	2021	2022	2030
Income 2 cycles/day	EUR	11569	10517	10484	30935	61140	15596
Number of cycles during lifetime (1 cycle/day)	cycles	5475	5475	5475	5475	5475	5475
Number of cycles during lifetime (2 cycles/day)	cycles	10950	10950	10950	10950	10950	10950
Gap to business case (1 cycle/day)	EUR	24584	25103	25089	14341	-1968	22659
Gap to business case (2 cycles/day)	EUR	19056	20107	20141	-310	-30516	15029

Figure 30 Spot market trading using large-scale LIB storage, the case of Spain

A negative gap to business case indicates that the potential revenue is positive.



Source: own calculation

3.4.2 Provision of frequency containment reserve

Due to their technical characteristics, battery storage systems are actively involved in the FCR market. While prices for activated balancing energy mainly compensate (partly) the procurement of energy, i.e., the loading of a storage, the provision of automated frequency reserve is attractive due to high prices for capacity.

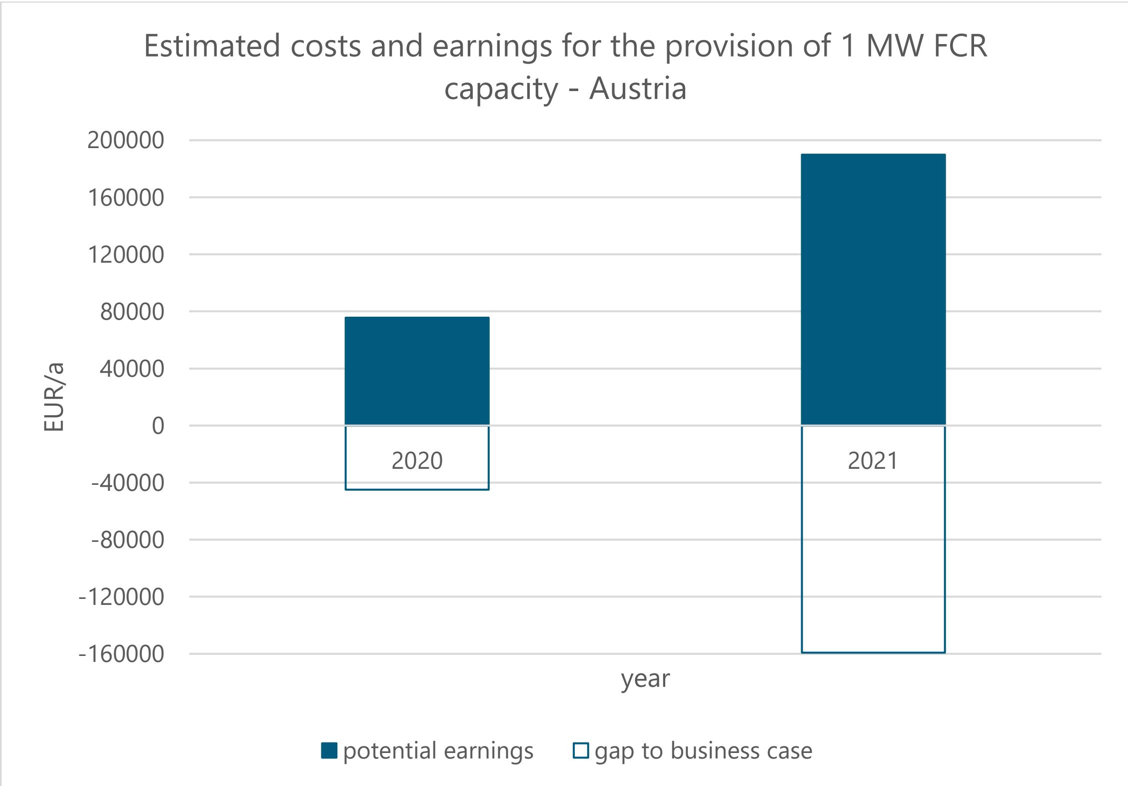
For the calculation of earnings on the FCR market, we assume that storage costs and technical parameters are identical to the ones used for arbitrage trading[122]. Figure 31 shows the potential

[122] In recent years, the rules for the market for FCR have changed in many countries. Therefore, data availability for many countries and years is still limited.

earnings for Austria assuming the average contracted price of each quarter hour (symmetric) for the years 2020 and 2021. As can be seen, capacity prices and thus potential earnings have increased largely between both years. Correspondingly, as the same storage system would be used, providing primary reserve would be profitable in 2020 but even more in 2021 with net revenues of approx. 160,000 EUR/MW. In France (Figure 32), earnings would have been slightly lower than in Austria due to a lower average level of capacity prices. This business case would, however, still be attractive for storage systems.

Figure 31 Provision of capacity to the FCR market using large-scale LIB storage, the case of Austria

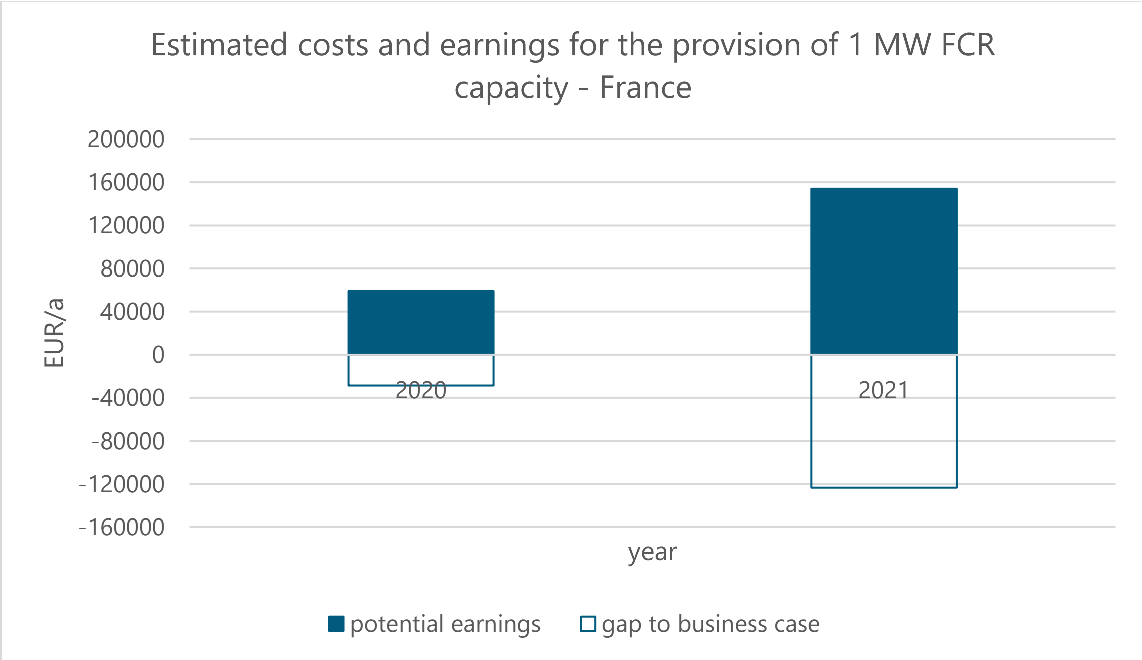
A negative gap to business case indicates that the potential revenue is positive.



Source: own calculation

Figure 32 Provision of capacity to the FCR market using large-scale LIB storage, the case of France

A negative gap to business case indicates that the potential revenue is positive.



Source: own calculation

3.4.3 Residential behind-the-meter storage technologies

Due to the fall of PV and battery prices as well as the increase of retail electricity prices (which particularly steep in recent years, see Section 3.2.4), self-consumption models are increasingly popular in Europe. While PV-storage systems also increase the self-supply of a household, the main driver for their installation are reduced electricity costs compared to buying electricity from the grid as well as a gradual reduction of feed-in tariffs in most European countries. In most countries, self-consuming avoids grid charges and other fiscal charges. Battery systems increase the share of self-generated electricity by storing excess energy during the day and covering the residential demand particularly in evening and night-time hours. Thus, storage systems reduce the amount of excess electricity that is curtailed or induced into the grid at comparably unfavourable rates. Correspondingly, Klingler et al. (2019) expect to see 80 million residential battery systems by 2050 (90% of all households) in the EU-27+UK+NO+CH[123].

In contrast to this, net metering schemes, in which energy that is induced back into the grid, is rewarded with high prices, e.g., the retail price (as performed in NL or PL), reduces or removes incentives for storage systems.

For the calculation of indicative revenue/cost gaps for behind-the-meter systems, we, again, use cost estimations given in Task 1.3 for PV-home storage systems. As the storage systems used here are much smaller in size than the ones, we assume to participate in spot market trading, their CAPEX

[123] A. Klingler; S. Schreiber; A. Louwen (2019): Stationary batteries in the EU countries, Norway and Switzerland: Market shares and system benefits in a decentralized world. In: 2019 16th International Conference on the European Energy Market (EEM). 2019 16th International Conference on the European Energy Market (EEM), S. 1–5

is higher. We assume that the storage increases the share of the household demand covered behind-the-meter by 13% compared to a PV system without storage[124]. For all cases assessed here, we further assume that self-consumption allows to save the full retail price including all charges and taxes.

The reader should be aware that we used average values for our assessment. Depending on country-specific regulatory conditions, retail prices as well as the energy consumption profile of a household, individual results can vary substantially.

Table 16 Behind-the-meter self-consumption parameter assumptions

Parameter	Description
Storage type	PV-home storage systems (LIB)
Storage size [kWh]	2.5
Lifetime [years]	15
CAPEX [€/kWh]	1000
OPEX [% of CAPEX]	1%
Round trip efficiency [%]	88
Lifetime [cycles]	3000
Storage annuity [EUR/a]	187.4
Capital costs [%]	1.5%
Annual household electricity demand [kWh/a]	3700[125]
Annual electricity demand electric vehicle [kWh/a]	3500
Self-consumption improvement through a storage system	13%[126]

Source: Task 1.3 / own assumptions

Table 17 shows the results for the savings through self-consumption using a behind-the-meter storage system as well as the "gap to business case" for France and under the given assumptions outlined above. Furthermore, Figure 33, Figure 34 and Figure 35 illustrate the savings as well as the "gap to business case" for France, Germany and Spain.

Retail prices in France increased slightly between 2018 and 2021 while remaining stable compared to prices on the day-ahead market. As illustrated in Section 3.2.4, France's price level in general is comparatively low. As a consequence, savings from self-consumption are limited (while costs for storage are assumed to be the same as in other countries. As a result, Figure 33 shows that there is still aslight revenue/cost gap under the given assumptions.

For Germany, savings are much higher as the underlying retail electricity price is higher than in France, as a result, behind-the-meter storage systems generate a positive net revenue in all years considered.

[124] We are aware that this calculation is approximative, since the self-consumption rate depends vastly on the household load, the household demand profile and the sizing of the storage.

[125] EU average residential demand 2019 - Odysee-Mure: Electricity Consumption per dwelling. Available online at https://www.odyssee-mure.eu/publications/efficiency-by-sector/households/electricity-consumption-dwelling.html, checked on 7/20/2021.

[126] The self-consumption improvement through energy storage depends on multiple factors such as the residents' behavior, the devices and appliances used in a household, the socio-demographic background of the residents or the sizing of the system. Based on modelling experience from previous projects by Fraunhofer ISI, we assume – on average – the self-consumption rate of a household can be improved by 13% if a storage system is installed.

In Spain, net revenues are lower than in Germany, due to lower retail electricity prices, but we observed that a positive net revenue would still be achieved.

In general, there would be larger savings achievable for all countries if the household electricity demand was higher, e.g., if a battery storage is combined with an electric vehicle (already integrated) or a heat pump.

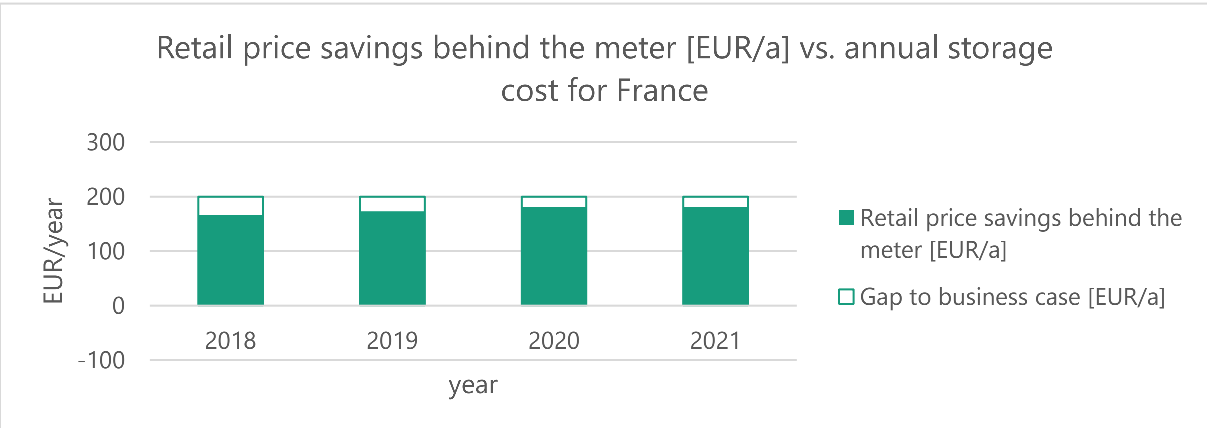
Table 17 Behind-the-meter residential storage in France - Potential savings and gap to business case for residential behind-the-meter storage technologies. The case of France

	2018	2019	2020	2021
Retail price [EUR/kWh]	0.18	0.18	0.19	0.19
Retail price Excluding VAT and other recoverable taxes and levies [EUR/kWh]	0.15	0.16	0.16	0.17
Saving per kWh through behind-the-meter-storage [%]	100%	100%	100%	100%
Retail price savings behind the meter [EUR/a]	166	172.74	180.23	180.93
Gap to business case [EUR/a]	33.86	27.12	19.63	18.93

Source: Task 1 / own assumptions

Saving per kWh through behind-the-meter-storage refers to the share of the retail electricity price that can be saved through self-consumption. We assume that no fiscal charges are due for self-consumed electricity and therefore assume a value of 100%.

Figure 33 Savings and gap to business case for residential behind the meter storage. The case of France



Source: own calculation

Table 18 **Behind-the-meter residential storage in Germany - Potential savings and gap to business case for residential behind-the-meter storage technologies. The case of Germany**

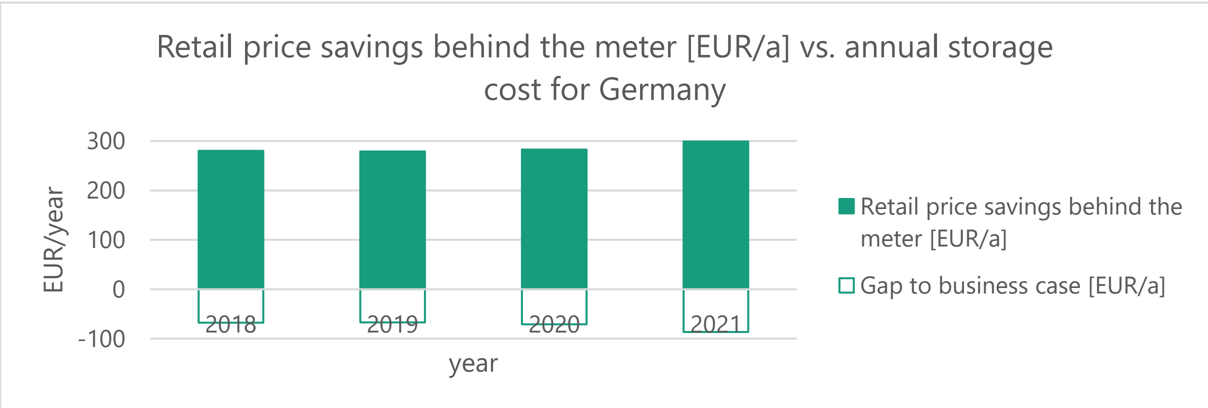
	2018	2019	2020	2021
Retail price [EUR/kWh]	0.30	0.30	0.30	0.32
Retail price Excluding VAT and other recoverable taxes and levies [EUR/kWh]	0.25	0.25	0.26	0.27
Saving per kWh through behind-the-meter-storage [%]	100%	100%	100%	100%
Retail price savings behind the meter [EUR/a]	280.19	279.21	283.09	298.86
Gap to business case [EUR/a]	-67.83	-66.85	-70.73	-86.50

Source: Task 1 / own assumptions

Saving per kWh through behind-the-meter-storage refers to the share of the retail electricity price that can be saved through self-consumption. We assume that no fiscal charges are due for self-consumed electricity and therefore assume a value of 100%.

Figure 34 **Savings and gap to business case for residential behind the meter storage. The case of Germany**

A negative gap to business case would indicate that the potential revenue is positive.



Source: own calculation

Table 19 **Behind-the-meter residential storage in Spain - Potential savings and gap to business case for residential behind-the-meter storage technologies. The case of Spain**

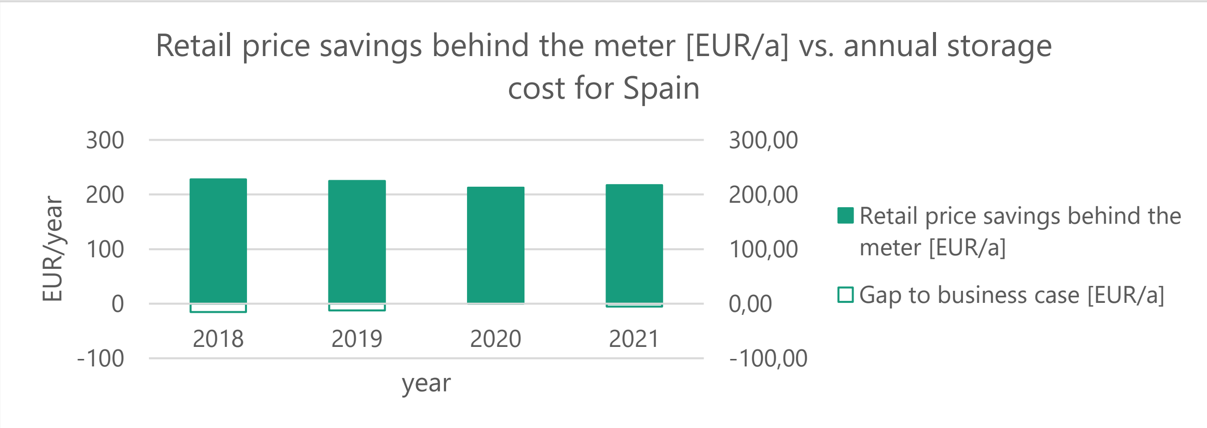
	2018	2019	2020	2021
Retail price [EUR/kWh]	0.24	0.24	0.23	0.23
Retail price Excluding VAT and other recoverable taxes and levies [EUR/kWh]	0.20	0.20	0.19	0.19
Saving per kWh through behind-the-meter-storage [%]	100%	100%	100%	100%
Retail price savings behind the meter [EUR/a]	227.45	224.50	212.33	217.43
Gap to business case [EUR/a]	-15.09	-12.14	0.03	-5.07

Source: Task 1 / own assumptions

Saving per kWh through behind-the-meter-storage refers to the share of the retail electricity price that can be saved through self-consumption. We assume that no fiscal charges are due for self-consumed electricity and therefore assume a value of 100%.

Figure 35 **Savings and gap to business case for residential behind the meter storage. The case of Spain**

A negative gap to business case would indicate that the potential revenue is positive.

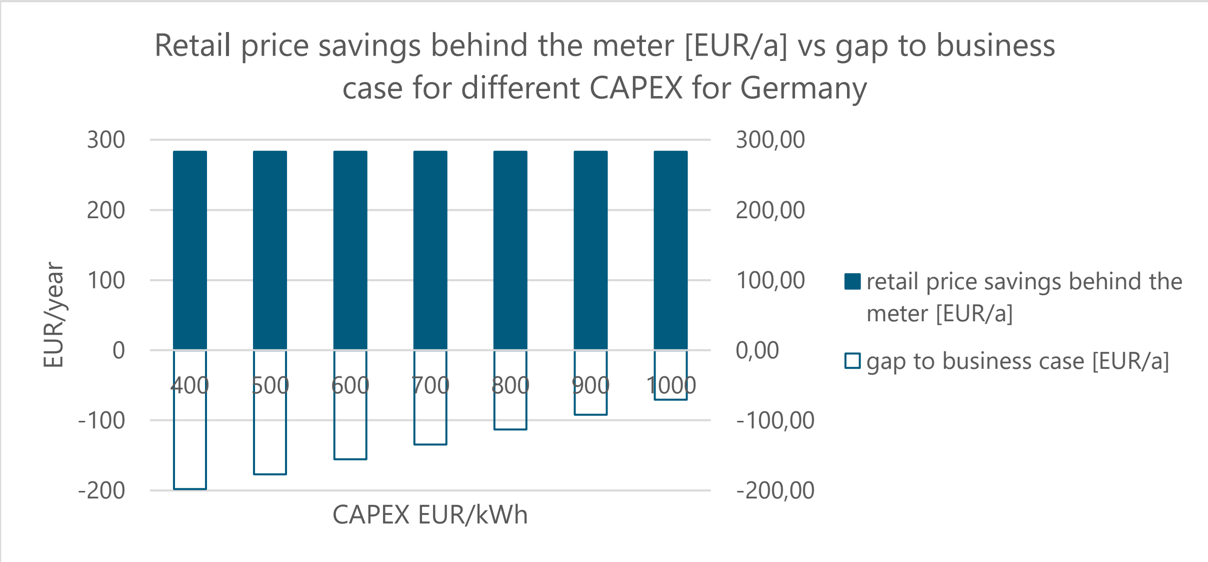


Source: own calculation

The revenue/cost gap for behind-the-meter storage systems depends not only on the avoided costs for electricity drawn from the grid but also vastly on the investment for storage systems. Figure 20 illustrates the influence of upfront investment costs for a storage system in the case of Germany. As outlined above, the storage system is already attractive under the current conditions (CAPEX of 1000 EUR/kWh), but net revenues would further increase for lower storage costs. Therefore, measures that reduce the cost of storage systems should be strengthened in order to increase the attractiveness of behind-the-meter systems.

Figure 36 Influence of storage costs on savings and gap to business case for residential behind the meter storage (using a 2.5 kWh storage system) for Germany

A negative gap to business case would indicate that the potential revenue is positive.



Source: own calculation

3.5 Survey results

3.5.1 Meta data survey

This survey was conducted by TNO on behalf of the EnTEC consortium, in the form of an online questionnaire coded in the Survalyzer environment. A full list of all questions and results is available as separate deliverable. Respondents were given the following background information:

> Thank you for participating in this questionnaire, which should only take approximately 15 minutes of your time. This questionnaire is conducted by the Energy Transition Expertise Center (EnTEC), a think tank collaboration of TNO, Trinomics and Fraunhofer, on behalf of the Directorate-General for Energy of the European Commission.
>
> The aim of this questionnaire is to provide valuable input on:
>
> - Current and future uses of energy storage.
> - Current and future revenue streams for energy storage.
> - Discrepancies between whole-system and private benefits of storage.
> - Barriers and drivers for energy storage.
>
> The responses to this questionnaire will be compiled into a report for the European Commission, helping to inform its energy storage policy. Although energy storage technology is advancing rapidly, high-quality evidence on the current and projected future revenue streams for a wide range of energy storage technologies is scarce. Nevertheless, this evidence is needed to help the Commission identifying key EU actions to support the development of electricity storage as a key flexibility tool, ensuring a level playing field and adequate economic signals. With this questionnaire, we aim to take a first step in closing this gap.
>
> This questionnaire includes four sections:
>
> - Your affiliation
> - Current revenues of energy storage technologies, projects or portfolio
> - Revenues of energy storage technologies, projects or portfolio in the future (2030)
> - Drivers and barriers of energy storage in the EU
>
> Responses to this questionnaire are collected anonymously. You will not be asked for your name, company name, or any other personal details. Your anonymous responses will be stored securely by TNO, in compliance with Dutch and EU data protection regulation (see our privacy statement for more information).

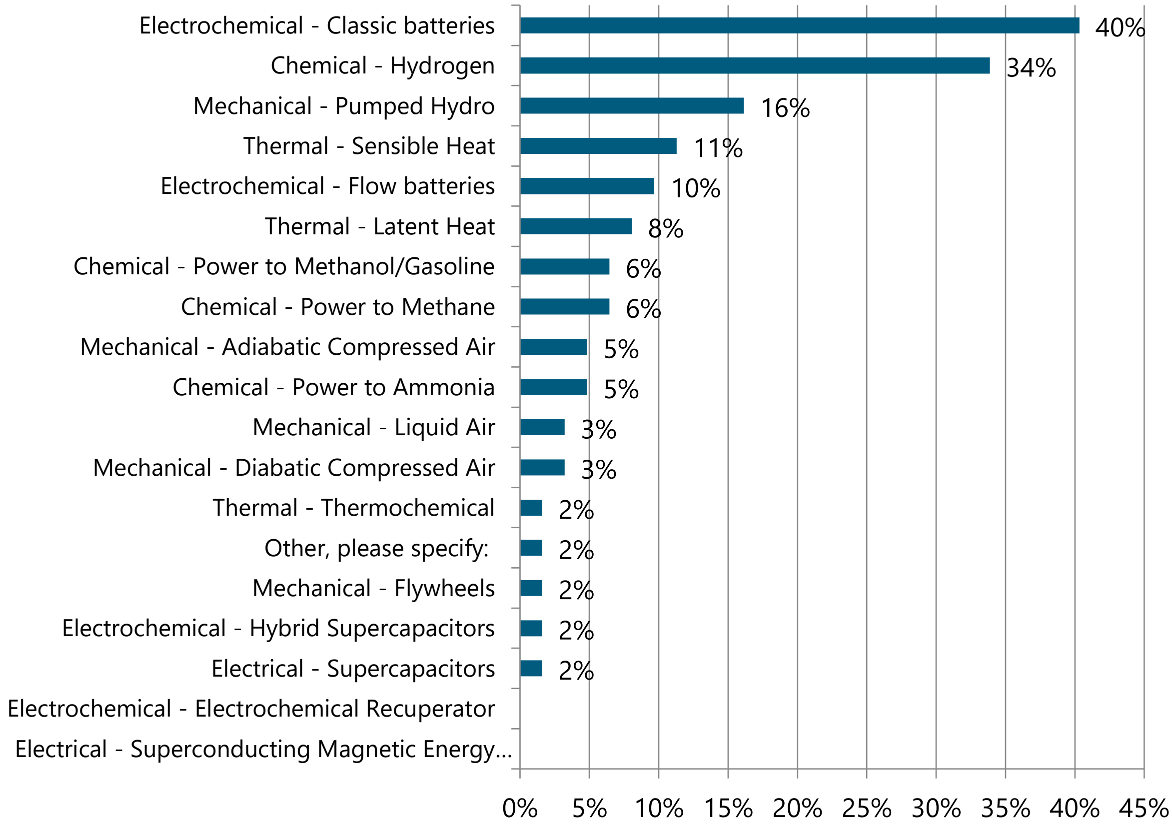
Invitations to complete the questionnaire were sent out by the European Association for Storage of Energy (EASE) to all of their members (including various associations) on the 23rd of March. In addition, the survey was shared with EGEC, GIE, Euroheat & Power and Solar Heat Europe. Respondents were given until the 8th of April to complete the questionnaire; this was later extended to the 13th of May.

93 respondents filled out the survey. Not all of these respondents completed all questions. Valid responses to individual questions have been included in the analysis even if participants did not complete the full questionnaire. Figure 37 and Figure 38 show the distribution of respondents across technologies and countries. Overall, our respondents provide a good cover of technologies and locations; there are higher concentrations of respondents in particular countries (e.g., Germany), which may be a result of the survey dissemination method, but since these countries are also the locations where energy storage investors are most active, the sample is still representative of the current state of the energy storage community.

Responses have been used in the analysis as-is, with the exception of a small number of responses to the questions asking for technology and/or product types. For these questions, responses of

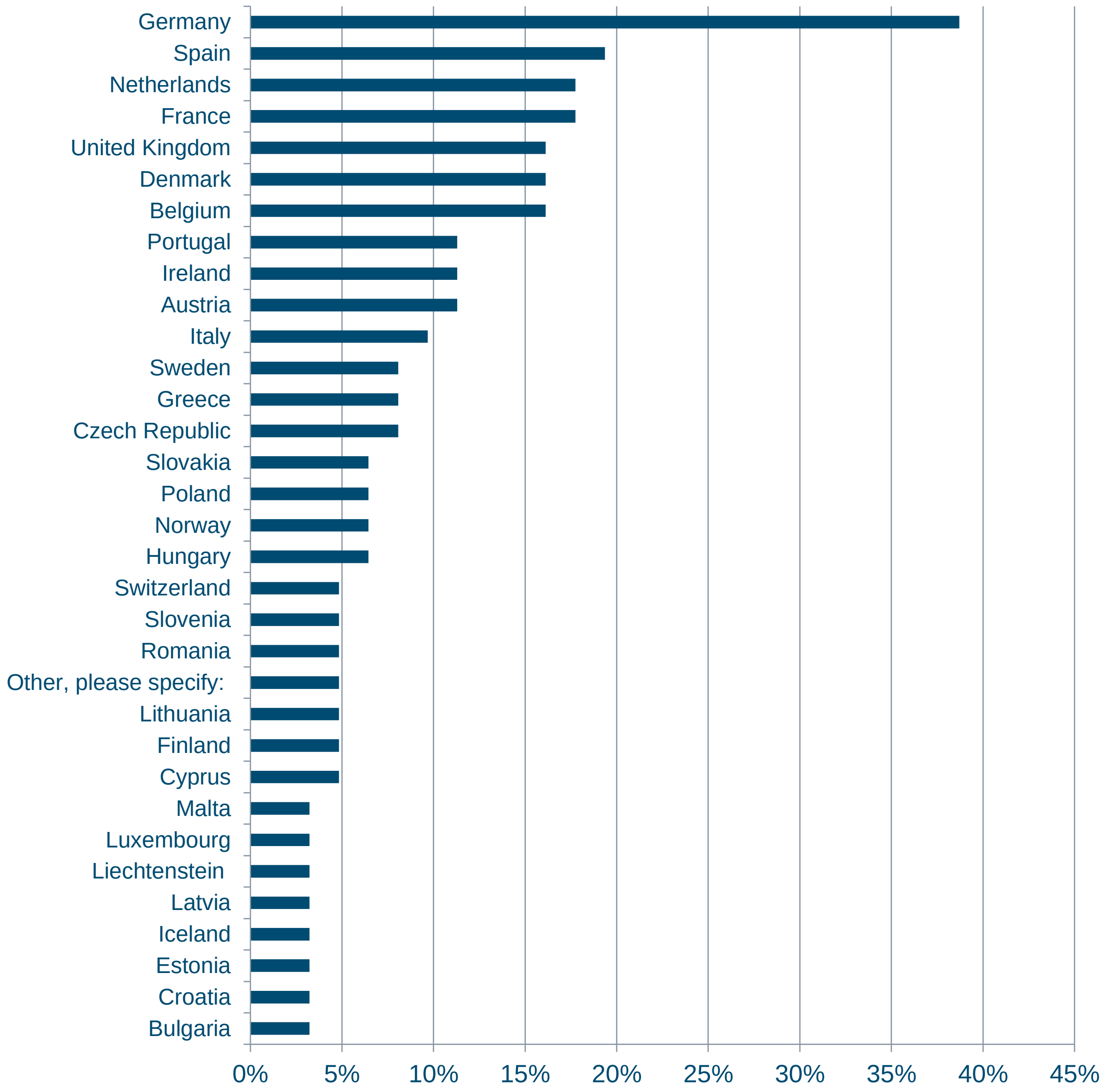
"Other, namely…" which clearly fit into one of the pre-defined categories have been changed to these categories. When there was any doubt about the allocation of responses in the "Other, namely…" category, they were left as-is.

Figure 37 Specified storage technology as part of the respondents' energy storage technology, project or portfolio



Source: ENTEC analysis

Figure 38 Location(s) of respondents' technology, project or portfolio



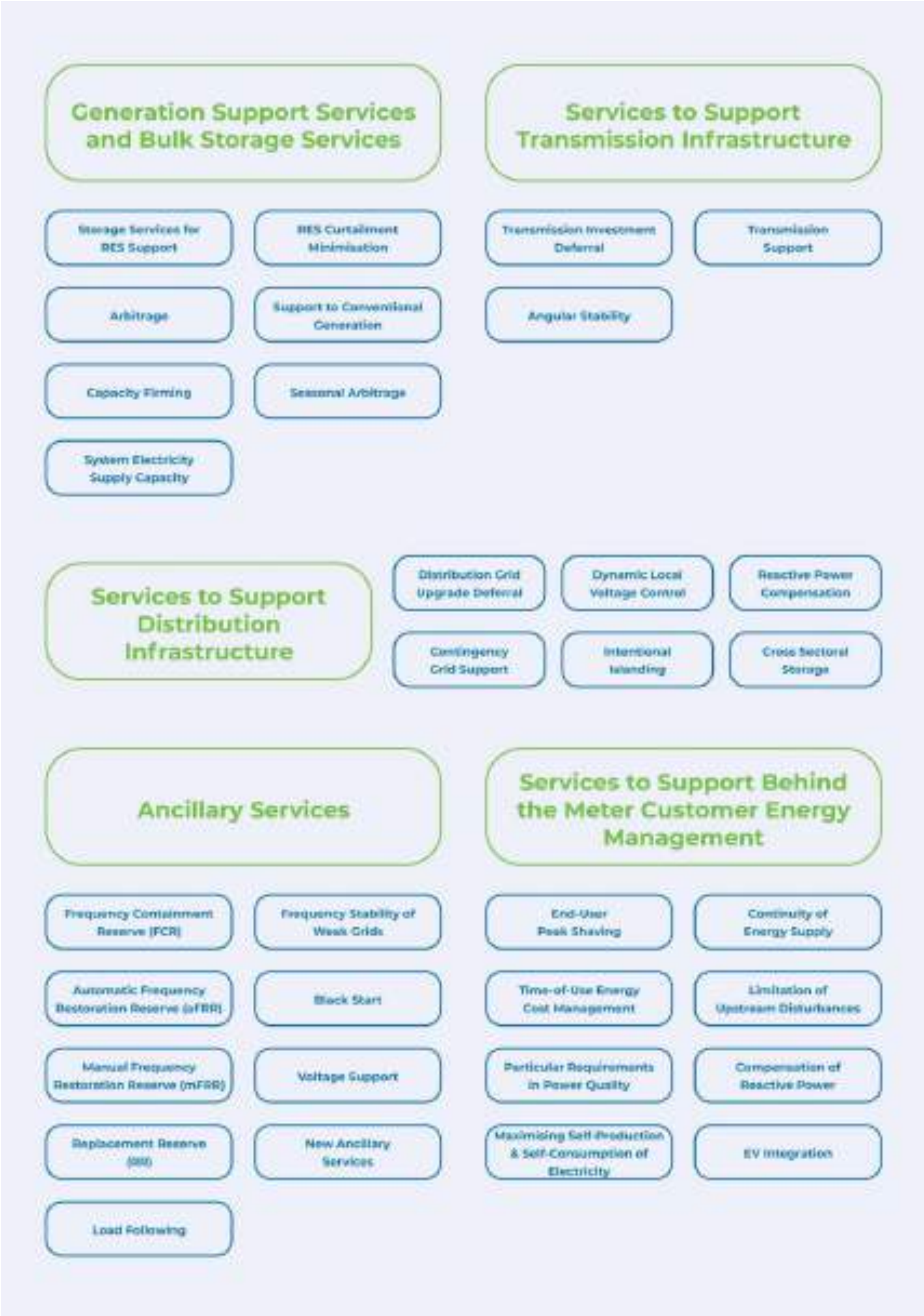
Source: ENTEC analysis

3.5.2 Categorisation and definitions of energy storage services

Energy storage projects, technologies and portfolios can provide many different services to the energy system. These services are changing and growing with the growing need of flexibility in the energy system. In the meanwhile, different definitions of such services exist. To enable an accurate and consistent results from the survey we have followed the categorisation and definitions of energy storage services from EASE. These have been published recently and are available in the public domain. Definitions of these services have been shared within the survey and can be downloaded here.[127]

[127] https://ease-storage.eu/energy-storage/applications/

Figure 39 Categorisation of energy storage services used in the survey



Source: EASE

3.5.3 Current roles and revenues of energy storage

Figure 40 shows the number of respondents that indicated that their energy storage technology, project or portfolio supplies a particular category of service. For each of the service categories, this is then further split out into services only for the respondents that indicated that they provided a service in this category. It is clear from this figure that a very wide range of services is already supplied by energy storage. Rather than contributing only in particular areas, storage is finding its way into a lot of different markets already. Generation support services and bulk storage services are currently dominant; within this category, arbitrage is the most mentioned service. Ancillary services are the second largest group of services provided by energy storage. And within that group Frequency Containment Reserve is the dominant service provided.

Services to support distribution networks and services to support behind-the-meter customer energy management are the least mentioned categories. Of course, these responses are specific to our sample, but they do suggest that energy storage is currently less active at distribution level and below, despite the significant demand for flexibility there.

Figure 40 Services provided by technology, project or portfolio

Generation Support Services and Bulk Storage Services	63%
Arbitrage	73%
RES Curtailment Minimisation	53%
Ancillary Services RES Support	47%
System Electric Supply Capacity	43%
Seasonal Arbitrage	40%
Capacity Firming	40%
Support to Conventional Generation	33%
other	7%

Services to Support Transmission Infrastructure	35%
Reactive Power Compensation	60%
Transmission Support	40%
Cross Sectoral Storage	40%
Contingency Grid Support	40%
Transmission Grid Upgrade Deferral	33%
Power Oscillation Damping (POD)	33%
Participation to Angular Stability	33%
other	0%

Services to Support Distribution Infrastructure	27%
Contingency Grid Support	67%
Reactive Power Compensation	58%
Dynamic Local Voltage Control	50%
Distribution Grid Upgrade Deferral	42%
Intentional Islanding	33%
Cross Sectoral Storage	25%
other	8%

Services to Support Behind the Meter Customer Energy Management	25%
End-User Peak Shaving	83%
Continuity of Energy Supply	83%
Time-of-Use Energy Cost Management	67%
Maximising Self-Production & Self-Consumption of Electricity	67%
Electric Vehicle Integration	58%
Particular Requirements in Power Quality	42%
Compensation of Reactive Power	42%
Limitation of Upstream Disturbances	25%
other	0%

Ancillary Services	49%	**other**	6%
Frequency Containment Reserve (FCR), prev. "Primary Reserve"	79%		
Automatic Frequency Restoration Reserve (aFFR), prev. "Secondary Reserve	67%		
Voltage support	54%		
Manual Frequency Restoration Reserve (mFRR)	54%		
Black Start	46%		
New Ancillary Services (EFR, SIR, SI, DRR, FFR, FPAPR, RM, etc.)	42%		
Replacement Reserve (RR), prev. “Tertiary Reserve”	38%		
Frequency stability of weak grids	33%		
Load Following	25%		
other	8%		

Source: ENTEC analysis

Figure 41 shows how these service categories are translated into revenue streams. There is a diverse range of business models, but the results suggest that each technology group does have a dominant source of income (see also detailed results in the appendix). Our respondents also indicate that value stacking is very important for many storage projects, technologies and portfolios, as most indicate a number of sources of revenue.

For Chemical storage technologies, this group is dominated by hydrogen storage and clearly shows ‘Generation Support Services and Bulk Storage Services’ as dominant revenue. Mechanical storage technologies, with pumped hydro as the main technology, have a more balanced revenue stream that is also dominated by ‘Generation Support Services and Bulk Storage Services’ but with ‘Ancillary services’ as clear second source of revenue. The group of electrochemical batteries is dominated by ‘Classic batteries’ and shows ‘Ancillary services’ as dominant revenue and ‘Generation Support Services and Bulk Storage Services’ as second best. The group of thermal storage options contains “Latent’ and ‘Sensible heat’ storage options and has ‘Services to Support Behind the Meter Customer Energy Management’ as clear dominant revenue. The respondents that indicated a mix of technologies in their portfolio have all but one ‘Classic batteries’ in their portfolio; as well indicating that half of them have ‘Hydrogen storage’ in the mix. Hence, the Mixed group shows a balance between ‘Ancillary services’ and ‘Generation Support Services and Bulk Storage Services’.

This indicates that energy storage policy that is intended to target the entire range of technologies should take into account that different technologies rely on different market mechanisms; there is no one size that fits all.

Figure 41 Share of revenue by service group and by technology in the present

Technology group	Generation Support Services and Bulk Storage Services	Services to Support Transmission Infrastructure	Services to Support Distribution Infrastructure	Services to Support Behind the Meter Customer Energy Management	Ancillary Services	Any other service
Chemical	59%	14%	9%	1%	3%	13%
Mechanical	49%	12%	16%	1%	21%	0%
Electrochemical	28%	3%	4%	10%	54%	1%
Thermal	0%	5%	13%	73%	3%	8%
Mix	35%	0%	4%	9%	35%	16%

Note: this analysis follows the definitions and descriptions of service segmentation provided by EASE[128]
Source: ENTEC analysis

3.5.4 Future services and revenues of energy storage

Figure 42 shows, for each of the respondents, the declared share of current revenues provided by each service category, and the expected shares in 2030. As this figure shows (see Figure 54 in appendix for further details), the average expected changes are relatively small, and most of our respondents do not expect major changes in business models. Some outliers exist where respondents expect a shift in their dominant service provided and associated revenue.

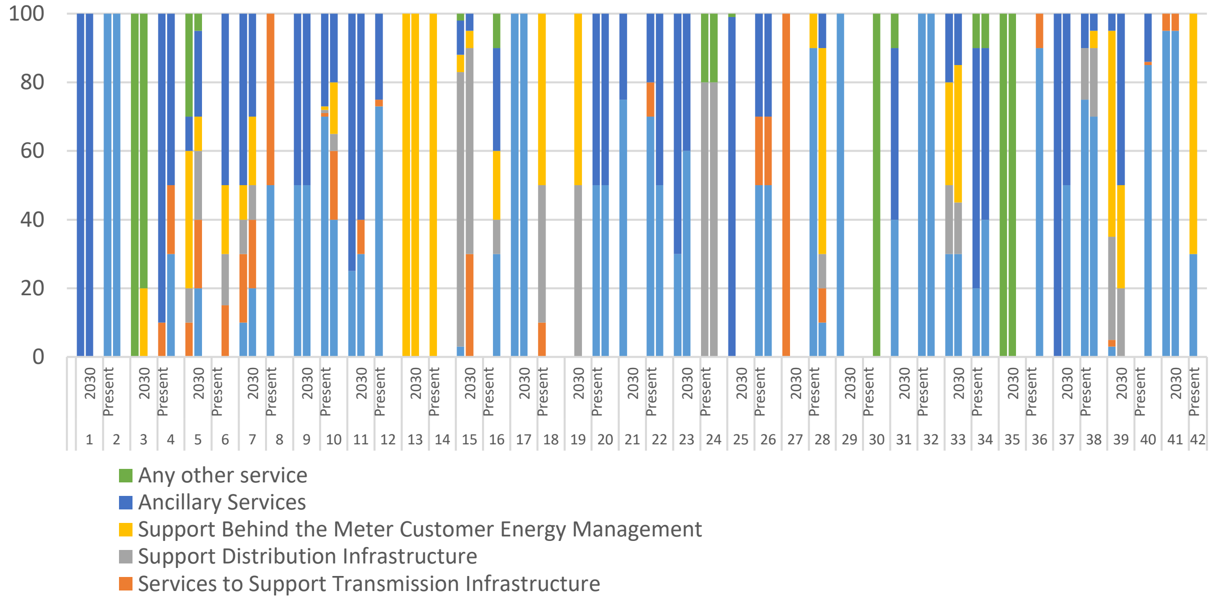
The results suggest that a more diverse business model with more value stacking is likely for all technologies. The technology groups do however show some differences, although the number of responses do not allow firm conclusions. For chemical and mechanical storage technologies there is a small shift from arbitrage towards ancillary services, behind the meter and 'other' services. For electrochemical storage the shift in revenue is in favor of 'Generation Support Services and Bulk Storage Services' at the cost of the other services provided. For thermal storages the respondents indicate that the business model is diversifying.

Respondents were also asked how confident they were that these revenue streams would add up to present a profitable business case. In general, respondents were confident, with 14% responding 'extremely confident', 37% 'quite confident', 18% 'somewhat confident' and 16% 'slightly confident'. Taken together with the previous results, this implies that respondents think that enough of the system value of storage can, in principle, be captured to warrant private-sector investment, even if this is not necessarily currently the case.

[128] https://ease-storage.eu/energy-storage/applications/

Figure 42 Comparison of revenue breakdown: present and 2030

Source: ENTEC analysis



3.5.5 Perceived opportunities, barriers and desired actions

Figure 43 shows how respondents rank their perceived market or regulatory barriers for the deployment of energy storage options. The perceived barriers that are ranked as most important by the respondents, are related to regulation and market access. The highest ranked one on average, interestingly, is 'insufficient incentives for long-term storage', which is also mentioned in the textual comments. This may be perceived as a barrier because long-term storage becomes particularly important in the absence of significant fossil fuel capacity. Therefore, attention for long-term storage has only increased relatively recently, and energy market prices do not yet vary sufficiently across longer periods of time to warrant investment in long-term storage.

The top four of dominant barriers is completed by the absence of long-term policy signals in general, the issue of double taxation and grid charging, and the lack of a regulatory framework for local flexibility markets. Barriers related to bankability and standardisation are ranked next, clearly perceived as secondary by the respondents but nevertheless still ranked high by many of them. More technical barriers, including technical limitations and incomplete data provision are ranked the lowest.

This suggests that it is not technology that is holding back storage deployment, that market operation (including financial markets) does present some barriers, but that especially long-term policy regulation and incentives are perceived to be missing.

This is further confirmed by the (textual) answers to the questions about services that are currently not valued, and countries that current present the best locations for investment in energy storage. A long list of services that storage owners are not currently rewarded for in particular member states is mentioned, ranging from short-timescale services such as fast frequency response, voltage support and virtual inertia to long-term services including grid upgrade deferral and energy security.

It is clear that no market exists in which storage operators are rewarded for all system services that they can or do provide, but also that there are significant discrepancies between different locations.

When given the opportunity to motivate their choices for particular countries, respondents also mention this, highlighting that some countries have better market access than others.

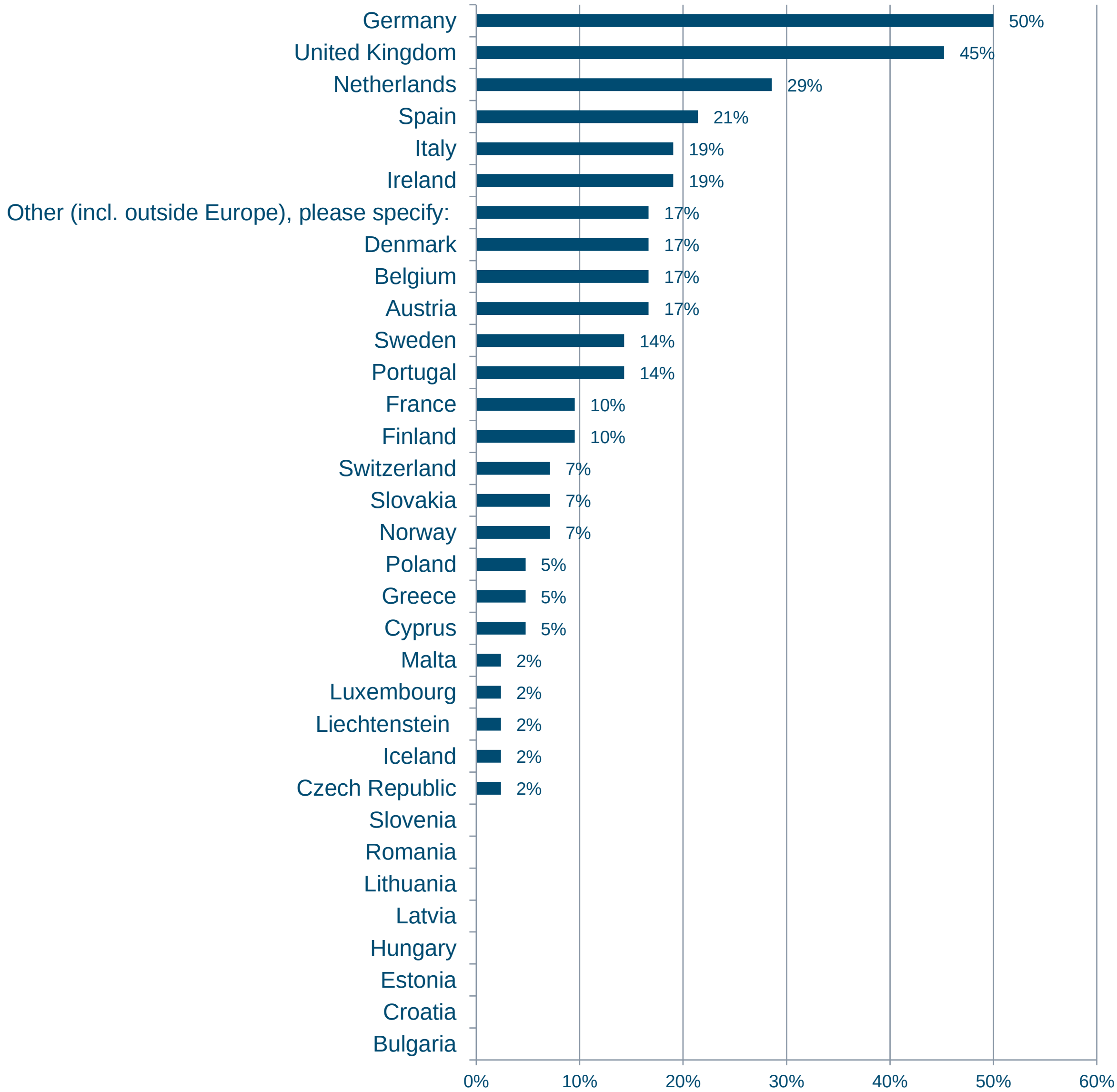
The respondents' policy wish list also corresponds to this. Many respondents are asking for a more consistent long-term energy storage vision in their particular member states; in addition, respondents are asking for more technology-neutral, fair and universal access to markets, again giving examples of markets in which they are not currently allowed to compete, or policies that are aimed at reducing price variability through other means, therefore undercutting the business case for energy storage.

Figure 43 Most important market or regulatory barriers for the deployment of energy storage options

	Rank 1	Rank 2	Rank 3	Rank Score
Insufficient incentives to long-term energy storage	13	6	1	52
Absence of long-term policy signals / strategy	8	7	5	43
Lack of a regulatory framework for local flexibility markets	3	7	7	30
Double taxation / grid charging issues	4	5	4	26
Bankability and perceived risk	3	2	1	14
Lack of / inappropriate certification / guarantees of origin (GO) rules	3	1	2	13
Absent / inadequate standardization & permitting rules	1	3	4	13
Other	2	2	1	11
Non-balancing ancillary services procurement issues	2	1	3	11
Discriminatory network planning and procurement of distribution flexibility services	1	2	3	10
Technical limitations	1	0	2	5
Absent / incomplete data provision by network operators	0	1	1	3
Wholesale market access / price formation issues	0	1	0	2
Insufficient incentives to behind-the-meter energy storage	0	0	1	1

Note that the final rank score is derived with the following weighing factors (Rank1 = 3; Rank 2 = 2; Rank 3 = 1)
Source: ENTEC analysis

Figure 44 Expected best locations for investing in energy storage, from the perspective of a private investor according to the respondents



Source: ENTEC analysis

3.5.6 Discussion on survey results

The survey was limited in scope and number of participants. This makes it difficult to draw firm conclusions on the outcomes. Nevertheless, it provides important insight into the current state of the market, and the expectations of market participants. It is clear that energy storage is currently already providing a wide range of services and expects to continue to do so in the future with growing capacity and new services provided. Not all of these services provided and anticipated are currently monetized, leading to a gap between private and public values of energy storage, and therefore the possibility of socially suboptimal investment levels. It is also clear that there is no 'one-size-fits-all' business model for each technology, although most technologies need to stack several value streams. The business models for storage options are expected to diversify further in the next decade.

Moreover, there are significant differences between member states in terms of long-term policy signals, market value drivers and market access. This suggests that there are countries with perceived (high) market potential to invest in energy storage. But it should be clarified that the survey was not equally distributed over all countries.

Nevertheless, the results suggest that more uniformity across member states, including a long-term vision for the role of energy storage, as well as fair valuation and technology-neutral access to markets for all services that energy storage can provide, in all member states, will help close the gap between public and private values of storage and lead to more optimal deployment levels and locations.

3.6 Conclusions on market value of storage

Several opportunities and business cases for storage technologies exist. Most profitable cases are the participation in ancillary services and arbitrage trading in power markets (with 2021 and 2022 electricity prices). Market assessments and the derived market indicators show potential revenues, which are also confirmed by respondents to the survey. Experiences from implemented projects show that project developers and storage operators typically stack different revenue streams to increase their profits. Therefore, market conditions and the regulatory framework are important to allow the stacking of different use cases. Valuation of potential benefits of storage technologies to the energy system is important. This is mentioned by survey respondents and can also be seen in the market indicator analysis. For use cases supporting transmission and distribution infrastructure typically payments or revenues are project specific. Analysis of behind-the-meter storage shows that it is beneficial especially in member states that have higher residential electricity prices. Cost gaps in member states with lower electricity price (e.g., in France or Spain) would disappear if prices for storage technologies i.e., batteries further decrease.

Conclusion on revenues and cost gaps based on market indicators

Power market arbitrage:

- Cost gaps existed in power markets before 2021. Power market prices and price spreads make storage technologies profitable in 2021 and 2022.
- Calculation with expected electricity price levels in 2030 still shows cost gaps for storage. Price spreads are calculated on a lower level compared to 2021

Ancillary service markets:

- Highest revenues on FCR market, e.g. earnings in Austria 76,000 Euro/MW in 2020 and 190,000 Euro/MW in 2021 makes use beneficial, but limited markets
- On aFRR and mFRR markets typically lower revenues can be generated, additional earnings from activated energy are possible, but trading strategies are more complex

Other storage applications

- Transmission/distribution infrastructure support: Typically, individual payments per project with payments similar to FCR payments, e.g. 26,000 Euro/MW per year in Australia. Use case stack revenues with other markets.
- Capacity provision, capacity markets/auctions: Storage technologies receives a capacity payment for the provision of firm capacity (e.g. 20,000 Euro/MW per year, capacity market UK). A specific capacity is auctioned or tendered and storage technologies receive the price bid from the auction or tender.

- Reduction of peak capacity and reduced grid connection fees by storage operation along with PV generation is emerging with payments related to local grid fees and grid capacity prices.
- Behind-the-meter storage is beneficial in member states with higher residential electricity prices. Cost gaps disappear in member states with lower residential electricity prices if costs for storage technologies (batteries) further decrease.

Conclusion on costs gaps based on stakeholder survey

- Energy storage currently already supplies a very wide range of services across all categories. Storage is already playing a role in a lot of different markets.
- A wide range of business models for energy storage exist. These differ across technologies, projects and storage project portfolios. Although each technology group has a dominant income stream, revenue stacking is important, as most respondents indicate a number of revenue streams.
- Arbitrage is currently the dominant revenue stream overall, followed by the provision of ancillary services. Interestingly, services to transmission and distribution network operators are a relatively small component of reported revenues. Behind-the-meter storage services and revenue streams are relative low compared to the other categories of products/service.
- Respondents do not expect their business models to change significantly towards 2030; although typically more diversification is expected. Respondents are highly optimistic about the future business case and growth potential for energy storage.
- A significant number of barriers to energy storage deployment are mentioned by the respondents. Regulatory barriers (e.g., related to market access) are mentioned most often, followed by financial barriers. Technological barriers are considered least important by most respondents.
- Most respondents indicate that fair access to technology-neutral competitive markets across the whole EU, including remuneration of energy system services that are currently not valued, would be the most desired way to support energy storage. There seems to be significant divergence between member states in terms of market access and level playing field. No member state is perceived to offer both perfect market access and sufficient policy guidance.

4 Policy and regulatory frameworks for energy storage

This chapter aims to:

- Analyse policy and regulatory issues for the development of energy storage in the EU;
- Update the national fiches of the 2020 study on energy storage[129];
- Identify policy & regulatory best practices and provide recommendations to support the development of energy storage.

The policy issues and best practices to energy storage covered in the 2020 study on energy storage[130] were classified in the following categories:

- Public support and strategy;
- Permitting;
- Energy markets and capacity mechanisms;
- Ancillary and grid management services;
- Grid aspects;
- Taxes & other levies;
- Involvement of network operators;
- Storage definition and other policy aspects.

This chapter should complement the 2020 study on energy storage and update its national fiches – the aim is to go beyond the analysis of the previous study and to analyse topics which were only partially or not covered in the first study, not to repeat the analysis or recommendations. The issues which are not re-assessed in this study are public support and strategy, involvement of network operators, storage definition, and other policy aspects. The results of this previous analysis and the identified best practices can be found in the 2020 study on energy storage commissioned by the European Commission.

The topics analysed in this study do not necessarily represent the largest current issues to energy storage in the EU27. Next to this analysis, international (i.e. in non-EU countries) best practices for the development of energy storage are detailed where relevant.

The following topics are analysed in this chapter:

- Section 4.1: MS intentions regarding targets and a regulatory framework facilitating the deployment of storage
- Section 4.2: Market design issues
- Section 4.3: Long-duration energy storage; added to complement the 2020 study
- Section 4.4: Double taxes, charges and grid tariff issues
- Section 4.5: Non-discriminatory network planning
- Section 4.6: Guarantees of origin for renewable energy; added to complement the 2020 study
- Section 4.7: Contributions of thermal energy storage
- Section 4.8: Permitting barriers and best practices

The analysis for each main topic 4.1 to 4.6 is structured as follows (sections 4.7 and 4.8 use a tailored structure):

1) Review of the importance of the topic for energy storage
2) Impact of the topic on the use cases defined in chapter 2

129 Artelys, Trinomics and Enerdata (2020) Study on energy storage - Contribution to the security of the electricity supply in Europe. https://op.europa.eu/en/publication-detail/-/publication/a6eba083-932e-11ea-aac4-01aa75ed71a1

130 Ibid.

3) Status of the topic in the EU27

Furthermore, an analysis of the international landscape on national targets, support schemes and market design is conducted in section 4.2.3.

4.1 Analysis of MS intentions regarding targets and a regulatory framework facilitating the deployment of storage

Summary of analysis of MS intentions and regulatory frameworks

- National goals for energy storage can provide a positive environment for energy storage, and are effective if supported by financing and regulative programs
- Several Member States have now a legislative definition of storage
- Goals for energy storage capacity to be installed have been announced by some Member States
- Tenders for energy storage or RE combined with energy storage are an effective means to support investments in energy storage

4.1.1 Review of intentions and national regulatory frameworks for energy storage

The "Study on energy storage – Contribution to the security of the electricity supply in Europe"[131] mentions that public support and strategy can be a barrier for energy storage. Therefore, intentions and regulations for energy storage in the EU are reviewed in this section. In the "Clean Energy for All Europeans Package", storage is recognized as a competitive activity. Business cases in the energy sector are commonly built on expectations rather than on current circumstances due to long design and construction lead times and technical lifespans of the concerned assets. Hence, policies and national targets can incentivize energy storage technologies by providing investment security. In this section, EU regulations and policies regarding energy storage will be analysed, with a focus on the definition of energy storage, regulatory framework and incentive programs for energy storage.

Why is a definition of energy storage needed? A definition of storage operators as a specific class of actors in the electricity sector can ensure they are treated specifically in the regulatory framework. Market access rules may otherwise discriminate against storage, as they were created for producers, traders/suppliers and (large) consumers. Also, in the absence of specific consideration for electricity storage, it can be treated as both consumer and producer of electricity and thus may have to pay double grid tariffs, taxes or fees. This negatively affects the business case of storage and does not reflect the benefits of storage to the system. If no definition of energy storage does exist, in order to address double grid charging or taxation grid tariffs, taxes or fee provisions need then to be adapted for each case, which complexifies regulation and can result in the provisions not being technologically neutral. Moreover, all in all, a specific definition of storage in national law could increase the investment security and therefore support the deployment of energy storage systems[132, 133].

[131] Trinomics (2020) Study on energy storage – Contribution to the security of the electricity supply in Europe. p.75

[132] Trinomics (2020) Study on energy storage – Contribution to the security of the electricity supply in Europe. p.77

[133] EU Directorate-general for internal policies (2015) Energy Storage: Which Market Designs and Regulatory Incentives Are Needed? Study for the ITRE Committee

The EU has defined energy storage, but this definition has not been adopted by all Member States yet. An EU definition of energy storage can be found in the Directive on the internal market for electricity[134]: 'energy storage' means, in the electricity system, deferring the final use of electricity to a moment later than when it was generated, or the conversion of electrical energy into a form of energy which can be stored, the storing of such energy, and the subsequent reconversion of such energy into electrical energy or use as another energy carrier". It is to be noted that this definition does not only include storage systems reconverting energy to electricity, but also technologies with another energy carrier as output; this means that also e.g. hydrogen conversion and storage as well as heat pumps combined with thermal storage are regarded as energy storage systems. In the EU, storage and hydrogen are considered as main fields for research and innovation alongside with the International Thermonuclear Experimental Reactor ITER, digitalisation and Carbon Capture & Storage. In the Strategic Action Plan on Batteries – Annex 2 to the Communication COM(2018)293 "Europe on the move"[135], the plan to establish a European batteries value chain is described. This value chain should cover all steps from raw materials over cell component manufacturing, cell manufacturing, battery pack manufacturing and EV manufacturing to recycling. The steps to be undertaken development of the action plan are the following[136]:

- Securing the sustainable supply of raw materials
- Supporting European projects covering different segments of the battery value chain, including cells manufacturing
- Strengthening industrial leadership through stepped-up EU research and innovation support covering the full value chain
- Developing and strengthening a highly skilled workforce in all parts of the value-chain
- Supporting a sustainable battery value chain – i.e., requirements for safe and sustainable batteries production - as a key driver for EU competitiveness
- Ensuring consistency with the broader enabling and regulatory framework

These steps show that the initiatives and support from the European Union are directed mainly on research and innovation as well as on capacity building.

4.1.2 Status of national goals and regulations in the EU27

Definition of energy storage in laws

The EU Member States are obliged to transpose the electricity directive into national law, including the definition of energy storage. In most of the national regulatory frameworks in the EU, energy storage is, according to our research, not yet defined. Legal definitions could be identified in several Member States, as detailed in Annex 4.1. The national definitions are not unified but vary in each of these countries, as illustrated next.

In the **Belgian** electricity law of the 13th of July 2017, electricity storage is defined as "any process whereby, through the same installation, electricity is withdrawn from the grid for the purpose to be completely re-injected into the system later on, subject to efficiency losses."

[134] EU (2019) Directive 2019/944 of the EU parliament and the council on common rules for the internal market for electricity. Article 2, Paragraph (59)

[135] EC (2018) Annex to the Communication from the commission to the European Parliament, the council, the European Economic and social committee and the committee of the regions. Europe on the Move. COM(2018)293 final

[136] EC (2018) Annex to the Communication from the commission to the European Parliament, the council, the European Economic and social committee and the committee of the regions. Europe on the Move. COM(2018)293 final

In **Poland**, in May 2021 the bill of amendments to change the definition of storage was adapted to "conversion of the electricity, received from the electricity grid and/or generated by the generation unit connected to such electricity grid and cooperating with such grid, to another form of energy, storage of such energy and subsequent conversion thereof to electricity and injection to the grid".

The **Spanish** legislation defines owners of storage facilities as natural or legal persons that own facilities in which the final use of electricity is deferred to a time after it was generated, or that carry out the conversion of electrical energy in a type of energy that can be stored for the subsequent reconversion into electrical energy[137].

Romania states that they plan to "clearly define the concept of energy storage in the primary law"[138].

In the **Czech** energy law, pumped hydro storage is not considered as storage but as a specific form of power generation.

Finland defines electricity storage only concerning electricity and fuel taxes[139].

Germany has in June 2020 provided a dedicated definitionof energy storage.[140]

Ireland has recently defined energy storage in Irish legislation under statutory instrument no. 76 of 2022.

Greece has defined hybrid installations where storage is a necessary part[141].

The **Italian** regulator has defined storage in the context of integration in the electricity system in its regulatory decision 574/2014/R/eel: "A storage system is a set of devices able to absorb and release electric energy, foreseen to work continuously in parallel to the grid or able to modify the energy exchange with the electricity grid. The storage system may or may not be integrated with a generating plant. Systems that enter into function only in emergency conditions such as during a black out are not considered to be a storage system." This definition is provided by the national regulator; no legislative definition could be found.

Energy storage goals and targets

The current National Energy and Climate Plans (NECPs) apply to the period from 2021 to 2030 and focus on the 2030 targets. The reports comprise five sections: Decarbonisation (including greenhouse gas emissions and renewable energy), Energy Efficiency, Energy Security, Internal Energy Market and Research, Innovation and Competitiveness. Since the publication in 2021, the Member States are required to submit a progress report every two years.[142]

Goals on energy storage are mentioned in five NECPs (see Table 20). Several European countries refer in their NECP to the increasing importance and the need of defining, supporting, and developing energy storage. This is commonly mentioned in the Chapters on dimensions of Energy Efficiency, Energy Security and Innovation and Competitiveness. Storage of energy is often seen as a solution in providing flexibility and efficiency to the energy system as well as increasing the use of

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137 Royal Decree-Law 23/2020, of June 23, which approves measures in the field of energy and in other areas for economic reactivation. https://www.boe.es/buscar/act.php?id=BOE-A-2020-6621. Article 4, Three

138 NECP Romania (2020) The 2021-2030 Integrated National Energy and Climate Plan, p. 114

139 C. Andrey, P. Barberi et.al. (2020) Study on energy storage – Contribution to the security of the electricity supply in Europe

140 https://www.energy-storage.news/germany-finally-gives-energy-storage-its-own-legal-definition/

141 Official Gazette (2006) Generation of Electricity using Renewable Energy Sources and High-Efficiency Cogeneration of Electricity and Heat and Miscellaneous Provisions law 3468/2006

142 https://energy.ec.europa.eu/topics/energy-strategy/national-energy-and-climate-plans-necps_en [last access 22.04.2022]

renewable energies. The problem of high costs or double taxation for grid connected energy storage facilities is mentioned frequently.

In its 2021-2030 NECP, **Croatia** announces its plan for a total storage capacity of 150 MW by 2030 through investments in various technologies, to be funded through the energy storage fund set up in 2019. **France** plans to commission 1.5 GW of pumped hydro stations between 2030 and 2035 and includes energy storage in its 'Batteries and Storage action plan' to support the development with funding of 20 million EUR. In **Germany**, the Ministry of Economic affairs and energy disposes of a budget up to 1 billion EUR until 2022 to support investments and development of energy storage. **Italy** plans new storage systems with a capacity of at least 6 MW by 2030.

Since the finalisation of the 2021-2030 NECPs, some countries have announced new storage goals: **Greece** announced in 2022 to double its 2030 energy storage target to 3 GW. **Spain** published its storage strategy in February 2021, aiming to install 20 GW of storage capacity by 2030 and to reach 30 GW by 2050 (starting from today's 8.3 GW).

Table 20 Energy storage goals and targets in EU Member States

Country	Goal or target	Source
Croatia	150 MW of energy storage by 2030	NECP Croatia p.162[143]
France	1.5 GW of pumped energy transfer stations (pumped hydroelectric storage systems) to be commissioned between 2030 and 2035	NECP France p.125
Italy	6 GW of energy storage by 2030 (composed of pumped hydro, centralized electrochemical as well as 4 GW distributed storage facilities)	NECP Italy pp.99
Greece	3 GW of energy storage by 2030	[144]
Spain	20 GW of storage capacity in 2030, 30 GW by 2050	[145]

Some countries have special laws on energy and storage, subsidy programs and/or regulations. In these countries, generation and use of renewable energies as well as development of renewable energy systems is more commonly addressed than electricity storage. In the **Austrian** National Electricity Act ("ElWOG"), energy storage is referred to as one of the components that will play an increasing role in the Austrian and European electricity systems. In the **Netherlands**, since 1st January 2022, storage of energy is not subject any more to double taxes[146].

Specific support for energy storage in EU MSs

In most EU Member States, there is no direct funding for large-scale deployment of energy storage. Only few countries such as Germany and Austria offer direct support for batteries in small scale applications. Some countries offer support for electric vehicle purchase. Financial support focuses

[143] The final National Energy and Climate Plans are available at https://ec.europa.eu/info/energy-climate-change-environment/implementation-eu-countries/energy-and-climate-governance-and-reporting/national-energy-and-climate-plans_en

[144] https://www.energy-storage.news/events/why-greece-is-becoming-a-key-energy-storage-market-hub-for-europe/ [last access 22.04.2022

[145] https://renewablesnow.com/news/spanish-govt-approves-energy-storage-strategy-sees-20-gw-in-2030-730720/ [last access 22.04.2022]

[146] Renewable energy policy database and support: Netherlands (res-legal.eu) [last access 22.04.2022]

mainly on R&D activities (e.g. in Austria, Bulgaria, Croatia, France, Germany, Luxemburg, Slovenia, Spain) and building up battery production capacities.

Germany has the largest penetration of PV home storage systems with about 750 MWh newly installed energy storage capacity in 2020[147]. Germany had a support program for home storage systems in place between 2013 and 2018, followed by 'Bundesland'-specific support schemes afterwards[148]. The support applied to small scale storage systems coupled to newly built PV systems. The market uptake was a clear result of the support scheme. Supporting this development is related to the fact that the electricity prices level and volatility are relatively high in Germany, which favours the economic viability of battery systems.

Large scale projects are in some EU MSs incentivized by tenders, such as in **France**[149] (tender for batteries only), **Germany**[150] and **Hungary**[151] (tenders combined with RE technologies in both countries). Greece has announced a 700 MW battery tender for 2021/2022[152]. Tenders clearly set a demand for electricity storage and reduce the investment risks by offering longer-term contracts.

[147] EES (2022) Europäischer Photovoltaik-Heimspeichermarkt wächst. https://www.ees-europe.com/markttrends/europaeischer-pv-heimspeicher-markt

[148] LG home battery blog (2021) Electricity storage subsidies in Germany. https://lghomebatteryblog.eu/en/electricity-storage-subsidies-in-germany/

[149] https://www.energy-storage.news/a-very-good-year-france-toasts-rapid-energy-storage-growth/

[150] https://www.energy-storage.news/solar-plus-storage-projects-win-258mw-of-capacity-in-germanys-latest-renewable-energy-auction/

[151] Renewables Now (2022) Hungary opens tender for 864 GWh of renewable power. https://renewablesnow.com/news/hungary-opens-tender-for-864-gwh-of-renewable-power-775890/

[152] Sdhakjf Greekreporter (2021) Energy Storage: Is Greece Becoming Europe's Battery? https://greekreporter.com/2021/11/02/greece-energy-europe-battery/

4.2 Market design issues for energy storage

Summary of market design issues

- Significant progress has been made in the removal of entry barriers for storage and other flexibility sources with the adoption and implementation so far of Clean Energy Package
- Some remaining national barriers to entry in spot and balancing markets, (various issues related to need for revision of certain market and product characteristics as well as, for balancing, of overall market rules to allow the participation of storage in specific Member States) should be further addressed when policy makers, regulators and TSOs adapt their national legislation and regulation (including terms, conditions and methodologies related), which is on-going in several Member States
- A regulatory framework for the procurement of flexibility by DSOs providing a level playing field for flexibility sources is still missing or in development in several Member States. Local flexibility platforms and market initiatives with the participation of DSOs, mostly pilots, are however on-going in several Member States, with a concentration of such initiatives in DE, FR, NL
- System operators are gaining more experience in adapting contracts for services procured in order to allow further value stacking by storage operators. Energy storage facilities in 6 out of the 7 MSs assessed have some level of value stacking (using a single storage asset to benefit of multiple revenue streams). However, value stacking is often only accepted between a few specified services, and further improvements are welcome to accept stacking of as many services as possible
- The provision of ‘conventional’ non-frequency ancillary services such as voltage control and black start was up until 2020 often not remunerated by network operators, or not accessible to storage. This situation is understood not to have changed significantly.
- Many storage technologies are well-suited to provide or support the provision of new ancillary services such as fast frequency response or synchronous inertia, which could thus represent a relevant revenue stream. The need for procurement of new ancillary services in the Continental Europe Synchronous Area and Nordics is currently limited, and thus procurement is mainly limited to the Irish SEM and the Baltic countries. There is therefore limited experience by network operators in the procurement of these new services. Nonetheless, Swedish and Italian TSOs have implemented Fast Frequency Response procurement schemes.
- The representation of locational aspects and provision of locational information to market parties could be improved, with CEP provisions expected to have a positive impact in the configuration of bidding zones in the coming years. There is no centralised platform for the provision of intra-zonal congestion information

4.2.1 Review of elements concerning electricity market design

As shown in chapter 2, opportunities for storage exist in multiple markets and end-user energy management applications across the EU27. Access to different markets and procurement mechanisms brings additional revenues and reduces the dependency of storage operators on one or few revenue streams. Efficient price formation in various markets reveals the actual flexibility needs and provides appropriate investment and operational signals to operators of flexibility resources, among which storage.

This section analyses how the current electricity market design at the EU and Member State level allows for the participation of storage and values the flexibility services provided by storage. This is critical for allowing storage operators to capture the existing market opportunities identified in chapter 2.

In this study, electricity market design also refers to the non-market-based procurement of ancillary services, as the article 31 of the Electricity Directive 2019/944 comprises a requirement for TSOs to switch to market-based procedures (unless NRAs deem this would have detrimental effects due to e.g. the possibility of strategic behaviour by market participants).

End-user energy management applications complement the market opportunities available to storage. This section is focused on active participation of storage in electricity markets. Therefore, end-user energy management is not addressed, unless relevant also to active provision of storage services. Behind-the-meter storage technologies such as home and mobile (EV) batteries coupled with PV enable the concerned end-users - without the need for specific regulatory provisions - to optimise their demand pattern based on network tariffs and commodity price signals.

The Study on Energy Storage[153] provided a comprehensive analysis of the new electricity market design arising from the revised Electricity Directive and Regulation. Therefore, the present analysis focuses on additional issues and data sources not covered in that study.

The issues analysed can be separated in two categories:

- Market design aspects which are defined in the Electricity Target Model (ETM)[154] but for which further implementation efforts by Member States and NRAs (and monitoring by the European Commission and ACER) are on-going; and
- Market design aspects which are not defined (or only at a high-level) in the ETM, and for which further actions at the EU level might be warranted – ranging from changes to the ETM to non-legislative actions such as dissemination of best practices by the European Commission.

Thus, the issues analysed in this section comprise:

- Lack of a proper legal framework to enable new entrants and small players
- Electricity price limits and restrictions on balancing market design
- Restrictive requirements to participate in capacity mechanisms
- Restrictive requirements in prequalification and/or the design of balancing products
- Maturity of framework to value distributed flexibility sources and revenue stacking
- Emergent state of new ancillary services
- Provision of locational signals and information to market parties
- New Guidelines on State Aid for Climate, Environmental Protection and Energy

The issues assessed in this section affect practically all storage technologies surveyed in chapter 1 capable of providing services in the electricity sector. Regarding the use cases analysed in chapter 1, the main ones impacted concern 'generation support services and bulk storage services', and 'ancillary services'. More specifically, a significant part of the analysis of this section focuses on the design of spot and balancing markets in the EU, which are critical for enabling storage operators to provide arbitrage and balancing services, respectively. The section also analyses the design of capacity mechanisms to procure 'electricity supply capacity' services from all flexibility sources, including storage, in an objective and non-discriminatory. Finally, specific attention is dedicated to

[153] Artelys, Trinomics and Enerdata (2020) Study on energy storage - Contribution to the security of the electricity supply in Europe

[154] Although not formally defined in EU legislation, the Electricity Target Model is the collection of electricity market design features which should be implemented across the EU as defined in the Electricity Directive, Regulation as well as other legislation such as the network codes and guidelines. ACER itself makes use of the term in the Market Monitoring Reports, most recently in ACER (2022) Market Monitoring Report 2020 – Electricity Wholesale Market Volume.

discuss the procurement of new ancillary services by system operators. Therefore, the issues discussed in this section should have a direct impact on the ability of storage operators to provide important services, given that chapter 2 indicates that currently arbitrage and the provision of ancillary services are the main revenue streams.

4.2.2 Status in the EU27

4.2.2.1 Lack of a proper legal framework at national level to enable new entrants and small players

In order for storage operators and other market participants employing storage to be able to actively participate in electricity markets, first the appropriate legal framework must be in place. We analyse here the national progress towards the implementation of relevant provisions of the Clean Energy Package and provide relevant best practices. A few countries (Germany, Denmark, France and Hungary) are frontrunners regarding a legal framework for new entrants and small players, such as (independent) aggregators and active consumers. Progress has been made since the entry into force of the revised Electricity Directive and Regulation, and Member States are expected to make further improvements at the national level for removing entry barriers for front-of-the-meter storage and the different market actors directly or indirectly employing behind-the-meter storage.

The analysis of the updated national fiches on policy & regulation from the 2020 study on energy storage[155] (presented in a separate annex) indicates that several Member States have updated in 2021-2022 or plan to update their regulatory framework to address storage, such as the Czech Republic (amendment to the Energy Law), Estonia (Electricity Market Acts), and Portugal (Decree-law 15/2022).

Provisions for a level-playing field for **demand side flexibility**, which directly impacts behind-the-meter energy storage, are set in the Electricity Directive 2019/944, such as articles 6-8, 18, 20-22 of the Electricity Regulation and articles 11, 13 or 17 of the Electricity Directive. But the provisions were still not yet implemented in most MS at the transposition deadline of end of 2020. Since then, Member States have made progress in transposing the Directive provisions regarding demand side flexibility, but much work remains. The upcoming **demand response network code** is discussed in section 4.2.2.5.

By the end of 2021, out of 11 Member States surveyed by the smartEn study,[156] France and Slovenia had adequately transposed the Electricity Directive article 17 provisions for **demand response through aggregation.** However, several other countries had planned further actions in this regard, and for example balancing markets have been opened for aggregation in Germany, Italy, and Spain.

One of the important barriers for independent aggregators is the **necessity of prior consent by suppliers,** as required by article 13(2) of the Electricity Directive. Some MS still had at the end of 2021 no legal provisions forbidding suppliers to discriminate against customers that have a contract with an aggregator, for example Greece, Ireland and Spain[157], as required by article 13(4) of the Electricity Directive. A method for calculating financial compensation for electricity suppliers during activation of demand side response is developed in for example France, Italy, Slovenia and Romania.

155 Artelys, Trinomics and Enerdata (2020) Study on energy storage - Contribution to the security of the electricity supply in Europe. https://op.europa.eu/en/publication-detail/-/publication/a6eba083-932e-11ea-aac4-01aa75ed71a1

156 smartEn (2022) The Implementation of the Electricity Market Design to Drive Demand-side Flexibility

157 smartEn (2022) The Implementation of the Electricity Market Design to Drive Demand-side Flexibility

Appropriate legal provisions for **active consumers (AC)** matters for small-scale consumers (including those employing behind-the-meter storage) willing to participate in energy markets. Without such a framework it will not be possible for AC (and BtM storage) to participate in the different markets. Active costumers (AC) had, at the end of 2020, the possibility to participate directly in DA, ID and balancing markets in 9 MSs. However, in Portugal for example, direct participation of AC is still not allowed in balancing markets as required by the Electricity Directive, hindering the business case for energy storage – even if steps have already been taken to allow the participation through aggregators. In some MSs (Germany, France, Hungary and Slovenia) it was possible for AC to provide re-dispatching and other congestion management services for TSOs. In 14 MSs, DA, ID and balancing markets were open to aggregators (another requirement of the Electricity Directive), the provision by aggregators of redispatch services to TSOs was allowed in 11 MSs.

Moreover, **independent aggregators**[158] faced more challenges than aggregators/suppliers do. In some MSs independent aggregators could still not participate in DA and ID markets in the end of 2021 (as required by the Electricity Directive), for example in Spain[159] although the Decree-law 23/2020 created the figure of the independent aggregator and further progress is expected in this regard. In 2021, in the context of the Recovery and Resilience Plan, the Spanish government launched a call for expressions of interest to identify action lines for smart grids, storage and flexibility – which included the topic of independent aggregation[160].

4.2.2.2 Price limits in spot and balancing markets and other restrictions on balancing market design[161]

This section analyses issues related to price limits in electricity markets and restrictions on balancing market design. Specifically, it assesses when such price limits or restrictions are not compliant with provisions of the Electricity Regulation or balancing guidelin and represent a barrier to a level playing field to all flexibility solutions, including storage.

Price limits across the market timeframes distort the ability of price signals to reflect actual system conditions, including scarcity or excess supply. Also, if applied in only certain Member States, price limits lead to cross-border distortions of the internal electricity market[162]. Moreover, price limits can act as an anchor, with market participants more likely to use the limit as a reference[163] instead of basing their bids purely on the analysis of the market conditions. Given that arbitrage in electricity markets is an important revenue stream for various storage technologies, price limits hampers price signals and reduce price differentials in time and thus reduce the willingness of storage operators to invest and to offer flexibility in the market.

Price limits can have a technical or non-technical character. **Non-technical price restrictions** refer to market design characteristics such as price caps or floors. According to the Electricity Regulation article 10.1, there shall be neither a maximum nor a minimum limit to the wholesale electricity price. This requirement applies to, inter alia, bidding and clearing in all market timeframes.

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158 Aggregators not affiliated to a customer's supplier

159 smartEn (2022) The Implementation of the Electricity Market Design to Drive Demand-side Flexibility

160 https://www.miteco.gob.es/eu/prensa/ultimas-noticias/el-miteco-lanza-una-expresi%C3%B3n-de-inter%C3%A9s-para-identificar-l%C3%AD-neas-de-actuaci%C3%B3n-en-redes-inteligentes-almacenamiento-energ%C3%A9tico-y-flexibilidad/tcm:35-522263?msdynttrid=MUqIQ41IT-pDb0deIYcvFCg4zocJLVf5IxTz8MK9k3xc

161 Unless mentioned this section is based on ACER (2022) Market Monitoring Report 2020 – Electricity Wholesale Market Volume

162 ACER (2022) Market Monitoring Report 2020 – Electricity Wholesale Market Volume

163 DNV (2021) Study on a Methodology to Benchmark the Performance of the Eu Member States in Terms of: I) Efficient Price Formation; and Ii) Easy Market Entry and Participation for New Entrants and Small Actors

While a small number of Member States still had some sort of price limits in day-ahead and/or intra-day markets in 2020, this had been addressed by 2021. ACER however has introduced a transitory price limit of 15 000 Euro/MWh until July 2026, 'for mitigating the possible risks of the initial phase of the European balancing platforms' go-live and to allow TSOs and market participants to gather experience on their functioning'[164].

Article 10(1) of the Electricity Regulation is without prejudice to the technical price limits which may be applied in the day-ahead, intraday and balancing timeframes. **Technical price limits** are set mainly for improving the efficiency of market clearing algorithms and at a level that they should not restrict the bids of market operators, and NEMOs should take measures to adjust the limits before they are reached. Price limits for balancing markets are however not harmonised across the EU, except for the technical price limits for balancing energy (+/-99,999 Euro/MWh).[165] The go-live of the balancing energy exchange platforms will make these price limits applicable to national markets. In the 2018-2020 period, some balancing markets reached price limits a number of times (IE, DE, EL, IT, RO)[166].

Marginal pricing **is the method for pricing of balancing energy markets** mandated by Electricity Regulation. However, methods other than marginal pricing, such as regulated pricing, pay-as-bid or hybrid methods were used in several MSs across all balancing timeframes (4 MSs for FCR, 12 for aFRR, 11 for mFRR, and 3 for RR in 2020). This is detrimental for storage and other small and new flexibility sources because other methods require them to estimate the correct bid to be 'in-the-money', while they will often not be the market clearing price-setting technology.

In addition, in balancing markets, **dual pricing** (that is, separate prices for imbalances against and in the direction of system imbalances) is less cost-reflective compared to single pricing. Single pricing provides to all Balancing Responsible Parties the same signal on system imbalance, thereby rewarding BRPs which reduce the system imbalance to the same extent that is penalises those which increase it. Single pricing is more beneficial than dual pricing for the deployment of energy storage since it provides more adequate economic insights on system imbalances. In 2020 11 Member States had some sort of dual pricing in place[167].

Moreover, shorter **imbalance settlement periods** (timeframe of 15 minutes) should be implemented according to article 8(4) of the Electricity Regulation to better reflect the actual system imbalances and thus the real value of capacity and energy, and therefore provide better incentives for energy storage operators, who can adjust injections and withdrawals in this timeframe. Shorter ISPs also support trading in the intra-day timeframe. Derogations on the ISP may be granted by regulatory authorities until 31 December 2024. In 2020, most MSs still had an ISP longer than 15 minutes.

4.2.2.3 Restrictive requirements in prequalification and/or the design of balancing products

Design elements of national balancing markets[168], such as regulated or pay-as-bid pricing, pro-rata activation of balancing reserves, long procurement lead times, balancing prices predetermined in capacity contracts and restrictions to submit free energy bids (that is, energy bids not associated

164 https://www.acer.europa.eu/events-and-engagement/news/acer-has-decided-amendment-common-pricing-methodology-european

165 ACER Decision No 01/2020

166 ACER (2022) Market Monitoring Report 2020 – Electricity Wholesale Market Volume

167 ACER (2022) Market Monitoring Report 2020 – Electricity Wholesale Market Volume

168 Meaning here the organised markets for TSOs managing residual imbalances – the trades of market participants in spot and other markets to reduce their own imbalances is not covered here.

with a reserve bid) can negatively influence wholesale electricity prices and therefore increasing the cost of providing flexibility. Moreover, some features of balancing markets, for example long delivery periods and large minimum bid sizes, limit participation of energy storage. In this section, design elements of balancing markets and how they affect energy storage are discussed.

- ***Duration of the delivery period:*** TSOs prequalify balancing service providers (BSPs) for a minimum and maximum duration of delivery period during which they should be able to deliver the requested change of injection or withdrawal. The Electricity Target model sets a minimum delivery period of 5 minutes for mFRR balancing products and 60 minutes for standard RR balancing products[169]. Five Member States (SI, FI, SK, AT, DE) had a maximum delivery period of 4 hours or more for mFRR. This can form a barrier, especially for behind-the-meter storage, which may be limited in its capacity to sustain a charge or discharge for 4 hours.
- ***Minimum bid size and possibility of aggregation:*** According to the Electricity Target Model the minimum capacity of the energy bid for standard balancing products shall be 1 MW for all reserve types,[170] and aggregation should be allowed. In some MS minimum bid sizes are still above the value of 1 MW and/or aggregation of bids is still not allowed. A high minimum bid size can hinder participation of small energy storage operators, particularly if aggregation is also not allowed.
- ***Procurement lead-time and balancing capacity contract length:*** Long procurement lead-times (the time from contracting of a balancing capacity service to delivery) may represent entry barriers to flexibility sources such as demand response but also energy storage, given the uncertainty of energy prices in the long-term and the opportunity cost associated with reserving the storage capacity for delivery. Storage operators may have nonetheless a preference for longer procurement lead times and balancing capacity contract lengths in order to provide revenue certainty for investments. Nonetheless, from a system perspective shorter lead times and contract lengths are still preferred in order to not discriminate any flexibility source and to "allow for efficient arbitrate between day-ahead and balancing capacity markets". In 2020, several Member States still contracted balancing capacity a month or even year ahead, including LT, SK, SI, HR, CZ, and HU[171].

4.2.2.4 Restrictive requirements to participate in capacity mechanisms

Capacity mechanisms are measures taken in support of medium and long term electricity supply security. Capacity mechanisms enable power plants to be available for generating electricity when needed. In exchange, the mechanisms provide payments to these power plants. Capacity mechanisms can be implemented by Member States only if there are adequacy concerns demonstrated by a European or national resource adequacy assessment, and the Member State commits to implement market reforms to eliminate distortions. In case capacity mechanisms are in place, they can represent an additional revenue stream for storage.

The recast Electricity Regulation article 22 states that any capacity mechanism shall be open to the participation of all resources that are capable of providing the required technical performance, including energy storage and demand side management. Furthermore, paragraph 343 of the new Guidelines on State aid for climate, environmental protection and energy 2022 requires that "the aid measure [for the security of electricity supply, including capacity mechanisms] should be open

[169] This delivery period for RR should decrease to 30 and 15 minutes as the number of daily gates in the RR platform increase. See https://extranet.acer.europa.eu/en/Electricity/MARKET-CODES/ELECTRICITY-BALANCING/02%20RR%20IF/Action%201%20-%20RR%20IF%20proposal%20approved.pdf

[170] See for example ACER Decision No 2/2020 and ACER Decision No 3/2020

[171] ACER (2022) Market Monitoring Report 2020 – Electricity Wholesale Market Volume

to all beneficiaries or projects technically capable of contributing efficiently to the achievement of the security of supply objective. This includes generation, **storage** and demand response, as well as the aggregation of small units of these forms of capacity into larger blocks. See section 4.3 for further information.

Nonetheless, current pre-qualification requirements at national level for capacity providers and other design features can still limit the entry and participation of new entrants and small actors, including storage operators. Almost all **capacity mechanisms** assessed by ACER[172] were in 2020 open to demand-side response, storage, and renewable power generation facilities. Of the mechanisms which procured capacity in 2020, Greece & Finland did not allow the participation of energy storage.

But besides formally allowing the participation of storage, the **technical rules of the capacity mechanisms** also matters. The minimum eligible capacity, impossibility for aggregation and the minimum bid size can represent entry barriers. For example, in Finland, the minimum bid size is 10 MW whereas in Sweden and Germany the minimum bid size is 5 MW. In Germany, aggregation is not allowed, and thus storage units lower than 5 MW cannot participate.

(Multi-)annual delivery periods[173] in Belgium, Bulgaria, Germany, Greece, Ireland, Poland, Portugal and Sweden are a barrier to the participation of energy storage since it is difficult for energy storage to demonstrate availability for the whole period of a year or more, given storage will be depleted at some point and time will be required for recharging (even long-duration storage). For this reason, capacity mechanisms with an annual delivery period usual de-rate storage capacity. Depending on the de-rating methodology, this may constitute a significant barrier to entry of storage. A delivery period shorter than a year thus reduces barriers to entry in capacity mechanisms and is beneficial for energy storage providers that may struggle to provide capacity over longer periods. Here the requirements of the French capacity mechanism of a delivery period of 10-25 days per year compares favorably to other MS that ask for annual delivery periods.

Alternatively, adequate **de-rating methodologies** should account for the fact storage is not available at all times while accurately representing the availability of some technologies. Thus, the new Italian capacity auctions have a methodology for de-rating storage – with de-rating factors of as low as 10-30% expected for storage with an energy/power ratio equal to or above 6,[174] meaning most of the storage capacity can be considered in the auction. The new Belgian capacity remuneration mechanism also employs such derating factors, which vary from 69% derating for storages with energy/power ratio of 1h to 21% for those of 4h.[175]

Given the objective to ensure long-term adequacy by incentivising sufficient investments in capacity, **multi-year contracts** may be justified for capacity mechanisms - contrary to balancing services, which address short-term system needs and where thus short-term contracts are preferred in order to reduce barriers to entry for new flexibility sources. This feature of capacity mechanism may be attractive to provide revenue certainty for storage investments. France in this regard has multi-year capacity contracts for seven years. ACER, however, is of the opinion that "multi-year capacity contracts in Ireland, Italy, Poland and Spain create a bias in favour of investing in fossil fuel power

172 ACER (2022) Market Monitoring Report 2020 – Electricity Wholesale Market Volume

173 Following ACER's terminology. This indicates the contractual period during which the provider should be available to provide capacity in case of adequacy issues.

174 Terna (2021) Mercato della Capacità - Disposizioni Tecniche di Funzionamento n.2 (Table 3). https://download.terna.it/terna/CM_DTF2_8d9ae88f34aeadb.pdf

175 Elia (2022) Elia Product Sheet - Capacity Remuneration Mechanism

plants, representing a barrier to the participation of demand response, energy storage and variable RES generation".[176]

Participation of non-hydropower storage technologies in capacity markets is increasing. Hydropower (pumped and reservoir-based) accounted for 15-18% of the capacity remunerated in selected MSs in 2020-2021.[177] Other energy storage technologies account for less than 1% of the remunerated capacity. Where long-term contracts in capacity markets exist and data was provided to ACER (for capacity mechanisms in Ireland, Italy Poland and Spain), the contracted storage capacity share increases from 7% of the total in 2026 to 12% in 2032. An increasing participation of storage technologies other than hydropower can be observed compared to 2020-2021, accounting for up to 4.8% of the contracted capacity (in 2032)[178].

4.2.2.5 Maturity of regulatory frameworks and initiatives to value distributed flexibility sources

With the increasing penetration of distributed energy resources, DSOs will need to further procure services to ensure the safe operation of the networks. These services include voltage control (dynamic and steady state), islanded operation as well as for congestion management. Moreover, DSOs may also contract flexibility sources, among which storage, to defer network investments

Several new provisions of the new electricity market design aim to promote market-based procurement of flexibility services at the distribution level. Article 32 of the Electricity Directive provides that Member States shall incentivize the procurement of flexibility services, at the distribution level. Article 32 also provides that DSOs shall be enabled to procure such services from providers of distributed generation, demand response of energy storage. Article 13 of the Electricity Regulation establishes provisions regarding redispatching (also at the distribution level), with market-based redispatching being the preferred approach. These are the main relevant rules at the EU level regarding local (i.e. distribution) flexibility. Other provisions besides article 13 impacting distributed flexibility sources exist, such as article 15 (active customers) and article 17 (demand response aggregation) of the Electricity Directive. However, the analysis focuses on the issues of procurement of flexibility by DSOs from distributed sources.

On article 15, for example by the end of 2021, of the 11 Member States surveyed by smartEN study[179] France, Finland, Greece, Italy, Slovenia and Spain had introduced legislation or otherwise in practice ensured that customers are able to act as active customers. France, Finland, Ireland had transposed Article 32 on DSOs incentives for flexibility. Where the article has been transposed, the exact rules for its application remain to be further specified and discussions are on-going. For example, in France the government is developing the rules in consultation with the regulator[180], which has not been yet completed.

Thus, the regulatory frameworks for DSOs procuring congestion management and ancillary services is still in development in several Member States. But DSOs are not the only actors which require local flexibility. Distributed flexibility sources, among which storage, can also provide services to TSOs or other market parties. The **number of local flexibility platforms and market initiatives**

[176] ACER (2022) Market Monitoring Report 2020 – Electricity Wholesale Market Volume. P.98

[177] BG, FR, FI, DE, EL, IE, PT, ES, SE

[178] ACER (2022) Market Monitoring Report 2020 – Electricity Wholesale Market Volume. Figure 45

[179] smartEn (2022) The Implementation of the Electricity Market Design to Drive Demand-side Flexibility

[180] Article L322-9 of the French Energy Code

in the EU is small but increasing. With the implementation of Article 32 and other regulatory measures as well as due to the increasing deployment of DERs, this is expected to change.[181] There are various overviews of local flexibility markets and platforms, but none presents a comprehensive inventory of initiatives.[182] Moreover, given the fast-changing environment, any overview will rapidly become outdated. We identified at least 15 local flexibility markets and platforms in the EU, within countries Germany, Denmark, Estonia, Spain, Finland, France, Italy, Lithonia, Latvia and the Netherlands. Germany and the Netherlands are leading with respectively 7 and 4 initiatives[183].

Article 32 foresees the harmonisation of flexibility products at least at the national level. However, article 32 still needs to be adequately implemented in several Member States. However, even for local flexibility needs a certain level of harmonisation at the EU level might be needed to remove entry barriers to market participants active in multiple markets, as otherwise participation in each individual service procurement territory will require becoming acquainted with bespoke methodologies. Network operators consider that a general EU harmonisation of the products for congestion management is not required but a common defined list of attributes could be used, from which all Member States can choose only those attributes required for the specific product definition[184].

The issue of potential harmonisation affects all flexibility resources, however for storage the harmonisation of flexibility products is a particularly important point due to its technical characteristics. **Product attributes such as the availability window and recovery time should have at least common definitions.** Different storage technologies will have varying availability windows and recovery times – common definitions on these aspects will facilitate the participation by storage operators in multiple markets, as they will more easily understand these product attributes in each market Availability window can be understood as the period of time during which the flexibility resource is available to providing (in case of a reservation product) or provides (in case of an energy product) the service, for example a certain number of hours or days. This attribute is relevant for storage as it cannot be available on a continuous basis, due to the need to self-discharge losses and the need to recharge. The recovery period is the period between the end of the last activation and the start of the next. It is important to allow storage technologies to recharge, and should be taken into account when selecting offers from flexibility providers in order that the market clearing result allows sufficient recharge time for accepted storage offers.

The upcoming **demand response network code** based on Art. 59(1)(e) of the Electricity Regulation will aim at addressing remaining regulatory barriers for the development of demand side flexibility. This will include demand response, but also storage (in particular when combined with load) and distributed generation. It shall aim at ensuring that no undue regulatory barriers hamper the participation of demand side flexibility in any of the existing electricity markets and at enabling the participation of demand side flexibility in market-based procurement of services needed by the system operators.[185, 186].

181 Schittekatte et al. (2022) Distributed energy resources and electricity balancing: visions for future organisation

182 Including Frontier Economics (2021) Review of Flexibility Platforms; Accenture (2021) An overview of local European flexibility markets

183 Including the following (project promotors indicated in parenthesis) - BG: Xflex (pilot); DE: Small-assets to CM & aFRR (TSO & third party), ENERA (TSO/DSO, power exchange, third party), New 4.0 Designetz WindNode (TSO/DSO), Pebbles (DSO & third party); Main driver of flexibility is HV congestion (Source: Accenture);ARGE FNB - 50 Hertz; Bne Flexmarkt; DA/RE; DK: INTERRFACE (T/DSO); EE: INTERRFACE (T/DSO); EL: Xflex (pilot); ES: SmartNet Spain (DSO); FI: INTERRFACE (T/DSO); FR: InterFlex (DSO, third party); NEBEF; ReFlex (Enedis); Main driver for flexibility are DSO needs (planification & operation) (Accenture); IT: EQUIGY; Platone; LT: INTERRFACE (T/DSO); LV: INTERRFACE (T/DSO); NL: Enervalis (DSO & third party), ETPA (power exchange, TSO/DSO); Main driver of flexibility is HV congestion (Source: Accenture); GOPACS (T/DSO); Dynamo flexmarkt Nijmegen-Noord; SE: INTERRFACE (T/DSO); SI: Xflex (pilot).

184 CEDEC et al. (2019) An Integrated Approach to Active System Management With the Focus on TSO– DSO Coordination in Congestion Management and Balancing

185 https://www.acer.europa.eu/events-and-engagement/news/acer-initiates-drafting-new-framework-guidelines-demand-response

186 ACER (2022) Framework Guideline on Demand Response (Draft for public consultation)

4.2.2.6 Restrictions on value stacking

Enabling storage to combine revenues from different services should be allowed in order to improve the business case of flexible resources, while ensuring the delivery of services contracted. Value stacking refers to the pooling of revenue streams from multiple services to build up the business case for investing in flexibility.

Exclusivity clauses are a straightforward way **to ensure that contracted resources are effectively available for delivery of the service.** However, they impede revenue stacking by storage. Thus, such clauses in flexibility service contracts should be allowed only if justified for technical reasons. Exclusivity clauses are not explicitly allowed nor forbidden in the EU regulatory framework. **Penalties for non-delivery** are a more appropriate way to ensure resource availability while allowing revenue stacking. However, defining the right penalty level is complex, as too high penalties can disincentivize providers to offer flexibility. Therefore, in cases where appropriate penalties cannot be established, exclusivity clauses should restrain from establishing a blanket prohibition and instead define the specific conditions under which storage capacity should be reserved for the contracted services

Transparent and objective rules by network operators on which services can be combined by storage can also provide the certainty necessary for value stacking. The markets in which storage operators are able to participate include frequency response and reserve products, as well as congestion management and other flexibility services such as on local markets. There are three different approaches which storage operators can use to stack revenues[187], namely:

1) Value stacking in time: participating in different markets in different timeframes (e.g. morning and evening).
2) Value stacking in pools: activating assets for different services
3) Double serving: Providing multiple services at the same time by stacking activation from one asset

The possibilities for value stacking and the stacking of services differ per MS. On exclusivity clauses for flexibility service contracts, there is an indication they represented an issue[188] but the situation may be improving.

Out of 7 MSs reviewed in the report of Flexibility Deployment in Europe[189], 6 MSs allowed revenue stacking between balancing services and/or of capacity mechanism contracts, but only 4 out of these 7 MS the are possibilities for dynamic pooling (i.e. "the ability to decide in real-time what assets to activate to deliver each service").

For example, in Belgium value stacking of balancing services in time is possible and can be offered at pool level, however each asset should be prequalified and the bid must include a list of those assets. In Denmark, it is possible to stack different balancing services, however, dynamic pooling (i.e. the ability to decide in real time what assets to activate) is not yet allowed. The analysis shows that in most countries which allow some level of value stacking, only a certain combination of service stacking is allowed, either because of rules not having been updated yet, and/or the need (from the system operator's view) to secure the asset for the contracted service and ensure delivery. The

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[187] USEF. (2021). Flexibility Deployment in Europe. White Paper. https://www.usef.energy/app/uploads/2021/03/08032021-White-paper-Flexibility-Deployment-in-Europe-version-1.0-3.pdf

[188] Bridge Horizon 2020 (2019) Recommendations on Selected Regulatory Issues from experience and knowledge. https://www.h2020-bridge.eu/wp-content/uploads/2018/10/BRIDGE-Regulations-WG-Findings-and-Reco-July-2019.pdf

[189] USEF. (2021). Flexibility Deployment in Europe. White Paper. https://www.usef.energy/app/uploads/2021/03/08032021-White-paper-Flexibility-Deployment-in-Europe-version-1.0-3.pdf

German TSOs have proposed rules clarifying how to allocate the provision of balancing products from different assets, even if multiple aggregators are active on a single flexible asset.[190] Further best practices in non-EU countries are indicated in section 4.2.3.

Optimally offering flexibility services across different markets while maximising the storage asset lifetime and minimising the risk of non-delivery is a complex task. Once excessively restrictive terms & conditions in contracts for the provision of ancillary and other services are removed, operators of storage and other flexibility assets still face the challenge of employing complex algorithms and systems in order to optimise stacking. Further innovation is required in this respect, although this constitutes a technical aspect rather than a regulatory barrier. Nonetheless, already several companies are offering services to allow energy consumers and flexible asset operators to optimise their operation and maximise revenues.[191]

4.2.2.7 Emergent state of new ancillary services

Ancillary services refer to services used by network operators to ensure the safe and secure operation of the electricity system and can be divided into frequency ancillary services (the balancing of supply and demand) and non-frequency ancillary services (such as voltage control and black-start). Congestion management is in European legislation not considered an ancillary service[192]. Flexibility services can be considered a broader term which includes not only ancillary services, but also congestion management services.

New ancillary services are those services which complement "traditional" ancillary services that are widely procured by system operators. The latter include balancing services (FCR, FRR, RR) defined in the Balancing Guideline, but also steady state voltage support and black start. It is important to note that these new ancillary services are to different extents already provided by market participants, but are not remunerated through specific mechanisms. There is, however, no common definition of new ancillary services. An overview of most traditional and new ancillary services is presented below.

[190] https://www.regelleistung.net/ext/download/Konsultation_Regelleistungsistwerte

[191] http://digital.erosioncontrol.com/publication/?i=467668&article_id=2982611&view=articleBrowser&ver=html5

[192] Article 2(48) of the Electricity Directive (EU) 2019/944: 'ancillary service' means a service necessary for the operation of a transmission or distribution system, including balancing and non-frequency ancillary services, but not including congestion management;

Figure 45 Overview of generic ancillary services according to EU-SysFlex[193]

System Service	Aim	Timeframe
Inertial Response	Minimise RoCoF	Immediate
Fast Response	Slow time to reach nadir/zenith	<2 secs
Frequency Containment Reserve	Contain the frequency	5 secs to 30 sec
Frequency Restoration Reserve	Return frequency to nominal	30 secs to 15 mins
Replacement Reserve	Replace reserves utilised to provide faster products	15 mins to hours
Ramping	Oppose unforeseen sustained divergences, such as unforecasted wind or solar production changes	1 hour, 3 hours, 8 hours
Voltage Control - Steady-State	Voltage control during normal system operation	Long or short timeframe for activation
Dynamic Reactive Power	Voltage control during a system disturbance and mitigation of rotor angle instability	<40 ms
Congestion Management	Manage congestion that occurs as a result of a range of situations	mins to hours

For this analysis, new ancillary services include at least:

- Fast frequency response services
- Synchronous inertial response
- Ramping products
- Dynamic reactive power

New ancillary services serve to remedy the lower system inertia and larger gradients of the residual load, which result from an increasing amount of intermittent renewable resources in the grid and from the reduced participation of synchronous generators. These issues are compounded by the fact that regions with large renewable energy potentials are frequently located far from load centres, and thus electricity has to transit further. Larger transit volumes can lead to larger imbalances in individual islanded systems in case of system separation events.[194] Therefore, currently, such services are mostly implemented in islanded systems (such as the all-island system of Ireland, the UK and Australia).[195] However, as the participation of renewable energy sources increases, there will be an increasing need for these services also in the Continental Synchronous Area.[196] We discuss next what are these new ancillary services, the potential for storage technologies to contribute to these services, and the current use by network operators.

Synchronous generators instantaneously dampen frequency changes through changes in its rotor kinetic energy. While synchronous generators may participate in balancing markets, they are generally not remunerated for the instantaneous damping effect on frequency changes. With the increased penetration of non-synchronous generators, there may aneed for explicitly incentivising the provision of synchronous inertia to the system with dedicated **synchronous inertial response**

193 EU-SysFlex (2018) D3.1 Product Definition for Innovative System Services

194 ENTSO-E (2020) Inertia and Rate of Change of Frequency (RoCoF)

195 EU-SysFlex (2018) D3.1 Product Definition for Innovative System Services

196 EU-SysFlex (2019) D2.4 Technical Shortfalls for Pan-European Power System with High Levels of Renewable Generation

services. In this way, the system should have sufficient inertia so that frequency deviations following a disturbance are manageable and can then be contained and resolved with slower-acting (i.e. non-instantaneous) resources. The key parameter to control is the rate of change of frequency (RoCoF) – the change in frequency in a defined period of time, after a disturbance and before any control actions. As the ENTSO-E states, "to fix a maximum RoCoF limit for an electrical power system means to determine the 'maximum stress' that it can sustain and survive; this implies that under these conditions all the control loops, active power control and protection systems, including defence systems are able to trigger and react in accordance with their system governance settings."[197] There is little experience in the procurement of inertial response products. Currently, only EirGrid and SONI procured and defined inertial response products. Nordic TSOs (Statnett, FinGrid, Energinet, Svenska Kraftnat) and National Grid are also looking into solutions to address falling inertia levels, which could include the procurement of synchronous inertial response.[198]

With the increasing amount of renewable energy sources and consequent reduced system inertia, assets providing frequency containment reserves might not be able to respond fast enough to address frequency imbalances. **Fast frequency response** (FFR, also called synthetic or virtual inertia) aims to contain frequency deviations by responding faster than FCR assets. Batteries (but also other storage technologies) are well-suited for providing this FFR service since they have a short response time. FFR differs from synchronous inertia as in FFR a measurement of the frequency is necessary before the control system activates a change in active power injection or withdrawal by the FFR provider. Therefore, synchronous inertia theoretically responds faster than FFR, and both are not fully interchangeable.[199] Nonetheless, technological improvements in grid-forming converter controls should improve the response time, making FFR providers respond in timeframes equivalent to synchronous inertia providers.[200] However, ENTSO-E does not know yet whether assets capable in the future of providing synthetic inertia will be sufficient to fully meet inertia needs.[201]

In Italy ARERA determined through Decision 200/2020 the procurement of FFR services with the first auction taking place in October 2021 and delivery starting in 2023. Eligible assets in include non-interruptible load units, stand-alone production units, and (behind-the-meter) storage systems.[202] In Lithuania, Energy Cells (a publicly-owned subsidiary) contracted 200 MW of battery storage to provide islanded operation in phase I of the project (until 2025) until the Baltic countries are synchronised with the Continental Europe Area and also balancing and synthetic inertia in phase II (post-2025)[203]. Currently, the Russian power system provides primary reserves.[204] The Swedish TSO Svenska Kraftnat started in 2020 a scheme for procuring FFR.[205] Also EirGrid (in Ireland), SONI & National Grid (UK) introduced schemes for procuring FFR.[206] However, the latter was scheduled to

197 ENTSO-E (2020) Inertia and Rate of Change of Frequency (RoCoF)

198 EU-Sysflex (2018) D3.1 Product Definition for Innovative System Services

199 TNO (2021) D3.3 Design of ancillary service markets and products - Challenges and recommendations for EU renewable power systems

200 ENTSO-E (2020) Inertia and Rate of Change of Frequency (RoCoF)

201 ENTSO-E (2020) Inertia and Rate of Change of Frequency (RoCoF)

202 RSE (2021) New rules for assets and novel regulation services to increase the Italian power system flexibility https://www.eera-energystorage.eu/component/attachments/?task=download&id=607:Canevese_Gatti_New-rules-for-assets-and-novel-regulation-servicesache/Content.Outlook/FR4S1YIZ/Canevese_Gatti_New%20rules%20for%20assets%20and%20novel%20regulation%20services.pdf Terna (2020) Fast Reserve – Information pack https://download.terna.it/terna/Fast%20Reserve%20-%20Information%20pack_8d82fe02cbed7ad.pdf

203 https://www.epsog.lt/en/news/cells https://blog.fluenceenergy.com/clean-energy-accelerator-storage-transmission-enhancement-lithuania

204 https://tyndp.entsoe.eu/2016/insight-reports/baltic-synchronisation/

205 https://www.svk.se/aktorsportalen/systemdrift-elmarknad/information-om-stodtjanster/ffr/

206 EU-SysFlex (2018) D3.1 Product Definition for Innovative System Services

be phased out by the end of 2022 with the complete restructuring of balancing services in the UK, as explained in section 4.2.3.

Ramping up/down refers to the ability of an asset to change its power supply or demand, respectively, from one time unit to the next in order to maintain the supply-demand balance.[207] **Ramping products** are used to deal with short-time frame system imbalances caused by, for example, large changes in wind or solar PV generation which lead to a significant up or downward ramp need. However, the duration of these imbalances is longer (up to several hours) longer than those addressed by Frequency Containment or Frequency Restoration Reserves (of the order of several seconds or minutes, respectively) Currently, Ireland and Northern Ireland use ramping products to mitigate technical scarcities to deal with rapid changes in the system balance. In Ireland and Northern Ireland one, three and eight hours are used as product time-horizons for ramping-up services. Other systems operators, such as CAISO (California) and MISO utilize ramping products as well, however used due to market design failures rather than technical scarcities on the operating reserve timeframe.[208]

Dynamic reactive power services aim to support voltage control during a system disturbance. This is different from steady state reactive power which applies voltage control during normal system operation. Currently, only the TSOs of the island of Ireland have designed dynamic reactive power products, however, the service has not yet been procured, as it is only deemed necessary at non-synchronous generation levels above 70%.[209]

The EU-SysFlex project indicated there would be scarcity or at least concern regarding the sufficiency of inertia and frequency containment in the systems of Continental Europe and particularly the island of Ireland in the high-renewables scenarios analysed. This indicates that the need for such services, which at the moment have been deemed necessary only in the Irish and British systems, should increase also for continental Europe.

The **procurement of these new ancillary services by network operators** represents a market opportunity for various storage technologies, which may often be competitively well-placed, especially with the improvement of grid-forming technology. TSOs are already required to procure balancing services in a non-discriminatory manner (Article 40(4) of Electricity Directive). This should include fast frequency response services, given the wording of the definition for 'balancing'.[210] TSOs and DSOs should also procure non-frequency ancillary services through market-based procedures in a non-discriminatory manner, although NRAs are allowed to provide a derogation for the use of non-market-based procedures (articles 31(7) and 40(5) of Electricity Directive, respectively). It is possible that some or several of these services will use non-market-based procedures, due to the localised nature of some of the services (which could increase the risk of strategic behaviour by market participants, i.e. gaming) and the transaction costs which may not warrant complex competitive procedures.

The new ancillary services described above could be to some extent procured in a shared manner, except for dynamic reactive power which has a strong locational component. It is possible that once these new services are needed at a larger scale throughout the EU due to increasing renewable energy penetration and the consequent reduction in synchronous generation, they could

[207] EU-SysFlex (2018) D3.1 Product Definition for Innovative System Services. https://eu-sysflex.com/wp-content/uploads/2019/08/D3.1_Final_Submitted.pdf

[208] EU-SysFlex (2018) D3.1 Product Definition for Innovative System Services

[209] EU-SysFlex (2018) D3.1 Product Definition for Innovative System Services

[210] Article 2(10) of the Electricity Regulation 2019/943: "'balancing' means all actions and processes, in all timelines, through which transmission system operators ensure, in an ongoing manner, maintenance of the system frequency within a predefined stability range and compliance with the amount of reserves needed with respect to the required quality"

be most efficiently procured at the regional level, as less units should suffice to provide e.g. the synchronous inertia needed (at least in the transition phase until variable renewable energy becomes the dominant source in a given synchronous system). Attention would be required to ensure that ancillary service provision does not affect cross-border flows as far as possible. This because if for example a single unit provided frequency regulation for several bidding zones, changes in the unit active power would lead to changes in cross-border flows. Besides utilising interconnection capacity which could be offered to the market otherwise, that could create issues in case of system separation. Nonetheless, as long as available interconnection capacities and safe system operation are considered, sizing and procurement of new ancillary services at the regional level could be beneficial, once the need for them increases. However, given the general absence of procurement mechanisms for such services in the EU (with the exception of Ireland) there is a need for further experience in the design of such processes. This could then provide the learning needed for initiatives e.g. harmonising the products at a regional level and even sharing these services.

Moreover, the resources eligible to provide some of the new ancillary services may also participate in established ancillary service procurement mechanisms such as for FCR, FRR and RR. There is a particularly strong connection between the FRR and FCR markets, as the same balancing resources could provide both – and there could be an overlap between FRR and FCR depending on the definition of response time. This also raises issues related to rules for value stacking and which combination of services is allowed or not. Thus, further understanding of the interaction of these new ancillary services and existing balancing services regulated at the EU level is needed.

Finally, it must be noted that the **provision of 'conventional' non-frequency ancillary services such as voltage control and black start are often not remunerated by network operators, or not accessible to storage.** For example, in 2020, out of 28 EU27 TSOs surveyed by ENTSO-E, only 6 allowed the participation of storage (in FI, DE and SK). Out of these, black start provision was mandatory and not remunerated in Germany.[211] Feedback on the national fiches has indicated that this situation had not significantly changed by the 1st half of 2022.

4.2.2.8 Provision of locational signals and information to market parties

While high temporal granularity in electricity markets is beneficial to storage, improving locational signals and locational information to markets parties could also improve the participation of all flexibility sources in the market, including storage. Ensuring electricity markets reflect locational aspects as much as possible should improve the overall system efficiency, by better reflecting network constraints and thus providing investment and operational signals to storage. However, a balance must be found between increasing locational signals and information, and ensuring market processes and algorithms are practical.

Several locational aspects affect storage – here we discuss the following:

- **Bidding zone review process:** The configuration of bidding zones in the EU should reflect structural congestions. This would allow zonal prices to better reflect system conditions in moments of congestion (besides reducing the need for TSOs adopting remedial actions). This could increase price volatility and thus incentivise the provision of flexibility by storage and other resources (which in turn should alleviate interconnector congestion). However, the 1st bidding zone review was considered a failure by ACER[212]. The bidding zone review process has since been altered with the Clean Energy Package and previous challenges around governance and

[211] ENTSO-E (2021) Ancillary Services Survey 2020

[212] ACER (2019) Monitoring report on the implementation of the CACM Regulation and the FCA Regulation

decision-making have been tackled. ACER has adopted a decision on the harmonised methodology and assumptions for the TSO assessment, which is expected to improve the process. The reconfiguration of the bidding zones if needed will be decided by the relevant Member States based on the assessment by TSOs r. It remains to be seen whether the next review process adequately identifies structural congestion and whether the new governance process leads to bidding zones better reflecting that congestion thereby increasing the availability of cross-zonal capacities.

- **Provision of system and network information by network operators:** This is essential to allow market participants to adequately anticipate system conditions. Such information is relevant in order for storage operators and other market participants to make for example siting and sizing decisions, as well as to decide which storage services to provide across the different markets, such as whether to offer the available storage capacity for balancing or redispatching. Currently, the level of information provided by network operators in ENTSO-E's Transparency Platform varies per data type and TSO/Member State. ACER indicates the information availability is more of an issue in the Baltics, Ireland and Sweden.[213] Moreover, further information than what is available in ENTSO-E's transparency platform could be of use to storage operators. The Platform currently provides information such as cross-border capacities (forecasted, allocated and utilised), as well as scheduled commercial exchanges. Several potential storage services are of a locational nature, including all those procured by DSOs as well as e.g. redispatch services and voltage control needed by TSOs. For example, in the Netherlands the network operators provide information on the network capacity for new injection connections (Figure 46). In areas shown in red, connection requests cannot be met, while areas in orange already show structural congestion. Information on internal network congestion would also be useful for storage and other (distributed) flexibility asset operators.[214] For example, the French DSO Enedis has a portal providing various information, including regularly updated information on D+2 irradiation data (for forecasting PV generation), new connection projects for various resources, and others.[215] Elia in Belgium also provides this information.[216]
- **Flexible connection contracts:** Flexible connection contracts are being used as a transitional solution in case of grid capacity constraints; they allow grid operators to reduce or interrupt injection or withdrawal during a limited number of hours per year, with or without a financial compensation for the concerned grid user. Flexible contracts could facilitate the connection of storage in grids reaching or beyond their nominal capacity, while distributed storage could be well suited to optimise its operation to avoid periods of access curtailment – or even relieve grid congestion. Such contracts exist in Belgium as well as in France. In France, the network user may choose for the reference connection contract, or for the smart connection contract, where these limitations in injection and/or withdrawal may be established by the DSO (leading to a cheaper and/or faster connection).[217] Moreover, besides new approaches for individual connection agreements, changes can be made to the maximum capacity that is allowed to be connected to a network. A draft network code was published in by the Dutch NRA to increase the connection limit to 200% of the technical grid capacity limit (instead of the current 120%). This means new users could be connected until up to twice the capacity of the network was reached

[213] ACER (2022) Market Monitoring Report 2020 – Electricity Wholesale Market Volume

[214] CEDEC et al. (2016) TSO – DSO data management report

[215] https://data.enedis.fr

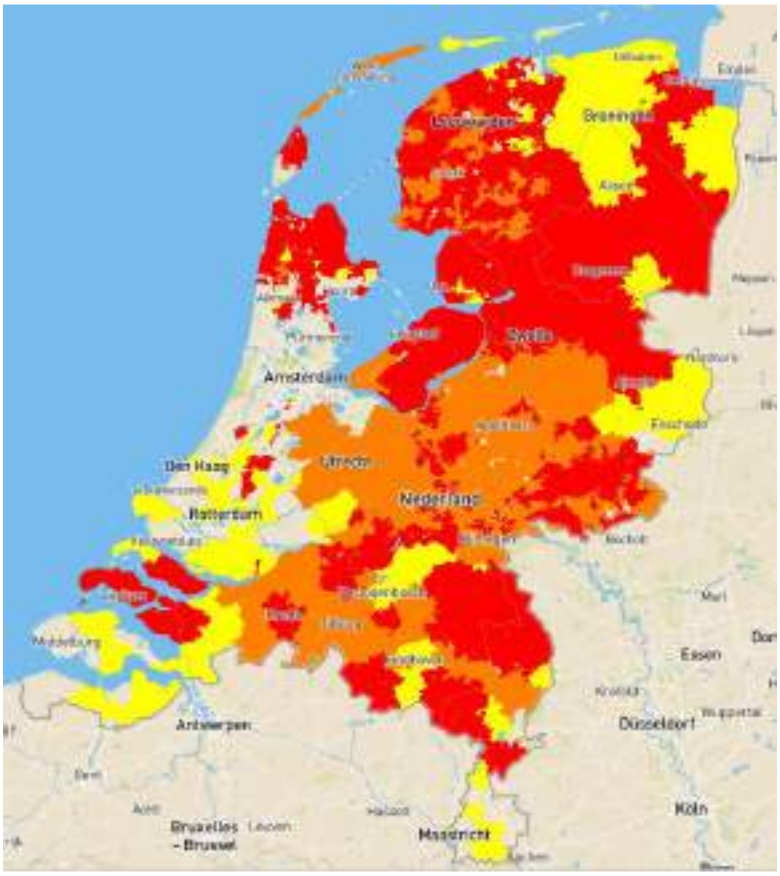
[216] https://opendata.elia.be/pages/home/

[217] https://www.enedis.fr/media/2361/download

(and access would be interrupted in moments of congestion).[218] However, network operators have indicated concerns regarding the stability of the network.[219]

Locational transmission tariffs are also relevant, as they can provide siting signals to network users, including for example renewable power plants. They can also lead to better siting of storage, but specific effects would be limited compared to other locational issues discussed here. Also, only few Member States currently employ locational signals in transmission tariffs, and there is no obligation for the others to adopt them. Therefore, it is not discussed further here.[220]

Figure 46 Capacity map of the Dutch electricity grid as of 14/04/2022 (injection)[221]



No capacity scarcity (yet)	Risk of capacity scarcity, adapted connection regime	Advanced notice of structural congestion to NRA	Structural congestion

[218] https://www.acm.nl/nl/publicaties/ontwerp-codebesluit-congestiemanagement

[219] https://www.acm.nl/sites/default/files/documents/zienswijze-netbeheer-nederland.pdf

[220] For further information, please see ACER (2019) - ACER Practice Report on Transmission Tariff Methodologies in Europe; and ACER (2021) - Report on Distribution Tariff Methodologies in Europe

[221] https://capaciteitskaart.netbeheernederland.nl/

4.2.2.9 New Guidelines on State Aid for Climate, Environmental Protection and Energy

In case Member States opt for developing specific support schemes for long-duration storage, this could constitute of course a main revenue stream. However, asides for innovation support to long-duration energy storage technologies with low to medium TRLs, Member States would have to identify a specific (new) system need that is not yet met by existing mechanisms, and likely open the mechanism to all flexibility solutions which meet the technical requirements.

The new Guidelines on State Aid for Climate, Environmental Protection and Energy (CEEAG) have been adopted in January 2022[222]. They allow for State Aid to storage when complying with requirements under a number of aid categories, namely:

- for the reduction and removal of greenhouse gas emissions including through support for renewable energy and energy efficiency
- for the improvement of the energy and environmental performance of building
- for clean mobility
- for the security of electricity supply
- for energy infrastructure[223]

The definition of 'energy from renewable sources' (section 2.4, paragraph 19(35)) excludes electricity produced as a result of storage system. This could potentially hinder the creation of support schemes for long-duration energy storage. However, this and potentially other issues with the CEEAG were not one of the main concerns by storage operators, based on our interviews and responses to the survey.

4.2.3 International landscape

A number of key markets worldwide are driving the growth of energy storage: Korea, China, the US and Germany accounted for more than 60% of the market in 2019[224], and led the world in new additions in 2020. In 2021, 10 GW / 22 GWh of storage were deployed worldwide, reaching 27 GW / 56 GWh by end 2021. The US are currently the world's biggest market with an installed storage capacity of 4 GW / 11 GWh in 2021, however, China is likely to overtake the lead as it already saw a significant jump from 0.6 to 1.6 GW in yearly installations in the same period. In place number three is Germany as the first EU country.[225] Finally , while utility-scale batteries lead the market, Japan is a market leader for behind-the-meter storage.

Looking forward, the IEA expects the main global markets in 2026 to comprise Europe (deployment of 38.6 GWh), China (34.1 GWh), India (31 GWh) and the US (23 GWh), where utility-scale batteries should remain the main market and constitute the majority of the deployment in the 2020-2026 period. It must be noted however that such forecasts are highly uncertain. Lithium-based batteries are the main technology deployed, with nickel-manganese-cobalt chemistries (the same currently

222 Guidelines on State aid for climate, environmental protection and energy 2022 (2022/C 80/01)

223 Aid to storage under the 'energy infrastructure' category can be given only until the end of 2023 and only for front-of-the-meter storage

224 https://www.iea.org/reports/tracking-energy-storage-2020

225 Energy Storage News (2022) BloombergNEF predicts 30% annual growth for global energy storage market to 2030. https://www.energy-storage.news/bloombergnef-predicts-30-annual-growth-for-global-energy-storage-market-to-2030/

used in EVs) being the most important in 2020 deployments, but expected to be surpassed by lithium-iron phosphate chemistries in 2021.[226]

A number of policies which improve the business case of storage in global markets are expected to be important,[227] namely economic and financial incentives, and increased revenues in the different electricity markets due to the increasing need for flexibility in high-RES systems, especially those where variable renewable energy meets the entirety of demand in some hours of the day. It is however interesting to look at country-specific policies as well as underlying motivations for their adoption for the past and future storage growth.[228] These include:

- **In Europe**, in specific markets such as Ireland and the Nordic countries, **market-based remuneration for ancillary services** exist which provide additional revenues for storage and can be an important driver for development, as discussion in section 4.2.2 – driven by the need to contract enough ancillary services in these synchronous systems. In the UK, besides the significant revenues that can be derived from ancillary services (especially the new Dynamic Containment service described below in this section)[229], capacity auctions have and continue to play a significant role in stimulating deployment.[230] Behind-the-meter storage is developing strongly in Germany, driven by a context **of strong development of rooftop PV and EVs (increasing incentives for energy management by consumers), prosumers becoming more acquainted with home batteries, and comparatively high energy prices**, particularly when all price components such as renewable energy surcharges are considered.[231] Finally, some **hybrid auctions** served to develop storage co-located with renewables, in Germany and Portugal (section 4.3), with another auction foreseen for Spain (section 4.7), where there is limited additional grid capacity to connect all planned RES projects. Although these auctions account for only a limited shared of deployment so far, dedicated auctions or at least the consideration of hybridisation in future auctions should support storage;
- The strong performance of the **US[232] storage market** is driven by large projects in specific states. System operators, regulators and the federal and state governments have realised they had a need for increased resilience after recent system disruptions and observed high peak prices in several markets. Such problems are compounded by the limited size of electricity markets in the US, compared to European ones, as discussed below. In 2020, the US *Better Energy Storage Act* authorized over 1 billion USD for a period of five years to support research and marketing of storage technologies[32]. The state officials used targets as tool to start-up their in-state storage industries. The leading states in energy storage targets include[233] California (11.5 GW by 2026) Virginia (3100 MW by 2035), New Jersey (2000 MW by 2030), New York (1500 MW by 2025), Nevada (1000 MW by 2030), Connecticut (1000 MW by 2030) and Massachusetts (200

[226] BNEF (2021) Global Energy Storage Market Set to Hit One Terawatt-Hour by 2030. https://about.bnef.com/blog/global-energy-storage-market-set-to-hit-one-terawatt-hour-by-2030/

[227] https://www.iea.org/articles/how-rapidly-will-the-global-electricity-storage-market-grow-by-2026

[228] Unless stated, the following is based on IEA (2021) Energy Storage https://www.iea.org/reports/energy-storage And IEA (2021) Renewables 2021 - How rapidly will the global electricity storage market grow by 2026? https://www.iea.org/articles/how-rapidly-will-the-global-electricity-storage-market-grow-by-2026

[229] https://www.energy-storage.news/uk-energy-storage-bumper-returns-in-2021-unlikely-to-continue-says-modo-energy/

[230] https://www.energy-storage.news/the-numbers-behind-the-record-breaking-rise-of-the-uk-battery-storage-market/

[231] https://www.energy-storage.news/german-energy-storage-market-2021-residential-dominates-but-utility-scale-bess-grows-nearly-6x/

[232] https://www.canarymedia.com/articles/energy-storage/grid-energy-storage-surged-in-2021-as-we-predicted

[233] Burwen, J., 2020. Energy Storage Goals, Targets, Mandates: What's the Difference? [online] American clean power. Available at: <https://energystorage.org/energy-storage-goals-targets-and-mandates-whats-the-difference> [Accessed 16 May 2022].

MWh by 2025)[234]. This corresponds to about 3 to 14% of today's installed generation capacity of each of the states (New York 3%, Nevada 8%, Connecticut 10%, Virginia 10%, New Jersey 12%, California 14%). These targets have been accompanied by e.g. tendering mechanisms in California to achieve them.[235] In the US overall, the driver of strong solar PV development and the associated policy of **tax incentives, particularly the solar investment tax credit** (which can benefit also hybrid deployments) also play an important role in creating a market for capacity firming by storage.;

- In **China,** a major driver is the **need to integrated renewables and reduce the observed curtailment** in the past years. This has led to the national policy target of 30 GW of energy storage by 2025 as well as other policies such as **priority connection to the grid** and the further changes to the power sector. In 2021, China broadcasted the plans to increase commutative installed non-pumped hydro energy storage over 30 GW by 2025[32] and 100 GW by 2030[236]. This corresponds to about 1% / 4% of today's installed generation capacity in the country. In the 2021 National Energy Conference, the Chinese officials announced to faster the pumped hydro energy storage development plan which may lead to an installed capacity of 65 GW by 2025[38]. corresponding to about 2.7% of today's installed electricity generation capacity. Altogether, this has led to hybrid projects becoming increasingly frequent. Moreover, the **commissioning of delayed projects** has played a role in the jump in yearly installations observed in 2020. According to the China Energy Storage Alliance (CNESA), China invested approximately 7.4 billion RMB (1.16 billion USD) on energy storage in 2020 and the source of investment were mostly from venture capital, generation companies, grid companies, solar companies, and local governments[237]. In contrast, the participation of standalone large-scale storage in electricity markets does not appear to be a strong driver, due to the low (regulated) prices[238].
- In Korea, **federal subsidy schemes** have played an important role in the development of storage.

In summary, it appears that for the fastest growing markets, various drivers are in play. High growth in the US and China is associated with the urgent need for additional system flexibility, and takes the form among others of hybrid projects. In the case of the US merchant front-of-the-meter projects are also being developed due to high peak prices (and thus higher spreads) in electricity markets. These drivers differ to the EU, where hybrid projects also start being developed but where a relevant share of renewable energy projects is publicly supported, with hybridisation starting to be explicitly supported or at least considered in auction design.

Another critical factor is the comparatively lower need for flexibility services in the Continental Europe Synchronous Area, compared to other systems in Europe, US and China. Figure 47 presents the technical scarcities for the continental European, island of Ireland and Nordic systems expected due to increasing renewable energy penetration and decreasing volumes of synchronous generation in the system. It can be seen that the island of Ireland system is most likely to face scarcities in the 2030 time horizon, due to higher penetration of variable (non-synchronous) renewables,[239] but also likely due to the limited system size, which reduces the possibility to share flexible assets and

[234] Plautz, J., 2022. *As states ramp up storage targets, policy maneuvering becomes key*. [online] Utility Dive. Available at: <https://www.utilitydive.com/news/as-states-ramp-up-storage-targets-policy-maneuvering-becomes-key/618218/>[Accessed 16 May 2022].

[235] https://www.canarymedia.com/articles/energy-storage/grid-energy-storage-surged-in-2021-as-we-predicted

[236] Standaert, M., 2021. *China ramping up ambitious goals for industrial battery storage*. [online] Energy Monitor. Available at: <https://www.energymonitor.ai/tech/energy-storage/china-ramping-up-ambitious-goals-for-industrial-battery-storage [Accessed 16 May 2022].

[237] China Energy Storage Alliance, (2021). Energy Storage Industry Research white Paper 2021.

[238] Wood Mackenzie (2021) Could China lead the global energy storage market by 2030?

[239] EU-SysFlex (2018) European Flexibility Roadmap - D10.5

reduce flexibility needs (by integrating areas with a lower generation and load profile correlation). Scarcities concerning especially steady state voltage and oscillation damping are nonetheless expected for CESA. The US markets are also characterised by a lower level of integration than the EU continental system.

Figure 48 illustrates this by presenting the US electricity markets, characterised by multiple adjacent and non-integrated markets, with in fact some of the markets shown being further fragmented with limited or no exchange of flexibility within them. As a comparison, the PJM[240] market has a peak load somewhat above 130 GW[241] versus over 500 GW in the ENTSO-E system.[242] China's system is larger, reaching over 1000 GW, but faced in the mid-2010s significant flexibility constraints leading to the curtailment of renewables and a focus on energy storage as a flexibility source.[243]

Figure 47 Technical scarcities' forecast for 2030 in 3 European synchronous systems of the EU-SysFlex project[244]

[240] One of the largest US electricity markets and covering 13 US states and the District of Columbia

[241] https://insidelines.pjm.com/pjm-2022-long-term-load-forecast-predicts-slight-growth/

[242] https://2020.entsos-tyndp-scenarios.eu/scenario-results/

[243] Liu et al. (2021) Bottlenecks and Countermeasures of High-Penetration Renewable Energy Development in China. https://www.sciencedirect.com/science/article/pii/S209580992030357X

[244] EU-SysFlex (2018) European Flexibility Roadmap - D10.5

Figure 48 US electricity markets

Outside the EU, some countries have announced storage goals. While goals by national operators and companies are common, goals set by the government are rather seldom. In the US and China, the governments have announced storage goals. In China this has been coupled with specific measures such as priority connection, which have boosted storage, while in the US the target is more recent and therefore is not a main cause for the growth observed until 2021. The design of organised markets, in contrast, does not seem to be a significant factor to explain strong development of storage in the US and China compared to the EU, as even in the US the relevance of renewable PPAs (which are much more common than in the EU) is likely more important for the development of storage than access to organised electricity markets.

This does not, however, reduce the importance of providing non-discriminatory access to electricity markets for all flexibility sources and to adequately source all necessary ancillary services using market-based procurement as far as possible, given these markets are the most significant ones to storage.

To complement the analysis of the main drivers, some specific best practices are highlighted below.

Facilitating market access to energy storage

The US Federal Energy Regulation Commission (FERC) order No 841[245] of 2018 mandates regional transmission organisations (RTOs) and independent system operators (ISOs) to:

1) "Ensure that a resource using the participation model is eligible to provide all capacity, energy, and ancillary services that the resource is technically capable of providing in the RTO/ISO markets
2) Ensure that a resource using the participation model can be dispatched and can set the wholesale market clearing price as both a wholesale seller and wholesale buyer consistent with existing market rules that govern when a resource can set the wholesale price;
3) Account for the physical and operational characteristics of electric storage resources through bidding parameters or other means; and

[245] https://www.ferc.gov/media/order-no-841

4) Establish a minimum size requirement for participation in the RTO/ISO markets that does not exceed 100 kW."

More specifically, the order includes several interesting provisions, such as requiring all RTOs/ISOs to:

- Allow storage to de-rate its capacity in order to meet minimum run-time requirements (in for example capacity mechanisms)
- Have provisions providing a participation model for electric storage resources that accounts for the physical and operational characteristics of electric storage resources through bidding parameters or other means. This would allow storage operators to submit in the bids or elsewhere (e.g. when registering with the RTO/ISO) information such as State of Charge, Upper and Lower Charge Limits, and Maximum Charge and Discharge Rates. In turn, this could then be considered in the market clearing algorithm.

FERC order 841 should improve the access of front- and behind-the-meter storage to electricity markets, and has a different approach to achieve this compared to the provisions of the revised EU Electricity Directive and Regulation (with for example the above-mentioned smaller minimum size requirement of 100 kW). Nonetheless, there is still no indication so far it provides a better framework for enabling the participation of storage than the EU regulatory framework, and as mentioned above significant storage growth in the US was seen already in 2020 due to other factors, as the major US market operators planned to implement order 841 only by August 2021.[246]

Value Stacking

Some network operators reviewed their exclusivity clauses, such as National Grid, which conducted a consultation[247] and then updated its ancillary services contract terms & conditions.[248] National Grid accepts the stacking of revenues from some services, with the following rules:

- "Providers can offer single or multiple services to single or multiple buyers [across Availability Windows]. The onus is on the Provider to ensure that asset(s) are available to perform under each contract they are party to. Providers can offer active and reactive services to the ESO and / or DNO across Availability Windows
- Multiple services can be provided to multiple buyers over an Availability Window if the requirements of the services are compatible and the provision of one service does not impede its performance under an existing contract.
- A single active or reactive power service cannot be provided to multiple buyers over an Availability Window, as this would result in the potential for double counting of MW or Mvars [or non-delivery of one of the contracted services].
- Multiple services can be provided to a single buyer over an Availability Window, if the requirements of the services are compatible and if the provision of one service does not impede the ability to perform against an existing contract."

Thus, the more restrictive condition affects delivery of two services in the same availability window, especially if this concerns two different clients, while there are much less restrictions for the delivery of services in different availability windows.

[246] https://dukespace.lib.duke.edu/dspace/bitstream/handle/10161/20484/Final%20Draft_print.pdf?sequence=1&isAllowed=y

[247] National Grid (2018b) Review of Exclusivity Clauses within Balancing Services Contracts. https://www.nationalgrideso.com/sites/eso/files/documents/Review of Exclusivity Clauses within Balancing Services Contracts Sep 2018.pdf

[248] National Grid ESO (2020) ESO Balancing Services: A guide to contracting, tendering and providing response and reserve services. https://www.nationalgrideso.com/document/142161/download

Another case of rules on revenue stacking is the use case of California. The Commission of Public Utilities of the State of California (CPUC) made a decision on providing guidance regarding the stacking of multiple electricity system services and therefore improving the economic viability for the energy storage industry in California.[249] The CPUC defined a number of services that storage can provide in different domains, as shown below.

Table 21 CPUC domains and reliability/non-reliability services of storage[250]

Domain	Reliability Services	Non-Reliability Services
Customer	None	TOU bill management; Demand charge management; Increased self-consumption of on-site generation; Back-up power; Supporting customer participation in DR programs
Distribution	Distribution capacity deferral; Reliability (back-tie) services; Voltage support; Resiliency/microgrid/islanding	None
Transmission	Transmission deferral; Inertia; Primary frequency response; Voltage support*; Black start	None
Wholesale Market	Frequency regulation; Spinning reserves; Non-spinning reserves; Flexible ramping product	Energy
Resource Adequacy	Local capacity; Flexible capacity; System capacity	None

* Adapted from CPUC (2018) Order Instituting Rulemaking to consider policy and implementation refinements to the Energy Storage Procurement Framework and Design Program (D.13-10-040, D.14-10-045) and related Action Plan of the California Energy Storage Roadmap

CPUC then created 11 stacking rules providing a hierarchy of services (with reliability services having priority) and domains. While it remains to be seen if the rules strike a good balance between facilitating revenue stacking while providing reasonable certainty of delivery of the contracted services, they illustrate how relatively simple rules can clarify what stacking is allowed and what is not:[251]

- Rule 1. Resources interconnected in the customer domain may provide services in any domain.
- Rule 2. Resources interconnected in the distribution domain may provide services in all domains except the customer domain, with the possible exception of community storage resources, per Ordering Paragraph 11 of D.17-04-039.
- Rule 3. Resources interconnected in the transmission domain may provide services in all domains except the customer or distribution domains.

[249] Clean Energy Law Report (2018). California Adopts Rules for Evaluating Multiple-Use Energy Storage Resources. https://www.cleanenergylawreport.com/energy-storage/california-adopts-rules-for-evaluating-multiple-use-energy-storage-resources/

[250] https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M206/K462/206462341.PDF

[251] https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M206/K462/206462341.PDF

- Rule 4. Resources interconnected in any grid domain may provide resource adequacy, transmission and wholesale market services.
- Rule 5. If one of the services provided by a storage resource is a reliability service, then that service must have priority.
- Rule 6. Priority means that a single storage resource must not enter into two or more reliability service obligation(s) such that the performance of one obligation renders the resource from being unable to perform the other obligation(s). New agreements for such obligations, including contracts and tariffs, must specify terms to ensure resource availability, which may include, but should not be limited to, financial penalties.
- Rule 7. If using different portions of capacity to perform services, storage providers must clearly demonstrate, when contracting for services, the total capacity of the resource, with a guarantee that a certain, distinct capacity be dedicated and available to the capacity-differentiated reliability services.
- Rule 8. For each service, the program rules, contract or tariff relevant to the domain in which the service is provided, must specify enforcement of these rules, including any penalties for non-performance.
- Rule 9. In response to a utility request for offer, the storage provider is required to list any additional services it currently provides outside of the solicitation. In the event that a storage resource is enlisted to provide additional services at a later date, the storage provider is required to provide an updated list of all services provided by that resource to the entities that receive service from that resource. The intent of this Rule is to provide transparency in the energy storage market.
- Rule 10. For all services, the storage resource must comply with availability and performance requirements specified in its contract with the relevant authority.
- Rule 11. In paying for performance of services, compensation and credit may only be permitted for those services which are incremental or distinct. Services provided must be measurable, and the same service only counted and compensated once to avoid double compensation

Ancillary services

In 2011, the FERC order 755 on "Frequency regulation compensation in the organised wholesale power markets" found that current practices by RTOs and ISOs were "unjust, unreasonable, and unduly discriminatory or preferential" as they failed to acknowledge the "greater amount of frequency regulation service being provided by faster-ramping resources". The order requires system operators to add a performance payment which reflects the quantity of frequency regulation provided by the resource in response to a dispatch signal.[252] FERC also issued in 2016 order 825 on settlement intervals and shortage pricing, requiring RTOs and ISOs to align settlement and dispatch intervals, and that they "trigger shortage pricing for any interval in which a shortage of energy or operating reserves is indicated during the pricing of resources for that interval". [253]

As mentioned in section 4.2.2, the UK also possess an FFR procurement mechanism. However, National Grid ESO notes that "the services that participants may offer into the monthly FFR tender are not completely standardised. There is a manual process to evaluate these monthly tender offers, which is becoming increasingly unmanageable as the number of providers grows".[254]

[252] https://www.ferc.gov/sites/default/files/2020-06/OrderNo.755.pdf

[253] https://www.ferc.gov/sites/default/files/2020-05/settlement825.pdf; Broeckx et al. (2019) Energy Storage - Our take on business models and regulation

[254] ESP Consulting (2020) Frequency Response Auction Trial - Evaluation Report

National Grid ESO is implementing a planned reform of its balancing markets, leading to introduction of three new services as shown below. National Grid ESO has provided a detailed roadmap for the reform of the frequency response services it procures.[255]

Table 22 New frequency response services introduced by National Grid ESO[256]

Product	Operational range	Response type
Dynamic regulation	+/- 0.015 to 0.1 Hz	Pre-fault
Dynamic moderation	+/- 0.1 to 0.2 Hz	
Dynamic containment	+/- 0.2 to 0.5 Hz	Post-fault

The existing FFR mechanism (named Enhanced Frequency Response) is planned to be phased out in Q3 2022, and also the Firm Frequency Response service will be phased out.

[255] https://www.nationalgrideso.com/research-publications/markets-roadmap

[256] Modo Energy in Energy Storage News (2020) What is Dynamic Containment and what does it mean for battery energy storage in the UK?

4.3 Long-duration energy storage (LDES)

Summary of analysis on long-duration energy storage

- Long-duration storage may have a different meaning for different systems, nonetheless, it can be understood that long-duration storage should be able to discharge continuously for multiple hours (more than 4, or even 10) up to even weeks and therefore contribute to daily, weekly and/or seasonal system flexibility needs.
- For long-duration storage in the weekly to seasonal timeframe, technologies are either still in development, such as power-to-gas-to-power, or the potential left in the EU is limited/located in some MSs only, such as is the case of reservoir and pumped hydropower.
- The needs for weekly and seasonal flexibility will increase in the future. Nevertheless, it is unclear how much new LDES will be necessary in the future EU electricity system to meet long-term flexibility needs, given competition with other flexibility sources. Increased renewable energy targets should increase flexibility needs. Some studies indicate the existing long-duration flexibility (such as gas-fired power plants) could be sufficient to meet long-duration flexibility needs to 2050. Further research is needed on how much long-duration flexibility the increased renewable energy targets and reduced gas consumption could require, among which from storage. The justification for specific support schemes for large-scale long-duration energy storage deployment should be driven by flexibility needs.
- The cost of new long-duration energy storage (LDES) technologies remains high compared to other existing flexibility solutions. Therefore, policy discussions are strongly related to need for further development of long-duration energy storage technologies' technical performance and costs
- Other issues for LDES could be addressed. This includes increasing the liquidity and improving products in forward markets, and improving capacity mechanism design where this are demonstrably needed to assure resource adequacy. Also, the market for hybrid RES-storage, which could significantly support LDES, is incipient, and measures could be foreseen to develop the PPA market, explicitly consider hybrid projects in RES support auctions (or have dedicated windows for it), and enable value stacking for co-located storage.

4.3.1 Review of issues concerning long-duration energy storage

It must be noted that while the current study is focused on the electricity system, the need for long-duration storage will exist across the energy system. Currently the bulk of long-duration storage is provided by the storage of fossil fuels.[257] Other energy storage technologies such as purely thermal energy storage can also make significant contributions to long-duration energy storage.

In order to discuss long-duration energy storage (LDES), it is first useful to define it. There is a general agreement on the definition of "duration", meaning the maximum continuous period of time during which the storage can "sustain power output at its maximum discharge rate".[258] The duration of discharge is related to the energy capacity of the storage, which contrasts with the

[257] CEER (2021) Long-Term Storage CEER "European Green Deal" White Paper series (paper I)

[258] U.S. Energy Information Administration (EIA). 2020. Battery Storage in the United States: An Update on Market Trends.

power capacity. The energy capacity of projects for many, but not all, long-duration energy storage technologies can be increased without increasing the power capacity. In this way, increased discharged durations could be achieved at a lower cost compared to an alternative where also the power capacity has to be increased (with correspondent increased CAPEX).

The disagreement between studies concerns the minimum duration which characterises long-duration energy storage. This can range from 'a few hours' to 10 hours or more. Thus, various definitions exist in the literature, such as "any technology that can be deployed competitively to store energy for prolonged periods and that can be scaled up economically to sustain electricity provision, for multiple hours, days, or even weeks, and has the potential to significantly contribute to the decarbonisation of the economy".[259]

NREL indicates that minimum durations of 4 and 10 hours are most commonly mentioned in the literature. However, NREL indicates that the definition will depend not only on the technical and economic characteristics of the storage technologies, but also on the exact resource adequacy services needed. The latter will change according to load patterns, RES penetration levels and storage deployment, and thus different systems could require different continuous discharge durations to meet various adequacy challenges. This means that long-duration storage may have a different meaning for different systems, and thus NREL does not recommend using a single definition for all systems. [260]Nonetheless, it can be understood that long-duration storage should be able to discharge continuously for multiple hours (4, or even 10) up to even weeks.

Moreover, commonly the energy capacity of some (but not all) long-duration energy storage technologies can be expanded without corresponding increases in the power capacity. That is, one can increase the maximum quantity of GWh stored without changing the power of the storage, expressed for example in MWs.

By being able to discharge for several hours, days or weeks, long-duration energy storage can contribute to daily, weekly and/or seasonal system flexibility needs. These flexibility needs are driven by changes in the power generation structure as well as in load patterns. Electrification of end-uses and increasing penetration of intermittent RES (mainly wind and solar PV) should increase the need for flexibility in the daily to seasonal timeframes. Solar PV deployment increases the need for daily flexibility needs, while wind penetration drives the weekly flexibility needs. Demand patterns as well as wind and solar PV generation profiles all drive seasonal flexibility needs.[261]

Mature storage technologies exist for short-duration storage, such as lithium-ion batteries (stationary or for mobile applications) and (pumped) hydro storage. Also, these and other mature technologies may also provide some long-duration storage, meeting for example daily flexibility needs, but are less suited for weekly or seasonal flexibility provision. For long-duration storage in the weekly to seasonal timeframe, technologies are either still in development, such as power-to-gas-to-power, or the potential left in the EU is limited or located in some MSs only, such as is the case of reservoir hydropower. Therefore, the policy discussions on long-duration storage are related to need for further development of LDES technologies' technical performance and costs.[262]

CEER estimates that up to 2040 there is no additional need for seasonal electricity storage[263], as the remaining fossil-based generators should be able to provide the necessary flexibility. However, this

[259] McKinsey (2021) Net-zero power Long duration energy storage for a renewable grid

[260] NREL (2021) Storage Futures Study - The Challenge of Defining Long-Duration Energy Storage. https://www.nrel.gov/docs/fy22osti/80583.pdf

[261] Artelys (2017) Mainstreaming RES - Flexibility portfolios

[262] McKinsey (2021) Net-zero power – Long duration storage for a renewable grid

[263] CEER (2021) Long-Term Storage CEER "European Green Deal" White Paper series (paper I)

analysis is conditional on assumptions of that study, such as the existence of sufficient natural gas and gas-based power generation capacity in that timeframe. Even if the overall gas volumes necessary in 2040 are set to decrease and the main use for gas in the power sector will be for flexibility purposes, security of gas supply may be a factor – among other uncertainties.

Hence, whether existing flexibility sources and additional pumped hydro capacity[264] will suffice to meet seasonal flexibility needs of the European power system is still uncertain. Also, besides the seasonal timeframe there could still be the need for flexibility in the daily to weekly timeframes, to which long-duration storage could contribute. Therefore, this section does not analyse further how important a role long-duration energy storage could have in the future European electricity system, but assumes it will have a role to a certain extent (in competition with other technologies capable of offering long-duration flexibility), in order to focus on the regulatory barriers and measures to enable LDES.

Support scheme designs for storage considered in the UK

Given it is unclear whether and how much long-duration storage will be necessary in the EU in the future, the justification for support schemes for large-scale LDES deployment does not yet exist. However, it is interesting to consider the adequacy of some support scheme designs, in case policy makers wish to implement those in the future.

In the UK, a number of different designs were considered:

- A **regulated asset base** (RAB) model, where the storage operator would receive a certain rate of return on investments, with revenues or wheeling charges eventually capped;
- **Cap and floor mechanism**, where the revenues of the storage operators would be guaranteed within a certain range, for an agreed number of years. In case revenues fell below the lower limit, the operator would be compensated, and conversely if revenues in a given year were above the upper limit, the operator would have to give back the excessive profits. A variation would be for only a floor to be set.
- **Contract for difference (CfD),** where the operator receives an agreed strike price for the energy generated, with the government covering any differences to the market price, if the strike price is lower, and pocketing the difference if it is higher. Contracts for difference are one variation of a sliding premium design, with others possible.
- A reformed **capacity market,** where the capacity provider receives a yearly payment for being available in scarcity situations.

The UK government considered that the RAB and CfD designs were not adequate for storage, as they did not incentivise storage to react to price signals and to provide flexibility when needed. Instead, the government considered a cap and floor as the most adequate design (although it still contained challenges for incentivising some new technologies such as hydrogen) and potentially also a reformed capacity market.

The most important barrier for new long-duration energy storage technologies remains the high cost compared to other existing flexibility solutions, such as gas storage or hydropower. Innovation policy for these technologies is therefore important, but is out of scope of the present analysis. Also, non-discriminatory system planning including all potential flexibility solutions is critical in order to provide a level-playing field for long-duration energy storage, by considering all solutions

[264] Artelys notes that pumped hydro storage could provide significant flexibility in the daily to weekly timeframes, with unused potential in ES and IT. See Artelys (2017) Mainstreaming RES - Flexibility portfolios

for inclusion in network development plans (also from third parties) and as alternative to network expansion – this is addressed in the network planning topic.

Aside from the issues above (improvements in technical performance and cost, and non-discriminatory system planning), the most common issues for the development of long-duration energy storage are:[265]

- **Lack of sufficient long-term price differentials**, either because of fundamental drivers such as limited renewable energy penetration or existence of other flexibility sources, or market failures distorting price signals;
- **Uncertainty about future project revenues and overall bankability difficulties**, as in order to obtain financing the projects need to have some level of revenue certainty for a number of years;
- **Design issues with the various wholesale**, **capacity and ancillary service markets and procurement mechanisms**, affecting not only the price differentials mentioned above but restricting participation to the markets;
- **Uncertainty about future market reforms and challenges to consider storage adequately,** leading to regulatory risk for storage projects;
- **High capital cost and/or long lead time for certain techs,** such as reservoir or pumped storage hydropower, increasing project uncertainty due to e.g. changed market circumstances once the project is commissioned;
- **Incentives for short-term cycling** due to lower uncertainty of short-term prices in all electricity markets, compared to prices in the future.

Many of these issues affect also shorter-duration storage technologies, and some are discussed in the other sections of the report. The present section focuses on issues which affect the technologies analysed in chapter 1 which are capable of sustaining discharges for a longer duration. This includes, among others, hydrogen (and other power-to-gas-to-power technologies) and redox-flow batteries with a long-term storage capacity, but also technologies where chapter 1 indicates having a short/mid-term storage capacity but still can sustain a discharge of 4 hours or longer, such as pumped hydro, compressed/ liquefied air energy storage (CAES/LAES), and stationary lithium-ion batteries.

4.3.2 Status in the EU27

De-risking market and economic risks for long-duration storage and providing access to long-term revenues stands out as an important topic, which should improve the application of long-duration energy storage in several use cases (i.e. the application of a storage technology for a certain service). Use cases for storage are further discussed in chapter 1. As there are still limited analyses on the topic, in particular focused on the EU, the following issues concerning de-risking and long-term revenues are analysed:

- Issues with forward markets hinder long-term energy arbitrage
- Entry barriers to capacity mechanisms and lack of maturity of grid capacity services procurement
- Incipient market for hybrid RES-storage

[265] As discussed in: CEER (2021) Long-Term Storage; Aurora Energy Research (2022) Long duration electricity storage in GB; BEIS (2021) Facilitating the deployment of large-scale and long-duration electricity storage: call for evidence; Helman (2020) Development of Long-Duration Energy Storage Projects in Electric Power Systems in the United States: A Survey of Factors Which Are Shaping the Market; Jacobs (2020) Strategy for Long-Term Energy Storage in the UK; McKinsey (2021) Net-zero power Long duration energy storage for a renewable grid; NREL (2021) Storage Futures Study The Challenge of Defining Long-Duration Energy Storage; REA (2021) Longer-Duration Energy Storage: The missing piece to a Net Zero, reliable and low-cost energy future

- Specific support to long-duration energy storage may not be justified

These issues may not be exclusive to long-duration energy storage, rather affecting all types of storage. However, here the focus of analysis is long-duration energy storage, even if removing the issues could help all types.

4.3.2.1 Issues with forward markets

Most existing market opportunities for energy storage surveyed in Chapter 1 are focused on the short-term (energy arbitrage in spot markets, provision of balancing and non-frequency ancillary services, customer energy management). Long-term markets are naturally the best suited to value long-duration flexibility and thus are a logical candidate for the participation of long-duration storage.

Long-duration storage could use arbitrage in forward markets as a significant source of revenue, exploring price differentials between long-term delivery periods as long as sufficient counterparties in the market exist. In this way, (organised) forward markets could be a main long-term market for storage, complementing other options such as PPAs.

However, the lack of maturity of forward markets and/or higher uncertainties with longer time horizons compromise the ability of these markets to represent significant revenue streams to storage. Forward markets (comprising all trades beyond the D-1 timeframe)[266] product delivery lead times can range anywhere from several days to years. Market liquidity in the main European forward markets has not changed significantly since 2016, and is considered by ACER to be 'modest' in most markets, although non-cleared over-the-counter trades have been decreasing. Germany has the highest forward market liquidity, with a churn rate above 7 for the 2016-2020 period.[267]

While market participants in other markets theoretically have access to the German market through cross-border hedging instruments (long-term transmission rights or other instruments in some borders), participants lack adequate hedging opportunities in some borders, and cross-border hedging does not fully compensate for lack of liquidity in local forward markets.[268]

Therefore, while storage operators in Germany might have access to liquid forward products in the daily to quarterly timeframe for long-term arbitrage, storage operators in other Member States may not easily find counterparties for long-term hedges, or only at high transaction costs – especially for Member States not immediately neighbouring liquid forward markets (such as the German one) or that cannot access adequate cross-border hedges to those markets. Furthermore, there is limited information on the liquidity of forward markets per product delivery lead time (i.e. daily, weekly, monthly, quarterly or annual), so it may be that liquidity is higher in annual products (which are not as relevant for storage as products with a shorter delivery lead time). Moreover, the Long-Term Transmission Rights products available do not generally match the products available in forward markets - ENTSO-E indicates that especially yearly and monthly products are available.[269]

Moreover, uncertainty naturally increases with the delivery horizon. Therefore, long-duration storage might have difficulty exploring price differentials across multiple days or weeks, if liquid market products are unavailable in those lead times. This can lead long-duration storage to focus on intra-

[266] Exceptions may exist, such as the Daily Products Market (MPEG) in Italy, with a D-2 timeframe.

[267] ACER (2022) Market Monitoring Report 2020 – Electricity Wholesale Market Volume

[268] ACER (2022) Market Monitoring Report 2020 – Electricity Wholesale Market Volume

[269] ENTSO-E (2021) Options for the design of European Electricity Markets in 2030

day cycles[270], which might not be the most adequate operational strategy for longer-duration storage technologies – leading to a higher number of cycles which may affect the operational lifetime of e.g. batteries, and to the operator having to focus on markets where other flexibility solutions might be more competitive.

4.3.2.2 Entry barriers to capacity mechanisms and lack of maturity of grid capacity services procurement

Barriers for the participation of storage in **capacity mechanisms** still exist, as discussed in section 4.2. The main storage technologies contracted in capacity mechanisms (for delivery in 2026-2035) are first of all pumped hydro storage, then technologies other than hydropower (likely to comprise mainly batteries) and finally reservoir hydropower.[271]

The need for a capacity mechanism must be demonstrated by the European resource adequacy assessment (ERAA), which can be complemented by the national adequacy assessment. In case of discrepancies between ERAA and NRAA, ACER will be required to issue an opinion on whether the differences between the two assessments are justified. Therefore, capacity mechanisms as a revenue stream for long-duration storage will likely not be available in all Member States.

Moreover, the main adequacy indicators employed by the ERAA, loss of load expectation (LOLE) and energy not served (ENS) do not provide information on the average resource scarcity period duration – that is, if say for a given area the scarcity period lasts, on average, 10 hours or 3 days. Therefore, even if an area may show high LOLE and ENS, indicating resource adequacy issues, this does not provide information whether for example weekly or seasonal flexibility needs are not being met. The design of specific capacity mechanisms will be attentive to this matter, but at the European level the ERAA fails to provide this information, which would be helpful to provide an indication on the need for flexibility which could be met by long-duration energy storage.

Thus, **capacity mechanisms** aim to address resource adequacy issues for which long-duration storage technologies with a discharge of several days or even weeks are well-suited for. But capacity mechanisms form currently only a small share of total revenue streams for storage operators,[272] even if the participation of storage in capacity mechanisms is increasing, as shown in section 4.2. It is possible adequacy services will constitute a significant revenue stream for some long-duration projects in the future, but it is unlikely the service will be able the main driver for long-duration energy storage deployment in most Member States. Moreover, entry barriers to (long-duration) storage in capacity mechanisms still exist in the EU.

Another storage application valuing long-term / seasonal flexibility is **support to transmission or distribution infrastructure to defer investments**, what is also called grid capacity services. This issue is addressed in the network planning topic, and its use by network operators is still at it's infancy, with important issues to be overcome. It's important to note, however, that it is likely that it will be more cost-effective to deal with highly-congested lines through network expansions rather than with the contracting of flexibility sources (unless permitting and other issues significantly hinder the expansion projects). Flexibility sources such as storage could be a suitable alternative to network expansion to address other forms of congestion, for example where lines are not necessarily congested for a high number of hours but still face structural congestion related to e.g. PV renewable electricity generation peaks or EV peak charging times. However, Therefore, the grid

[270] McKinsey (2021) Net-zero power Long duration energy storage for a renewable grid

[271] ACER (2022) Market Monitoring Report 2020 – Electricity Wholesale Market Volume

[272] UK Department for Business, Energy and Industrial Strategy (2021) Facilitating the deployment of large-scale and long- duration electricity storage: call for evidence

capacity firming market for very long-duration storage may not represent an important share of the revenues (although it could represent a relevant market for long-duration storage with a discharge of 4-10 hours).

In any case, there are few market mechanisms valuing long-term flexibility currently. It is likely that long-duration storage will need to rely on short-term markets focusing on flexibility in the (intra-)hourly to at most daily timeframes to complement revenues from the provision of flexibility in the weekly to seasonal timeframes. However, when participating in these short-term markets long-duration energy storage may be at a competitive disadvantage to other storage technologies and flexibility solutions.

4.3.2.3 Incipient market for hybrid RES+storage

Capacity firming – "use of energy storage to render variable RES output more constant during a given period of time"[273] - is recognised as an important service that can be provided by storage, as shown in the market analysis (task 2). The present analysis focuses on the capacity firming case where storage is combined on or off-site with large-scale renewable energy plants for sale of the electricity to third-parties – i.e. merchant projects. Behind-the-meter storage combined with for example solar PV for self-consumption is a relevant application for both residential and commercial & industrial self-consumers, but not analysed here due to the different business case and regulatory issues it raises.

Existing examples of RES+storage currently focus on the use of battery storage. However, in the future other storage technologies could gain relevance. Long-duration storage could be of interest to firm capacity in a multi-day to even multi-week period. This could be interesting especially for firming wind (onshore and offshore capacities). Storage can also be used for firming solar PV generation on a daily basis. Depending on penetration levels and the system needs, this could required firming over multiple hours[274], thus requiring long-duration storage. Solar PV is also characterised by a strong seasonal component, meaning long-duration storage in the seasonal timeframe could eventually be of interest. However, the daily timeframe is of more immediate interest to solar PV.

RES+storage can be valued through different market mechanisms:

- The corporate or utilities PPA market may provide a premium for firmed renewable energy
- Renewable energy producers may want to combine with storage in order to improve their opportunities for participation in spot (arbitrage) and ancillary services markets
- Renewable support mechanisms may explicitly target RES+storage, providing additional revenues or higher scores compared to a pure renewable energy facility, or even assigning specific support windows to RES+storage
- Capacity mechanisms may also foresee specific rules for RES+storage which account for the higher firm energy they are able to provide

Each of these opportunities for merchant RES+storage plants may face regulatory (and market) issues. We focus here on selected issues which could affect particularly long-duration storage.

The RES+storage PPA market in Europe is still incipient, while more experience is available in the US.[275] The development of the PPA market is dependent on a number of factors – among which

[273] EASE (2020) Energy Storage Applications Summary

[274] As the penetration of storage increases, any new additions would have to discharge for longer duration, as the 'short-duration' peaks would be covered by already-existing storage assets. See NREL (2021) Storage Futures Study - The Challenge of Defining Long-Duration Energy Storage. https://www.nrel.gov/docs/fy22osti/80583.pdf

[275] https://www.dena.de/fileadmin/dena/Publikationen/PDFs/2019/dena-REPORT_How_to_use_PPAs_for_cost-efficient_extension_of_re.pdf

the level of support mechanisms available to large-scale renewable projects (which represent an opportunity cost for RES project developers considering the PPA market). For off-site storage, the possibility to operate virtual power plants (if e.g. portfolio bidding is allowed instead of only unit-based bidding) is a requirement. Where bilateral contracts restrictions are in place in order to increase the liquidity of organised markets, as in Greece[276], they can represent a barrier. As mentioned in section 4.2.3, the ability of promotors in the US to make use of tax incentives to solar PV which also covered hybrid plants is a significant enabler of merchant hybrid projects.

It is rare that renewable support mechanisms in the EU have dedicated tenders or rules for hybrid power plants. As of April 2021, hybrid power plants were eligible only in tenders in Portugal and Germany.[277] Since then, solar PV+storage was awarded further contracts in the German innovation tender of August 2021.[278] Hungary also just conducted a tender for renewable energy where co-location with storage was obligatory.[279]

Another case identified is in the Spanish renewable energy tender, where the price received by hybrid power plants is adjusted to expose these facilities more to the market price, compared to a renewable energy plant without storage, which is exposed less to the market price.[280] Therefore, while specific rules for hybrid power plants are in place in Spain, this does not necessarily value the greater dispatchability of the hybrid power plants – as greater market exposure may increase the risks to the project. However, in the Royal Decree 960/2020 an auction calendar is foreseen, with specific auctions for new or repowered installations making use of storage or dispatchable technologies.[281] Also, frequently the hybrid power plant is not allowed to withdraw energy from the grid, only to inject. While this is a simple way to ensure all energy injected is of renewable origin, it makes value stacking by the storage+RES operator impossible, which could otherwise lower costs.

Currently, there is limited information on the consideration of hybrid power plants in recent capacity mechanism tenders. Given the issue is quite novel, this aspect has not been covered by ACER's analysis of entry barriers to capacity mechanisms.[282] As an example, on one hand the revised rules for the Italian capacity mechanism foresees that for production units combined with storage, the combined firm capacity is equivalent to the sum of the separate firm capacities (i.e. for example the derated capacity of the RES generation plus that of the storage system).[283] On the other, the capacity obligations mechanism in France names only a few storage technologies as explicitly eligible for participation (among which batteries and pumped hydro storage).[284]

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276 Market Reform Plan for Greece. https://energy.ec.europa.eu/consultations/consultation-greek-market-reform-plan_en

277 AURES II (2021) Database. http://aures2project.eu/auction-database/

278 BNetzA (2021) Statistiken: Innovationsausschreibungen. https://www.bundesnetzagentur.de/SharedDocs/Downloads/DE/Sachgebiete/Energie/Unternehmen_Institutionen/Ausschreibungen/Statistiken/Statistik_InnAusV.xlsx?__blob=publicationFile&v=2

279 https://renewablesnow.com/news/hungary-opens-tender-for-864-gwh-of-renewable-power-775890/

280 http://aures2project.eu/wp-content/uploads/2021/10/AURES_II_case_study_Spain.pdf

281 https://www.miteco.gob.es/es/prensa/estrategiaalmacenamiento_tcm30-522655.pdf

282 ACER (2022) Market Monitoring Report 2020 – Electricity Wholesale Market Volume

283 Terna (2021) Mercato della Capacità - Disposizioni Tecniche di Funzionamento n.2 (section 4.3). https://download.terna.it/terna/CM_DTF2_8d9ae88f34aeadb.pdf

284 RTE (2022) MECANISME DE CAPACITE - Arrêté du 21 décembre 2021 modifiant les règles du mécanisme de capacité et pris en application des articles R. 335-1 et suivants du code de l'énergie - Dispositions complémentaires résultant des délibérations de la Commission de régulation de l'énergie du 1er décembre 2016 et du 24 janvier 2018 et prises en application des articles R. 335-7, R.335-49, R. 335-55, et R.335-63 du Code de l'énergie. https://www.services-rte.com/files/live//sites/services-rte/files/documentsLibrary/2021-12-29_REGLES_MECANISME_DE_CAPACITE__6631_en

4.4 Double taxes, charges and grid tariffs issues for storage

Summary of double taxes, charges and grid tariff issues for storage

- Cases where taxes, surcharges and/or grid tariffs are imposed twice on electricity that is stored and fed back into the grid constitute a penalty for the business case of energy storage solutions
- The issue affects many of the potential applications including arbitrage, all ancillary services and various services to support transmission and distribution infrastructure
- A provision in a revised Energy Taxation Directive is being considered to address double taxation and to ensure that grid tariffs are cost-reflective and non-discriminatory
- While it is too early to assess the transposition of the relevant EU regulation, recent progress in some Member States has been identified, including the Netherlands and Slovenia.
- Several other Member States, including Finland, Germany, Luxembourg and Sweden already made progress with addressing the issue before.

4.4.1 Review of issues concerning double taxes, charges and grid tariffs

Most electricity taxes, levies and tariffs have been designed on the assumption that electricity flows in one direction, from producer to consumer. The tariff or tax is charged at the point of consumption or injection, which generally leads to each unit of consumed electricity being charged once. But when electricity is stored and reinjected into the grid this may lead to a situation where the final consumption of electricity is effectively taxed twice, for instance once at the storage facility and once at the final consumer. This situation leads to additional costs for electricity storage facilities and adversely affects the viability of its business case, which constitutes a barrier to its uptake. We define the barrier as:

'Double application of taxes, charges and tariffs for stored electricity'

This barrier can apply to a different extent depending on the storage technology (pumped hydro is for instance often already exempted from consumption-based taxes and tariffs), grid connection level (transmission or distribution) and whether the storage capacity is placed in front-of-the-meter or behind-the-meter. Additionally, the situation and logic may be different for taxes (excises) and surcharges (e.g. for RES) on the one hand, and grid tariffs on the other hand, because for grid tariffs the double application of charges may make more sense when considering that the grid is effectively used twice (although double tariffs may still not be warranted due to benefits of storage in reducing grid congestion).

Within the rest of this section, we discuss the situation for taxes and charges separately from the situation for grid tariffs, also because the data sources and data collection approach differ between the two. This effectively leads to two sub-issues:

1) 'Double application of taxes and surcharges for stored electricity'
2) 'Double application of grid tariffs for stored electricity'

The issue is recognised and already partially addressed in the latest EU regulation. The recast Electricity Regulation indicates that energy storage should not be discriminated, either positively or negatively.[285] Additionally, article 15(5)(b) of the Electricity Market Directive[286] states that '*Member States shall ensure that active customers that own an energy storage facility are not subject to any double charges, including network charges, for stored electricity remaining within their premises or when providing flexibility services to system operators'*. For grid tariffs, further relevant articles are included in the Electricity Market Regulation[287], which states that '*network charges shall be cost-reflective, transparent, take into account the need for network security and flexibility and reflect actual costs incurred and are applied in a non-discriminatory matter*' (art. 18(1)), which may imply that it would be logical to charge a grid tariff any time the grid is used, irrespective of whether it's used for final consumption or for charge or discharge of electricity storages, unless that charge or discharge relieved network congestion. On the other hand, the regulation states that '*the network charges shall not discriminate either positively or negatively against energy storage or aggregation and shall not create disincentives for self-generation, self-consumption or full participation in demand response'* (art. 18(1)). If electricity markets and network tariffs are well-designed they could incentivise storage to operate in a way that reduces the system flexibility needs and grid congestion. IN this case, art. 18(1) would warrant that network tariffs are set in a way that recognises this positive externality of storage to the system, with the use of tariff discounts or other means to avoid double charging.

The proposed revision of the Energy Taxation Directive also would eliminate double taxation of electricity excise taxes in the EU for energy storage. Article 22 (4)(1st subpar) proposes that "for the purposes of the first subparagraph, electricity storage facilities and transformers of electricity may be considered as redistributors when they supply electricity".[288] The question is to what extent and how these provisions have been implemented in the Member States. Through this report we aim to provide an up-to-date view on this, focusing on the identification of best practices.

The double taxes and charges barrier, if in place, affect any application of storage that involves charging with electricity from the grid and discharging electricity to the grid. This means that the barrier affects many of the services, including arbitrage, all ancillary services and various services to support transmission and distribution infrastructure. The main category of services which are not or less affected by the issue are customer energy management services. For the services impacted, the importance of the issue depends on the frequency of charging and discharging and the value of the services offered. For instance, for arbitrage on the daily fluctuations of electricity prices the impact will be more significant than for specific ancillary services that are only provided irregularly but capture a high value. As an example, double taxation and grid charges can significantly affect the profitability of energy arbitrage, but the value of providing e.g. balancing energy services is high compared to spot prices. Therefore, in case of double taxation, taxing the energy 'consumed' by the storage does not affect the business case significantly. Network tariffs are also generally lower than the balancing energy services value, and thus again do not affect the business case.

285 Regulation 2019/943 on the internal market for electricity

286 Directive 2019/944 on common rules for the internal market for electricity

287 Regulation 2019/943 on the internal market for electricity

288 Proposal for a COUNCIL DIRECTIVE restructuring the Union framework for the taxation of energy products and electricity (recast). COM/2021/563 final

4.4.2 Status in the EU27

4.4.2.1 Taxes and surcharges

For **taxes and surcharges**, **front-of-the-meter**, a first assessment of the status of the existence of this barrier across the EU has been compiled in our 2020 study on energy storage[289] which has been translated into a summary overview in another study for the European Commission[290]. These findings have been updated and validated within this study, in particular to identify recent progress in addressing this barrier and best practices for doing so. Through this update we identified progress in the Netherlands, where energy storage facilities with a large-scale consumption connection are exempted from paying taxes per January 1st, 2022[291]. Furthermore, it should be noted that several countries already had addressed double taxation for front-of-the-meter storage. For example, Finland already eliminated electricity taxation for large batteries before and further exemptions for pumped storage and smaller batteries are foreseen. Germany and Luxembourg also already had several exemptions in place for storage providers to address double taxation. And in Sweden, the possibility to refund consumption taxes paid by storage providers already existed.

For **behind-the-meter** storage, limited information is available from transversal sources. Going by the status for double application of grid tariffs for behind-the-meter storage it seems likely that this barrier will be mostly in place, as for grid tariffs this is still the case for all EU MS. One of the reasons for this is that it is hard to distinguish between energy that is consumed and energy that is stored and energy that is self-produced and energy that is fed back from a storage facility as this all happens behind the meter. The issue for behind-the-meter storage is also somewhat different due to the ability to avoid taxes by storing self-produced electricity at times of excess supply and using it later, thereby avoiding taxes, charges and tariffs on the electricity that would be taken from the grid otherwise (in case no net metering scheme applies).

4.4.2.2 Grid tariffs

For **grid tariffs** the situation is monitored by ACER in publications on the transmission tariffs[292] and on distribution tariffs[293]. In both cases, we consider ACER's findings comprehensive and up-to-date and have not conducted any additional data collection or validation ourselves. A summary of ACER's findings is provided below.

Transmission tariffs

Two types of transmission tariffs can be distinguished, namely: transmission tariffs for injection and for withdrawal. Transmission tariffs for injection are any charges from the Transmission System Operator (TSO) applied to electricity injected in the grid from a storage facility whereas transmission tariffs for withdrawal are any charges from the TSO applied to electricity withdrawn from the grid by a storage facility. Electricity tariff design consists of two main aspects, mainly: recovering costs and efficiency. Recovering costs is the main objective of setting tariffs and efficiency is about cost-

[289] Artelys, Trinomics and Enerdata (2020) - Study on energy storage – Contribution to the security of the electricity supply in Europe

[290] Trinomics, E3-Modelling and DIW (2021) - The role of energy taxation and prices for the clean energy transition in the context of sector integration and carbon border mechanisms: Energy system modelling and future scenarios, Lot 1: Impact of fiscal and non-fiscal charges on the energy system, Study 1 - Framework, methodology and mapping of current situation

[291] https://business.gov.nl/amendment/no-double-taxation-energy-storage/

[292] ACER (2019) - ACER Practice Report on Transmission Tariff Methodologies in Europe

[293] ACER (2021) - Report on Distribution Tariff Methodologies in Europe

reflectivity and sending correct economic signals to network users for optimal use of the network. Transmission costs might vary according to location or time.

The applicability of transmission tariffs for storage facilities in 2019 is summarised in Table 23. 8 EU Member States apply injection charges for pumped hydro and/or other storage facilities, although partial exemptions apply for two of those Member States (Belgium and France). 12 MS apply withdrawal charges for pumped hydro and/or other storage facilities. There are 5 MS that explicitly exempt all storage providers from all transmission tariffs (Italy, Lithuania, Latvia, Poland, Slovenia) and several others where it is not fully clear yet as the rules are not explicitly stated for certain network users, often because such network users (e.g. battery storage providers) did not exist yet.

Table 23 Applicability of transmission tariffs for relevant network user groups

	Application of injection charges			Application of withdrawal charges	
Network User:	*Pumped hydro*	*Other storage (e.g. batteries)*	*Other network users who both inject and withdraw*	*Pumped hydro*	*Other storage (e.g. batteries)*
Austria	Yes	N/A	No	Yes	N/A
Belgium	Partially	Partially	No	Yes	Yes
Bulgaria	No	No	No	Yes	Yes
Cyprus	No	No	No	N/A	N/A
Czech Republic	No	No	No	Yes	N/A
Germany	No	No	No	Partially	Partially
Denmark	N/A	N/A	No	N/A	N/A
Estonia	No	No	No	N/A	N/A
Greece	No	No	No	Yes	N/A
Spain	Yes	N/A	No	Yes*	N/A
Finland	N/A	Yes	No	N/A	Yes
France	Partially	Partially	No	Partially	N/A
Croatia	No	No	No	Yes	N/A
Hungary	No	No	No	N/A	N/A
Ireland	Yes	Yes	No	Partially	Yes
Italy	No	No	No	No	No
Lithuania	No	No	No	No	No
Luxembourg	No	No	No	N/A	N/A
Latvia	No	No	No	No	No
Malta	No	No	No	No data	No data
Netherlands	No	No	No	N/A	N/A
Poland	No	No	No	No	No
Portugal	Yes	N/A	No	No	N/A
Romania	Yes	N/A	No	Yes	N/A
Sweden	N/A	N/A	No	N/A	N/A
Slovenia	No	No	No	No	No
Slovakia	No	N/A	No	No	N/A

N/A = No such network user group in that jurisdiction[294]
No = Network user not subjection to injection/withdraw charges
Yes = Network user subject to injection/withdrawal charges
Partially = exemptions apply
* = In 2020, PHS should pay charges, however under the Spanish NRA's methodology proposal, PHS facilities do not pay transmission charges

[294] ACER (2019) - ACER Practice Report on Transmission Tariff Methodologies in Europe

The composition of transmission tariffs can vary across the different MSs and can be energy-based, power-based and lump sum. According to ACER (2019), the majority of MSs apply energy-based tariffs for *injection* whereas Ireland & Slovak Republic use a power-based component. The decision on how these tariffs are built-up (i.e. power-based, energy based or lump sum) can influence (long-term) investment choices and the (short-term) operation decisions of a producer. Regarding *withdrawal*, in the majority of MSs the transmission tariffs have both an energy-based and a power-based component. 6 MSs apply only an energy-based component whereas the Netherlands combine power-based and lump sum for withdrawal tariffs.

Distribution tariffs

In this section the applicability of distribution grid tariffs for energy storage for different MSs is analysed and discussed.

The number of DSOs vary from MS to MS and the size of a country is not necessarily a key driver for the amount of DSOs. For example, there are 883 DSOs in Germany whereas there is only one DSO in Hungary, Czech Republic, Ireland, Malta and Slovenia. In 16 out of 22 MSs with multiple DSOs, the DSOs apply the same distribution tariff methodology, either because of national law or because of a decision by the NRA. For the remaining 6 MSs with multiple DSOs different tariff methodologies apply, for example in Denmark, Finland and Sweden, the DSOs can design their own tariff structures within certain legal boundaries.[295]

Similar to the transmission tariff methodology, the structure of distribution tariffs can be differentiated in energy-based, power-based and lump sum (or a combination). For example, in Austria and Belgium (Flanders) the charges are energy-based, whereas in France, Malta, the Netherlands and Luxembourg the tariff setting is lump sum.

Network users who use the distribution grids can be subject to **injection charges** and **withdrawal charges**. Network users who **inject** electricity into the network are divided into four groups:

- Producers, including both RES and non RES producers who do not withdraw electricity from the network except for the purpose of feeding in the auxiliary services. This group is does not provide energy storage services and is therefore not of interest for this study;
- Pumped hydro storage;
- Other storage facilities (e.g. batteries);
- Other network users, who both inject and withdraw (e.g. prosumers).

From the summary in Table 24 we observe that 10 MSs apply **injection** charges to storage providers (including prosumers). These injection charges can be divided per group: 3 MSs (AT, FR, SE) apply injection charges to PHS, 4 MSs (BE, FR, LT, SE and) apply injection charges to the network group 'other storage (e.g. batteries)', and 9 MS apply injection charges to 'other network users', for example prosumers or self-consumers. For Estonia and Sweden, charges only apply above certain installed capacities for prosumers.

Network users who **withdraw** electricity from the network and offer storage services can be subdivided into:

1) Pumped hydroelectric energy storage facilities (PHS);
2) Other storage facilities (e.g. batteries);
3) Other network users, who both inject and withdraw.

[295] ACER (2021) - Report on Distribution Tariff Methodologies in Europe

Regarding the withdrawal charges for the distribution grid, 6 MSs apply withdrawal charges to PHS facilities (see Table 24). Moreover, 8 MSs apply withdrawal charges to other facilities (e.g. batteries) and all MSs apply withdrawal charges to other network users (e.g. prosumers).

It should be noted that double application of grid tariffs does not always affect prosumers when a net-metering scheme is in place. In particular, when grid tariffs are energy-based, the ability to offset produced and consumed electricity and only pay/earn based on the net balance results in a situation where grid tariffs on stored electricity that is fed back into the grid are not paid.

In 8 MSs (DE, DK, ES, FR, HU, IE, IT and SI) active consumers (AC) are protected from having to pay double charges (status in 2020), including network charges for storage facilities since the MS incorporated the provision of active consumers into national law.[296]

[296] ACER (2020). Market Monitoring Report – Electricity Wholesale Market Volume

Table 24 Applicability of distribution tariffs for relevant network user groups

Grid tariffs distribution grid	Application of injection charges			Application of withdrawal charges		
Network user:	*Pumped hydro storage*	*Other storage (e.g. batteries)*	*Other network users who both inject and withdraw (e.g. prosumers)*	*Pumped hydro storage*	*Other storage (e.g. batteries)*	*Other network users who both inject and withdraw (e.g. prosumers)*
Austria	Yes	N/A	Yes	Partially	N/A	Yes
Belgium	N/A	Yes	No	N/A	Yes	Yes
Bulgaria	-	-	-	No	No	Yes
Cyprus	-	-	-	N/A	N/A	Yes
Czech Republic	-	-	-	N/A	N/A	Yes
Germany	-	-	-	Partially	Partially	Yes
Denmark	-	-	-	N/A	N/A	Yes
Estonia	N/A	N/A	Partially	N/A	N/A	Yes
Greece	-	-	-	N/A	N/A	Yes
Spain	-	-	-	No	No	Yes
Finland	No	No	Yes	No	No	Yes
France	Yes	Yes	Yes*	Yes	Yes	Yes
Croatia	-	-	-	No	No	Yes
Hungary	-	-	-	N/A	Yes	Yes
Ireland	-	-	-	N/A	Yes	Yes
Italy	-	-	-	No	No	Yes
Lithuania	N/A	N/A	Yes	N/A	N/A	Yes
Luxembourg	N/A	Yes	Yes	N/A	Yes	Yes
Latvia	-	-	-	N/A	N/A	Yes
Malta	N/A	N/A	No	N/A	N/A	Yes
Netherlands	N/A	N/A	Yes	N/A	N/A	Yes
Poland	-	-	-	No	No	Yes
Portugal	-	-	-	No	N/A	Yes
Romania	-	-	-	Yes	Yes	Yes
Sweden	Yes	Yes	Partially	Yes	Yes	Yes
Slovenia	-	-	-	N/A	No	Yes
Slovakia	No	N/A	Partially	Yes	N/A	Yes

N/A = No such network user group in that jurisdiction
Yes = Network user subject to injection/withdrawal charges
- = No injection charge applies for any user of the distribution grid
Yes = Network user group partially subject to injection/withdrawal charges
Partially = exemptions apply
*In France active consumers are only subject to a lump-sum management fee for injection.

4.5 Non-discriminatory network planning

Summary of issues related to non-discriminatory network planning

- The role of storage assets should be properly reflected by network operators in their network planning, in order to evaluate correctly their potential to contribute to network development and system operation. Similarly, network operators should take fully into account the potential of storage when conducting the resource adequacy assessment.
- The EU legislative framework for inclusion of storage in network planning is largely set in place, but there are some lags in implementation on national level – in national network development plans and in distribution network development plans. Storage assets (pumped hydro and/or others) are included in the transmission network development plans of BG, GR, IE, LV, SI and PT.
- Moreover, the incentives for network operators to consider alternative measures to investing in new power lines (such as electricity storage) are used only scarcely in MSs.
- Only large-scale storage assets are considered by network operators, in particular in the resource adequacy assessments – this means the potential contribution of storage is not fully analysed and it puts smaller storage assets in disadvantage.
- These issues impact in particular arbitrage and provision of ancillary services by storage operators, but in general almost all services and technologies are impacted by shortcomings in network planning processes.

4.5.1 Review of issues for storage

Including storage assets into the network models can enable rationalisation of network assets, avoiding costly (and lengthy/otherwise problematic) investment in energy transport and distribution projects, besides contributions to system flexibility. In case storage or other non-conventional flexibility sources such as demand response are not considered in the network plans, the necessary system flexibility will have to be met by conventional solutions, such as interconnectors. Network planning can also indicate the value of storage assets for network operation to the investors, facilitating build-up of storage assets that are beneficial for the system operation.

The network operators are also responsible for assessing the resource adequacy (RAA) of the electricity system. In these assessments, the network operators analyse whether sufficient resources are available to meet the expected demand (in the 10-year time horizon) and whether additional remedial measures are needed. As storage assets can be one of the most significant sources of flexibility needed to balance the supply and demand in electricity networks, the proper inclusion of storage assets in the RAA is also important to accurately indicate the systemic value of storage for the electricity system. As both the RAA and network planning process can deliver similar benefits to storage operators, they are considered together in this section.

Energy storage assets are not sufficiently considered, mainly on national level, in network planning processes as a flexibility source and as an alternative to network expansion

In the EU TYNDP, large-scale storage projects (at least 225 MW capacity) are included in network modelling and there is a specific CBA methodology for them.[297] In the 2022 draft common scenarios report[298], the ENTSOs estimate the volume of future flexibility needs, distinguished between peaking units, demand-side response and batteries. The scenario building methodology mentions modelling of the following flexibility assets, related to energy storage:

- Residential-scale batteries, modelled in connection with rooftop PV development
- Utility-scale batteries, as a function of system needs
- DR: electric vehicles capacity
- Electrolyser capacity available for flexibility services
- Electricity demand for heat pump is modelled, but flexibility/storage potential is not assessed

The updated TEN-E regulation[299] (which entered into force in June 3rd 2022) proposes improvements of the planning process. Among other changes, a dedicated article on scenarios for TYNDP was added. According to the new rules, ACER shall prepare framework guidelines for the development of the joint ENTSO-E – ENTSOG scenario. The guidelines shall ensure that the scenarios reflect the Energy Efficiency First principle and are in line with the EU decarbonisation targets. Moreover, ENTSO-E and ENTSOG will have to prepare a new "infrastructure gaps" report within the TYNDP process, reflecting the energy efficiency first principle

At the national level, every two years, TSOs should submit a ten-year National Development Plan (NDP) to the regulatory authority based on existing and future supply and demand forecasts. According to article 51 of Electricity Market Directive TSOs should consider alternatives to network expansion, such as energy storage, when planning network development.[300]

Moreover, article 32 of the Directive sets new requirements on the use of flexibility in distribution networks. Paragraphs 1 and 2 of article 32 stipulate that MSs shall provide the necessary regulatory framework to allow and provide incentives to distribution system operators to procure flexibility services, including congestion management in their areas. The regulatory framework "shall ensure that distribution system operators are able to procure such services from providers of distributed generation, demand response or energy storage and shall promote the uptake of energy efficiency measures, where such services cost-effectively alleviate the need to upgrade or replace electricity capacity and support the efficient and secure operation of the distribution system". [301]

According to article 32 (3) at least every two years the DSO should publish NDPs and provide transparency in regard to the medium and long-term flexibility services required in the network. The NDP should include the use of energy storage facilities or other resources that the DSO could use as an alternative to network expansion.[302] Moreover, regarding public consultations on the NDP the DSO shall consult all relevant system operators and TSOs and publish the results accordingly.

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[297] ENTSO-E (2021). 3rd ENTSO-E Guideline for Cost Benefit Analysis of Grid Development Projects. Available at: https://eepublicdownloads.blob.core.windows.net/public-cdn-container/tyndp-documents/CBA/210322_3rd_ENTSO-E_CBA_Guidelines.pdf

[298] ENTSO-E and ENTSOG (2021). TYNDP 2022 Draft Scenario Report. Available at: https://2022.entsos-tyndp-scenarios.eu/wp-content/uploads/2021/09/2021-10-TYNDP_2022_Draft_Scenario_Report.pdf

[299] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020PC0824

[300] Article 51 (3) Directive (EU) 2019/944

[301] Article 32 Directive (EU) 2019/944

[302] Article 32 (3) (EU) Directive 2019/944

ACER has identified several shortcomings of the network planning process that are related to the role of storage:[303]

- Not all national development plans are aligned with the NECPs; this might result in network development scenarios that assess differently the role of storage providers (especially in case of DSR, electromobility, residential-scale batteries and other smaller assets);
- Storage projects are not allowed to be included in planning in several MSs; In some other MSs, storage projects are allowed, but not actually included in the planning process.
- Public consultation process has limitations in some countries; this reduces the ability of storage asset operators to contribute their views to the planning process;
- Not all DSOs prepare network development plans; Not all countries have an established process of planning coordination between TSOs and DSOs; this limits the ability to correctly assess the value of storage assets on both network levels;

Network operators are not sufficiently incentivised to consider alternative network development measures (alternatives to building new power lines)

Energy storage asset operators are under risk of discrimination in the current network planning process. Currently, the TSOs propose methodology for and carry out the cost-benefit analysis of projects included in the network development plans. Given that the transmission infrastructure owned by the TSO is in direct competition with alternatives such as storage, the TSOs can be incentivised to prefer the transmission infrastructure solutions.[304] This bias towards capital expenditure-heavy investments and the lack of incentives for TSOs to opt for less-costly investment was recently reiterated by ACER as one of the areas where the EU regulation should improve, in order to incentivise smart investment in network infrastructure.[305] However, while ACER MMR's indicates the barrier "Lack of incentives to consider non-wire alternatives", it did not assess it due to low priority and/or absence of data

ENTSO-E does not include sufficiently the role of storage in the resource adequacy assessment

The ENTSO-E is responsible for producing annual pan-European resource adequacy assessment (ERAA). The first iteration of this assessment in 2021[306] was not approved by ACER[307], among other reasons also because the assessment did not recognise sufficiently the value of demand-side response. In case of storage, ACER concluded that the assessment methodology is sufficient for the time being, but will require improvements in the future. The relevant shortcomings of the assessment are in particular[308]:

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303 ACER (2021). OPINION No 05/2021 on the electricity national development plans. Available at: https://documents.acer.europa.eu/Official_documents/Acts_of_the_Agency/Opinions/Opinions/ACER%20Opinion%2005-2021%20on%20the%20electricity%20national%20development%20plans.pdf

304 ACER and CEER (2021). Position on Improving the Regulation on Guidelines for Trans-European Energy Networks (TEN-E Regulation). Available at: https://www.ceer.eu/documents/104400/-/-/d83e6f21-ab19-bc92-25f1-5f7c70cac6ba

305 ACER (2021). Position on incentivising smart investments to improve the efficient use of electricity transmission assets. Available at: https://documents.acer.europa.eu/Official_documents/Position_Papers/Position%20papers/Position%20Paper%20on%20infrastructure%20efficiency.pdf

306 ENTSO-E (2021). European Resource Adequacy Assessment: 2021 edition. Available at: https://www.entsoe.eu/outlooks/eraa/

307 ACER (2022). ACER decides not to approve ENTSO-E's first pan-European resource adequacy assessment due to shortcomings. Available at: https://www.acer.europa.eu/events-and-engagement/news/acer-decides-not-approve-entso-es-first-pan-european-resource-adequacy

308 ACER (2022). DECISION No 02/2022 on the European Resource Adequacy Assessment for 2021. https://extranet.acer.europa.eu//Official_documents/Acts_of_the_Agency/Individual%20decisions/ACER%20Decision%2002-2022%20on%20ERAA%202021.pdf

- Limited scope – covering only pumped-hydro and large-scale batteries (the ERAA methodology states that only market-participating battery storage is modelled; behind-the-meter batteries should be covered exogenously in the demand profiles based on information provided by TSOs[309]). This is assessed by ACER as not being fully compliant with the requirements of the Electricity Regulation but acceptable in 2021 given the impacts on the ERAA's purpose are limited;
- Unclear data sources;
- Untransparent assessment methodology used.

However, the ENTSO-E aims to implement further advancements in the analysis in the following iterations, as indicated in its implementation roadmap.[310]

Barriers specific for distribution networks

DSOs (and TSOs) are prohibited from owning storage assets, but not other grid management devices (such as VAR control).[311] DSOs might be therefore incentivised to prefer investment in latter options, when considering network upgrades, given that most revenue-setting frameworks for DSOs still favour capital over operational or total expenditures. This barrier can be addressed through a number of measures recommended by CEER, including proper network planning process, as described above, by reviewing the revenue-setting frameworks to avoid any CAPEX biases, and by ensuring the DSO request for tenders is as broad as possible. [312]

As the network planning process shows significant lag in implementation, it means the potential of storage assets to contribute to network management was largely not explored by the DSO. This is also due to the fact that, although the Article 23 of the Electricity market directive mandates the DSOs to consider storage assets in network planning, there is no harmonised methodology to do so.

The shortcomings in proper evaluation of the role of storage (and other flexibility resources) are also related to the lack of required resources (human, expertise, capital) reported by the DSOs. This mainly applies to smaller DSOs, which are however numerous in some countries.[313] As a result, it might lead to a situation where there is a significant difference in the level of integration of storage and flexibility resources between the system operators.

Impact of the issues on storage technologies and services

The ideal situation would in fact be, if the network operators would consider all relevant storage technologies services listed in chapter 1, both in the network planning process (to include the projects in the plans as well as to consider them as alternatives to network expansion) as well as in their resource adequacy assessment. All technologies are therefore potentially affected by the issues listed above.

But more specifically, addressing the issues discussed in this chapter would particularly allow to improve the possibilities for storage to provide services to support transmission and/or distribution

[309] ENTSO-E (2021). European Resource Adequacy Assessment: Annex 3 Methodology. Available at: https://eepublicdownloads.azureedge.net/clean-documents/sdc-documents/ERAA/ERAA_2021_Annex_3_Methodology.pdf

[310] ENTSO-E (2021). ERAA Implementation roadmap. Available at: https://www.entsoe.eu/outlooks/eraa/implementation-roadmap/

[311] CEER (2020). CEER Paper on DSO Procedures of Procurement of Flexibility. Available at: https://www.ceer.eu/documents/104400/-/-/e436ca7f-a0df-addb-c1de-5a3a5e4fc22b

[312] CEER (2020). CEER Paper on DSO Procedures of Procurement of Flexibility. Available at: https://www.ceer.eu/documents/104400/-/-/e436ca7f-a0df-addb-c1de-5a3a5e4fc22b

[313] Trinomics (2021). The road to energy efficiency. Available at: https://www.europarl.europa.eu/RegData/etudes/STUD/2021/695480/IPOL_STU(2021)695480_EN.pdf.

infrastructure. Therefore, the issues will affect particularly pumped hydro, CAES/LAES, stationary batteries, and mobile batteries (vehicle-to-grid), which are specific technologies well-suited to provide those services, according to the analysis of chapter 1. Of course, other technologies could provide such services, once alternatives to network expansion are adequately considered in network development plans at the EU and national level.

4.5.2 Status in the EU27

4.5.2.1 Status in EU27 and analysis of patterns/trends

The paragraphs below summarise the status of selected issues in EU Member States. This summary is based on the 2021 ACER opinion on the electricity national development plans.[314]

NDP aligned with NECP

The National Energy and Climate Plans (NECP) should be taken into consideration while developing the NDPs. Possible reasons to not take the NECPs into consideration are related to timing, or there is no obligation by law in for example Cyprus. 18 out of 27 MSs took the NECPs into account while developing the NDPs.

Storage (PHS & other storage facilities, e.g. batteries) allowed and/or included in the NDPs

ACER reviewed which infrastructure categories are allowed and/or included in the NDP. Regarding Hydro-pumped energy storage facilities, 4 MSs allow and included these facilities in the NDP (BG, GR, IE, and PT), where 10 MSs only allowed this project infrastructure in the NDPs. Regarding other energy storage facilities, such as batteries, 5 MSs allowed and included this category in the NDPs (BG, GR, IE, LV, SI), whereas 12 MSs only allowed them.

For example, storage assets (pumped hydro and/or others) are included in the network development plans of. In 2018, the Portuguese TSO REN updated its dynamic system models to simulate among others storage assets, and the latest NDP includes a large pumped hydro storage project – the Gouvães plant with 880 MW.[315]

Issues in public consultations of NDPs

NDPs should be submitted to the NRA after having consulted all relevant stakeholders according to article 51 of Directive (EU) 2019/944. According to the study of ACER, in 15 MSs the NRA have the power or obligation to carry out a public consultation on the NDP. In Slovenia, no public consultation is carried out, however there are bilateral consultations with stakeholders carried out whereas in Estonia, and Sweden no public consultations or bilateral consultations are carried out.

14 MSs published stakeholders' comments and responses, 4 MSs published only the stakeholders' comments and 3 MSs published a summary of stakeholders' comments.

Coordination between TSO and DSO NDPs

The majority of the DSOs prepares NDPs and in almost all of them there is some level of alignment between the DSO and TSO. Alignment between the TSO and DSO NDPs are about data exchanges

314 ACER (2021). ACER opinion on the electricity national development plans. Available at: https://documents.acer.europa.eu/Official_documents/Acts_of_the_Agency/Opinions/Opinions/ACER%20Opinion%2005-2021%20on%20the%20electricity%20national%20development%20plans.pdf

315 https://www.erse.pt/media/nx3ittiy/pdirt-2022-2031-mar%C3%A7o-2021-relat%C3%B3rio-final.pdf

regarding scenarios and/or assumptions, consultations between the two parties and other alignment/join activities. For example, in Belgium and the Netherlands each DSOs prepares NDPs and there is data exchange between the TSO and DSOs. Whereas in for example, Austria there is no DSO NDP and is therefore identified as high barrier.

In Hungary, the TSO and DSO prepare a single country wide high voltage NDP (> 132 kV) whereas in Bulgaria and Sweden there is no alignment at all between the TSO and DSO NDPs.

4.5.3 International best practices concerning network planning

4.5.3.1 United Kingdom

In the United Kingdom, the electricity system operation and ownership parts were legally separated in 2019, and the transmission system operation (including network planning) activities are now managed by the National Grid ESO (NG ESO).[316] Furthermore, the British government has announced the intention to create a unified "Future System Operator". This publicly owned entity will take over the NG ESO activities, as well as the longer-term planning, forecasting and market strategy functions with regards to gas system operation, in order to achieve an independent whole-system approach to the network planning in the future.[317] While the explanatory documents do not explicitly refer to the role of energy storage (as they offer mainly high-level general analysis), the creation of independent entity responsible for network planning would address the potential conflict of interest that owners of transmission infrastructure owners have in the network planning process.

4.5.3.2 United States/North America

NERC – Long-term reliability assessment[318]

The North-American Electric Reliability Corporation released in 2021 the 2021 Long-Term Reliability Assessment. The main relevant points of this assessment are:

- The development of flexibility resources is viewed as necessary to support the increasing level of variable generation. However, storage solutions are in general not expected to reach sufficient scale within the next 10 years.
- The high-level assessment focuses on grid-level battery and hybrid generation (+ pumped hydro storage)
- The following activities related to network and resource adequacy planning are noted:
    - The California Independent System Operator (ISO) conducts an annual flexible capacity technical study to assess the needs in the following three years. The flexibility assessment considers storage assets, including behind-the-meter storage. The 2021 edition however mentions that the current methodology for storage assessment is insufficient and might

[316] NG ESO (2022). Who we are. Available at: https://www.nationalgrideso.com/who-we-are

[317] UK Government (2022). Proposals for a Future System Operator role. Available at: https://www.gov.uk/government/consultations/proposals-for-a-future-system-operator-role

[318] NERC (2021). 2021 Long-Term Reliability Assessment. Available at: https://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/NERC_LTRA_2021.pdf

even overestimate the potential contribution of storage assets to meeting the flexibility needs and therefore updated methodology will be developed for the future versions.[319]

- The Electric Reliability Council of Texas (ERCOT) has introduced a classification system for distributed energy resources that specifically includes storage.[320] The assets fitting the definition for distributed energy resources and registered with ERCOT are modelled in ERCOT transmission planning studies. For the rest, ERCOT relies on further information from member transmission and distribution operators.

[319] CAISO (2021). CALIFORNIA INDEPENDENT SYSTEM OPERATOR CORPORATION FINAL 2022 FLEXIBLE CAPACITY NEEDS ASSESSMENT AND FINAL 2022 AVAILABILITY ASSESSMENT HOURS. Available at: http://www.caiso.com/Documents/May14-2021-Final2022FlexibleCapacityNeedsAssessment-Final2022AvailabilityAssessmentHours-ResourceAdequacy-R19-11-009.pdf#search=flexible%20capacity%20needs

[320] "An electrical generating facility located at a Customer's point of delivery (point of common coupling) 10 MW or less and connected at a voltage less than or equal to 60 kV that may be connected in parallel operation to the utility system. Distributed generators include energy storage resources as well." NERC (2021). 2021 Long-Term Reliability Assessment. Available at: https://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/NERC_LTRA_2021.pdf

4.6 Guarantees of origin for renewable energy storage

Summary of guarantees of origin analysis

- The current EU legislation for guarantees of origin (GOs) does not foresee a role for energy storage, since GOs can only be issued to producers of energy.
- There is only limited experience with GOs with a high temporal granularity and inclusion of storage. The current draft European GO standard foresees higher time granularity as an option, but there is no legal basis for (standalone) storage issuing GOs.
- However, the proprietary EnergyTag GO standard was developed with the aim of introducing granular GOs and also covers energy storage use cases. This standard has been used in some pilot projects and should be a basis for an hourly GO market introduced in the UK.
- There could be a potential value in extending the GO system that could do a closer tracking renewable energy flows from production to consumption . This would include introducing GOs with a more detailed time granularity. Energy storage could then offer a "time shifting" service to allow conserving GOs in time.
- Although a potential value exists, the scope of demand for the GO "time shifting" service is not known and probably limited at the moment. Moreover, the cost of introducing such system is probably higher than the expected benefits, in particular due to the current low price of GOs.

4.6.1 Review of the topic

Energy storage enables to physically decouple the consumption and production of renewable electricity. This is in contrast to the current system of Renewable Guarantees of origin (GOs), which does not require a physical link between the producer and consumer (e.g. electricity network) and only ensures limited temporal coordination between production and consumption of renewable electricity.

Therefore, the GO system aims to reflect the value of renewable energy for the producer and consumer, but does consider infrastructure aspects, and considers temporal aspects only to a limited extent. Supporting the deployment of storage is not a direct objective of the GOs system – that is rather to support the deployment of renewable energy. However, it could be interesting to consider how the system can better support storage, as long as this is not incompatible with its main objectives.

While providing locational investment signals to energy storage would require a complete overhaul of GO system, it is conceivable to consider the changes to the temporal validity of GOs, to establish a closer link between the renewable energy production and consumption. In such case, energy storage assets could be allowed to provide a "time-shifting" service, meaning shifting the validity of GOs in time. Given that the functioning of the GO system was recently evaluated and updated in the proposed revision of the Renewable Energy Directive, only the potential of time-shifting service will be explored in this section. As detailed below, the demand for such service is currently limited or even non-existing, therefore these considerations are also at the moment hypothetical, with a more long-term view in mind.

The role of storage is not included in the GO system design

The possibility to include electricity storage in the GO system is not defined in the Renewable Energy Directive. Therefore, there is no legal base for storage operators cancelling and issuing GOs.

This also reflects the current situation, as there are no established GO schemes in operation that would include storage facilities.

The scope of demand for the GO "time shifting" service is not known and probably limited

As there is no (or very limited) real-word experience with storage offering time shifting services, there is only limited basis to estimate whether there would be a demand for such service. Although there is in theory great potential for demand for such services if more granular accounting of GOs is introduced, if the current yearly period of GO validity is preserved, the demand will likely remain limited.

The adaptation cost of GO design and associated IT systems to have a high time granularity currently outweighs the potential benefits to energy storage providers/ the potential value of price signals for investments to energy storage that would contribute to renewable electricity integration

Previous assessments of the possibilities to enhance the functionality of the GO system have shown that one major issue are the significant compliance cost associated with the required changes.[321] At the same time, the price of GOs still remains very low (not reaching over 1 EUR/MWh[322]), especially in relation to energy prices that have even risen in the recent years. Price volatility (and thus price differentials) might be a more relevant indicator in case of electricity storage than average energy price levels, but it is still apparent that the potential benefits of GOs for storage operators will probably be outweighed by the overall compliance costs.

Moreover, the actual price of GOs is not publicly available, as the GO market relies primarily on over-the-counter trading.[323] This also limits the potential value of price signals to storage operators.

The current GO design is not suited for the cost-efficient inclusion of energy storage:

- The process of handling the GOs by storage operators is not defined, leaving some of the key conceptual questions unsolved;
- GOs do not contain all the necessary information to enable greater time granularity (in particular they only mark the date of production, not the exact time).

4.6.1.1 Overview of relevant EU legislation and upcoming implementation

Renewable energy certification is covered under the **Renewable Energy Directive (RED)**.

According to Article 3(9) of RED, all MSs were required to establish renewable GOs and to increase the level of transparency to customers. The version of RED currently in force (RED II) was adopted in 2018 and had to be fully implemented by all MSs by 1 July 2021.

Recital 55 of RED II states that:

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321 Trinomics et al, 2021. Technical support for RES policy development and implementation: Delivering on an increased ambition through energy system integration. Available at: https://op.europa.eu/en/publication-detail/-/publication/6fcc38cb-1440-11ec-b4fe-01aa75ed71a1/language-en/format-PDF/source-253831298.

322 Argus media, 2020. ARGUS Guarantee of Origin assessments. Available at: https://view.argusmedia.com/rs/584-BUW-606/images/POW-Sample%20Report-Argus-GOO-Rego-Report-Extract-Nov-2020.pdf

323 AIB, 2021. Sources of price and market information. Available at: https://www.aib-net.org/facts/market-information/sources-price-and-market-information.

- “Guarantees of origin issued for the purposes of the Directive have the sole function of showing to a final customer that a given share or quantity of energy was produced from renewable sources.
- A guarantee of origin can be transferred, independently of the energy to which it relates, from one holder to another. However, with a view to ensuring that a unit of renewable energy is disclosed to a customer only once, double counting and double disclosure of guarantees of origin should be avoided.
- Energy from renewable sources in relation to which the accompanying guarantee of origin has been sold separately by the producer should not be disclosed or sold to the final customer as energy from renewable sources.
- It is important to distinguish between green certificates used for support schemes and guarantees of origin.”[324]

According to Article 19(2):

Issuance of guarantees of origin may be made subject to a minimum capacity limit. A guarantee of origin shall be of the **standard size of 1 MWh**. **No more than one guarantee of origin shall be issued** in respect of each unit of energy produced.

Member States shall ensure that the same unit of energy from renewable sources is taken into account only once.

Member States shall ensure that when a producer receives financial support from a support scheme, the market value of the guarantee of origin for the same production is taken into account appropriately in the relevant support scheme.

Guarantees of origin shall be **valid for 12 months after the production of the relevant energy unit**. Member States shall ensure that all guarantees of origin that have not been cancelled expire at the latest 18 months after the production of the energy unit. Member States shall include expired guarantees of origin in the calculation of their residual energy mix.

A guarantee of origin shall specify at least:

(a) the energy source from which the energy was produced and the start and end dates of production;
(b) whether it relates to:
  (i) electricity;
  (ii) gas, including hydrogen; or
  (iii) heating or cooling;
(c) the identity, location, type and capacity of the installation where the energy was produced;
(d) whether the installation has benefited from investment support and whether the unit of energy has benefited in any other way from a national support scheme, and the type of support scheme;
(e) the date on which the installation became operational; and
(f) the date and country of issue and a unique identification number.”[325]

4.6.1.2 Impact of the issues on storage technologies and services

The essential aim of storage GOs is to conserve the renewable quality of energy in time. Therefore, the value of storage GOs is in supporting renewables with **capacity firming** while maintaining the

[324] Recital 55 of Directive (Eu) 2018/2001 promotion oft he use of energy from renewable sources. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2018.328.01.0082.01.ENG&toc=OJ:L:2018:328:TOC

[325] Article (19) 2 RED II

renewable characteristics (or other sustainability criteria). Hence, the main service category enabled would be "generation support services and bulk storage services". The main storage technologies that can provide such services are, as mentioned in chapter 1, pumped hydro storage, CAES/LAES, and batteries (both stationary and mobile employed for vehicle-to-grid purposes). Such services will however provide additional revenue streams to storage operators only when they are sufficiently valued by final consumers or other market participants in order to cover the costs to revise the GO system and associated systems, or implement another system.

4.6.2 Status in the EU27

In general, the issues described above apply to all member states equally, as the use of GOs is not allowed by the current regulation. The following sections however describe some pioneering activities and pilot projects that aim to explore the possibility of using granular GOs and inclusion of storage.

4.6.2.1 EECS rules

The EECS rules[326] are the "principles and rules of operation of the Association of Issuing Bodies (AIB) for the European Energy Certificate System (EECS)", setting the standard for operation of GO schemes in the EU. The current version of the rules sets the framework for the use of GOs in gas storage only. In case of electricity storage, the only relevant provision relates to pumped hydro storage and it clarifies that GOs can be used only for electricity generated from natural inflow of water.

4.6.2.2 Austria: inclusion of storage in the supplier mix disclosure

The Austrian law requires all electricity supplier to disclose the exact composition of primary energy sources to their customers in the annual electricity bill. The Electricity Act of 2010[327] mandates that energy sourced from storage facilities (including pumped hydro, other electricity storage and facilities converting electricity into hydrogen and other renewable gases that are not directly feeding the gases to gas network) shall be disclosed separately with the use of "secondary labels". These secondary labels disclose the origin of the primary energy used for charging the storage device. Operators of storage facilities with capacity larger than 250 kWh are mandated to keep track of all charges and discharges and the source of energy used to provide that information.[328] [329]

4.6.2.3 EnergyTag granular certificate (GO) standard

Although technically based in UK, this standard was developed with the backing and support of European energy industry, with the aim to be globally applicable.[330]

326 AIB (2021). EECS Rules. Available at: https://www.aib-net.org/eecs/eecsr-rules.

327 Bundesministerium für Digitalisierung und Wirtschaftsstandort (2022). Bundesgesetz, mit dem die Organisation auf dem Gebiet der Elektrizitätswirtschaft neu geregelt wird (Elektrizitätswirtschafts- und -organisationsgesetz 2010 – ElWOG 2010). Available at: https://www.ris.bka.gv.at/GeltendeFassung.wxe?Abfrage=Bundesnormen&Gesetzesnummer=20007045

328 E-control (2021). STROM- UND GASKENNZEICHNUNGSBERICHT FÜR DAS PRÜFUNGSJAHR 2020. Available at: https://www.e-control.at/documents/1785851/1811582/E-Control_Stromkennzeichnungsbericht_2021.pdf/aa3761f8-010d-77db-d328-1de84cb030dc?t=1638530800624

329 E-control (2022). Verordnung der E-Control über die Regelungen zur Stromkennzeichnung und zur Ausweisung der Herkunft nach Primärenergieträgern (Stromkennzeichnungsverordnung 2022 – KenV 2022). Available at: https://www.e-control.at/documents/1785851/0/V+KEN+0121+-+V+KEN+0121+VO+-+HAAS+Florian%2C+Dr.+%281%29.pdf/5aa12848-8014-669a-be78-8bf55059b189?t=165035279149

330 EneregyTag (2022). Available at: https://www.energytag.org/

On top of standard information included in the (European) GOs, the standard proposes to include further information to enable temporal and geographical matching of production and consumption:[331]

- For temporal matching, the GOs would include information on the exact time (up to seconds) of the start and end of energy production. This enables **ex-post temporal matching** on all levels of time granularity (hourly, 15, 5 minutes…), but, to be noted, not real-time matching of renewable consumption and production.
- For geographical matching, the standard proposes to include information on the bidding zone the producer is connected to.[332] This will ease the geographical matching on the bidding zone level (although still not enabling further granularity or taking in consideration network constraints within a bidding zone).

The EnergyTag standard also crucially defines the use for storage temporal shifting of GOs. This should consist of following steps:[333]

1) When the storage device is charged, the original GO is cancelled. The storage operators issues a "Storage Charge Record" (SCR)[334] instead.
2) When the storage device is discharged, the storage operator produces a "Storage Discharge Record" (SDR)[335].
3) Storage operator may issue a "Storage Discharge GO" to be traded in the GO market or can also disclose the discharged energy to end customers in other use cases.

The EnergyTag use case guidelines[336] provide further details on some key issues:

- Temporal shifting of GOs: The process of issuing temporarily shifted GOs is presented in Figure 49 below. In is noteworthy that according to the guidelines, the resulting GO shifted in time should indicate the storage facility as the source of energy and the time of storage discharge as the time of production. Therefore, the recording the information on the original source of RE production is not mandatory (although it is possible). This approach allows for more flexibility and less administrative burden, but might reduce the emission accountability potential of the overall system.
- Quantification of storage losses: the guidelines propose three methods – 1) measuring all charges and discharges, where the delta would be the losses; 2) preforming periodical measurements of storage facility efficiency; 3) using globally accepted efficiency values for given technology.
- Storage records allocation: This issue pertains to situations where multiple SCRs are produced for a storage facility and they need to be matched with an SDR. The guidelines suggest two approaches: a) First in – First out, where the oldest SCRs are matched with the SDR; or 2) letting the operator choose which SCR is to be matched with the SDR.
- Storage device management: The guidelines also address a situation when the storage facility capacity is discharged, but there are some remaining SDRs that cannot be matched with an SDR. This would mean that the storage operator would claim to store more renewable energy

[331] EnergyTag (2022). Granular Certificate Scheme Standard: Version 1. Available at: https://www.energytag.org/wp-content/uploads/2022/03/20220331-EnergyTag-GC-Scheme-Standard-v1-FINAL.pdf

[332] In addition to the identification of concrete physical location of the production facility, as mandated in the current GO schemes.

[333] EnergyTag (2022). Granular Certificate Scheme Standard: Version 1. Available at: https://www.energytag.org/wp-content/uploads/2022/03/20220331-EnergyTag-GC-Scheme-Standard-v1-FINAL.pdf.

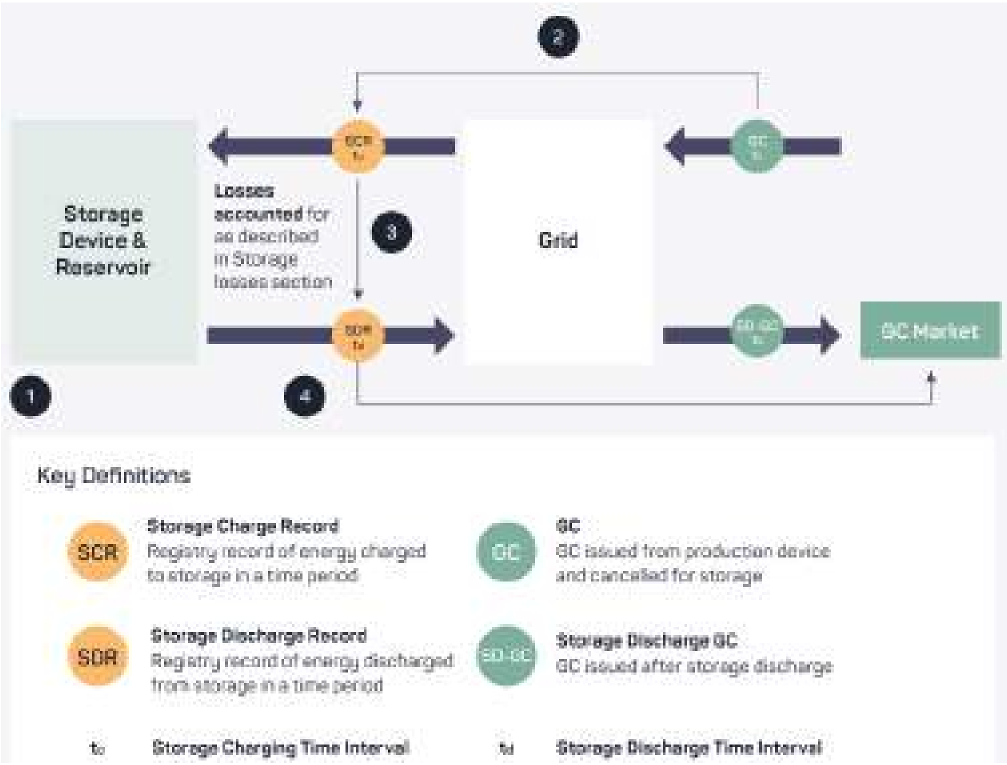
[334] SCR = Registry record of energy charged to storage in a time interval

[335] SDR = Registry record of energy discharged from storage in a time interval

[336] EnergyTag (2022). Granular Certificate Use Case Guidelines: Version 1. Available at: https://www.energytag.org/wp-content/uploads/2022/03/20220331-EnergyTag-GC-Use-Case-Guidelines-v1-FINAL.pdf.

in the facility than is the actual total amount of energy stored there at the same time. According to the guidelines, the storage operator could decide to cancel the SCR (match it with SDR with unknown beneficiary) or to keep the SCR anyway. The latter option, although possibly allowing more flexibility for storage operators, might however distort the market competition between different storage technologies that offer different storage time horizons.

Figure 49 Storage Temporal Matching Use Case Schematic[337]



Pilot implementation of EnergyTag hourly GOs

Nordpool hourly GOs market

The energy exchange Nord Pool has announced in January that it plans to open a market for hourly GO certificates in the third quarter of 2022, based on the EnergyTag standard. The pilot project will be available for the UK market and will initially run for 1 year. Nord Pool will provide a trading platform that will enable over-the-counter trading as well as exchange-based transactions.[338]

FlexiDAO pilot programs

The company FlexiDAO has recently announced successful completion of two pilot projects in which the supplier (Eneco) and consumer (Microsoft) exchanged granular hourly GOs. Importantly, the GOs used in the project, although using the EnergyTag standard, were also in compliance with the existing EU GO scheme.[339] These pilot project have, however, not included energy storage assets.

337 EnergyTag (2022). Granular Certificate Use Case Guidelines: Version 1. Available at: https://www.energytag.org/wp-content/uploads/2022/03/20220331-EnergyTag-GC-Use-Case-Guidelines-v1-FINAL.pdf.

338 Argus Media (2022). Nord Pool pilots hourly GOO market in UK. Available at: https://www.argusmedia.com/en/news/2296076-nord-pool-pilots-hourly-goo-market-in-uk

339 FlexiDAO (2022). Hourly certification of renewable electricity a step closer. Available at: https://www.flexidao.com/news/hourly-certification-of-renewable-electricity-a-step-closer

4.7 Contributions of thermal energy storage[340]

Summary of thermal energy storage analysis

- Thermal energy storage (TES) needs are expected to grow significantly in order to allow for the increased deployment of renewable energy
- TES can contribute to the EU energy system in multiple ways, including facilitating the integration of renewable electricity and renewable thermal energy, moderating the need for increase in electricity generation capacity, increasing the energy efficiency of the system (especially through the utilisation of waste heat), and providing ancillary services to the electricity system
- Through these contributions, TES can lead to significant investment savings, help replace fossil fuel use, especially gas and coal, increase the energy system flexibility and reduce greenhouse gas emissions throughout the EU27
- There exists a wide variety of thermal energy storage technologies and applications, varying in temperature levels, possible sectors and technological maturity. TES forms therefore a diverse field present throughout the EU energy system
- Recent best practices with TES in the EU and abroad are presented – but given the differences across Member States, best practices in a Member State are often not readily applicable elsewhere, and need to be adapted to the local context.

Thermal energy storage (TES) will be an important pilar to the decarbonisation of the EU energy system

Thermal energy storage (for storage of heat and/or cool) is already widely used in the EU and worldwide and is an important enabler for the utilisation of renewable energy. According to the Heat Roadmap Europe 4 study,[341] the total storage capacity deployed in the 13 Member States of the study amounted to 584 GWh.[342] It is likely that actual TES capacities today in the EU surpass 1 TWh, but reliable statistics do not exist.[343] See further details in Chapter 2.1.4. The most common form of heat or cool storage technology in use today are (domestic) hot water tanks/installations. Some underground thermal energy storage (UTES, in Canada, Germany and other European countries) has been deployed, and experiments in ice and chilled water storage (mainly in Australia, US, China and Japan) have taken place. About half of global district heating storage needs is related to seasonal storage needs.[344]

The decarbonisation of heat will be an important contributor to the overall decarbonisation of the EU energy system. Heat final consumption[345] in the EU is expected to increase 36% by 2050 compared to 2020, according to the Fit for 55 package MIX55 scenario (which is aligned to full net decarbonisation of the EU energy system by 2050). This represents an increase from 701 TWh (60

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[340] In order to focus on the most relevant points for this study, this analysis is not presented in the same structure as the previous topics.

[341] Heat Roadmap Europe 4 (2018) HRE4 summary tables and figures. https://heatroadmap.eu/roadmaps/

[342] The 14 countries of the study (AT, BE, CZ, FI, FR, DE, HU, IT, NL, PL, RO ES, SE plus the UK) account for approximately 80% of the EU28's heating and cooling demand. Heat Roadmap Europe 4 (2018) HRE4 summary tables and figures

[343] Project discussion with TES experts, June 17th 2022

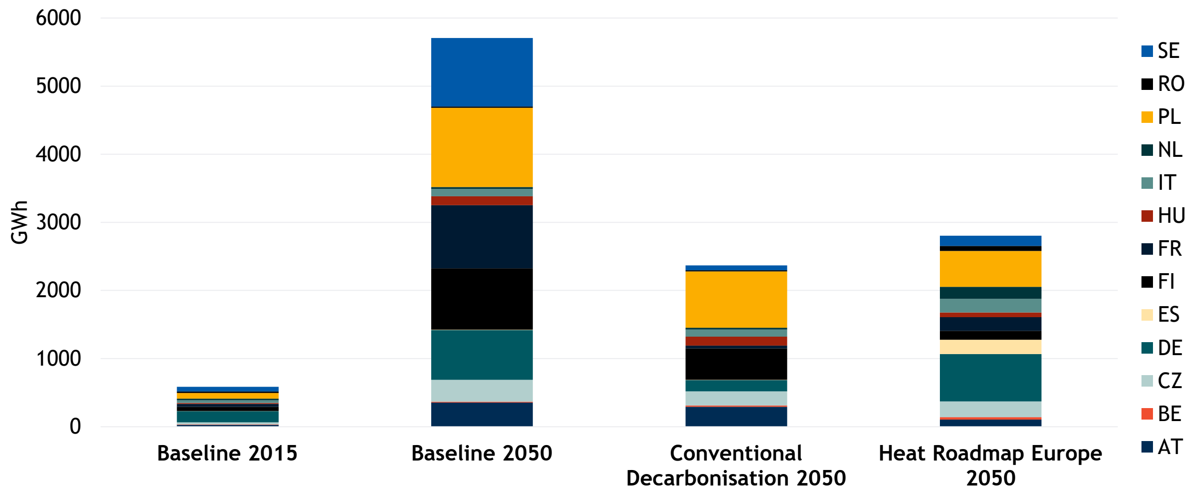
[344] IRENA (2020) Innovation Outlook – Thermal Energy Storage

[345] From CHP, district heating as well as geothermal, solar and ambient heat

352 ktoe) in 2030 to 955 TWh (82 144 ktoe) in 2030. The main driver of this increase is the deployment of heat pumps, as especially the heat final demand from CHP and district heating is overall the same.

The foreseen increase in renewable and waste heat and cool in a context of full net decarbonisation of the EU energy system will be coupled with increased thermal storage needs. **Heat storage needs are expected to grow by 4-10 times by 2050 according to the Heat Roadmap Europe 4 study**, depending on the scenario, as shown in Figure 50.[346]

Figure 50 Heat storage needs in the Heat Roadmap 4 scenarios



Thermal energy storage can contribute to the EU energy system in multiple ways

The contributions of thermal energy storage are varied and present in various steps of the energy value chain. Therefore, there is no single accepted classification of the different contributions. Nonetheless, main contributions include:

- **TES facilitates the integration of (variable) renewable electricity for heating and cooling:** storage allows to decouple the renewable electricity supply from electricity-based heating and cooling end-uses. Due to differences in the generation profile of renewable electricity supply and the demand profile of heat and cool end-uses, storage (of some sort) is necessary. While electricity (and renewable/low-carbon gas) storage is an alternative, thermal energy storage is often the cheapest alternative as shown in chapter 1;
- **TES also facilitates the integration of renewable thermal energy,** again by allowing to decouple the renewable thermal energy production profile from demand. The residual thermal energy demand would otherwise have to be met through other energy sources, potentially fossil fuel based.
- **TES reduces the need for electricity generation capacity to meet peak heating/cooling demand**, by shifting electricity demand to periods with abundant RES-based supply. By providing appropriate incentives to electricity consumers, such as time-differentiated network tariffs and wholesale market based commodity prices for end-users, along with other measures, consumers (or prosumers) can be incentivised to install and operate TES in a manner that reduces the electricity peak generation capacity needed;

[346] Heat Roadmap Europe 4 (2018) HRE4 summary tables and figures. https://heatroadmap.eu/roadmaps/

- **TES enables the utilisation and trade of waste heat**, thus increasing the overall energy system efficiency. There is a significant untapped waste heat potential in the EU (which is usually the cheapest form of heat). For example, the EU industrial waste heat production would be enough to meet the total building space heating demand – but waste heat sources are often distant from urban centres.[347] This includes waste heat from industry, but also more diffuse and lower-temperature heat sources such as from data centres, tunnels and metro stations, as well as from building cooling systems, and waste heat from thermal power plants and power-to-gas processes.[348] Waste heat may not be utilised either because of a mismatch between the waste heat generation and use profiles, or because the waste heat producer and user are not the same – thus requiring transportation and trade of the waste heat. Thermal energy storage allows to match the supply and demand profiles, as well as enable the trading of waste heat, which will become increasingly important in the EU[349] Waste heat can also be used to provide cooling in e.g. summer periods through the use of adsorption or absorption chillers[350];
- **TES also increases the efficiency of the energy system by allowing the optimal utilisation of energy production and conversion assets.** This includes enabling not only the operation of assets at stable levels (which should increase their efficiency as well as improve their lifetime), but in some situations also facilitate the operation of combined-heat-and-power in moments where electricity prices are high but heat may not be needed (being thus stored for later use). If electricity market prices formation is efficient, this should incentivise CHP operators to operate in a way that improves the overall system efficiency (which is only possible if the stored heat can be employed later on);
- **TES facilitates the provision of ancillary services to the electricity system,** including not only balancing services but also other services such as synchronous inertial response (see section 4.2). Several TES technologies are being applied for electricity generation using synchronous generators, including concentrated solar power, geothermal power, adiabatic compressed air energy storage, and liquid air energy storage.[351]

Through these different contributions, TES can not only reduce the costs for operating the EU energy system, but also **lead to significant investment savings**, in grid expansion, electricity storage, peak electricity generation capacity, and assets to provide system services. TES will also facilitate the accelerated deployment of renewable electricity and thermal energy required to **replace the use of fossil fuels, especially gas and coal,** to meeting heating and cooling demand in the EU, thereby **reducing greenhouse gases emissions and the EU external energy dependency**. Finally, thermal energy storage can **significantly increase the energy system flexibility**, not only by allowing to match supply and demand from the short- to long-term (seasonal) timeframes, but also by supporting the electricity system stability and the overall resilience of the energy system.

There exists a wide variety of thermal energy storage technologies and applications

TES applications have very different temperature needs. The heat that could be potentially stored by TES does not have a unified quality – differing by volume, and most importantly temperature according to the heat sources. Thermal energy storage can be used in various applications, including in the cold chain, industry, the power sector, buildings, and district heating and cooling,

[347] Trinomics et al. (2021) Policy Support for Heating and Cooling Decarbonisation - Roadmap

[348] Euroheat and Power (2020) Discussion Paper - The barriers to waste heat recovery and how to overcome them?

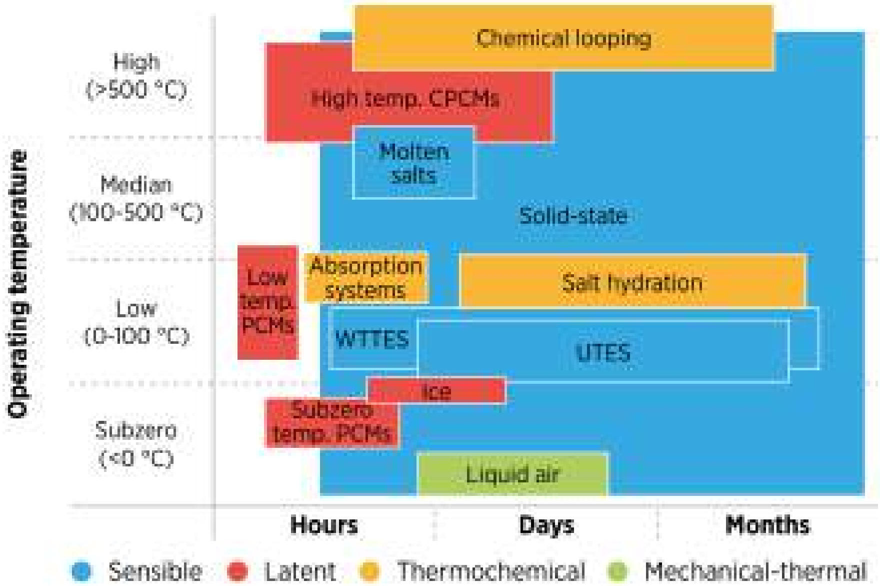
[349] Euroheat and Power (2020) Discussion Paper - The barriers to waste heat recovery and how to overcome them?

[350] Euroheat and Power (2020) Discussion Paper - The barriers to waste heat recovery and how to overcome them?

[351] IRENA (2020) Innovation Outlook – Thermal Energy Storage

whose needs for heat differ significantly, for example between industry and buildings space heating. **Different thermal storage technologies are also suitable for different temperatures and applications**, as shown in Figure 51. In case of large-scale storage application, locational properties, such as geological and hydrogeological conditions also play a significant role.[352] As a result, the potential business cases and real-world applications have to be developed specifically for each concrete situation. Given the diversity of technologies and applications as well as their distributed use throughout the EU, **a single EU integrated market for heating or cooling does not exist** as the ones for electricity and gas, nor do comparable associations of market parties (although several EU-level associations exist covering different aspects of heating and cooling).

Figure 51 TES operating temperatures and storage timeframes[353]



Several TES technologies beyond the widespread water tanks are mature and even deployed at large scale, including molten salt storage for CSP, UTES for ground-sourced heat pumps, ATES storage, and TTES or UTES for district heating. However, issues may exist for their further development, many of which are specific for each technology or application.

Recent best practices with TES in the EU and abroad

This sub-section presents recent best practices with TES in the EU and abroad. It must be noted, however, that given the differences across Member States regarding the applications for TES, available potential (for example in the case of subsurface TES, highly dependent on subsurface potential) and existing regulatory framework, best practices in a Member State are often not readily applicable elsewhere, and need to be adapted to the local context.

Description	Technology	Application	Geography
Long- and short-term TES storage for district heating	Pit and tank TES	District heating	Denmark

[352] AEE INTEC (2021). Giga-scale thermal energy storage for renewable districts. Available at: https://www.gigates.at/images/Appendix16_publishable_report_graphically_designed_EN.pdf

[353] RENA (2020) Innovation Outlook – Thermal Energy Storage

Large-scale Pit- and Tank-TES applications (with charge/discharge capacity up to several 100 MW) are becoming commercially viable for district heating applications in advanced markets such as Denmark, where currently 10 pit and tank TES storages are in operation, all developed since 2017, indicating the technology was considered appropriate even before the current high gas prices. An online database shows the current status of some of the storages.[354] An important contribution of TES in district heating lies in seasonal storage, integrating waste heat from industry and abundant heat from renewable sources,[355] including solar thermal heat and wind and solar PV electricity to drive heat pumps. However, in Denmark smaller TES is also used for making use of wind-driven low electricity prices to run large heat pumps or electric boilers, with cycles of one week or 4 days.

In Denmark, heat pumps and electric boilers are used in a complementary way. Heat pumps are CAPEX-intensive but efficient due to their coefficient of performance (COP) , while boilers have low CAPEX but also lower efficiency. Moreover, the efficiency of heat pumps decreases with temperatures, meaning that other peaking technologies are needed to meet peak heat demand in winter. Currently, the peak demand is often covered by gas boilers but also (renewable-driven) electric boilers. Moreover, Danish district heating operators also make use of gas-driven CHP, meaning they can be indifferent to electricity prices – in periods of high prices (driven by natural gas prices) they operate the CHP plants, while during periods of low electricity prices they employ the heat pumps – all enabled by TES. TES can be useful even in the case of biomass-fired CHP for district heating, as although biomass itself can be stored (with no or much lower losses than heat), TES still allows operators to operate during periods of high electricity prices and store the heat for later use. Currently, the use of heat pumps and TES for district heating is already the cheaper alternative compared to the use of natural gas for district heating or residential heat pumps (although further research would be needed to ascertain if sufficient renewable electricity will be available).

To incentivise the deployment of heat pumps, the Danish government has reduced the excise tax for electricity used to power heat pumps[356], and introduced a support scheme for large heat pumps.[357] Moreover, the government has reduced taxes on excess heat for own use or trade, as well as reduced the reporting requirements.[358]

Description	Technology	Application	Geography
Development of new and retrofitted TES-equipped solar thermal electricity	Molten salts	Solar Thermal Electricity	Spain

There is a significant potential to retrofit existing CSP installations with thermal storage. “Currently, around half of CSP installations worldwide do not have any storage capability, especially in Spain and the United States”. Retrofitting existing CSP in Spain is recognised as an important measure to facilitate the deployment of renewable energy, especially given there is limited electricity grid capacity to connect new renewable energy projects.[359]

354 Varmelagre.dk

355 AEE INTEC (2021). Giga-scale thermal energy storage for renewable districts. Available at: https://www.gigates.at/images/Appendix16_publishable_report_graphically_designed_EN.pdf

356 https://ec.europa.eu/energy/sites/default/files/dk_ca_2020_en.pdf

357 https://solarthermalworld.org/news/denmark-large-heat-pumps-take-dh-market-storm/

358 https://www.emb3rs.eu/danish-parliament-cuts-taxes-on-excess-heat/

359 https://www.iea.org/articles/how-rapidly-will-the-global-electricity-storage-market-grow-by-2026

However, the existing CSP plants were developed under past feed-in tariff support schemes which do not expose the plants to market prices and thus do not incentivise the retrofits. Moreover, the possibility of retrofitting the plants was not foreseen and is thus not possible without changes to the contracts.[360]

The Spanish government has announced a new renewable energy tender focused on biomass and CSP[361], currently foreseen to take place in December 2022. The tender is proposed to require CSP to have a capacity for 6 hours of storage, and will allow hybridisation with solar PV, biomass or biogas.

Description	Technology	Application	Geography
Reduction of winter peak electricity demand for water heating	Water Tank TES	Domestic water heating	France

By a more flexible utilisation of domestic water heaters, it was possible already around 2011 to reduce winter electricity demand peaks by 5% in France[362]. This demand peak reduction was enabled by introducing dedicated tariff structures (for peak and off-peak hours) and also by introducing remote start/stop controls that allow grid operators to control the operation of these water heaters.

Description	Technology	Application	Geography
Aquifer TES for building heating and cooling and other uses	ATES	Building H/C, other	Netherlands

The Netherlands is a leader on ATES, with over 3000 ATES systems,[363] making up the large majority of all systems installed worldwide – in 2018, the Netherlands had 85% of the projects installed worldwide. The Netherlands Enterprise Agency maintains a website providing interested parties with information about the technology, including on requirements to install the system and links to sectoral associations and a GIS database indicating among others where it is allowed to install ATES systems and providing a calculator to size the system and estimate the payback time.[364] ATES can also be used for other purposes – such as in the case of Stockholm's Arlanda airport, where ATES provides heat and cool to e.g. melt snow on runways.[365]

Description	Technology	Application	Geography
Creation of databases and methodologies for estimating waste heat potential	Various	Waste heat utilisation	Various

Euroheat and Power[366] provides an overview of existing databases developed in the past years to map the waste heat potential in different Member States and regions, including in Germany,

[360] Interview with CSP operator representatives

[361] https://www.miteco.gob.es/es/prensa/ultimas-noticias/el-miteco-lanza-la-tercera-subasta-de-renovables-con-500-mw-para-solar-termoel%C3%A9ctrica-biomasa-fotovoltaica-distribuida-y-otras-tecnolog%C3%ADas/tcm:30-534735

[362] IEA (2014) Technology roadmap: Energy storage. Page 24. Available at: https://iea.blob.core.windows.net/assets/80b629ee-597b-4f79-a236-3b9a36aedbe7/TechnologyRoadmapEnergystorage.pdf

[363] https://iea-es.org/wp-content/uploads/public/Netherlands_Country_Report_2021.pdf

[364] https://www.rvo.nl/onderwerpen/technieken%2C-beheer-en-innovatie-gebouwen/warmte-en-koudeopslags

[365] IRENA (2020) Innovation Outlook – Thermal Energy Storage

[366] Euroheat and Power (2020) Discussion Paper - The barriers to waste heat recovery and how to overcome them?

Czechia, and France. Moreover, it identifies initiatives related to the definition and application of methodologies for estimating waste heat potential, which is relevant specially to map the potential from low and medium temperature heat sources.

4.8 Permitting barriers and best practices[367]

Complex and lengthy permitting procedures are considered an important barrier for large-scale energy storage projects. Our interviews with pumped hydro developers in Austria and Germany indicated that permitting regulation is still very complex and that the procedures are costly and time consuming. The length of permitting procedures ranges from 1 to 7+ years with several examples of permitting procedures of 4+ years, with the risk of projects being abandoned due to long permitting times. Also in the case of front-of-the-meter battery storage, permitting is considered an important barrier in some Member States, including Ireland and the Netherlands.[368] In the Netherlands, permitting is delegated to municipalities without any national guidelines, which creates an incoherent approach throughout the country.

The consulted experts[369] indicated that streamlining and digitalisation permitting procedures while setting clear time limits would be helpful in addressing the barrier. Currently, several documents have to be delivered on paper (e.g. in Germany) and timelines and procedures for permitting are not always clear (e.g. in Italy) and are lengthy with multiple administrations involved (e.g. in Spain). Furthermore, interviewees indicated that better knowledge and application of the ecological points system in the Water Framework Directive by regional authorities would be useful.

The adjustments to the Renewable Energy Directive to accelerate permitting for renewables that are proposed in the context of REPowerEU address the issues of permitting, in part also for storage projects. The REPowerEU plan aims to "rapidly reduce the dependence on Russian fossil fuels and fast forward the green transition".[370] Part of this plan is to accelerate the rollout of renewables, by tackling slow and complex permitting for renewable energy projects (among others). A key feature of this is to recognise renewable energy projects as an 'overriding public interest'. Additionally, Member States are asked to implement maximum deadlines for permit granting, digitalise procedures, design 'one-stop-shops' for granting permits. Furthermore, shortened and simplified permitting procedures in designated 'go-to' areas should be made available as well as regulatory sandboxes for innovative projects. The recommendation around speeding up permit-granting procedures for renewable energy projects may in fact (partly) be considered to apply for energy storage projects too as 'renewable energy projects' are understood to also include the assets needed for the grid connection and storage of the energy produced by the renewable production plants.[371] However, in Germany hydropower (incl. pumped hydro) is thus far explicitly excluded from the projects that are considered an ''overriding public interest'. **The revised TEN-E regulation also contains provisions for facilitating the permitting of Projects of Common Interest (PCIs),** on priority status for permitting of PCIs, one-stop shops, and limit to the permitting procedure duration. This should facilitate the permitting of electricity storage projects eligible for PCI status[372].

[367] In order to focus on the most relevant points for this study, this analysis is not presented in the same structure as the previous topics.

[368] STEPS (2021). Energy storage - trends and challenges in a rocketing market.

[369] Inputs were gathered through two interviews with pumped hydro operators in Germany and Austria and the validation of the national fiches with experts in all EU countries.

[370] https://ec.europa.eu/commission/presscorner/detail/en/IP_22_3131

[371] C(2022) 3219 final. Commission Recommendation on speeding up permit-granting procedures for renewable energy projects and facilitating Power Purchase Agreements

[372] A s defined in article 1(c) of Annex II, "energy storage facilities, in individual or aggregated form, used for storing energy on a permanent or temporary basis in above-ground or underground infrastructure or geological sites, provided they are directly connected to high-voltage transmission lines and distribution lines designed for a voltage of 110 kV or more. For Member States and small isolated systems with a lower voltage overall transmission system, those voltage thresholds are equal to the highest voltage level in their respective electricity systems"

List of figures

List of tables

A.1 Annex 2.1 Energy Storage Database and Use Case Matrix

The relevant Excel file is available here.

A.2 Annex 3.1 Market Indicators Dashboard

The relevant Excel file is available here.

A.3 Annex 3.2 Survey Results

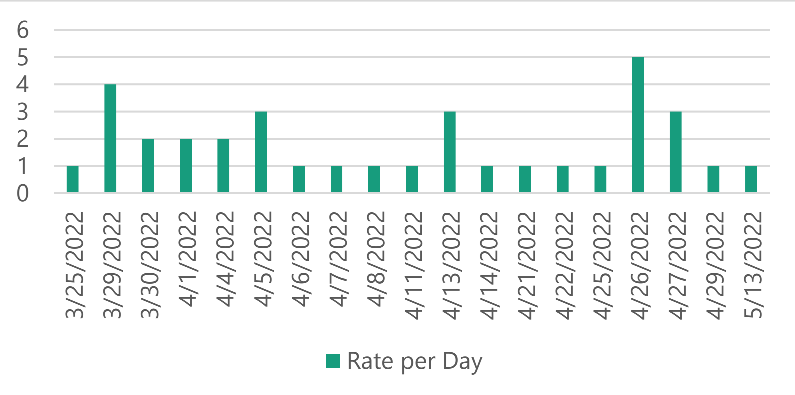
A.3.1 EnTEC Energy Storage questionnaire

Survey Details

Survey Description	Thank you for participating in this questionnaire, which should only take approximately 15 minutes of your time. This questionnaire is conducted by the the Energy Transition Expertise Center (EnTEC), a think tank collaboration of TNO, Trinomics and Fraunhofer, on behalf of the Directorate-General for Energy of the European Commission. The aim of this questionnaire is to provide valuable input on: Current and future uses of energy storage. Current and future revenue streams for energy storage. Discrepancies between whole-system and private benefits of storage. Barriers and drivers for energy storage in the UK The responses to this questionnaire will be compiled into a report for the European Commission, helping to inform its energy storage strategy. Although energy storage technology is advancing rapidly, high-quality evidence on the current and projected future revenue streams for a wide range of energy storage technologies is scarce. Nevertheless, this evidence is urgently needed to help the Commission formulate a strategy that can help the energy storage industry achieve its full potential in the energy transition. With this questionnaire, we aim to take a first step in closing this gap. Responses to this questionnaire are collected anonymously. You will not be asked for your name, company name, or any other personal details. Your anonymous responses will be stored securely by TNO, in compliance with Dutch and EU data protection regulation (see our privacy statement for more information). If you have any questions or concerns, now or after completing the questionnaire, please contact Dr Joris Koornneef (joris.koornneef@tno.nl) and/or Dr Harry van der Weijde (harry.vanderweijde@tno.nl).
Date of export	**5/17/2022 5:16 PM**
Number of Questions and Content Elements	41
Survey Language	**English**
Admin Link of this survey	https://tno.survalyzer-eu.app/workspace/10768/survey/3489/build

Anonymous Link			**https://survey.tno.nl/bfkgpahqfd?l=en**
Response Rate	Invited	324	100%
	Not responded	0	0 %
	In Progress	289	89 %
	Completed	35	11 %
	Screenout	0	0 %
	QuotaFull	0	0 %
	Hard Bounces	0	0 %
	Soft Bounces	0	0 %

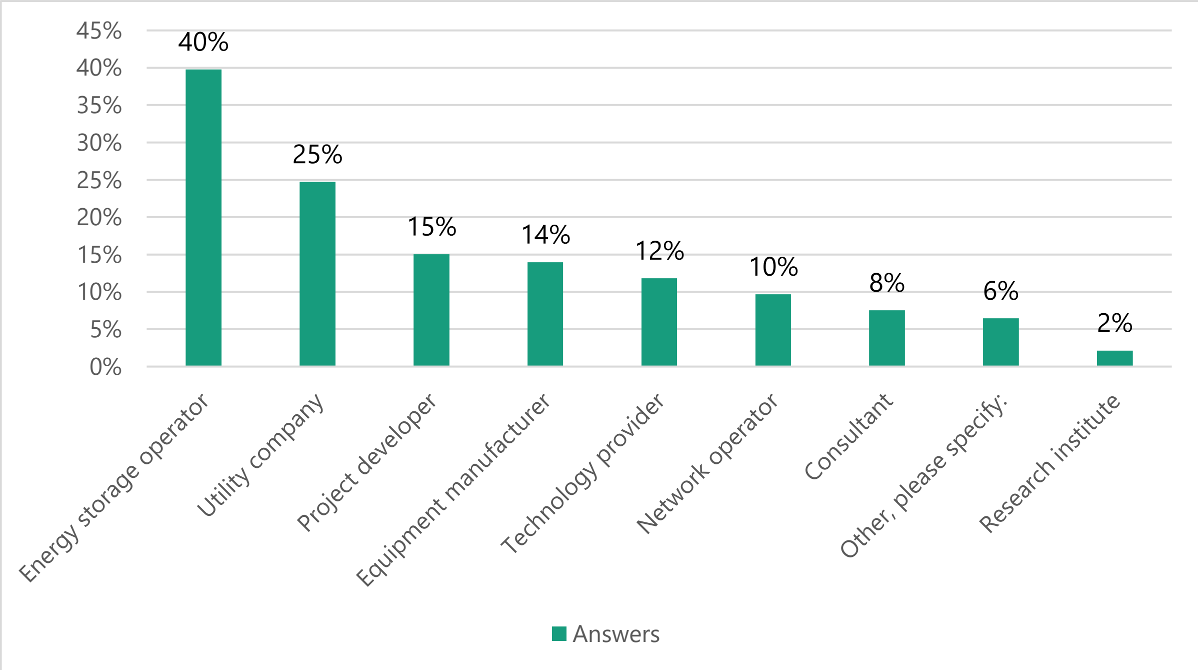
Response Rate per Day



Applied Filter	No filter applied to this report

Your affiliation - Please indicate your type of affiliation.

Responses: 93 / Missings: 231



Answer option	Absolute	in %
Energy storage operator	37	40%
Utility company	23	25%
Project developer	14	15%
Equipment manufacturer	13	14%
Technology provider	11	12%
Network operator	9	10%
Consultant	7	8%
Other, please specify:	6	6%
Research institute	2	2%
Number of answers	***93***	
Number of N/A	***0***	
Number of missings	***231***	

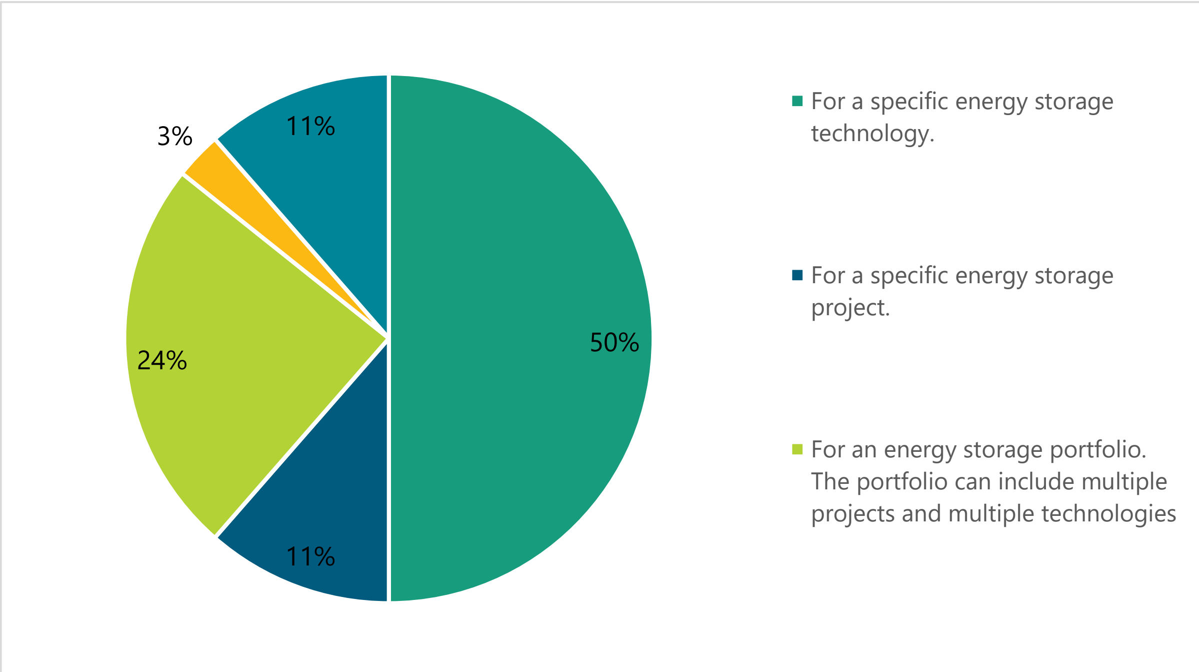
Other, please specify:

Number of Responses: 6

Values
Branch organisation
EnTec: unclear answer
EnTec: unclear answer
National Association
Energy storage technology association
Service Supplier of mobile BESS Battery Energy Storage Systems

Please indicate from which perspective you are filling in this section

Responses: 70 / Missings: 254



Answer option	Absolute	in %
For a specific energy storage technology.	35	50%
For a specific energy storage project.	8	11%
For an energy storage portfolio. The portfolio can include multiple projects and multiple technologies	17	24%
Other, please specify:	2	3%
I cannot answer any questions about current energy storage technologies; please take me directly to the questions about future storage technologies.	8	11%
Mean	2.1	
Number of answers	**70**	
Number of N/A	**0**	
Number of missings	**254**	

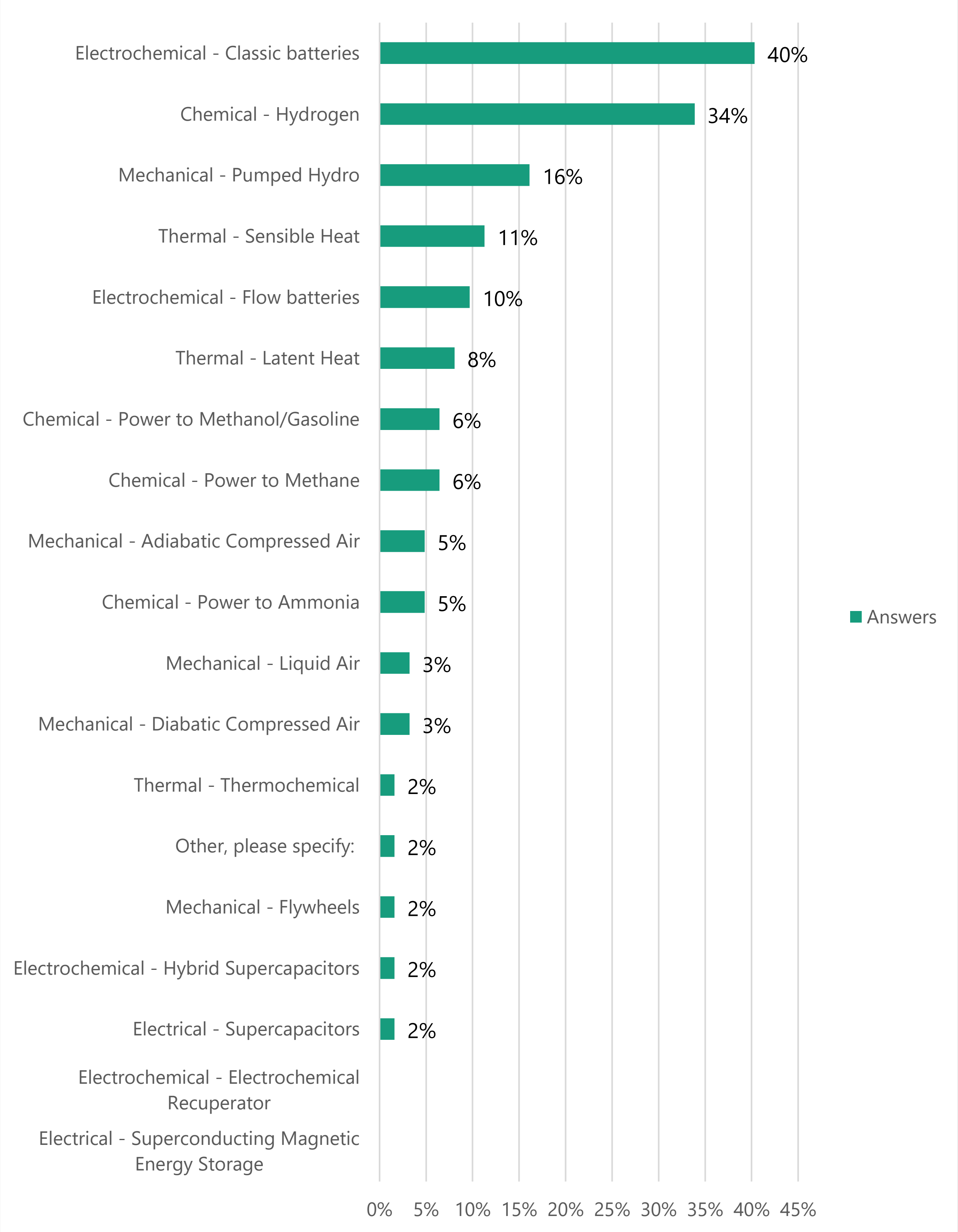
Other, please specify:

Number of Responses: 2

Values
Implementation so far politically not supported though ready for demonstration
Service provider of Mobile BESS Battery Energy Storage Systems

Please specify the technology or technologies.

Responses: 62 / Missings: 262



Answer option	Absolute	in %
Electrochemical - Classic batteries	25	40%
Chemical - Hydrogen	21	34%
Mechanical - Pumped Hydro	10	16%
Thermal - Sensible Heat	7	11%
Electrochemical - Flow batteries	6	10%
Thermal - Latent Heat	5	8%
Chemical - Power to Methanol/Gasoline	4	6%
Chemical - Power to Methane	4	6%
Mechanical - Adiabatic Compressed Air	3	5%
Chemical - Power to Ammonia	3	5%
Mechanical - Liquid Air	2	3%
Mechanical - Diabatic Compressed Air	2	3%
Thermal - Thermochemical	1	2%
Other, please specify:	1	2%
Mechanical - Flywheels	1	2%
Electrochemical - Hybrid Supercapacitors	1	2%
Electrical - Supercapacitors	1	2%
Electrochemical - Electrochemical Recuperator	0	0%
Electrical - Superconducting Magnetic Energy Storage	0	0%
Number of answers	**62**	
Number of N/A	**0**	
Number of missings	**262**	

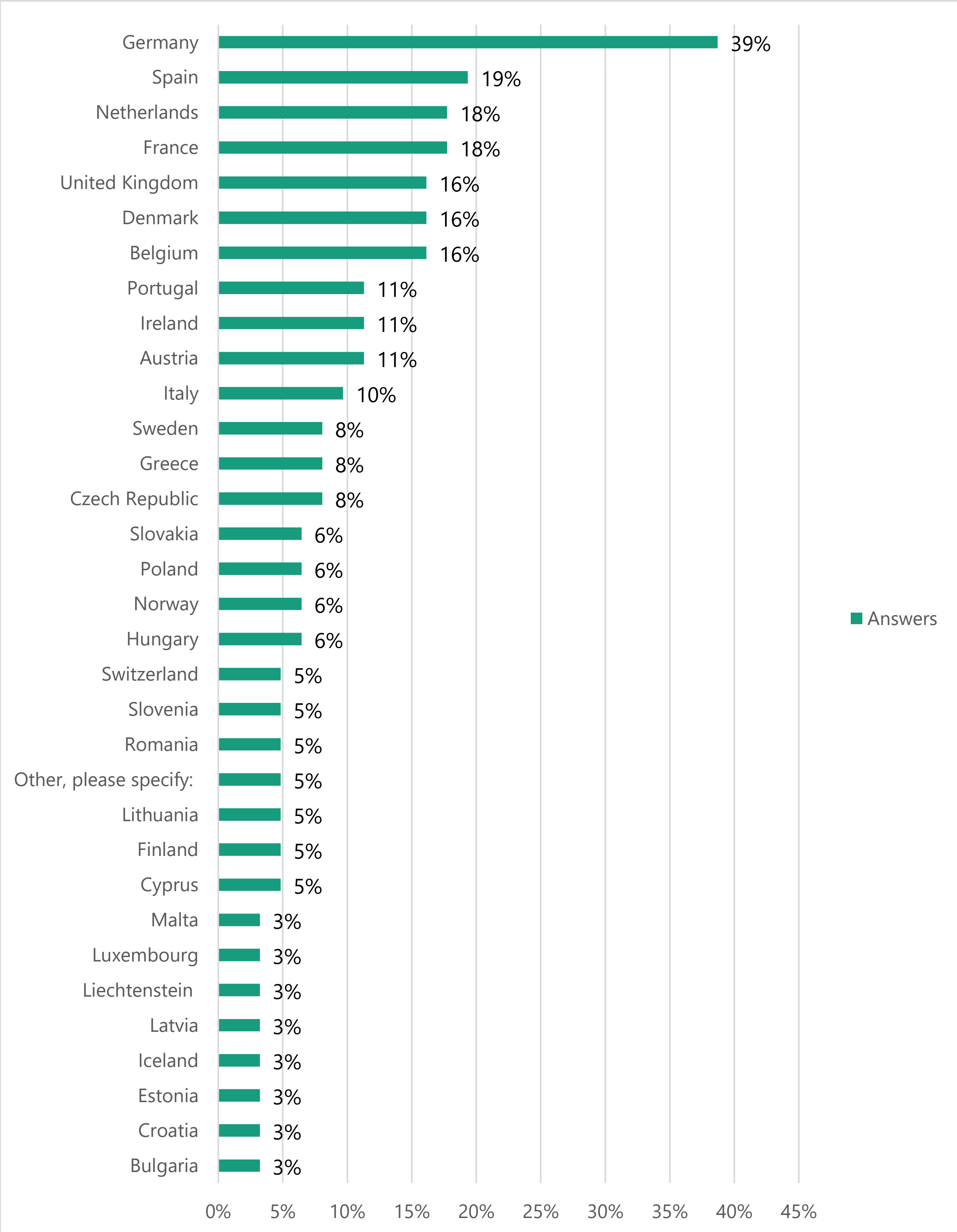
Other, please specify:

Number of Responses: 4

Values
pumped hydro storage
Thermal Hot Water Storage
Pit Pond Storage
Methane Pyrolysis-Carbon Microwave-Watergas Methane-Synthesis from HFC-Water effluent regenerative Green Hydrogen

Please specify the location(s) of your chosen technology, project or portfolio.

Responses: 62 / Missings: 262



Answer option	Absolute	in %
Germany	24	39%
Spain	12	19%
Netherlands	11	18%

Answer option	Absolute	in %
France	11	18%
United Kingdom	10	16%
Denmark	10	16%
Belgium	10	16%
Portugal	7	11%
Ireland	7	11%
Austria	7	11%
Italy	6	10%
Sweden	5	8%
Greece	5	8%
Czech Republic	5	8%
Slovakia	4	6%
Poland	4	6%
Norway	4	6%
Hungary	4	6%
Switzerland	3	5%
Slovenia	3	5%
Romania	3	5%
Other, please specify:	3	5%
Lithuania	3	5%
Finland	3	5%
Cyprus	3	5%
Malta	2	3%
Luxembourg	2	3%
Liechtenstein	2	3%
Latvia	2	3%
Iceland	2	3%
Estonia	2	3%
Croatia	2	3%
Bulgaria	2	3%
Number of answers	**62**	
Number of N/A	**0**	
Number of missings	**262**	

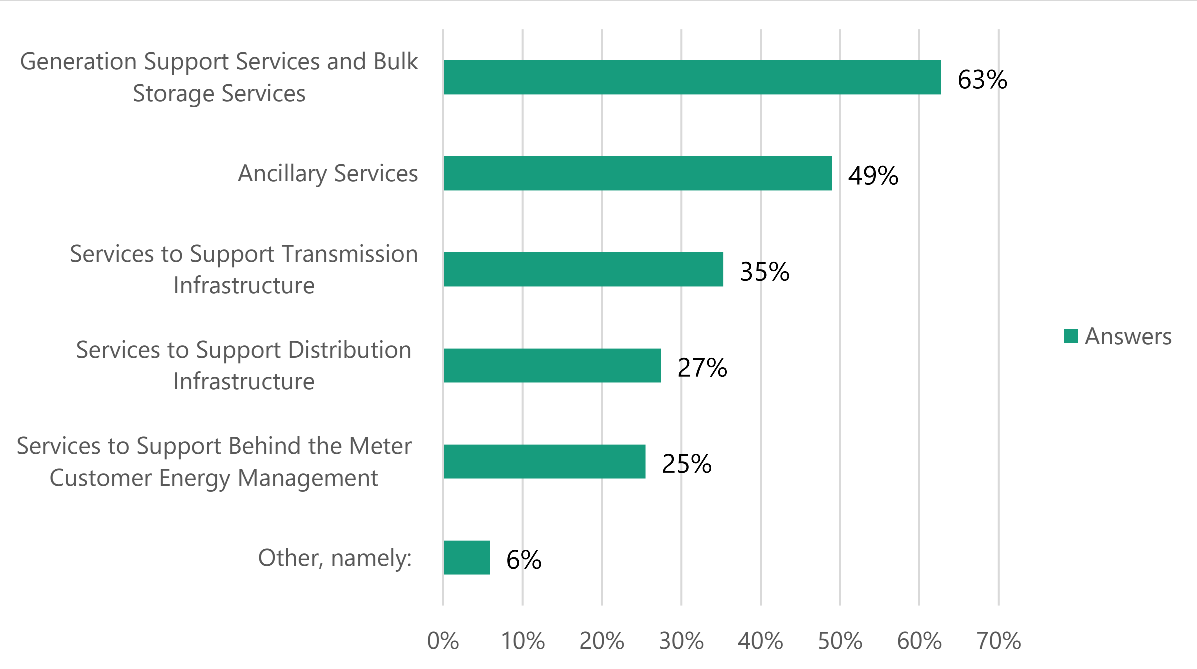
Other, please specify:

Number of Responses: 3

Values
Global
Turkey
Wherever not rejected

Which category of product/service does your technology, project or portfolio provide?

Responses: 51 / Missings: 273



Answer option	Absolute	in %
Generation Support Services and Bulk Storage Services	32	63%
Ancillary Services	25	49%
Services to Support Transmission Infrastructure	18	35%
Services to Support Distribution Infrastructure	14	27%
Services to Support Behind the Meter Customer Energy Management	13	25%
Other, namely:	3	6%

Number of answers	**51**
Number of N/A	**0**
Number of missings	**273**

Other, namely:

Number of Responses: 3

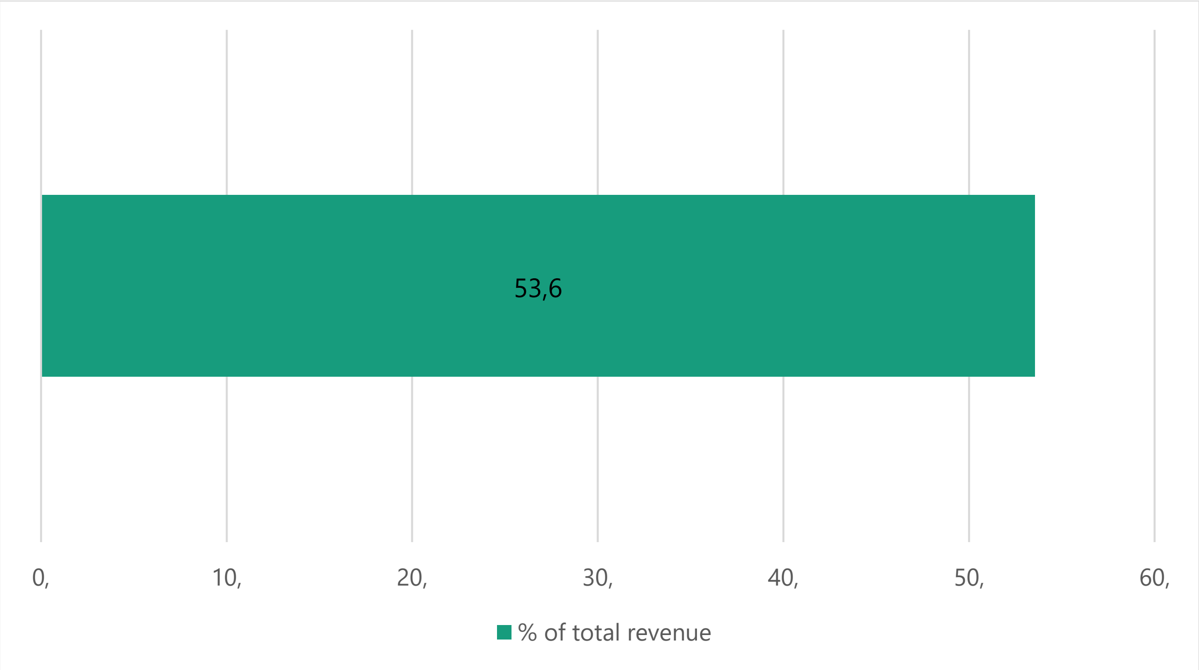
Values
portable electronic devices
on going candidature for local congestion management for French TSO RTE. Remuneration based on investment deferral.
saasf

Please indicate the approximate share of the total revenue by category of product/service provided.

Responses: 38 / Missings: 286

Generation Support Services and Bulk Storage Services

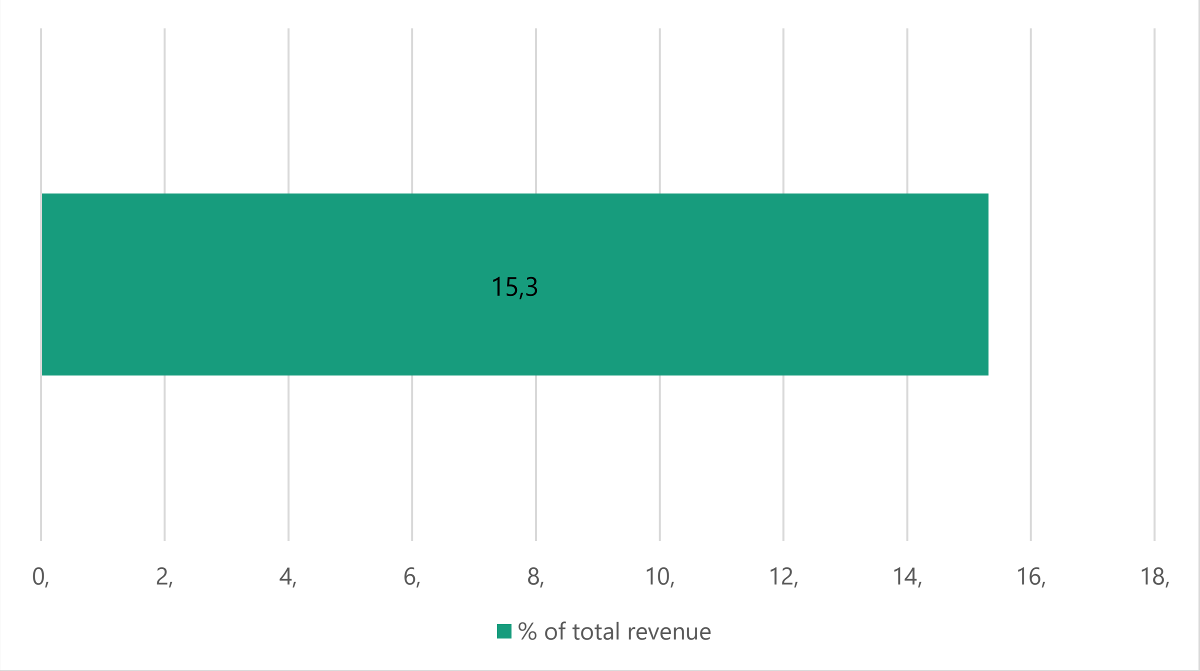
Number of Responses: 25



Generation Support Services and Bulk Storage Services	Minimum value	Mean	Median	Maximum value
% of total revenue	0	53.6	50	100
Number of answers	**25**			

Services to Support Transmission Infrastructure

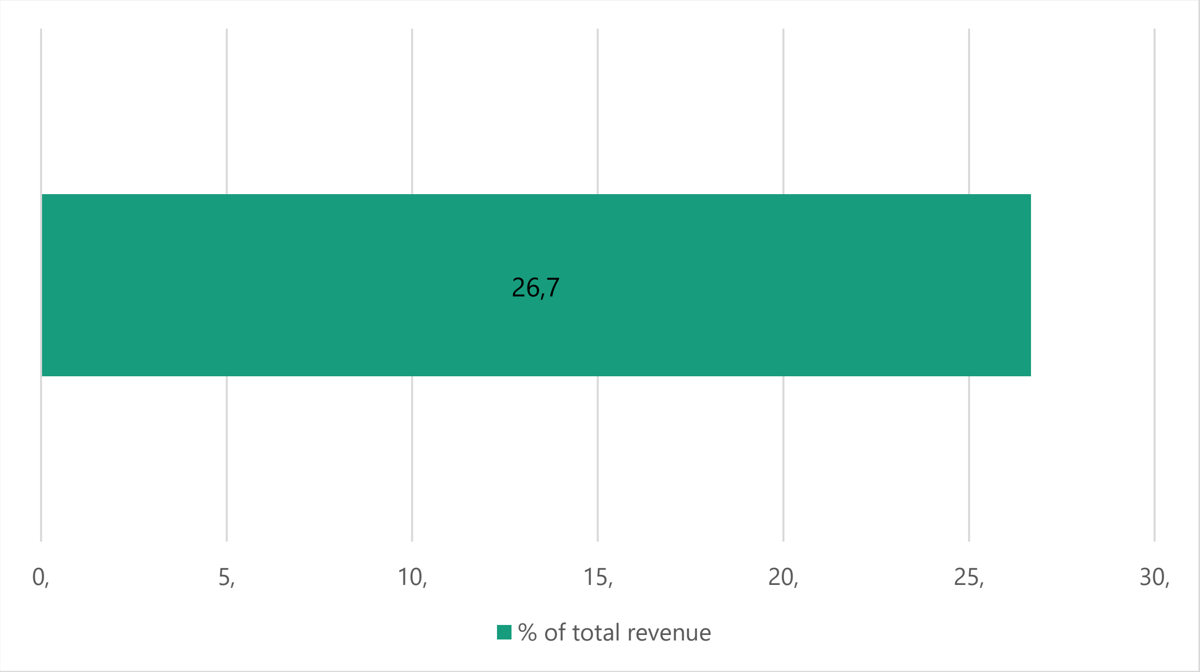
Number of Responses: 16



Services to Support Transmission Infrastructure	Minimum value	Mean	Median	Maximum value
% of total revenue	0	15.3	8	100
Number of answers	**16**			

Services to Support Distribution Infrastructure

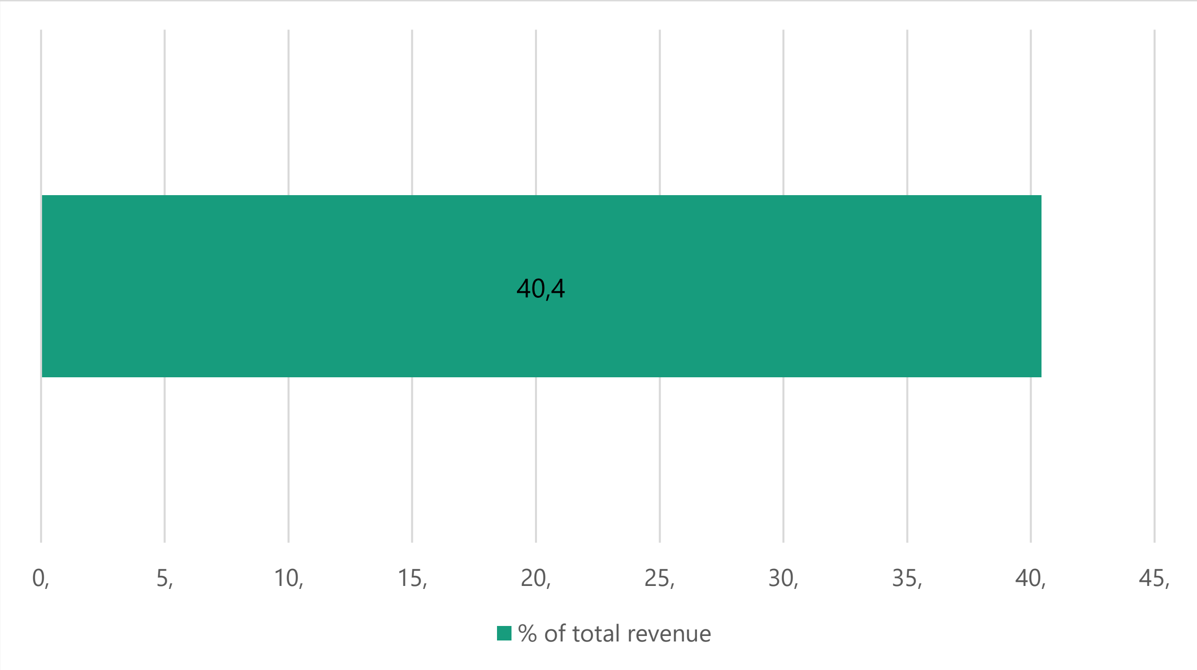
Number of Responses: 12



Services to Support Distribution Infrastructure	Minimum value	Mean	Median	Maximum value
% of total revenue	0	26.7	18	80
Number of answers	**12**			

Services to Support Behind the Meter Customer Energy Management

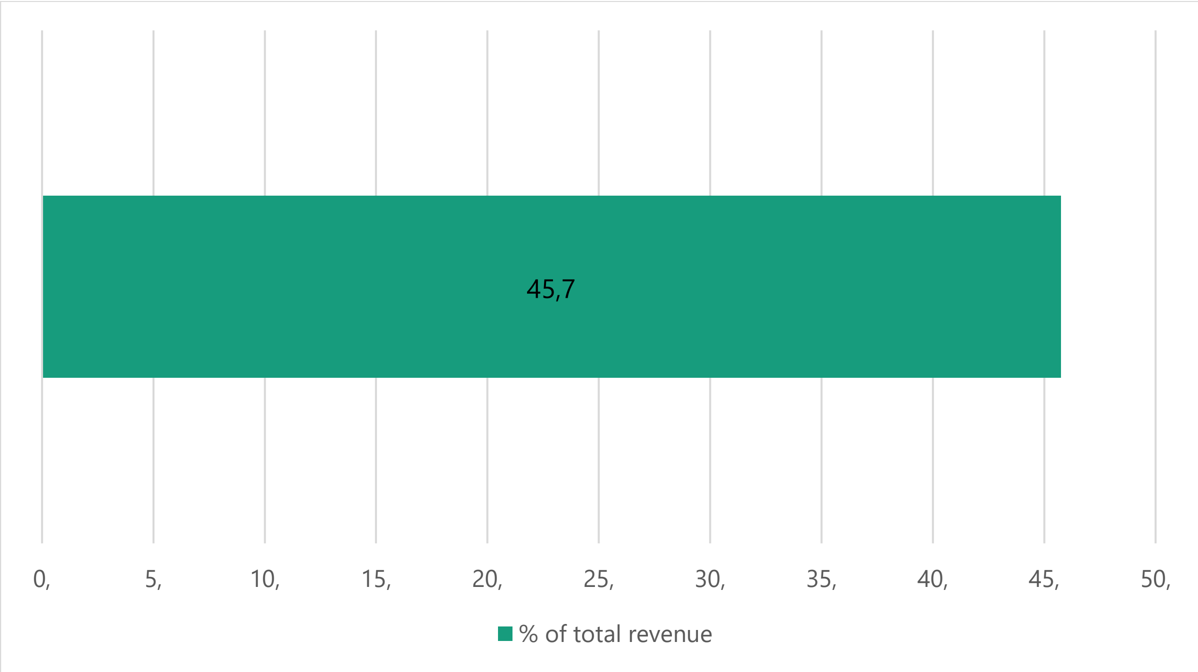
Number of Responses: 14



Services to Support Behind the Meter Customer Energy Management	Minimum value	Mean	Median	Maximum value
% of total revenue	0	40.4	35	100
Number of answers	**14**			

Ancillary Services

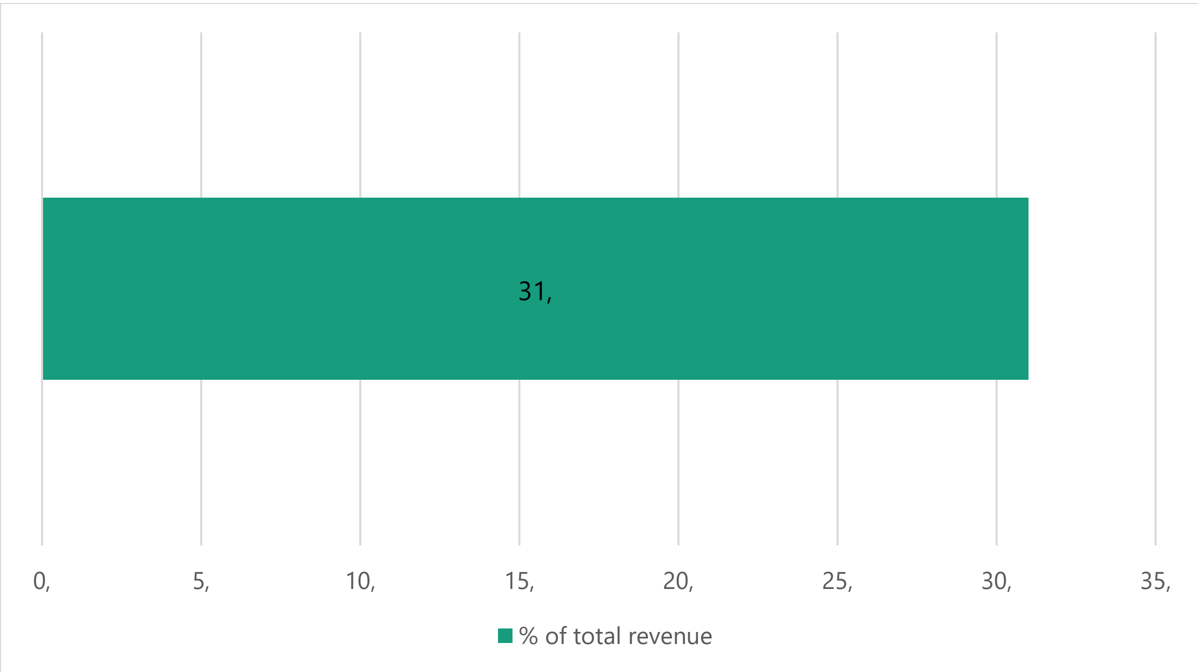
Number of Responses: 23



Ancillary Services	Minimum value	Mean	Median	Maximum value
% of total revenue	0	45.7	50	100
Number of answers	**23**			

Other

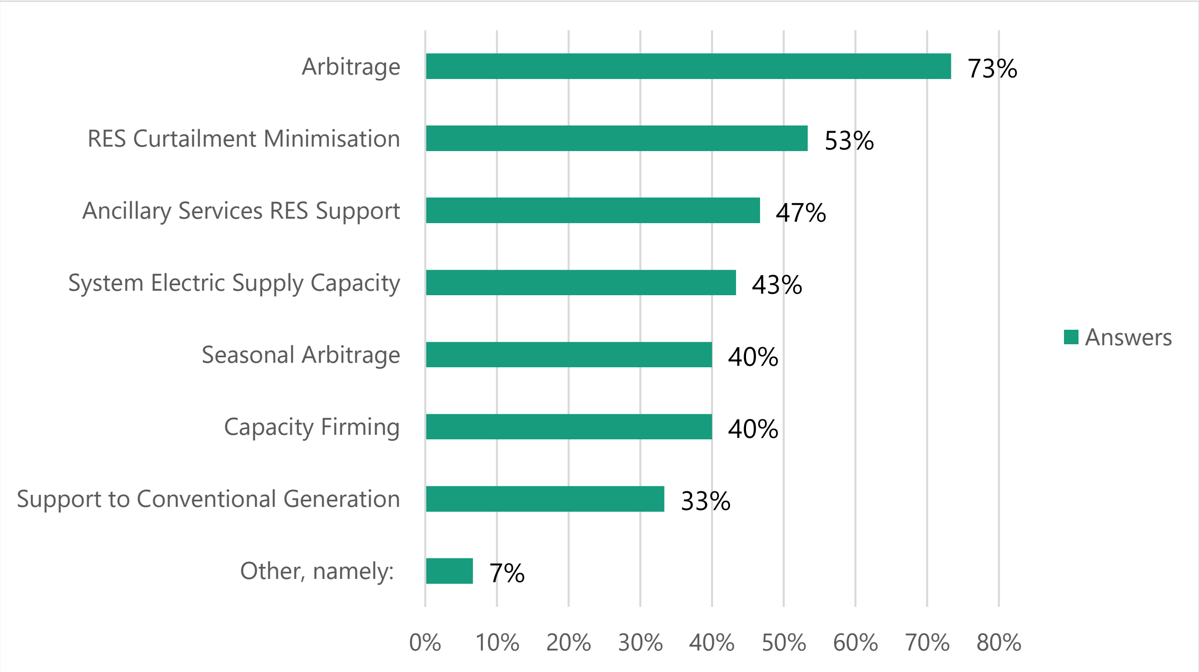
Number of Responses: 9



Other	Minimum value	Mean	Median	Maximum value
% of total revenue	1	31	10	100
Number of answers	**9**			

Which Generation Support Services and Bulk Storage Services does your technology, project or portfolio supply?

Responses: 30 / Missings: 294



Answer option	Absolute	in %
Arbitrage	22	73%
RES Curtailment Minimisation	16	53%
Ancillary Services RES Support	14	47%
System Electric Supply Capacity	13	43%
Seasonal Arbitrage	12	40%
Capacity Firming	12	40%
Support to Conventional Generation	10	33%
Other, namely:	2	7%
Number of answers	**30**	
Number of N/A	**0**	
Number of missings	**294**	

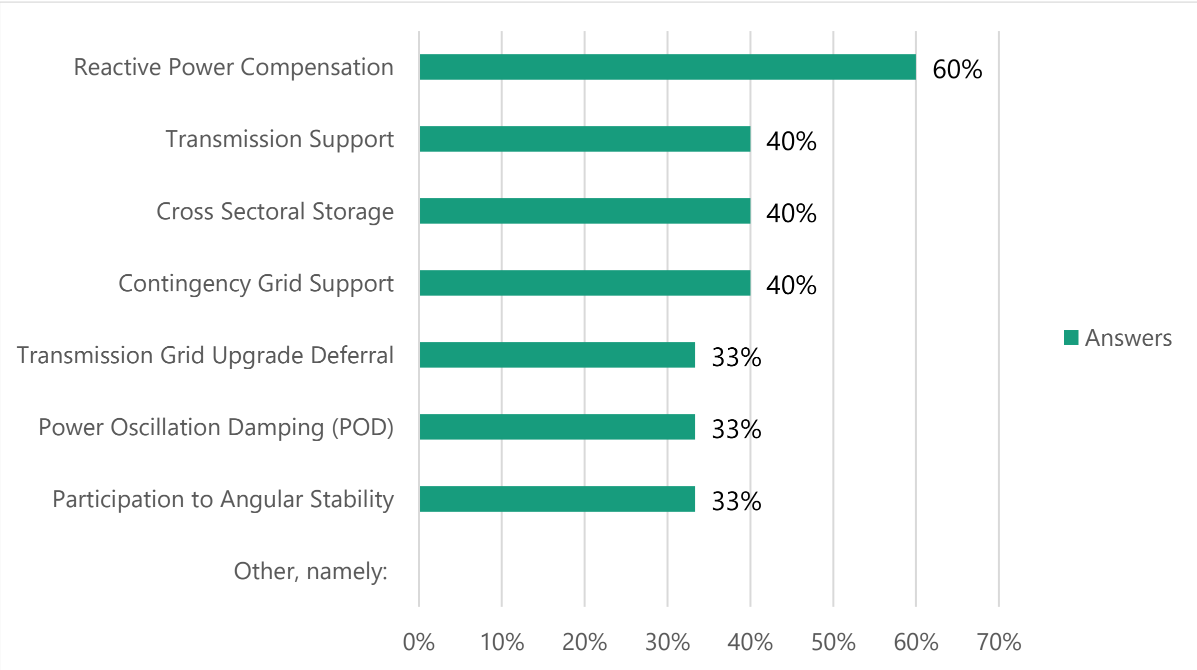
Other, namely:

Number of Responses: 3

Values
weekly arbitrage
back up or firming of intermitent eletrolyser production
Supporting renewable generation

Which Services to Support Transmission Infrastructure does your technology, project or portfolio supply?

Responses: 15 / Missings: 309



Answer option	Absolute	in %
Reactive Power Compensation	9	60%
Transmission Support	6	40%
Cross Sectoral Storage	6	40%
Contingency Grid Support	6	40%
Transmission Grid Upgrade Deferral	5	33%
Power Oscillation Damping (POD)	5	33%
Participation to Angular Stability	5	33%
Other, namely:	0	0%
Number of answers	**15**	
Number of N/A	**0**	
Number of missings	**309**	

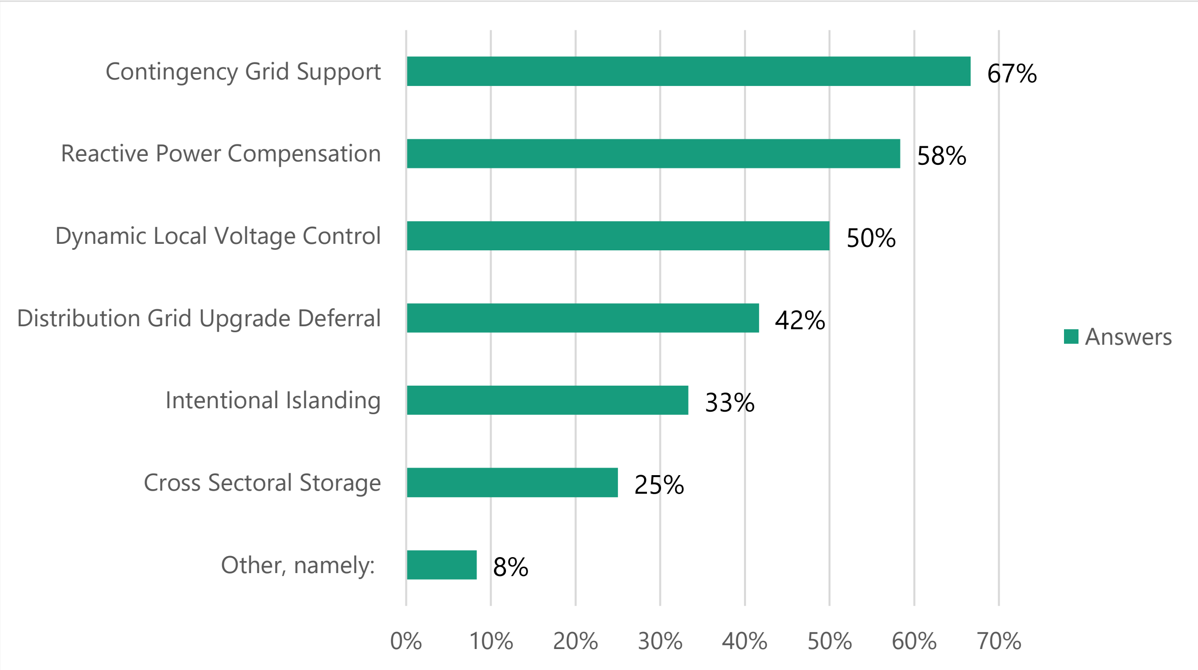
Other, namely:

Number of Responses: 1

Values
0

Which Services to Support Distribution Infrastructure does your technology, project or portfolio supply?

Responses: 12 / Missings: 312



Answer option	Absolute	in %
Contingency Grid Support	8	67%
Reactive Power Compensation	7	58%
Dynamic Local Voltage Control	6	50%
Distribution Grid Upgrade Deferral	5	42%
Intentional Islanding	4	33%
Cross Sectoral Storage	3	25%
Other, namely:	1	8%
Number of answers	**12**	
Number of N/A	**0**	
Number of missings	**312**	

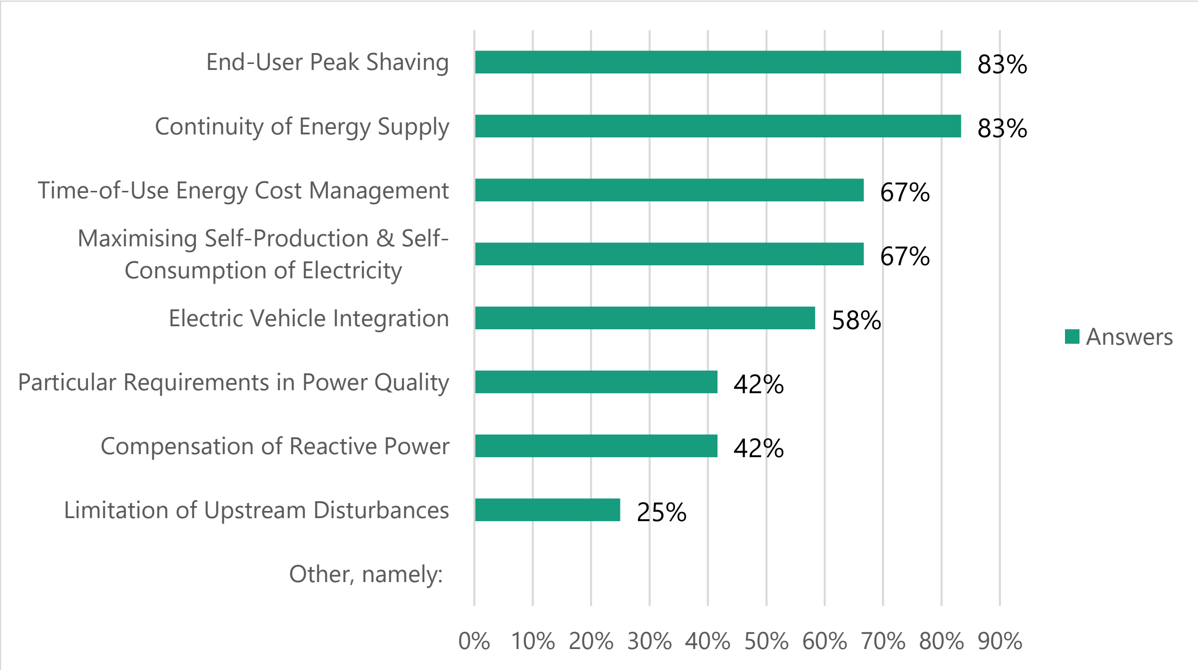
Other, namely:

Number of Responses: 1

Values
Distributed energy communities

Which Services to Support Behind the Meter Customer Energy Management does your technology, project or portfolio supply?

Responses: 12 / Missings: 312



Answer option	Absolute	in %
End-User Peak Shaving	10	83%
Continuity of Energy Supply	10	83%
Time-of-Use Energy Cost Management	8	67%
Maximising Self-Production & Self-Consumption of Electricity	8	67%
Electric Vehicle Integration	7	58%
Particular Requirements in Power Quality	5	42%
Compensation of Reactive Power	5	42%
Limitation of Upstream Disturbances	3	25%
Other, namely:	0	0%
Number of answers	**12**	
Number of N/A	**0**	
Number of missings	**312**	

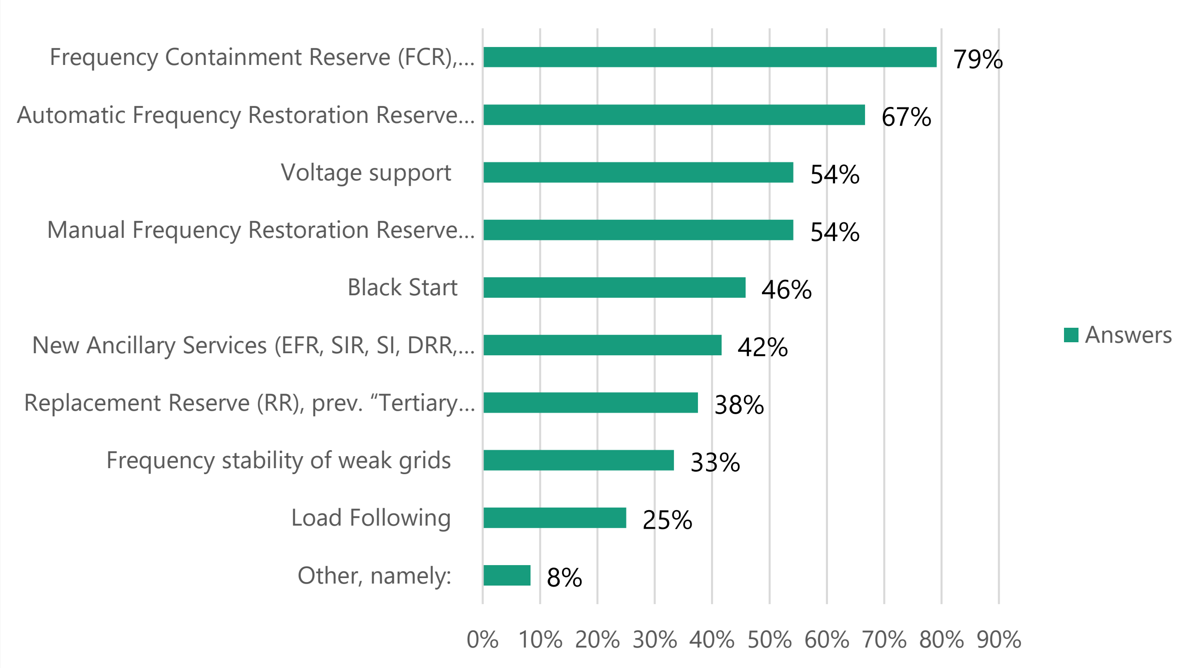
Other, namely:

Number of Responses: 0

Values

Which Ancillary Services does your technology, project or portfolio supply?

Responses: 24 / Missings: 300



Answer option	Absolute	in %
Frequency Containment Reserve (FCR), prev. "Primary Reserve"	19	79%
Automatic Frequency Restoration Reserve (aFFR), prev. "Secondary Reserve	16	67%
Voltage support	13	54%
Manual Frequency Restoration Reserve (mFRR)	13	54%
Black Start	11	46%
New Ancillary Services (EFR, SIR, SI, DRR, FFR, FPAPR, RM, etc.)	10	42%
Replacement Reserve (RR), prev. "Tertiary Reserve"	9	38%
Frequency stability of weak grids	8	33%
Load Following	6	25%
Other, namely:	2	8%
Number of answers	**24**	
Number of N/A	**0**	
Number of missings	**300**	

Other, namely:

Number of Responses: 2

Values
Safety
network restoration, islanded grigs

You have indicated that some of the revenues of your technology, project or portfolio are related to products and/or services in the 'Other' category, not

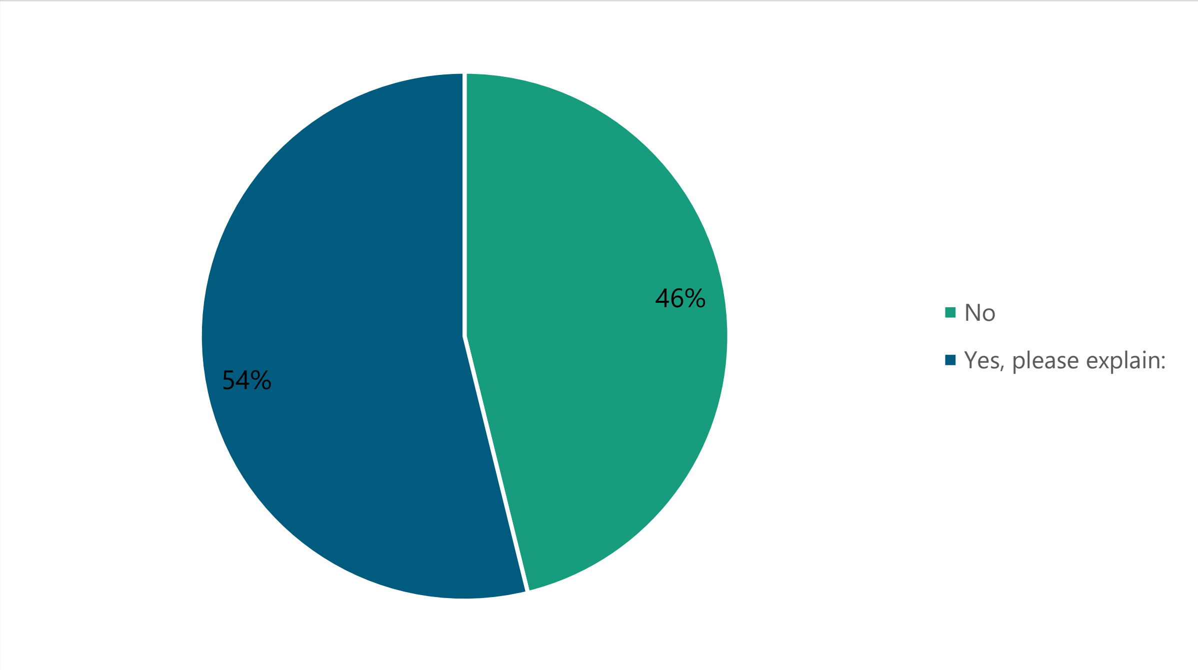
captured by any of the other categories. Which products and/or services are this?

Responses: 2 / Missings: 322

Values
Batteries and supercapacitors dedicated to portable electronic devices.
on going candidature for local congestion management for French TSO RTE. Remuneration based on investment deferral.

Is there any service or social benefit that you believe energy storage (or a specific storage technology) can deliver, but for which there is currently no market and/or other incentive in your location?

Responses: 52 / Missings: 272



Answer option	Absolute	in %
No	24	46%
Yes, please explain:	28	54%
Mean	1.5	
Number of answers	**52**	
Number of N/A	**0**	
Number of missings	**272**	

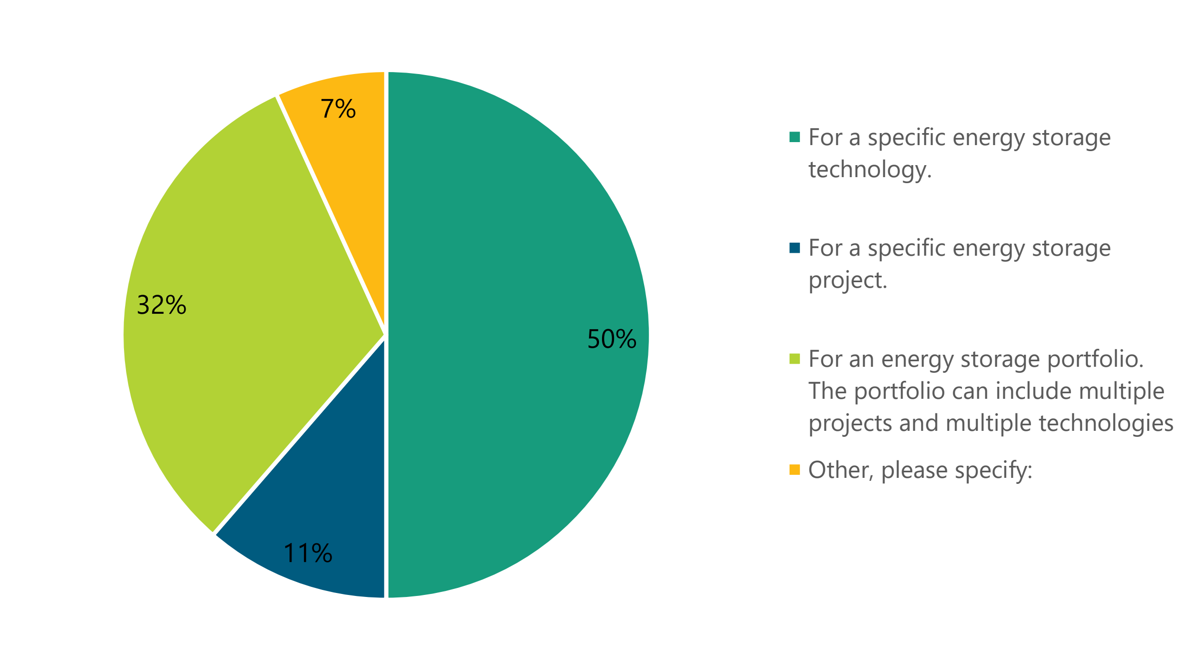
Yes, please explain:

Number of Responses: 28

Values
Increase of renewable energy resources in the European grip. Storage can buffer fluctuations.
Long duration storage is the solution to keep the grid balanced with a higher REN penetration. This is a unique value proposition which bring economic and social benefits.
Conversion technologies between different energy infrastructure such as electricity, thermal and gas
The benefits of ES are widely understood, and include facilitating the increase in intermittent renewable generation, peak shaving and times shifting. Gravity energy storage is a particular case, with advantages including fast response, high round trip efficiency and locational flexibility. Unlike chemical batteries, there is no degradation in perforamnce over time, a very long lifetime of 25 years +, no mining of rare raw materials or high end of life costs.
Services of storage in system operation and system resilience, especially around virtual inertia, grid-following capability of storage
1) Grid upgrade deferrals - redistribution of potential savings to incentivise the most optimal development storage vs. grid upgrades 2) Support curtailment compensation to drive incentives for avoiding renewable energy curtailment 3) Contingency grid support 4) Revenue stability of ancillary services
No remuneration for reactive power compensation, grid restoration, system inertia, flexibility capacity
Referring to Cyprus - Market and grid regulations still under development
Storing green electricity by converting it into hydrogen is the only way so far to keep climate-neutral energy available in very large capacity over long periods of time. Establishing this technology is essential for the success of the energy transition and would combine climate protection and security of supply. Unfortunately, market readiness is still a long way off for various economic, political and regulatory reasons.
The local energy storage is not valorised for end user
Flood adjustment
Excluding the markets where not all storage technologies are allowed to offer all the services (energy, adequacy and ancillary services), in all markets a specific incentive mechanism measuring the CO2 avoided for displacement of thermal generation is lacking.
Current utility suppliers do not like energy democratisation by distributed energy communities
The advantage of low noise with the use of BESS. Using storage will avoid breaking up the environment for renewal of the grid
Benefits for future hydrogen market
We can avoid outages and shortages of the electricity grid
SoS
SOS
Decentralised generation and lower cost for distribution of electricity
Continuous supply of renewable energy for many hours of the year
SOS
Ability of storage assets to avoid over-investments in other infrastructure elements, across the entire energy sector, to ensure the hydrogen demand can be met in a secure and efficient way.
Security of Supply, Avoidance against Dunkelflaute, Emission Reduction (currently not directly compensated)
Currently, there is no H_2 market in the region.
Balancing of fluctuationg renewable energy production
Yes, VRFB sustainability! VRFB are best in class compared to other storage tech. Please see various independent LCA's. EOL costs are low. >95% re-usable!
Off grid and micro grids
Support to conventional generation. Transmission investment deferral. RES curtailment minimisation. Additional support to RES, i.e. enhanced business case for new RES to ensure adequate build-out.

Please indicate from which perspective you are filling in the questionnaire for the year 2030. This may, but need not, be the same as the perspective you used when answering the questions above.

Responses: 44 / Missings: 280



Answer option	Absolute	in %
For a specific energy storage technology.	22	50%
For a specific energy storage project.	5	11%
For an energy storage portfolio. The portfolio can include multiple projects and multiple technologies	14	32%
Other, please specify:	3	7%
Mean	2	
Number of answers	**44**	
Number of N/A	**0**	
Number of missings	**280**	

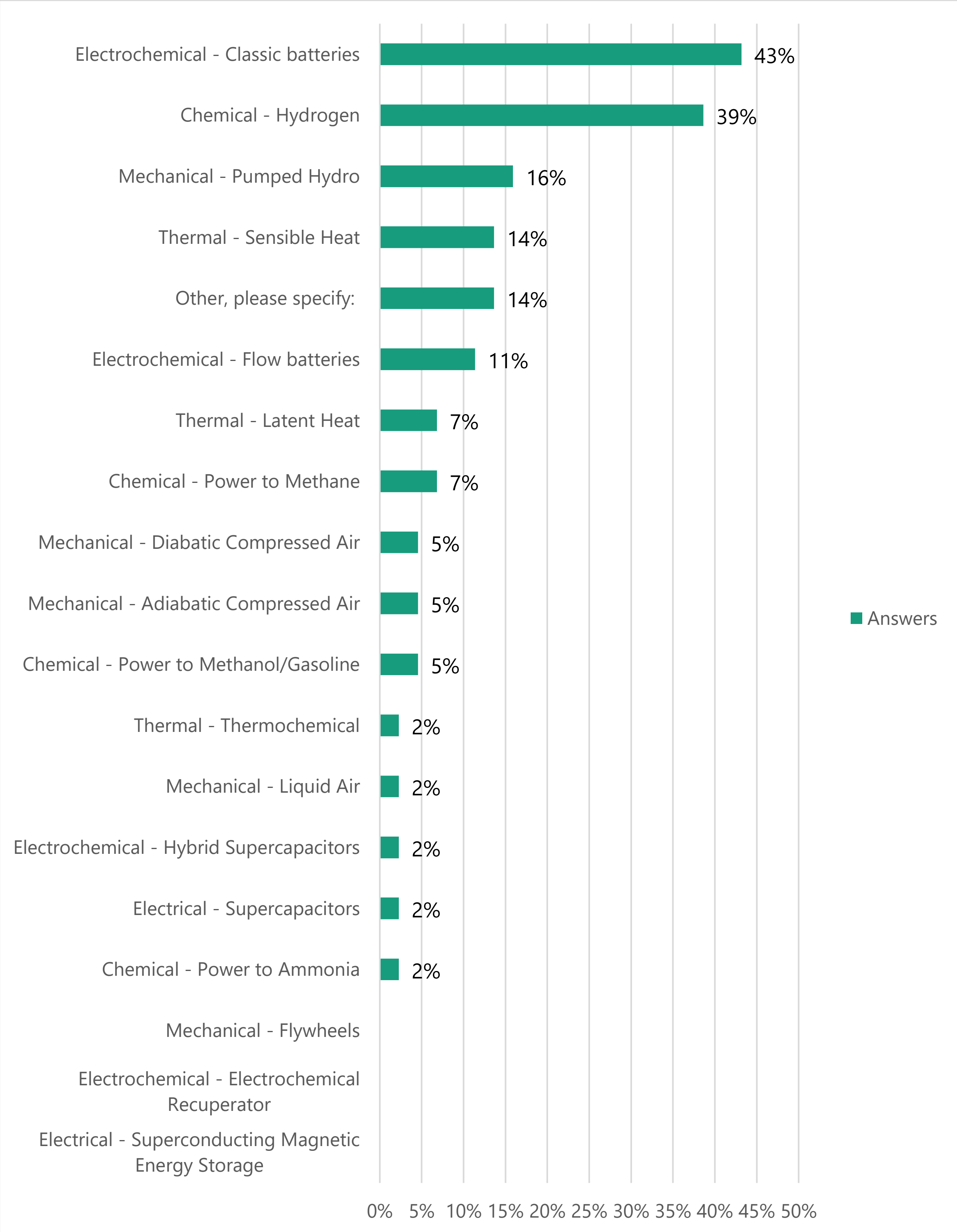
Other, please specify:

Number of Responses: 3

Values
market
For a game-change in energy infrastructure and its use
Mobile BESS. In combination with Mobile Generators on alternative non fossil fuels —> hydrogen, methanol, biomethane etc.

Please specify the technology or technologies.

Responses: 44 / Missings: 280



Answer option	Absolute	in %
Electrochemical - Classic batteries	19	43%
Chemical - Hydrogen	17	39%

Answer option	Absolute	in %
Mechanical - Pumped Hydro	7	16%
Thermal - Sensible Heat	6	14%
Other, please specify:	6	14%
Electrochemical - Flow batteries	5	11%
Thermal - Latent Heat	3	7%
Chemical - Power to Methane	3	7%
Mechanical - Diabatic Compressed Air	2	5%
Mechanical - Adiabatic Compressed Air	2	5%
Chemical - Power to Methanol/Gasoline	2	5%
Thermal - Thermochemical	1	2%
Mechanical - Liquid Air	1	2%
Electrochemical - Hybrid Supercapacitors	1	2%
Electrical - Supercapacitors	1	2%
Chemical - Power to Ammonia	1	2%
Mechanical - Flywheels	0	0%
Electrochemical - Electrochemical Recuperator	0	0%
Electrical - Superconducting Magnetic Energy Storage	0	0%
Number of answers	**44**	
Number of N/A	**0**	
Number of missings	**280**	

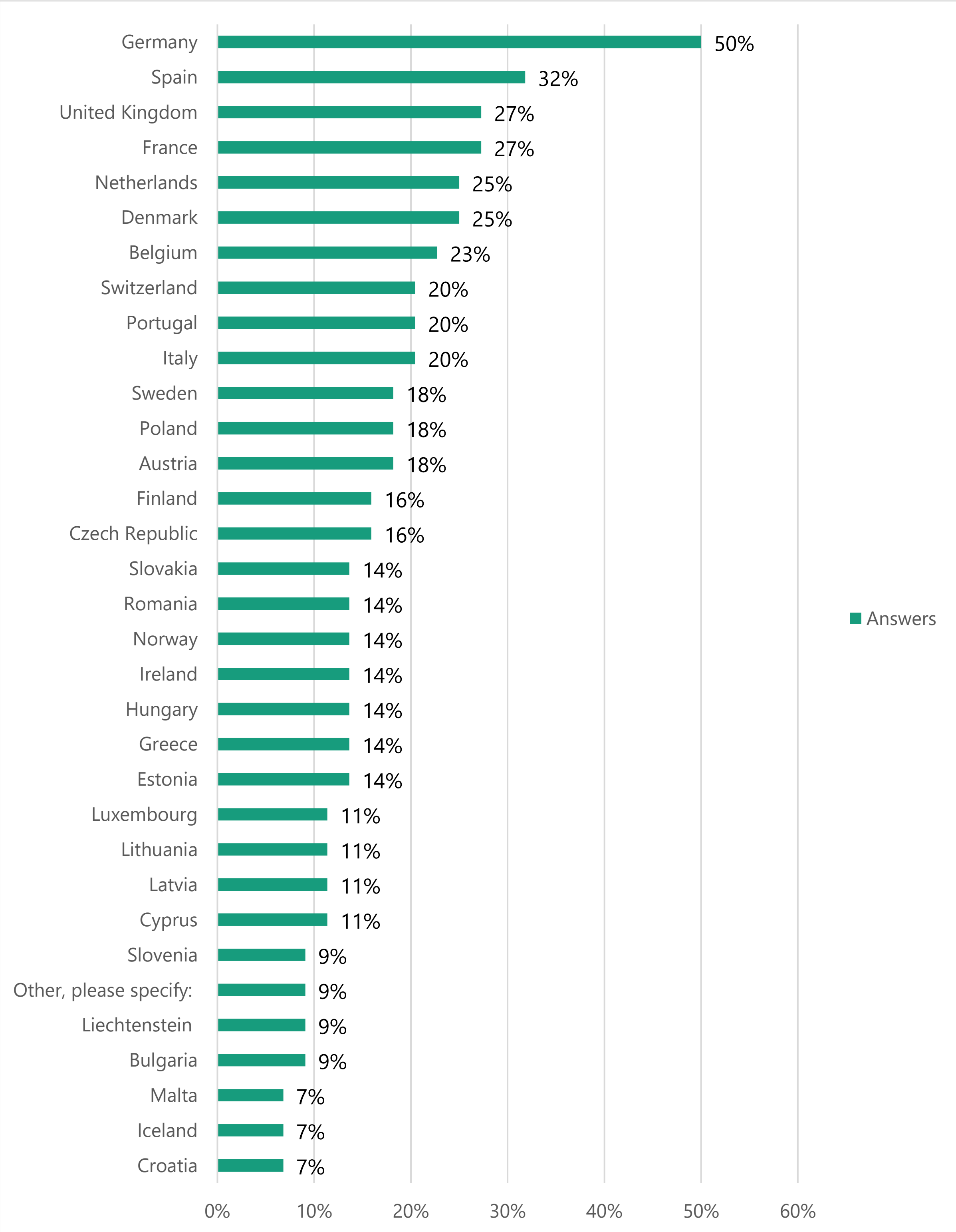
Other, please specify:

Number of Responses: 8

Values
Mechanical - gravity.
hydro pumped storage
Compressed CO2
Thermal Hot Water Storage
Pit Pond storage
all
See answers above: Methane Pyrolysis-Carbon Microwave-Watergas Methane-Synthesis from HFC-Water effluent regenerative Green Hydrogen
Geothermal power

Please give your best estimate of the location(s) of your chosen technology, project or portfolio in 2030.

Responses: 44 / Missings: 280



Answer option	Absolute	in %
Germany	22	50%
Spain	14	32%
United Kingdom	12	27%
France	12	27%
Netherlands	11	25%
Denmark	11	25%
Belgium	10	23%
Switzerland	9	20%
Portugal	9	20%
Italy	9	20%
Sweden	8	18%
Poland	8	18%
Austria	8	18%
Finland	7	16%
Czech Republic	7	16%
Slovakia	6	14%
Romania	6	14%
Norway	6	14%
Ireland	6	14%
Hungary	6	14%
Greece	6	14%
Estonia	6	14%
Luxembourg	5	11%
Lithuania	5	11%
Latvia	5	11%
Cyprus	5	11%
Slovenia	4	9%
Other, please specify:	4	9%
Liechtenstein	4	9%
Bulgaria	4	9%
Malta	3	7%
Iceland	3	7%
Croatia	3	7%
Number of answers	**44**	
Number of N/A	**0**	
Number of missings	**280**	

Other, please specify:

Number of Responses: 4

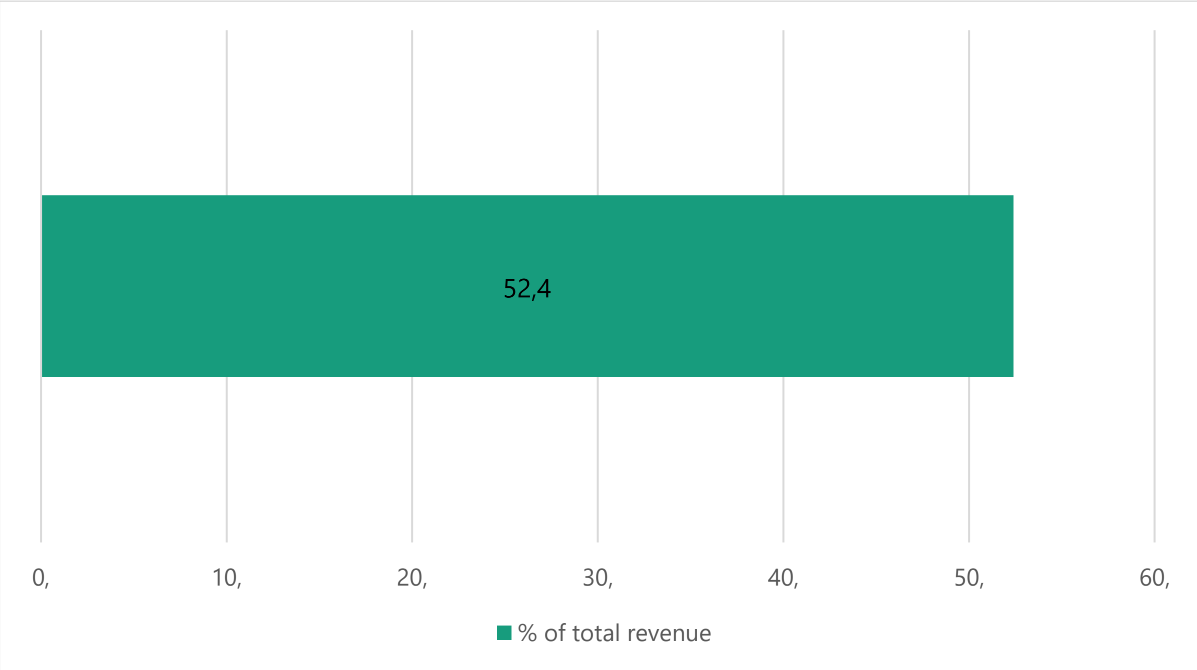
Values
Global
Turkey
EU
Please see answers above

For your technology, project or portfolio, please indicate your assessment of the share of the total revenue by category of product/service provided in 2030.

Responses: 33 / Missings: 291

Generation Support Services and Bulk Storage Services

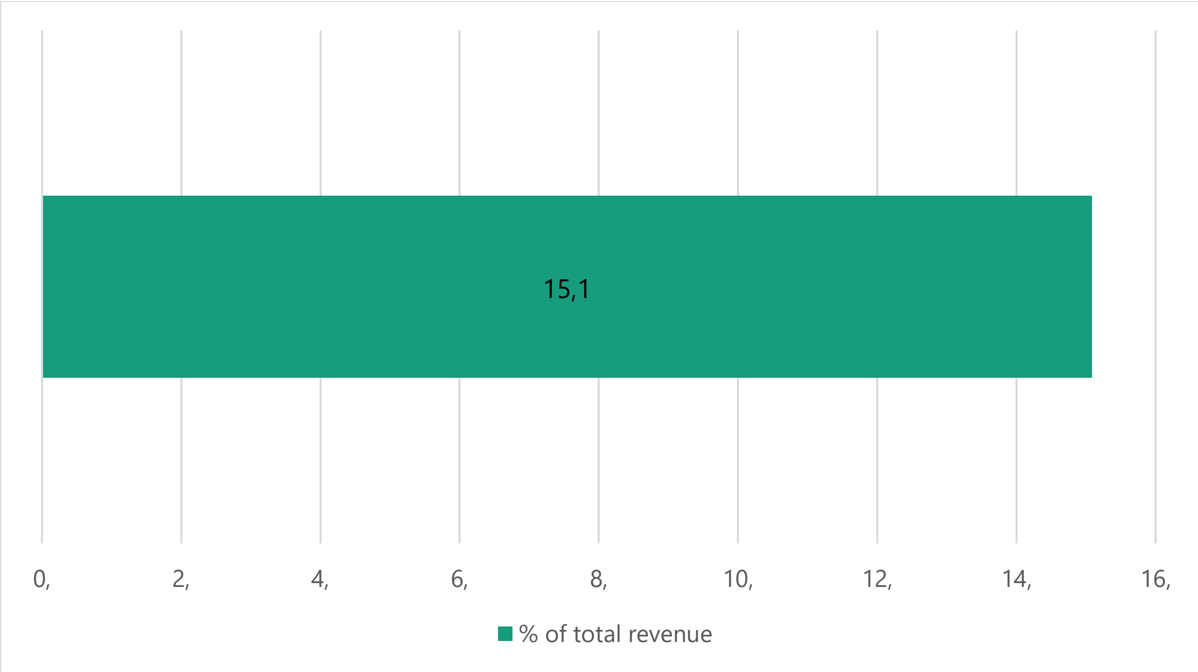
Number of Responses: 23



Generation Support Services and Bulk Storage Services	Minimum value	Mean	Median	Maximum value
% of total revenue	5	52.4	50	100
Number of answers	**23**			

Services to Support Transmission Infrastructure

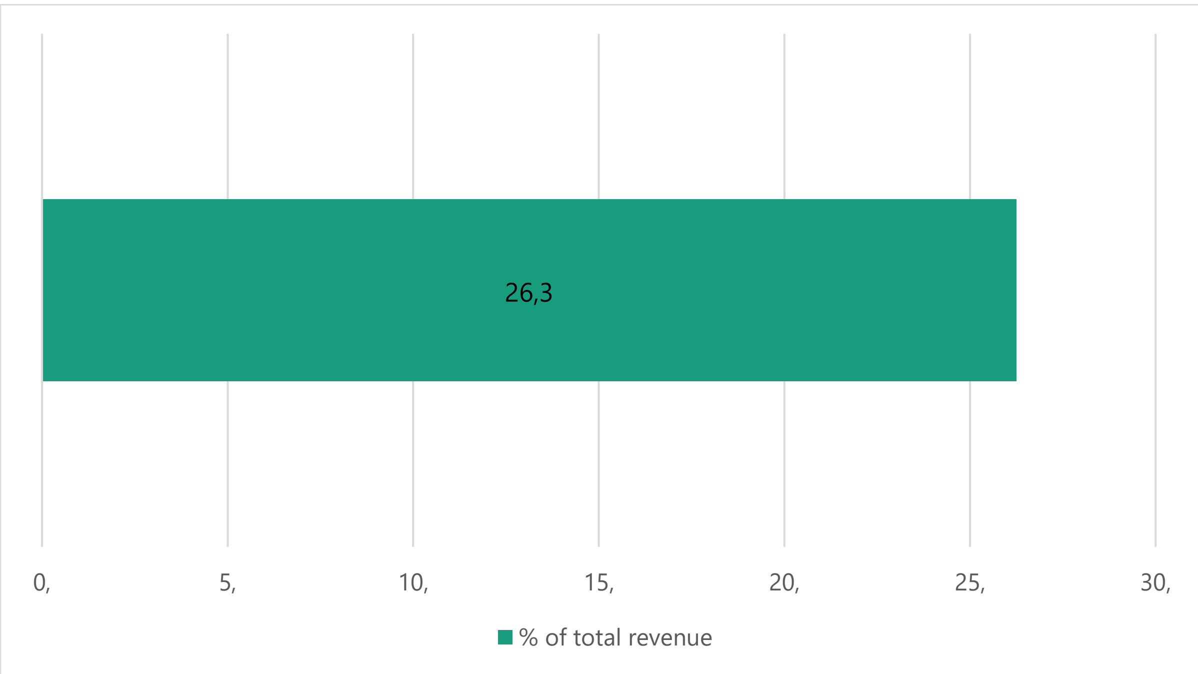
Number of Responses: 12



Services to Support Transmission Infra-structure	Minimum value	Mean	Median	Maximum value
% of total revenue	1	15.1	18	30
Number of answers	**12**			

Services to Support Distribution Infrastructure

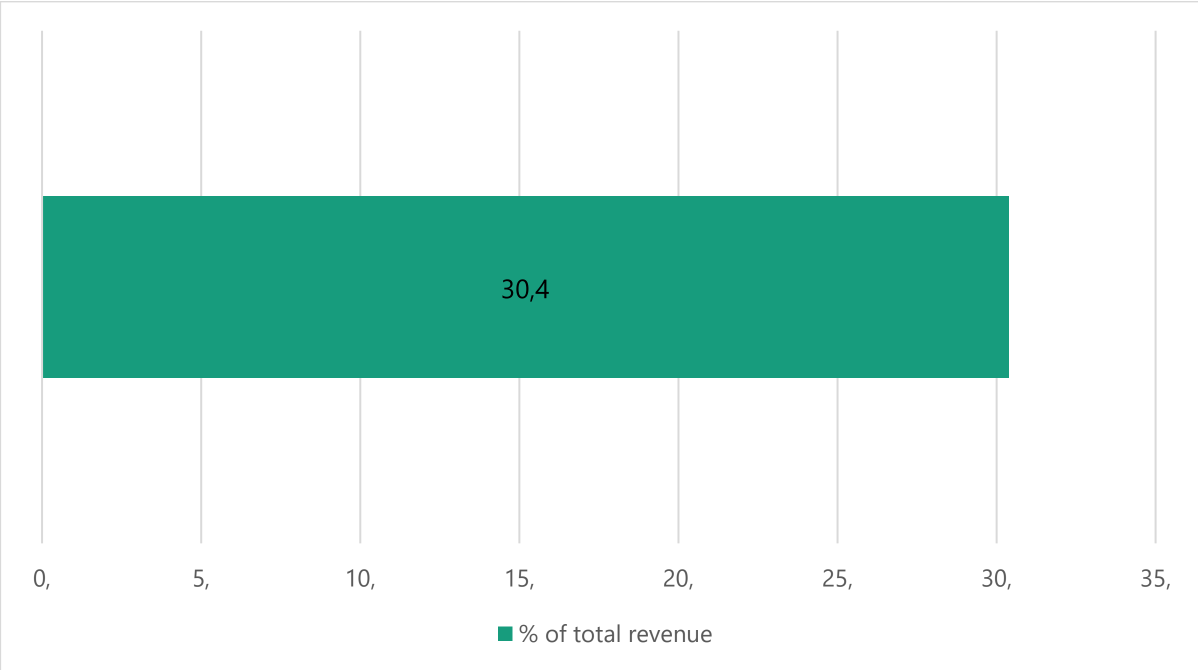
Number of Responses: 12



Services to Support Distribution Infra-structure	Minimum value	Mean	Median	Maximum value
% of total revenue	5	26.3	18	80
Number of answers	**12**			

Services to Support Behind the Meter Customer Energy Management

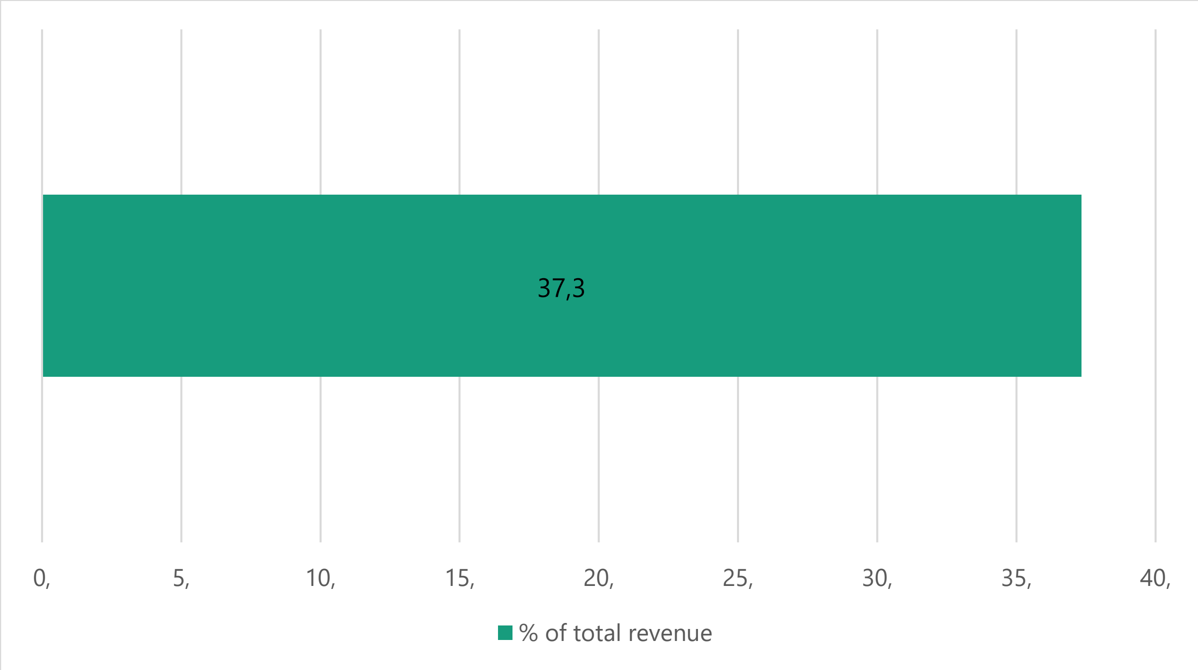
Number of Responses: 13



Services to Support Behind the Meter Cus-tomer Energy Management	Minimum value	Mean	Median	Maximum value
% of total revenue	5	30.4	20	100
Number of answers	**13**			

Ancillary Services

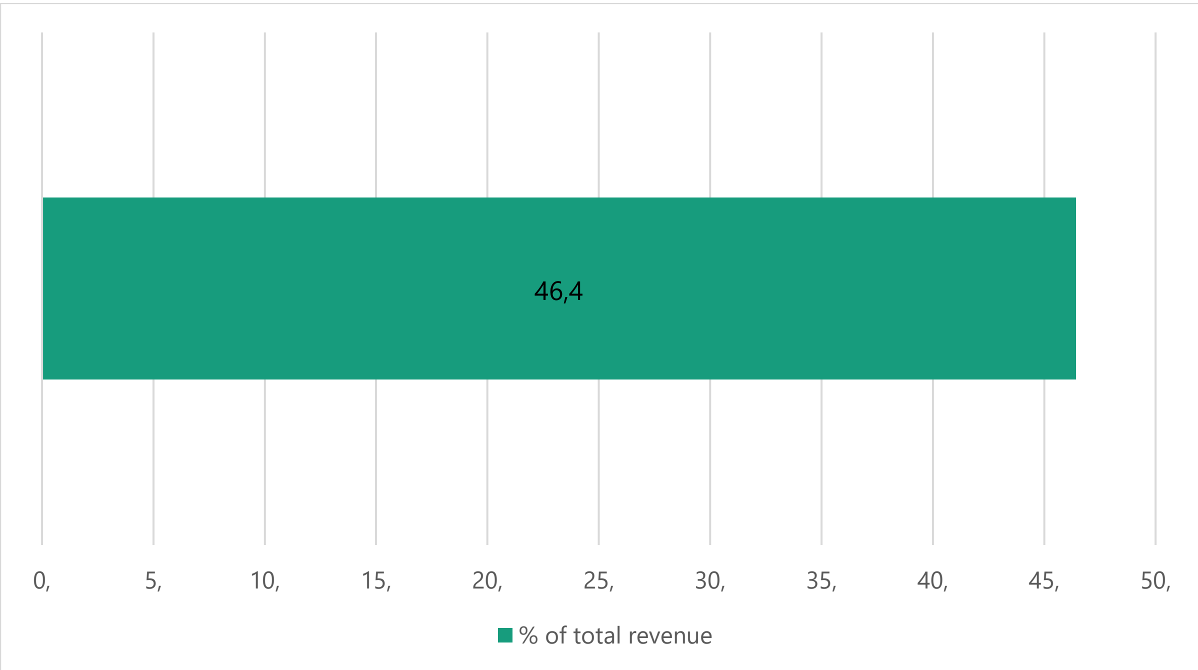
Number of Responses: 21



Ancillary Services	Minimum value	Mean	Median	Maximum value
% of total revenue	5	37.3	40	100
Number of answers	**21**			

Other

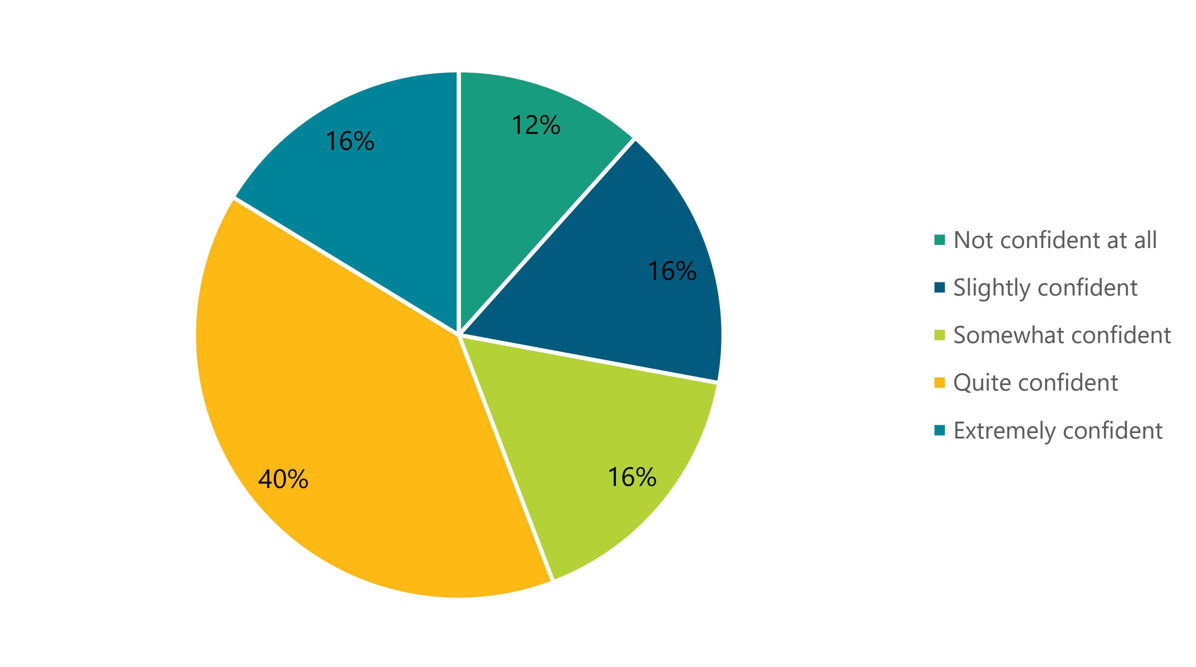
Number of Responses: 7



Other	Minimum value	Mean	Median	Maximum value
% of total revenue	5	46.4	20	100
Number of answers	**7**			

How certain are you that the revenue streams ranked above will result in the technology/service/portfolio being profitable in 2030?

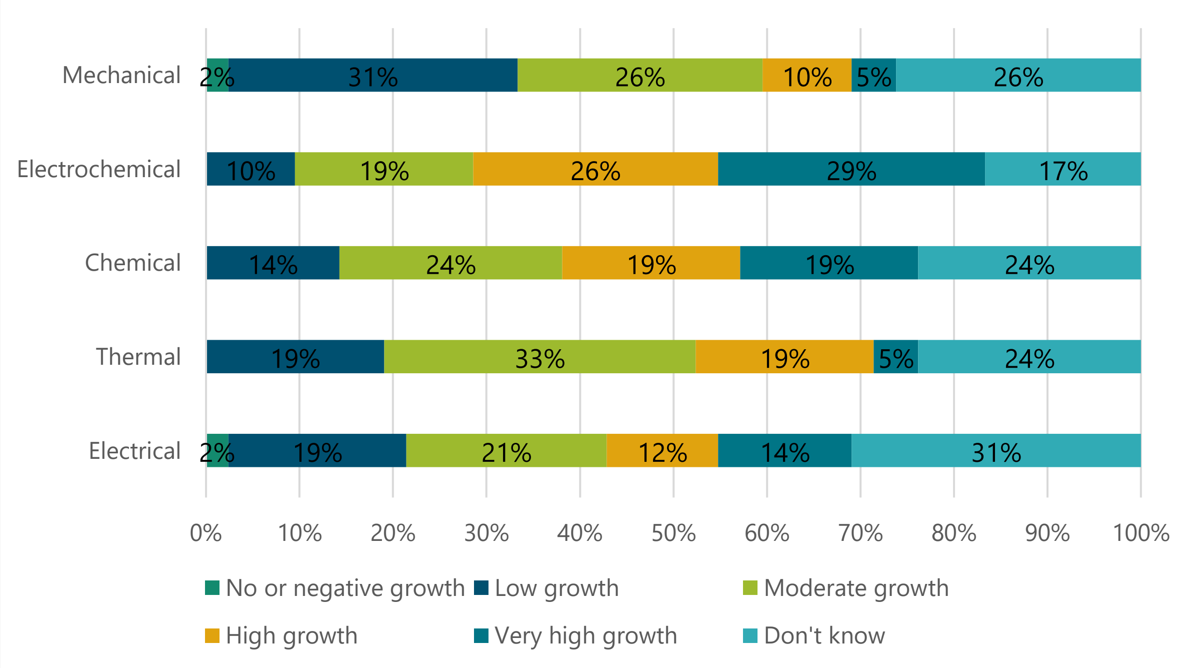
Responses: 43 / Missings: 281



Answer option	Absolute	in %
Not confident at all	5	12%
Slightly confident	7	16%
Somewhat confident	7	16%
Quite confident	17	40%
Extremely confident	7	16%
Mean	3.3	
Number of answers	**43**	
Number of N/A	**0**	
Number of missings	**281**	

What level of market growth do you expect for each group of energy storage technologies by 2030 in the EU?

Responses: 42 / Missings: 282

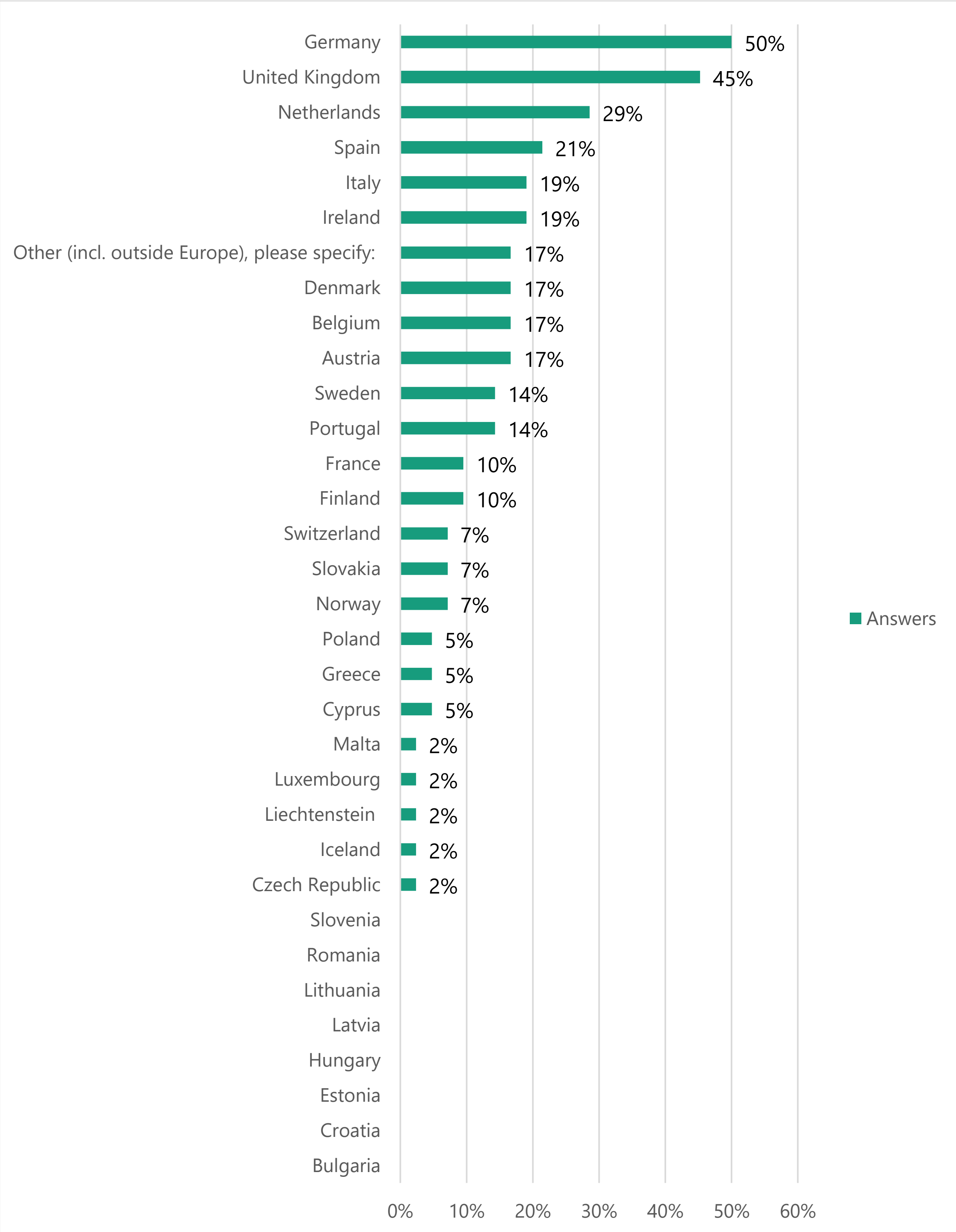


	No or negative growth		Low growth		Moderate growth		High growth		Very high growth		Don't know	
Answer option	Absolute	in %	Absolute	in %	Absolute	in %	Absolute	in %	Absolute	in %	Absolute	in %
Mechanical	1	2%	13	31%	11	26%	4	10%	2	5%	11	26%
Electrochemical	0	0%	4	10%	8	19%	11	26%	12	29%	7	17%
Chemical	0	0%	6	14%	10	24%	8	19%	8	19%	10	24%
Thermal	0	0%	8	19%	14	33%	8	19%	2	5%	10	24%
Electrical	1	2%	8	19%	9	21%	5	12%	6	14%	13	31%

	Mean	Count	Not applicable	Missings
Mechanical	3.6	42	0	282
Electrochemical	4.2	42	0	282
Chemical	4.1	42	0	282
Thermal	3.8	42	0	282
Electrical	4.1	42	0	282

Which country or countries are currently the best locations for investing in energy storage, from the perspective of a private investor?

Responses: 42 / Missings: 282



Answer option	Absolute	in %
Germany	21	50%
United Kingdom	19	45%
Netherlands	12	29%
Spain	9	21%
Italy	8	19%
Ireland	8	19%
Other (incl. outside Europe), please specify:	7	17%
Denmark	7	17%
Belgium	7	17%
Austria	7	17%
Sweden	6	14%
Portugal	6	14%
France	4	10%
Finland	4	10%
Switzerland	3	7%
Slovakia	3	7%
Norway	3	7%
Poland	2	5%
Greece	2	5%
Cyprus	2	5%
Malta	1	2%
Luxembourg	1	2%
Liechtenstein	1	2%
Iceland	1	2%
Czech Republic	1	2%
Slovenia	0	0%
Romania	0	0%
Lithuania	0	0%
Latvia	0	0%
Hungary	0	0%
Estonia	0	0%
Croatia	0	0%
Bulgaria	0	0%
Number of answers	**42**	
Number of N/A	**0**	
Number of missings	**282**	

Other (incl. outside Europe), please specify:

Number of Responses: 7

Values
Every market needs storage solutions
do not know
Non UE countries and non interconnected areas, outermost regions
eu
Anywhere where there is openness for the necessary game-change, unlikely Europe
Ukraine
Ucraine

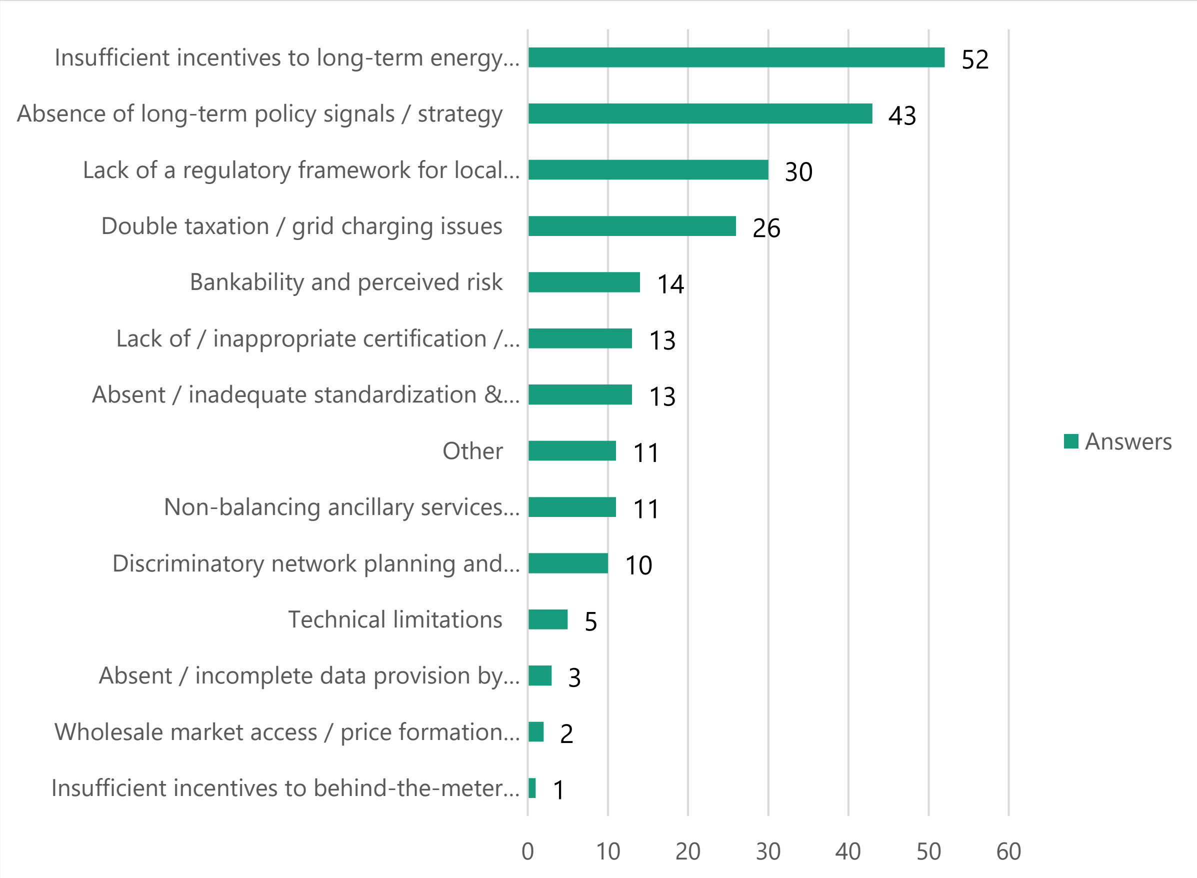
If you would like to, please explain your answer to the previous question.

Responses: 11 / Missings: 313

Values
these countries have highly developed business model for BESS
The need linked to the grid (weak or with high congestion) and the actual localisation of Renewables and Industrial consumption
Largely based on current ancillary services revenues
Clear guidance on the value of energy storage and supportive environment from government and regulators is activating private/investor capital into those market.
Our answer is based on current profitability and a view on the future RES integration needs driving an expectation of future profitability.
Italy and Spain seem to have potential needs for battery storage but the current market framework is not really favourable.
More favourable support mechanisms for PHS outside europe today
By moving away from nuclear energy and coal, Germany must invest in renewable energies.
We have been sabotaged since 12 years and refused from Lighthouse project applications to not evidence our TRL, likely to be detrimental for subsidising renowned big name clients.
Ukraine is considered to be one of the most promising nations for large-scale and high-volume hydrogen production on the mainland of Europe: the land areas, as well as the solar, wind and biogas potential are enormous. In addition, Ukraine also has sufficient water resources. Also of central importance is the fact that Ukraine, as a neighboring country to the EU, has access to inter-border gas infrastructure.
I would perfer countrys with lower bureaucracy and lower lobby of engergy provider compared to Germany - there I expect more innovations (e.g. time based energy price, community energy share etc.).

In your opinion, what are currently the three most important market or regulatory barriers for the deployment of energy storage options in the European Union?

Responses: 41 / Missings: 283



If you used "Other" in the previous question, please specify here.

Responses: 5 / Missings: 319

Values
cost of raw material of BESS still to high to make projects less profitable
connection rules issues and market access rules for batteries are still under construction in Member States.
lack of adequate national support mechanisms for long-lived assets (approximately 75 years life duration for PHS)
commercial
Conflicting interests of powerful industry stakeholders

If you would like to, please explain your ranking of the most important market or regulatory barriers.

Responses: 3 / Missings: 321

Values
Ploicy Signal about the long-term value of storage, such as a European storage target would kick-start storage adoption in many market around Europe.
- PHES have long planning horizon, thus are in need for a stable framework. This is not given in Germany due to biased focus on "new" technologies. Furthermore, storage regulation in Germany does not provide a level playing field, as seen in existing PHES planning and permitting procedures. - There is no proper definition of energy storages in Germany, thus storages have to pay end user levies, from which they may or may not be excluded by specific regulations. There are a lot of cross references in energy law, which makes it hard to follow and insecure for further planning/permitting.
Prioritisation of a maximisation of the most expensive solution for consumers and furthest away from Natural principles - power to Gas based CO2 resurrection previously squandered most lavishly instead of taking Carbon and Water into terrestrially closed loops

In your opinion, which, if any, additional policies or other mechanisms are needed at the national or EU level to support energy storage?

Responses: 23 / Missings: 301

Values
Refering to the NextGenerationEU plan(recovery plan), we think there should also be a sepcific plan or fund to support the grid infrastructure considering the boosting of green transition, so as to tackle the energy crisis which had just got worsen by the Russian-Ukraine war. and within the plan, these measure should be taken to better activate the market of energy storage: 1. countries need to set higher rebate rate for pv-storage/standalone projects to boost deployment of systems. 2. introducing low-interest financing plan for new investers based on EU level policies. 3. allow energy storage to function as independent power plant and participating in all ancillary service, as well as allow revenue stacking. 4. publish mandatory obligation for new buildings or factories to couple with energy storage for better damand side control.
We need a clear target and a common plan how to achieve it.
all possible energy storage technologies are needed to be included in general frame work rather than prioritising based on other agendas.
Policies ensuring greater certainty of revenues into the future
Provision of stronger guidance on storage policy and elimination of barriers. At the moment, many rules, e.g. about double-taxxation of energy storage are not being adopted in member states.
Long term energy storage provides several benefits to more than one party at the same time (Generators, TSO, DSO, Governments), however most of these values are not recognised to a vialble degree in the market. An economic incentive could be a potential way forward, however rewards for provision of inertia, reliability of green energy supply and flexibility would give very good signals and incentives to the energy storage owner or investor.
Rather than the definition of additional policies or mechanisms dedicated to storage, first of all a full enforcement of the CEP provisions are required meaning removing the remaining barriers to all kind of national and EU markets. If necessary, additional policies and mechanisms should be technology neutral and competition based.
NO price regulation - market based price formation and fluctuation would be best for the developmetn of storages
In a world where energy generation will be dependent on fluctuating sources such as solar and wind, greater importance should be attached to climate-neutral energy storage in general, which can be expressed, for example, in start-up funding or other incentives to achieve technology maturity and thus market entry.
reducing financal risks for long-term (> 30 years) investments in pumped hydro
- Energy storage definition and exclusion of end user levy payments - level playing field for all technologies (we need them all to some extent) - pragmatic planning/permitting procedures
In general, apart from capacity auctions for resource adequacy in some EU markets, long term remuneration mechanisms specifically designed for energy storage are missing.
Tokenise recovered Carbon valorised by its re-use (as crude oil substitute) and prohibit linear water consummation for energy purposes
define a clear incentive framework make sure that infrastructure plans include storage aspects
More homogenous and standardised rules within the EU territory.

Values
Chemial Storage Solutions (i.e. Li-Ion Batteries) should be seen as "Neutral" in perspective of beeing "Consumer/Generator". As an extrem it could be seen as a "wire", which has just a few losses - but with the abillity to act decisively as generator or load (w/o consuming!!). We need to over-comer thinking in the old electrical scheme and open to broaden the view and accept losses fo rold incum-bants.
For a sustainable and secure energy supply, it would be important that GOs (Guarantees of origin) are no longer balanced over the year but on an hourly basis. This will give storage facilities a very important role.
1) substantial political, financial and economic EU support is currently needed (especially more funding for R&D of H2 tech-nologies and scale up of TRL as well as for market and infrastructure development), 2) to facilitate the creation of a competi-tive hydrogen market in the EU a European framework for the certification (certificates of origin) and transport of green hy-drogen must be implemented 3) certificates of origin from third countries must be eligible for customers in the EU (e.g. from Ukraine)
Standardisation (including gas quality standards) and more flexible permitting procedures. Financial support of modernisation of existing infrastructure.
Level playing field
energy storage systems supporting the stable energy supply; an asset that need to be considered as an own category for safe energy supply; it is wether a source nor a consumer; it is bidirectionl dynamic assest in the power grid system; supporting con-sumer, supporting the grid, supporting the energy market; we need more profitable business modes to accelerate to become a decentral und decarbonised energy system in the broad range
Improved, streamlined permitting procedures & processes to allow timely assessmwent of permitting applications. Improved GoO rules for clear identification of green electricity & hydrogen product as a % of total production.
Financial guarantees as infrastructure projects, like storage, will need to be developed prior to the maturation of a renewable energy market

Do you have any other comments you would like to share?

Responses: 9 / Missings: 315

Values
no, thanks a lot for your side of effort.
Wholesale Energy and ancillary services markets should be standardised and unified Policies for virtual behind the meter set up for co-located assets where the transmission grid (f.ex offshore export cable) is not owned by the same party. Prioritisation to storage and CO2 free technologies for provision of services Ad-hoc regulation for reliability of supply from green energy sources Regulation that recognize and re-distribute the benefits and cost savings related to storage technologies (Grid expansions deferral) Regulation that recognize and incentivized the provision of inertia from CO2 free/storage technologies
Carbon circular economy can fully refinance itself within the cost spent on waste remedial and saves Carbon replenishing cost of 2.5bbl crude oil per squandered Tonne of CO2
We too often forget about flexibility needs in planning future energy system, le'ts not forget energy storage this time.
We need to act speedly and coherent to realize 100% Rewable Energy (PV, Wind, Hydro) in shortest time possible < 2035 across Europe. Let's assume a single massive failure in any Nuclear Power Station in Europe - what would happen ? Just a following on national nuclear plants plan's ? Or let's assume two consecutive years with extreme low water in major rivers, like: Rhone, Rhein, Donau, etc. With shutdown's of power stations alongside europe wide. Just black painting ? No, just statistic &/or climate crisis. We need to act now ! No further delays allowed.
Uniform regulations and market rules in a market are essential. Currently, there are still different regulations (e.g. PCR) in the countries although there is a common market.
It would be helpfull if there would exist some knowledge sharing among the operators.
no
the future is a european decentral energy grid with energy cells very locally cobined to bigger energy cells overlayed by an intercountry power grid; storage will be the key enabler

--end of survey --

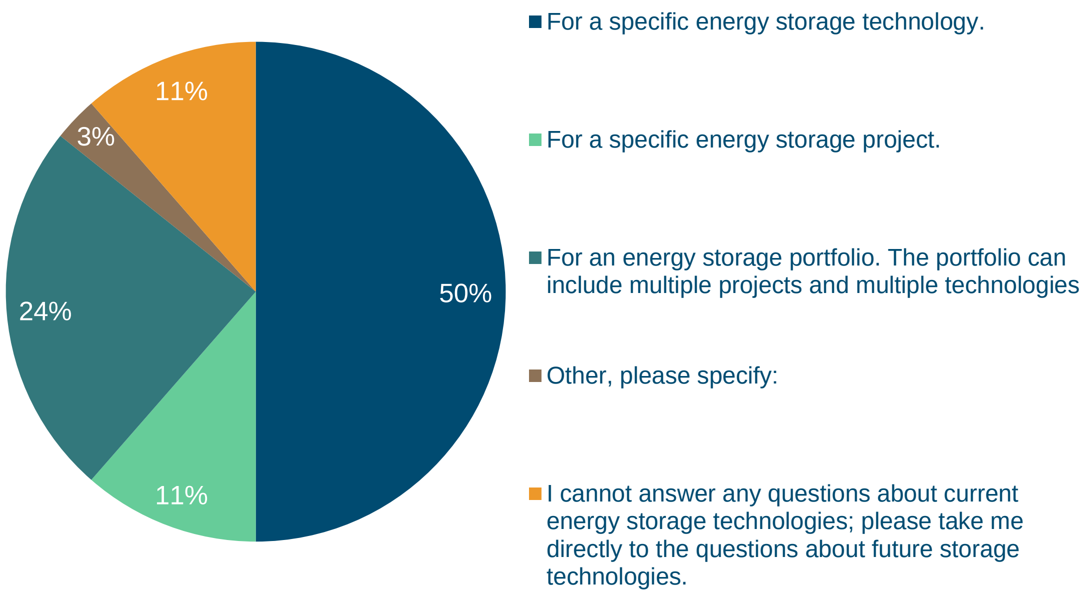
A.3.2 Annex 3.2 Survey Results in Graphics

As part of this study an online survey was conducted on behalf of the EnTEC consortium. The aim of this survey was to provide complementary input on:

- Current and future uses of energy storage;
- Current and future revenue streams for energy storage;
- Barriers, opportunities and drivers for energy storage.

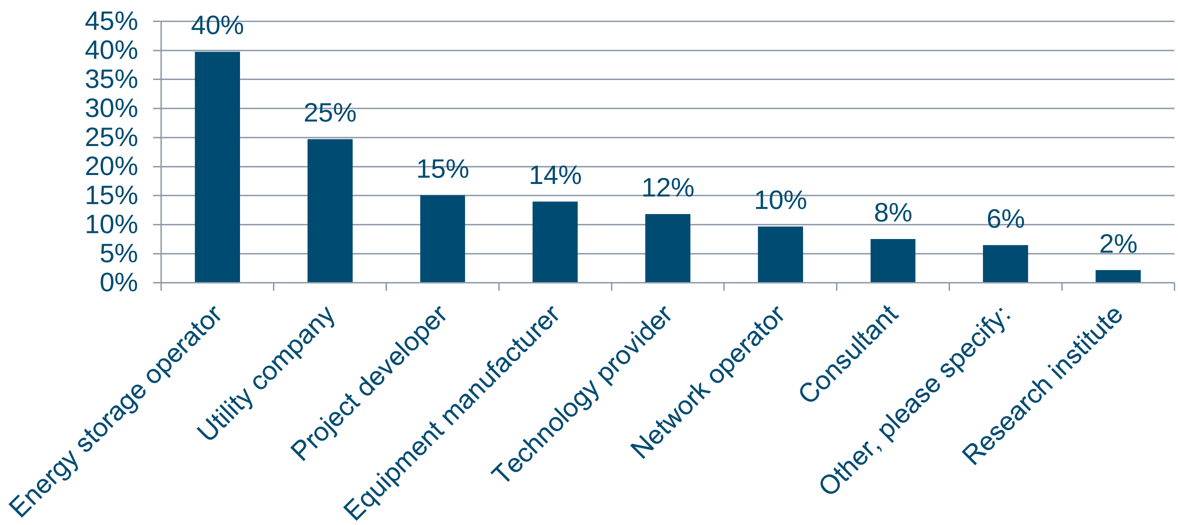
Detailed graphs are presented in this appendix supporting section 3.5. A full list of all questions and results is available as separate deliverable.

Figure 52 **Perspective of the respondent when providing information on the current situation**



Source: ENTEC analysis

Figure 53 **Affiliation of respondents**



Source: ENTEC analysis

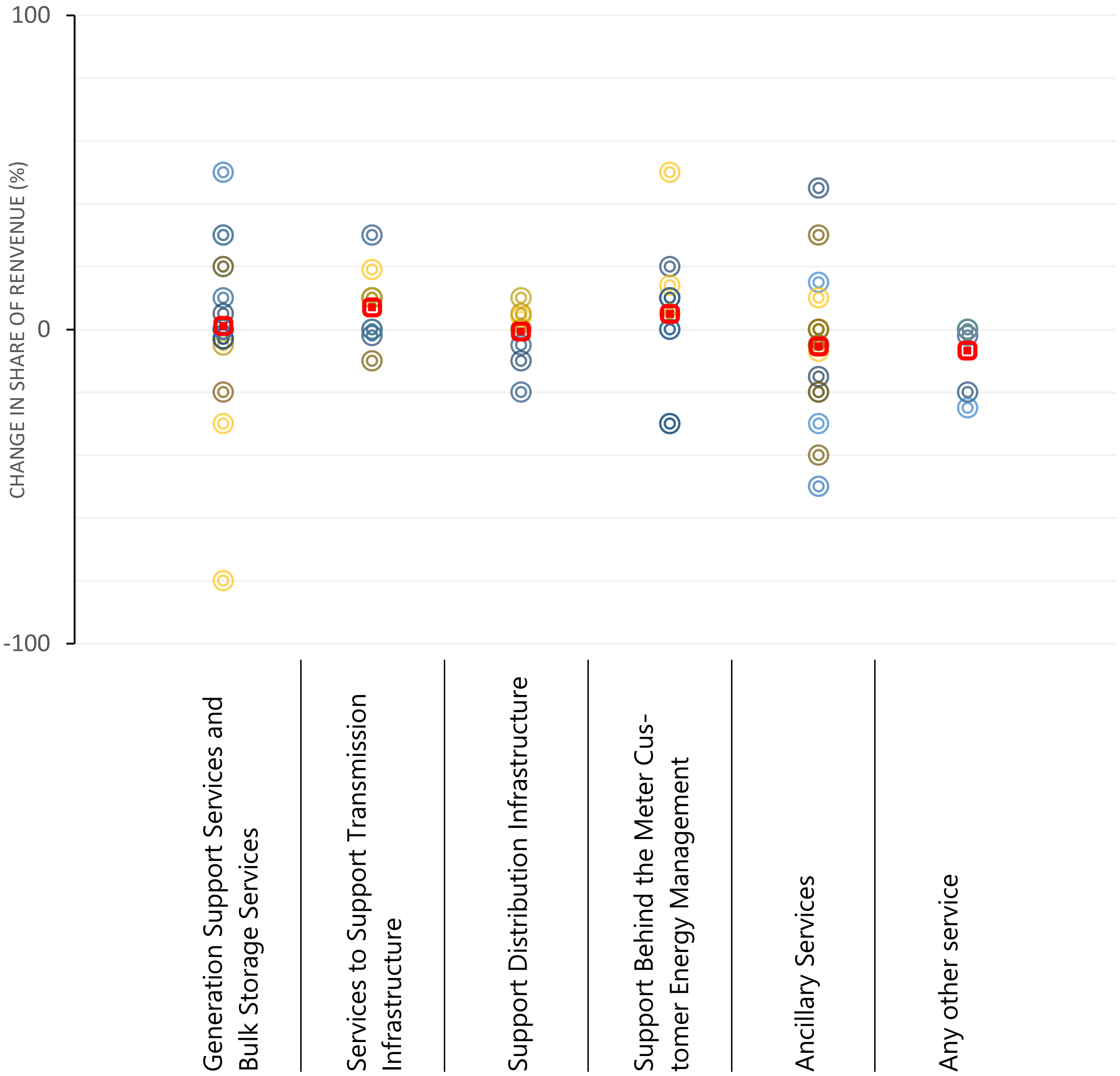
Figure 54 Share of revenue by service group and by technology in 2030

Technology group	Generation Support Services and Bulk Storage Services	Services to Support Transmission Infrastructure	Services to Support Distribution Infrastructure	Services to Support Behind the Meter Customer Energy Management	Ancillary Services	Any other service
Chemical	49%	5%	10%	7%	4%	24%
Mechanical	33%	10%	20%	2%	35%	0%
Electrochemical	41%	6%	6%	8%	39%	0%
Thermal	7%	7%	23%	53%	8%	2%
Mix	32%	3%	4%	11%	35%	15%

Note: this analysis follows the definitions and descriptions of service segmentation provided by EASE[373]
Source: ENTEC analysis

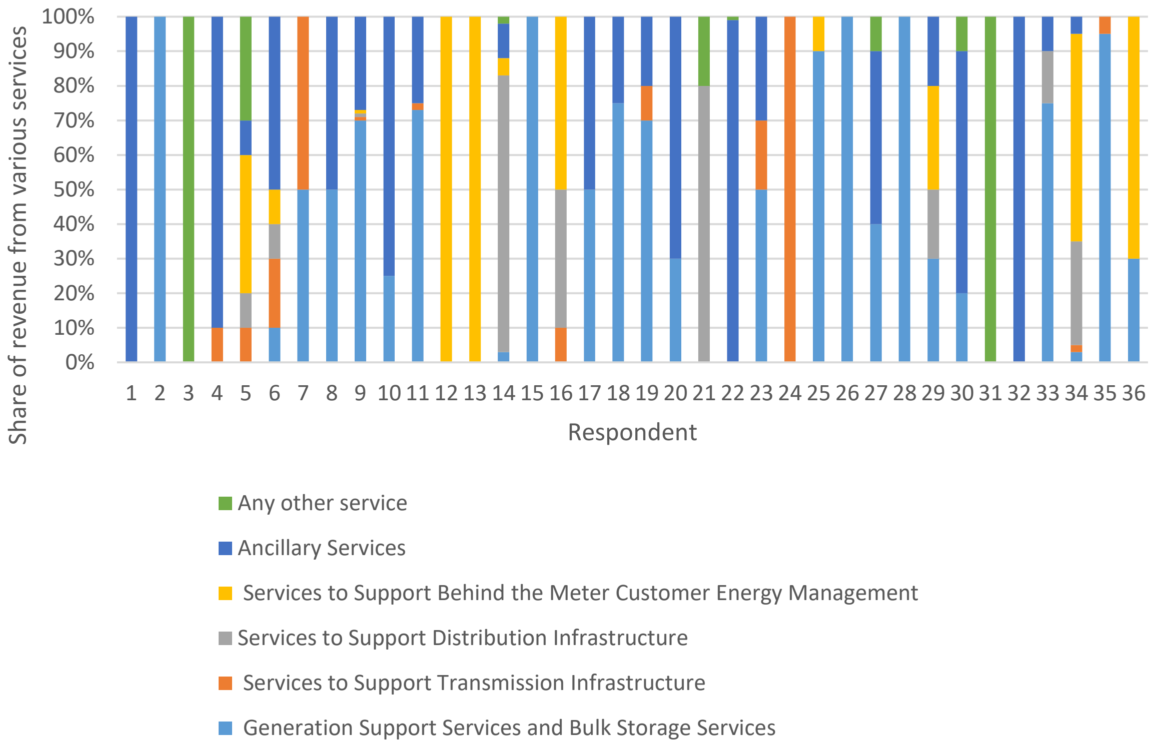
373 https://ease-storage.eu/energy-storage/applications/

Figure 55 Change in the share of revenue by service group between present and 2030



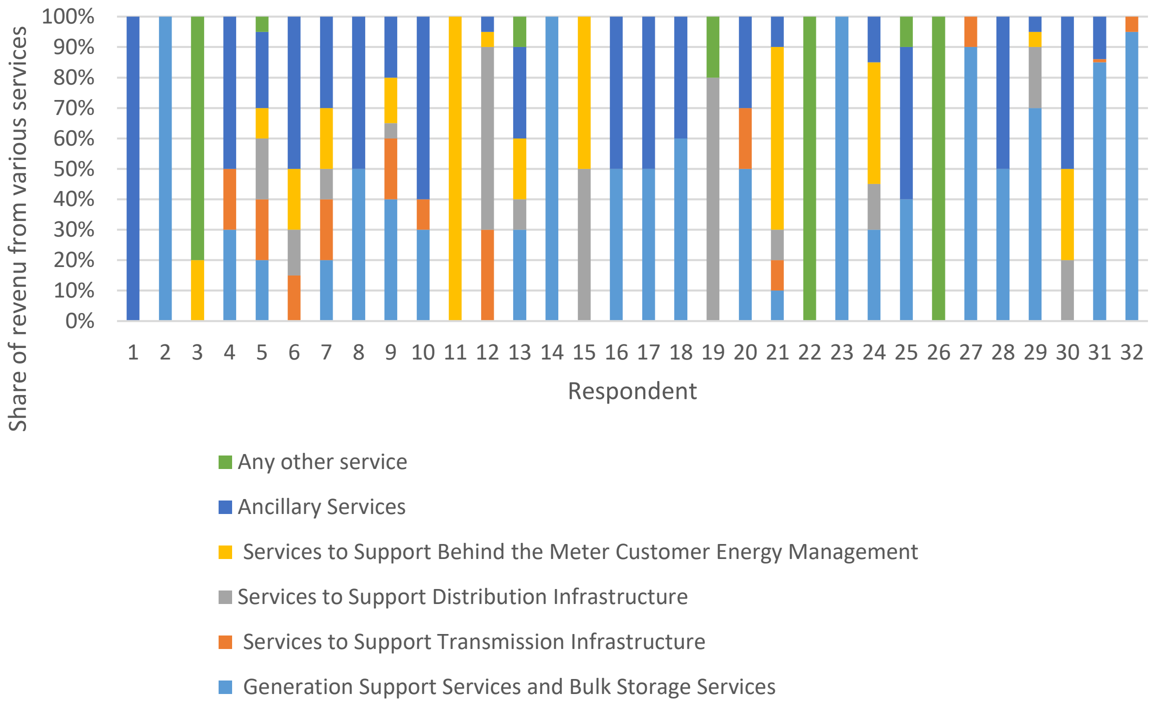
Note: a positive/negative value indicates in growth/decline in revenue expected from providing this service. The red marker indicates average change in revenue for all cases included (n = 26).
Source: ENTEC analysis

Figure 56 Share of revenue from various services in the present



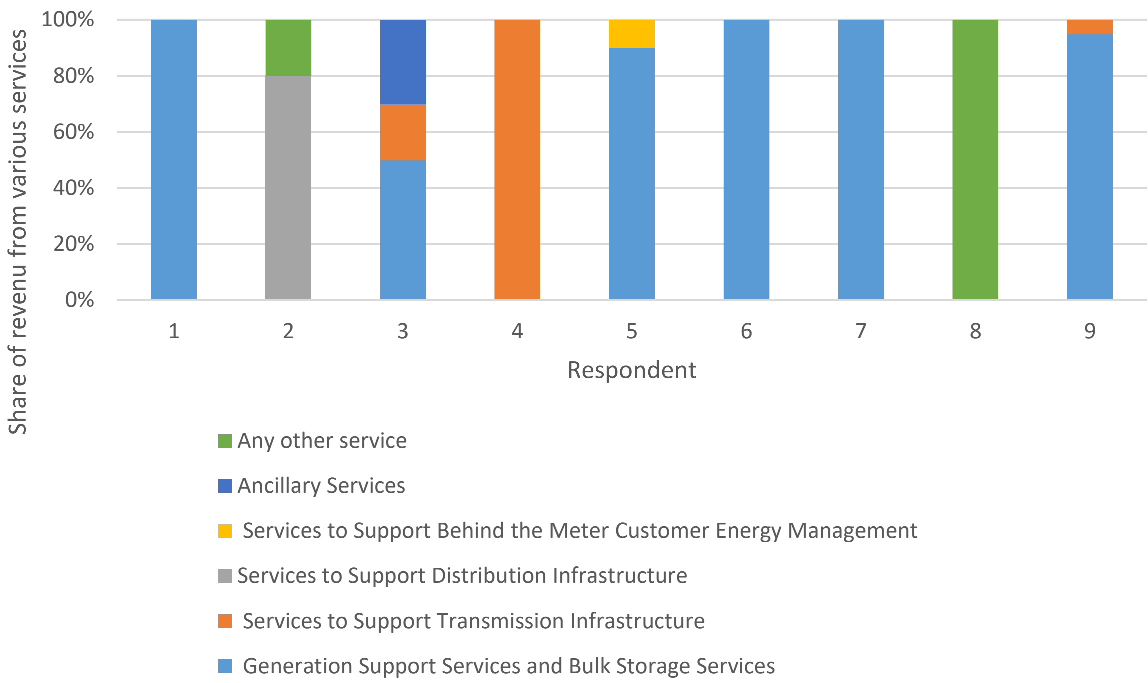
Source: ENTEC analysis

Figure 57 Share of revenue from various services for 2030



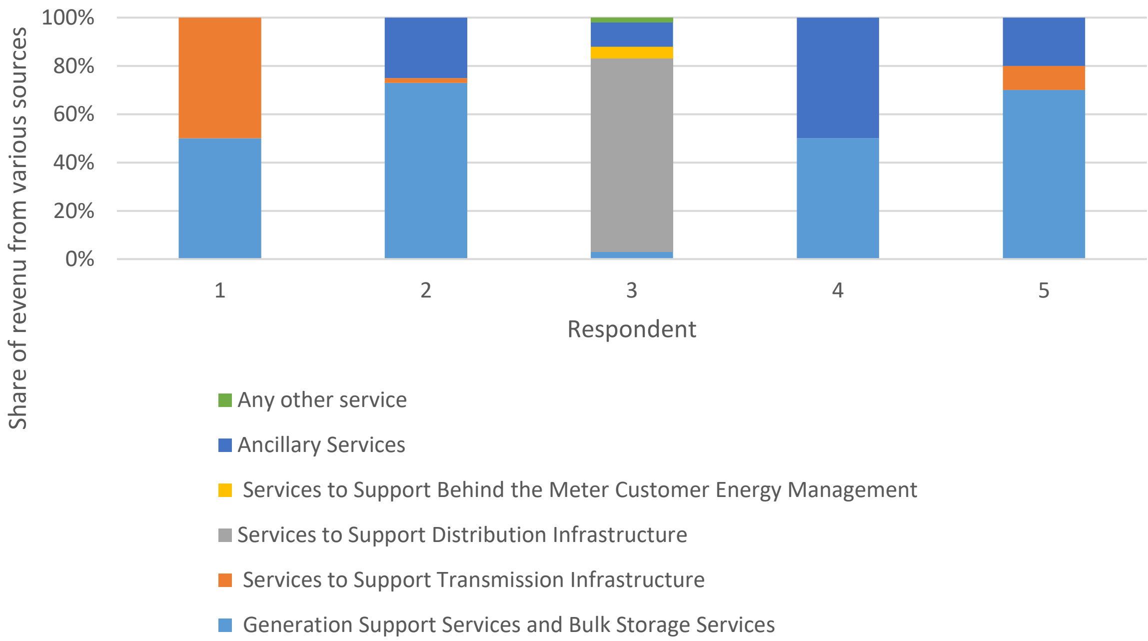
Source: ENTEC analysis

Figure 58 Share of revenue from services using only chemical technologies in the present



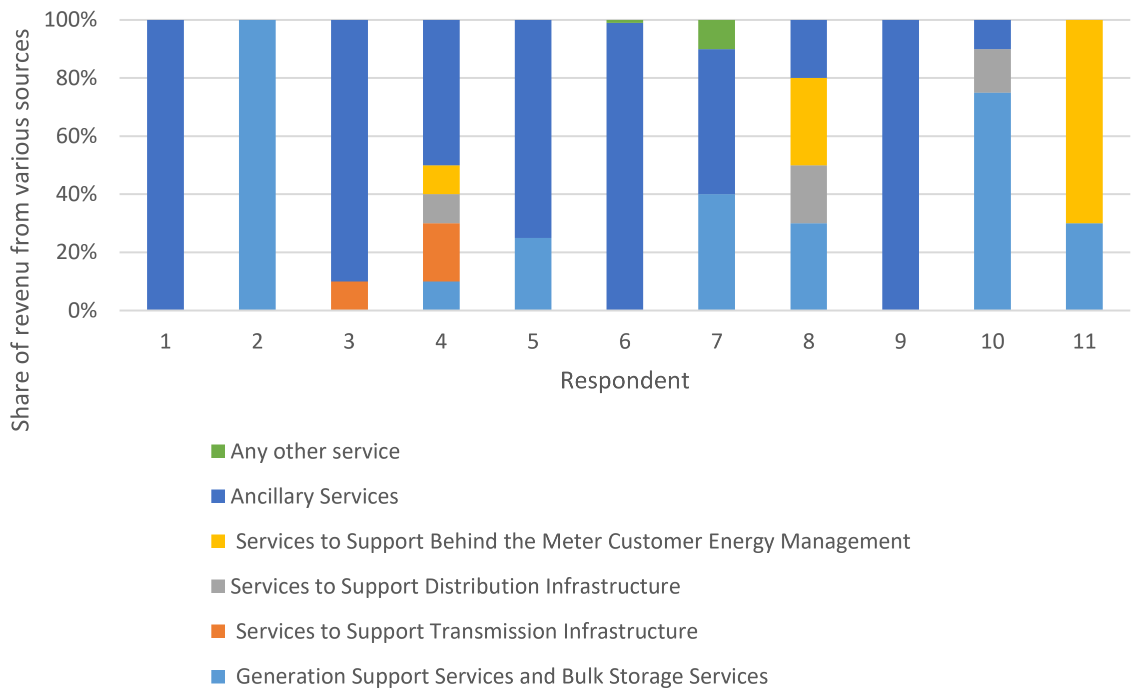
Source: ENTEC analysis

Figure 59 Share of revenue from services using only mechanical technologies in the present



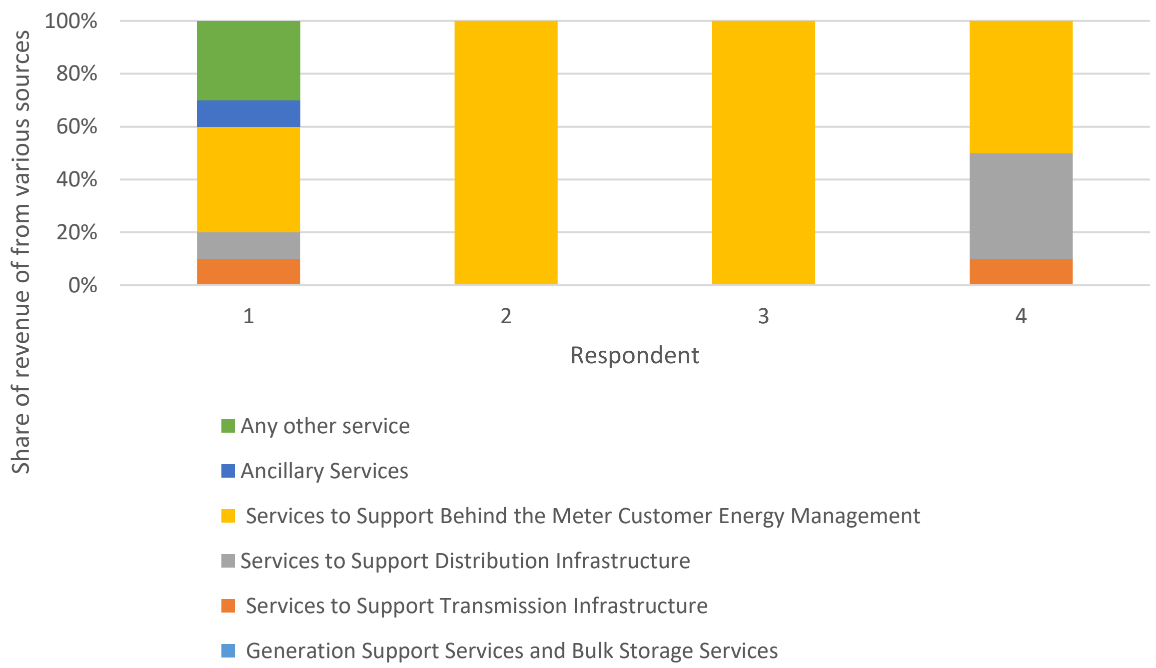
Source: ENTEC analysis

Figure 60 **Share of revenue from services using only electrochemical technologies in the present**



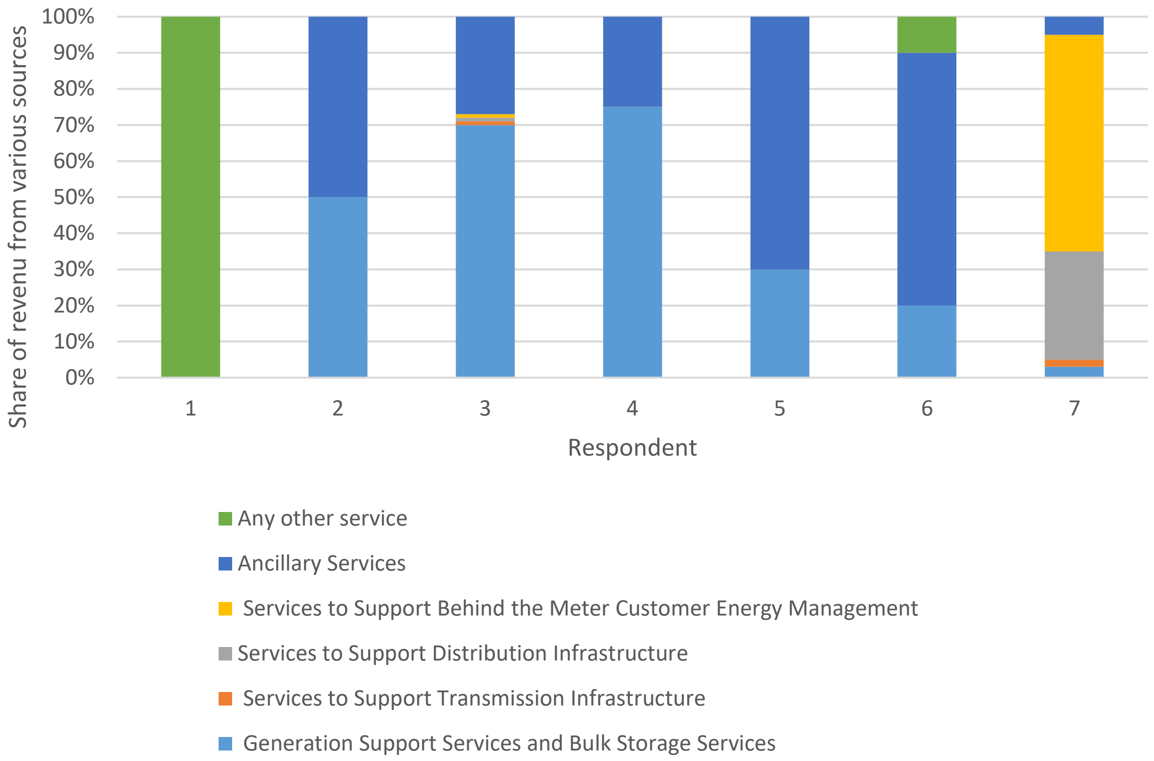
Source: ENTEC analysis

Figure 61 **Share of revenue from services using only thermal technologies in the present**



Source: ENTEC analysis

Figure 62 Share of revenue from services using a mix of technologies in the present



Source: ENTEC analysis

A.4 Annex 4.1 EnTEC Study on energy storage – Updated national fiches

These files presented the updated national fiches first developed in the 2020 'Study on Energy Storage'. The fiches have been updated with the use of transversal sources (i.e. covering the EU27) published since 2020 and then revised by national stakeholders.

Austria

Topic	Austria – Policy description
1. Public Support	The NECP version refers to electricity storage * small-scale photovoltaic and storage system programme * Increase the share of efficient renewable energy sources and district heating/cooling for heating, hot water and cooling, including component activation, active use of hot water storage tanks and buildings as reservoirs for load balancing and load flexibility Investments in storage facilities, including heat storage facilities, rewarding storage facilities for system capacity * Storage (including hydrogen technologies) is currently addressed as a high priority cross-cutting issue with cross-references to the mission-oriented priorities and the broad implementation initiatives * Increase of pumped storage capacity in Kaunertal * The countries of the Pentalateral Energy Forum address the impact of the implementation of flexibility options, including the role of demand response, PTX and hydrogen as well as the role of storage and electro-mobility, and analyse specific electricity-related barriers to sector coupling * In addition to storage and pumped storage, a particular role is played by high-efficiency combined heat and power (CHP) plants, which are necessary to maintain the supply of electricity (for balancing purpose) and heat, particularly in agglomerations. * Activation of components, the active use of hot water storage tanks and the use of buildings as reservoirs for load balancing and load flexibility increase or adapt investments in storage infrastructure (from short-term storage to seasonal storage) and transmission and distribution networks to increased demand * Digital and smart energy: Ensuring system integration of new energy storage and energy supply system flexibility technologies as basic enablers for a high proportion of renewable energy, coupled with security and resilience * particularly in the interests of the system, to establish as far as possible the control and controllability of decentralised small and medium-sized storage units * The long-term storage of electricity by hydrogen is to be made possible and encouraged. * The 100.000 roofs of photovoltaics and small-scale storage are intended to stimulate the increased use of roofs through photovoltaic modules for individuals and economic operators. There will also be implicit guidance to combine photovoltaics and storage by implementing self-supply as a ranking criterion for investment support * In future, buildings should not only have high energy standards, but above all play an active role in the supply of energy and its storage for self-consumption * Photovoltaics and small-scale storage: Prolongation of support for a further three years, taking into account self-consumption; a total of EUR 108 million in investment support (per year PV:EUR 24 million, storage: EUR 12 million) ; production limits for electricity storage is 50 kWh * Significant investments in storage infrastructure and transmission and distribution networks, adapted to increased needs, will be made * Electrochemical energy storage is to be accelerated, as these are large-scale or small-scale storage units as a solution to compensate for the demand-driven production characteristics of renewable energy (for mobile and stationary applications) * As new storage technologies make a vital contribution to the transformation of the energy system, their flexibility in the design of network tariffs will be rewarded. Storage facilities should be exempted from end-use charges and benefit from support for green electricity * The availability of competitive energy storage facilities that can store electricity from renewable energy sources on a larger scale and for longer periods of time will be of great importance. Particular attention will therefore be given to the promotion of such applied research projects with pilot plants demonstrating the market maturity of scalable storage technologies * Key elements of a new electricity market law: Definition of new actors: Storage facilities, PTX facilities, aggregators, ...

Topic	Austria – Policy description
	* Austria already has an important position in storage, which is to be developed and strengthened through research and development * Technology Roadmap[374] – Energy Storage Systems in and from Austria (2018).
2. Permitting	* Lithium battery storage standards are foreseen in the OVE guideline R20. Although the industry is responsible for the production, consumer safety is the responsibility of installers. The current standard ÖVE EN 50272 covers lead-acid batteries and nickel-cadmium storage. * The Electrical Engineering Ordinance sets binding standards for the construction, testing and operation of electrical systems. However, storage is not explicitly treated but is arguably within the ordinance scope. * The transport of batteries is subject to hazardous goods legislation and have to be labelled accordingly (highly flammable), there is no specific legislation for the storage and transport of lithium batteries. * In the area of fire protection, the ÖVE guideline R11 must be supplemented with storage in internal and external environments.
3. Energy Markets and Capacity Mechanisms	DA/ID Markets: * Energy storage is able to participate in DA and ID markets" for all countries * Regulatory framework for active consumers to participate in ID & DA was not in place in 2020 (was possible only via supplier, not open for independent aggregators in 2020) Capacity mechanisms: *NA * In 2018, the EPEX energy exchange introduced loop block orders, where two block orders are executed or rejected together, representing for example the storage cycle. * Heat and electricity systems are integrated in several ways, e.g. in co-generation of electricity and heat, or when DH is produced with electric boilers or heat pumps. Heat is stored more easily than electricity, and thermal storages are used to improve the system balancing of variable power generation. By utilising co-generation, heat pumps and thermal storages, a DH supplier can respond to price signals on the electricity market. In times of high electricity prices, DH production can be adjusted to maximise the power generation and thermal storage used to cover heat demand, and in times of excess power, DH suppliers can utilise more heat pumps. These large water storage tanks in CHP and district heating will increase in the future.
4. Ancillary Services and Congestion Management	Balancing market: * FCR cooperation project active, allowing for provision of FCR capacity by storage. *No other information identified on storage not being eligible to participate in balancing markets * Regulatory framework for active consumers to participate in balancing markets was not in place in 2020 (only via supplier) * Design of some products not compliant to Electricity Target Model including: max delivery period of 4 hours (mFRR:), minimum bid size energy/capacity (aFRR), validity period energy bids (aFRR, mFRR), settlement rules (aFRR, mFRR) *min/max price limits are compliant with Electricity Target Model * Balancing single pricing, single position is compliant with Electricity Target Model * Storage not allowed in 2020 to provide transmission-level voltage control services New ancillary services: NA Mechanisms to value distributed flexibility sources NA * Pumped hydro participates in the provision of aFRR/mFRR services; * Batteries are under the same requirements (such as prequalification) as other units eligible to provide services * In distribution networks, storage will provide additional services such as voltage control, reactive power or used as a phase shifter
5. Grid Aspects	* Double charging in 2020 for pumped hydro storage * injection & withdrawal charges for distribution grid for storage. PHES units receive a discount on the withdrawal charge, called "system utilisation charge" (§ 4 Z 8 SNE-VO 2012 as amended)

[374] https://www.klimafonds.gv.at/wp-content/uploads/sites/6/Technologieroadmap_Energiespeichersysteme2018.pdf

Topic	Austria – Policy description
	* The qualification of storage facilities as consumer and producer makes the storage operator a network user, who is obligated to pay system usage fees twice (according to SNE-VO 2012 as amended in accordance with § 51 ff ElWOG 2010) * Being considered generators, storage has the following obligations: join a balance group; comply with generator technical specifications of the network operators including maximum balance deviation, fault tolerance, frequency and voltage control (reactive power capability); pay fees for the provision of primary balancing power in proportion to their annual production quantities, provided that the generating plant has a capacity of over 5 MW; have a metering point; follow data exchange obligations above a certain size * No new grid usage fee or network loss fee is payable for new installations of pumped-storage power plants and plants for the conversion of electricity into hydrogen or synthetic natural gas, and for the purchase of electrical energy until the end of 2020 (IWOG 2010). * Providers of the reserve services (including storage) are exempted from paying grid usage fee * (battery) storages can be operated as integrated grid assets for non-frequency ancillary services * (battery) storage can be used at integrated grid nodes (Quartierspeicher) and at Energy Communities * Market-sourced (battery) storages services can/will be used for congestion management to avoid curtailment of local renewable generation. Alternatively, they must undergo the procedures laid out in Art. 36/54 of the IEM-Directive * no information available that state that NDP is aligned with NECP * PHS & other storage facilities (e.g. batteries) are not allowed in network planning process; * Published stakeholders' comments in public consultations * Distribution level: no DSO who prepares NDP
6. Taxes & Levies	* No information identified on absence of double taxation for energy storage, thus assume it exists * Storage operators also pay renewable electricity sources support surcharges, which are paid by the end-users connected to the network. * Storage operators, with the exception of pumped hydro, pay the surcharges for the promotion of CHP systems, which are paid by all end-users connected to the network, according to the CHP Act.
7. Other & General	* There is no general definition of the term 'storage' in the electricity and heat sectors, the definition of the Clean Energy Package has not been transposed * All electricity traders and other suppliers who supply end customers in Austria are legally obligated to inform the end customers of the primary energy sources of the power generation (with proof of origin). A special provision is made in the Electricity Labelling Ordinance for those quantities of electricity that are delivered by pumped storage power plants (adjusted with an efficiency of 75%)
8. Barriers	* There is no common definition of energy storage in the regulatory framework * Development of regional hydraulic-thermal models for overall concepts of groundwater management in areas with high degree of utilisation of geothermal fields or groundwater wells as heat storage * (battery) storages acknowledged as grid integrated assets for (non-frequency ancillary services) system operation
9. Best practices	* A special provision is made in the Electricity Labelling Ordinance for those quantities of electricity that are delivered by pumped storage power plants (adjusted with an efficiency of 75%), so the impact of storage is considered in the guarantees of origin value chain. * Electricity consumption tax for PV has been abolished, according to the recently adopted government programme the electricity consumption tax shall be removed for all RES (previously suppliers and consumers had to pay the electricity consumption tax, except for self-produced renewable electricity up to a limit of 25 MWh/y, following § 2 of the Electricity Supply Act (Elektrizitätsabgabegesetz))

Belgium

Topic	Belgium - Policy description
1. Public Support	The NECP refers to electricity storage * Storage will be one of the solutions in addressing need for flexibility in internal energy market * Greater emphasis will be placed on flexibility (including storage and demand management) and interconnections to ensure security of supply * Different levels of government will ensure the continuous development of new centralised and decentralised storage systems * The regions are working on a clear regulatory framework, intended to place storage behind-the-meter or at the neighbourhood level * Objective to create energy storage potential as means to integrate intermittent, decentralised renewable energy into the grid * Residential, SME, local, electric vehicle storage methods expected to increase further by 2030 * Legal frameworks revised to different regional contexts to allow prosumers to choose whether generated energy should be fed back into the grid at peak times, or a battery storage system should be used * Clear regulatory framework needed to govern installation of individual home or neighbourhood batteries * 2018 National Investment Pact with private sector to foster public-private partnerships within six strategic sectors, including 'the development of storage facilities for heat and electricity' * Particular area of focus for research in Wallonia (i.e., energy storage technologies): expertise developed in batteries, phase-change materials, compressed air storage, accumulators, hybrid batteries, storage management tools *In Flanders region, a premium for home batteries was introduced in 2019. This premium is available until the end of 2024.
2. Permitting	*According to the law (24 February 2022), not only electricity production facilities but also energy storage facilities are subject to the granting of an individual authorisation (according to the law of 29 April 1999 [electricity law], art. 4). For CRM auctions in 2022 and as far as necessary according to the law, an authorisation request must be submitted to the federal authority within the 15 days following the publication of the start of an auction process at the latest. However, energy storage facilities are considered to be authorised as existing facilities and therefore do not require to request and be granted an authorisation if they have been selected through the 2021 auction and their operators have entered into a capacity contract within the time limits as defined by the CRM functioning rules, or the main contracts regarding investment costs, financing cost, operating costs and the proceeds from electricity sales, which are necessary for achieving the project, have been concluded prior to 26 February 2022 (date of entry into force of abovementioned art. 4 of the electricity law).
3. Energy Markets and Capacity Mechanisms	DA/ID markets: * Energy storage is able to participate in DA and ID markets Capacity mechanism: *delivery period is annual * CRM allows participation via a pool of assets; value stacking in time is possible; Provision of capacity via CRM is expected to be stackable with other services; aims to enable real time control of flexibility transactions to facilitate dynamic pooling * Storage facilities in Belgium can participate in the electricity spot and balancing markets, either directly (with a minimum bid volume increment of only 0.1 MW), or via aggregators. * In 2018, the EPEX energy exchange introduced loop block orders, where two block orders are executed or rejected together, representing for example the storage cycle. * A new CRM will be implemented in 2020 (law of 22 April 2019); energy storage will be eligible for participation, either directly (if concerned capacity > threshold) or indirectly (via aggregation). The introduction of a CRM could be positive for the development of storage. However, there are no incentives for low-carbon emissions flexible units * Despite the fact that the concept of storage has been recently defined in the electricity law, the grid cost exemption mechanism that is foreseen in the transmission tariffs (and the CREG tariff methodology) remains difficult to implement and is more constraining than in neighbouring countries. * Storage applications like heat storage (e.g. water as a heat storage medium, powered by cogeneration or electrically powered), borehole thermal energy storage (BTES), storage heater (accumulator) are already implemented in Belgium

Topic	Belgium - Policy description
4. Ancillary Services	Balancing market: * FCR cooperation project active, allowing for provision of FCR capacity by storage. * Pumped hydro as well as batteries are also eligible to provide aFRR/mFRR services. * No other information identified on storage not being eligible to participate in balancing markets *max/min price limits not compliant Electricity Target Model but will be adapted when Belgium joins the PICASSO and MARI platforms * Single pricing, single position compliant with Electricity Target Model * In 2021, a regulatory framework was created in Flanders that allows a DSO and operator of the local transport grid to purchase flexibility services for congestion management and non-frequency ancillary services for network operation. Via this framework, a DSO and operator of the local transport grid can make a trade-off between, on the one hand, grid investments and, on the other hand, the use of flexibility as a (temporary) alternative to a grid investment. Batteries are allowed to participate in this system. * Pumped hydro as well as batteries are eligible to provide voltage control services. * Pumped hydro as well as batteries are eligible to provide black start services subject to their technical ability to provide the service. * Pumped hydro has historically had an important role in the procurement of ancillary services.
5. Grid Aspects	* Double charging is applicable for end users with an energy storage installation or energy storage installation that is (directly) connected to the low-voltage and medium-voltage distribution grid that have separate distribution tariffs for off-take and injection. This has already been addressed for the Brussels region and should be solved partly for the others with the transposition of Directive (EU) 2019/944 article 15(5) * Exemption mechanism available. Art. 4. of the Electricity Law of 2017: For storage facilities connected to transmission or networks with a transmission function, the tariff methodology contains incentives that encourage the storage of electricity in a non-discriminatory and proportional manner. A separate tariff regime for the storage of electricity may be determined by the CREG (Federal Regulator). The first special transmission tariff has been implemented for storage plants commissioned 1) After 1 July 2018: exemption from network tariffs during first 10 years or 2) before 1 July 2018: can benefit from 80% reduction in transmission tariffs for 5 years if they increase both the energy stored volume and capacity by at least 7.5%. * National/regional connection requirements and tariffs contain no specific connection tariffs for storage assets. For production and storage facilities with an injection capacity above 1 MW, specific technical connection requirements apply * For small scale storage connected to DSO grids, no specific grid tariff measures exist * Compensation of avoided transmission network losses is under consideration * In Flanders, the network tariff structure will change in 2022 and will be both based on kWh-use and kVA (peak-use). Peak shaving can provide additional incentives for storage. However, the decreased kWh price could worsen the home-battery business case. * No information available that state that NDP is aligned with NECP * PHS & other storage facilities (e.g. batteries) are not allowed to be included in network development plan * From the public consultations the stakeholders' comments and responses are published. * Each DSO prepares an NDP, data exchanges between TSO/DSO regarding scenario's and/or assumptions
6. Taxes & Levies	* Since 2022, electricity consumption by storage is exempt from federal taxes. * Double taxation for energy storage installation connected to the distribution grid where the energy storage is used as an intermediate is the general rule for all storage * Investors in energy storage assets are eligible for a federal tax discount; for physical persons the deduction on the taxable income amounts to 20% of the eligible investment amount, versus 13.5% for companies. * All consumers are obliged to submit regional green certificates (directly linked to the volume consumed). In Wallonia, all storage is exempted with the order of 11/04/2019 (art 10.6°). It was previously the case only for pumped hydro located in Wallonia * No further exemptions exist for electricity storage with regard to taxes, surcharges and other obligations imposed on off-take and injections * An exemption from the quota obligation for green power and cogeneration certificates is introduced for the electricity taken from the grid and re-injected. These measures are taken to encourage stand-alone grid-connected energy storage facilities.

Topic	Belgium - Policy description
7. Other & General	* 'Electricity storage' : any process whereby, through the same installation, electricity is withdrawn from the grid for the purpose to be completely re-injected into the system later on, subject to efficiency losses. (Electricity Law of 13th of July 2017, modifying the 29th of April 1999 Electricity Law) * "electricity storage": a form of energy storage which consists in postponing the final use of electricity until a moment later than the moment when the electricity is generated, or converting electrical energy into a form of energy that can be stored, such energy on to store and then convert such energy into electrical energy or into another energy carrier (Flemish energy decree) * The Brussels Capital Region Electricity Ordinance (the Electricity Ordinance as amended by the Ordinance of March 17, 2022) uses the same definition as in the European directive and provides that: Art 13bis, § 1: Any active client may engage in one or more of the activities listed below: (...) 2° store self-generated electricity on its premises, by means of a storage unit; (...) Art. 13bis, § 2: Any active customer with a storage unit 1° is connected to the grid within a reasonable period of time in accordance with the conditions laid down in the technical regulations 2° is allowed to provide several services simultaneously insofar as this is technically possible. A ban on the DSO owning, developing, managing or operating storage units, except by derogation granted by the Government, after approval by Brugel, for fully integrated components of the grid (articles 5bis, § 3 and 8, § 7 of the electricity ordinance as amended by the ordinance of 17 March 2022). The DSO must systematically install a smart meter when a DSU stores electricity (article 26octies, § 2, paragraph 1, 8° of the electricity ordinance as amended by the ordinance of 17 March 2022). Energy communities (3 types) can - among other things - store electricity (articles 28ter, § 1, 28quinquies, § 1 and 28septies, § 1 of the Electricity Ordinance as amended by the Ordinance of 17 March 2022).
8. Barriers	* The profitability of Belgian pumped hydro was impacted by transmission tariffs (before the recent law providing investment incentives)
9. Best practices	* 2018 National Investment Pact with private sector to foster public-private partnerships within six strategic sectors, including 'the development of storage facilities for heat and electricity' * Notification OR permitting requirement depends on storage capacity * CRM design allows the participation of storage directly or through aggregation * Regulatory framework explicitly allows the regulator to provide specific tariffs to storage * Storage is exempted from some electricity taxes * Storage is exempted from the obligation to submit green certificates

Bulgaria

Topic	Bulgaria - Policy description
1. Public Support	The NECP refers to electricity storage: * "Increase the electricity and natural gas storage capacity by developing the existing storage facilities and by building new storage facilities. Measures supporting the development of energy infrastructure, the integration of electricity from renewable sources in the electricity grid and the wider uptake of smart energy storage systems will be introduced in the period 2021—2030." The National Recovery and Resilience Plan envisage more ambitious penetration of electricity storage facilities. According to the NRRP 1,4 GW renewables are planned to be support along with requirement for storage facility (investment 6). The storage facility should have a capacity of at least 4 hours and a capacity of at least 30% of the total installed capacity of the RES facility. The total planned resource is EUR 1026 million (EUR 342 million from the Mechanism for Reconstruction and Sustainability and EUR 684 mln million private financing with an implementation period of 2022-2026. The second initiative regarding storage facilities under NRRP (investment 8) is the RESTORE project. It includes purchase, installation and commissioning of national infrastructure of electricity storage facilities with a total charge capacity of 6000 MWh. The facilities (consisting of batteries, inverters, transformers, power electronics / intelligent electronic devices and control automation) will be strategically distributed evenly on the territory of the Republic of Bulgaria. The total planned resource is EUR 799mln which will be provided by the Mechanism for Recovery and Sustainability with an implementation period of 2022-2026."
2. Permitting	* Licensed activities (generation license) are explicitly listed in the Energy Act. Those are for example production, trading, distribution, but storage is not addressed. The production license is required for a capacity above 5 MW, and as legislation does not distinguish between technology types, any production above 5 MW must have a license, including e.g. pumped hydro. * Licensing reported by stakeholders as a costly and time-consuming process
3. Energy Markets and Capacity Mechanisms	DA/ID markets: *Energy storage is able to participate in DA and ID markets Capacity mechanisms: NA * There are various small projects where consumers utilise battery storage technology for domestic purposes, such as reducing the demand charges of large energy users * There are currently three operational pumped hydro storage projects in the Republic of Bulgaria. Their combined capacity is around 1.4 GW, operated by the National Electricity Company EAD
4. Ancillary Services	Balancing market: *No information identified on storage not being eligible to participate in balancing markets *Design of some products not compliant with Electricity Target Model because of minimum bid size energy/capacity (aFRR & mFRR), validity period, length of balancing capacity contracts, activation rule * Storage not allowed in 2020 to provide transmission-level voltage control services * According to the electricity market rules, pumped hydro shall be considered as dispatchable load when in a pump regime
5. Grid Aspects	* No double charging in 2020 for transmission-connected storage * no withdrawal charges for distribution grid for storage, only prosumers are charged for withdrawal charges * There are no specific rules for connection or access charges for storage facilities * Consumer network charges are based on energy consumption and capacity to all consumers (households only pay network charges based on consumption) . The RES pay grid taxes on injected energy, as well. * All producers network charges are based on energy injected (kWh). * The forecast of the 10-year NDP elaborated by ESO for the development of the generation capacities of Bulgaria until 2030 is based on the investment intentions expressed by the generation companies. Regardless of the investment intentions of the companies, they have been aligned with the set installed capacities in the NECP. *No information is available about the expected decomissioning of renewable capacities * PHS & other energy storage facilities (e.g. batteries) allowed & included in network development plan * From the public consultations summary of stakeholders' comments is published * No alignment between TSO/DSOs NDPs.

Topic	Bulgaria - Policy description
6. Taxes & Levies	* No specific rule identified on exemption, meaning storage charging is subject to the electricity consumption tax
7. Other & General	* Energy storage is regulated under the Energy Act (of 9 December 2003). But while gas storage is specifically regulated by the Energy Act, the electricity storage is not addressed in the legislative framework. Definition of electricity storage and some aspects of electricity storage are stipulated in the provisions of Trade Rules * NRRP envisages the legislative/regulatory amendments that have to be undertaken in order to remove the barriers and introduce specific regulatory and support framework for the construction, connection and operation of electricity storage facilities Due to a heavy technology accident in the beginning of the year the largest pump-storage hydro power plant in the country, also in South East Europe (HPP Chaira installed power in generator mode, MW: 864 and installed power in pump mode, MW: 772), is expected to be out of operation for an year or even more
8. Barriers	* There is a large variation between summer and winter as well as daily electricity loads. Heating is primarily based on electricity, and direct use of wood biomass with low penetration of gas for households. Services of district heating is available in large Bulgarian cities (15 cities). * Multiple regulations need to be adapted, like the Energy Act, market rules, permitting. It is of importance also to introduce clear rules for service procurement, the rules for cost recognition and cost coverage of the grid operators in case such services are procured.
9. Best practices	* The PCI Bulgaria-Yadenitsa hydro-pumped storage project is considered key to balance the system

Croatia

Topic	Croatia - Policy description
1. Public Support	The NECP version refers to electricity storage * Contains specific policies and measures section ES-2: Construction and use of energy storage facilities "In order to increase the energy storage capacity of the system and increase the regulatory capacity of the electricity system, it is planned to build additional reversible power plants with a capacity of 150 MW before 2030, then the development of heat storage tanks for end customers, the development of battery tanks, the introduction of charging stations for electric vehicles that allow energy storage, the development of underground energy storage in the form of compressed gas, and the use of other innovative energy storage technologies (EU- funded)" * Among the national energy security objectives are, comes the increase of storage capacity of gas and energy in the electricity system * Energy storage in the EES will allow for the construction of pumping plants, thus also providing more flexibility for the system and greater integration of variable renewable energy sources, mainly solar and wind. * Croatia will increase (by 2030 and 2050) investment in research, development and innovation in low carbon technologies, among which advanced energy storage systems * Existing legal solutions need to be complemented by the development of a regulatory framework for active customers, aggregators, energy communities, renewable energy communities (participation in local energy production, distribution, storage, supply and provision of energy and aggregation services) and own-account production of energy, in accordance with the provisions of the Directive on the promotion of the use of energy from renewable energy sources, the electricity directive and the regulation on the internal market for electricity * In order to increase the energy storage capacity of the system and the increased control power of the electricity system, the development of battery tanks, the introduction of recharging points for electric vehicles and the use of other innovative energy storage technologies (financed by EU funds) are planned.
2. Permitting	* Behind-the-meter installations of battery storage are allowed (for self-production or hybrid storage and renewable energy projects).
3. Energy Markets and Capacity Mechanisms	DA/ID markets: * Energy storage is able to participate in DA and ID markets * Regulatory framework for active consumers to participate in ID & DA was not in place in 2020 Capacity mechanisms: NAP * Market barriers include a minimum bid capacity of 1 MW in wholesale markets, availability requirements, and limiting the price spread.
4. Ancillary Services	Balancing market: * Pumped hydro can participate in provision of FRRm services; * Storage plants (incl. batteries) are allowed to provide ancillary services to the TSO * Regulatory framework for active consumers to participate in balancing markets was not in place in 2020 * Design of some products not compliant Electricity Target Model for min bid size energy & capacity (mFRR), validity period, procurement lead time 92% year ahead, length of balancing contracts, settlement rule, activation rule * Storage not allowed in 2020 to provide transmission-level voltage control services * Storage plants (incl. batteries) can be used to guarantee the N-1 criterion for a limited amount of time to radial networks, but are not deployed in practice.
5. Grid Aspects	* No double charging in 2020 for transmission-connected storage * no withdrawal charges for distribution grid for storage, only prosumers are charged for withdrawal charges * There is no regulatory framework for procurement of flexibility services allowing for the deferral of network investments. * No information available that state that NDP is aligned with NECP * PHS & other storage facilities (e.g. batteries) are allowed to be included in the network development plan, however are not included. * From the public consultations the stakeholders' comments and responses are published.

Topic	Croatia - Policy description
	* There is coordination between the TSO and DSOs NDPs, however focused on other alignment/joint activities DSO/TSO * The PCI smart grid project, SINCRO.GRID, is under implementation as a cooperation between TSOs and DSOs from Slovenia and Croatia, with a 10MW/50MWh battery energy storage system (BESS) being trialled in Slovenia
6. Taxes & Levies	* Electricity consumption for charging is taxed like other consumers.
7. Other & General	* Energy storage is not defined in the national regulatory framework.
8. Barriers	* There is no common definition of energy storage in the regulatory framework
9. Best practices	

Cyprus

Topic	Cyprus - Policy description
1. Public Support	The National Energy and Climate Plan (NECP) refers to electricity storage. * If Cyprus remains electrically isolated from other electricity networks, the penetration from RES-e will only be increased once RES-e, coupled with storage technologies, materialises. The need of storage systems (both behind and in front of the meter) is included in the electricity system investments, but their need might be limited ifCyprus will get electrically interconnected by 2026. * The pumped hydro storage facility was presented as an option, but its deployment is delayed until 2027 (estimated 130MW pumped storage potential by 2030 in Cyprus), in addition to the uncertainties concerning project maturity and technical feasibility of the project. * The objective to deploy an Advanced Metering Infrastructure, including the roll-out of 400.000 smart meters by 2026 will enable the optimisation and control of the distribution system, increase the penetration of distributed renewable sources, enable aggregation of RES, demand response and storage and increase direct final customer participation in all market stages (active customers). * The use of Interconnector can help the RES to further penetrate earlier, while in the WEM scenario it seems that more RES will be introduced in the post 2030 period with technologies that using storage behind the meter. These technologies, based on the existing available data, include Concentrated Solar Thermal (CSP) and other storage technologies like Li-Ion Batteries.A detailed overview of Storage technologies that can be deployed in Cyprus was made under an SRSS study by University of Cyprus[375] and JRC[376]. * In its scenario modelling, several storage options play a role in the further penetration of RES due to the absence of Electricity Interconnector, including: pumped hydro storage; lithium-Ion battery storage; concentrated solar power storage (thermal Storage that is converted to electricity). * Enabling participation of storage is one of five objectives to promote competitively-determined electricity prices & increase system flexibility: 'revise the regulatory framework to enable the participation of storage in the electricity market' (the regulatory framework was revised). Ensure that generators, aggregators and consumers will be allowed to own and operate storage systems, buy and sell on the day-ahead, forward markets; also enable participation in the balancing market. *Storage technologies can be used also as a support for conventional power generating units and limit the start-up and shut-down cost. This will increase both the performance and the efficiency of the conventional power generating units. *Pre-notified to DG Competition a state aid scheme for the installation of 130-150MW/ 2h storage systems in front of the meter.
2. Permitting	* According to the Law for the Regulation of the Electricity Market of 2021 (L.130(I)/2021), a licence from CERA is required for the installation and/or operation of an electricity storage facility, with the exception of electricity storage facilities operating exclusively for own use. CERA had recently launched a public consultation concerning the licencing regulations and currently the proposed licence regulation (which includes the standard licence terms of a storage facility) is being forwarded to the Council of Ministers through the Minister of Energy, Commerce and Industry, as provided by the Law. Stakeholders indicate that once network codes are finalised regarding e.g. battery storage, special environmental requirements will be developed especially concerning fire hazard. * Ground contamination by leakages is already covered in the law for the environment, requiring appropriate measures.
3. Energy Markets and Capacity Mechanisms	* Energy storage enabling regulatory framework for storage systems in front-of-the-meter has been approved by CERA on 30/12/2023 (Transmission and Distribution Rules) and 5/1/2022 (Trade and Settlement Rules) and will be put in operation on 30/9/2024 (Regulatory Decisions 386/2001, 4/2022 and 72/2022). DA/ID markets: * Front-of-the-meter energy storage will be able to participate in DA and ID markets on 30/9/2024. * Regulatory framework for active consumers to participate in ID & DA was not in place in 2020 Balancing market: * Energy storage in front of the meter will be eligible to participate in balancing markets on 30/9/2024. * Regulatory framework for active consumers to participate in balancing markets was not in place in 2020 Capacity mechanisms:

375 http://www.mcit.gov.cy/mcit/EnergySe.nsf/All/4CFADF62B303D228C22584D6004AAB42/$file/JRC%203-%20Storage.pdf

376 JRC study for storage

Topic	Cyprus - Policy description
	* Currently, there is no capacity remuneration mechanism. * Regulatory framework enabling front-of-the-meter storage has been approved by CERA on 30/12/2021 and 5/1/2022 and will be put in operation on 30/9/2024 (Regulatory Decisions 386/2021, 4/2022 and 72/2022) * At present, the only service of storage for end-users is to increase self-consumption to 100% when using the net metering and net billing schemes. The time of use tariff for net billing users provides an additional signal.
4. Ancillary Services	* Regulatory framework enabling front-of-the-meter storage has been approved by CERA on 30/12/2021 and 5/1/2022 and will be put in operation on 30/9/2024 (Regulatory Decisions 386/2021, 4/2022 and 72/2022)
5. Grid Aspects	* No double charging in 2020 for in front of the meter storage * Only prosumers are charged for withdrawal charges at distribution level * There are no specific connection rules for storage, so same connection rules for other generators and/or loads apply. Upcoming regulatory changes should not change this. * According to regulatory decision by CERA 03/2019 in-storage during the charging cycle is exempt from network tariffs. *According to the Law for the Regulation of the Electricity Market of 2021, CERA shall ensure that the 10-year transmission network development plan and the 10-year distribution network development plan are consistent with objectives, targets, policies and measures defined within the NECP, which is elaborated in accordance with the Regulation (EU) 2018/1999 and adopted by the Council of Ministers. * There is coordination between the TSO and DSOs NDPs.
6. Taxes & Levies	* No information identified on absence of double taxation for energy storage.
7. Other & General	* In 2020, there were four research projects on storage: StoRES, PV-ESTIA, ERIGENEIA and FLEXITRANSTORE, SREC. Through the R&I (with EU partners) there is willingness to diffuse best practice solutions for the deployment of storage in Cyprus
8. Barriers	
9. Best practices	

Czech Republic

Topic	Czech Republic - Policy description
1. Public Support	The NECP refers to electricity storage * Electric vehicle batteries are acknowledged as potential storage option within the electricity market * 'Electricity storage, including the use of hydropower' is mentioned as a specific sub-area in the national priorities for research, experimental development and innovation * Energy storage can be supported in the framework of the Modernisation fund RES+ program provided that it is a part of a new RES installation and serves to balance its output (it cannot be used to provide ancillary services).
2. Permitting	* There is no specific licence issued by the Regulator for battery storage systems yet. The licence parameters are foreseen to be addressed in the market design of the Energy Act. * Pumped hydro is operated on the basis of a license for production, granted through the standard process as for other power plants.
3. Energy Markets and Capacity Mechanisms	DA/ID markets: * PHS is able to participate in DA and ID markets * Regulatory framework for active consumers to participate in ID & DA was not in place in 2020 * Stand-alone battery units are not allowed to participate in the energy markets according to the amendment to the Energy law from 2021. Capacity mechanisms: NAP * Storage facilities can participate in the electricity markets (including intraday and balancing) only together with the spinning reserves. Stand-alone batteries are completely forbidden for any kind of use in the energy markets in the Czech Republic, use with RES officially allowed * Storage is used primarily for active customers to avoid network charges. * Large boilers, usually inside of district-heating and power plants, are used for ancillary services
4. Ancillary Services	* Czech TSO (CEPS) updated the network code in 2021 to allow participation of battery storage units in the balancing markets, including stand-alone battery units. Balancing market: * Trans-European Replacement Reserves Exchange (TERRE) in place for exchange of replacement reserves, and allowing the participation of storage. * No other information identified on storage not being eligible to participate in balancing markets * Regulatory framework for active consumers to participate in balancing markets was not in place in 2020. According to the amendment to the Energy law from 2021, integrated aggregators are allowed to provide ancillary services from aggregated consumers and/or suppliers. *Not open for independent aggregators in 2020. After the update of the network codes, aggregation blocks including battery storage can participate in the balancing service market. * Design of some products not compliant with Electricity Target Model for min required capacity (FCR, aFRR, mFRR, RR), aggregation of load, validity period, procurement lead times, settlement prices (pay as bid mFRR), activation rule *max/min price limits not compliant with Electricity Target Model * Dual pricing, single position not compliant with Electricity Target Model * Storage not allowed in 2020 to provide transmission-level voltage control services, still relevant in 2022.
5. Grid Aspects	* Czech legislation does not allow direct connection of batteries to the grid, for storage purposes, only together with the generation site. * No double charging in 2020 for transmission-connected storage * Distribution network charges are applied only to consumers. * PHS & other storage facilities (e.g. batteries) are not allowed to be included in network planning, which involves specifically grid infrastructure, such as transmission lines, transformers or substations. * From the public consultations stakeholders' comments and responses are published.
6. Taxes & Levies	* Support for the development of storage facilities is primarily provided in the form of investment grants. * No tax exemptions or rebates are applied or considered at the moment. * No information identified on absence of double taxation for energy storage, thus assume it exists

Topic	Czech Republic - Policy description
7. Other & General	* Works on the completely new Energy Act started and relevant stakeholders participate in its preparation, including the Association for Energy Storage & Batteries AKU-BAT. However, this new act should be proposed towards the end of 2022.
8. Barriers	* Some changes in the ancillary services are not completely addressing storage: stand-alone batteries still cannot provide non-frequency ancillary services, only in connection with spinning reserves. * Stand-alone batteries can be connected to the grid (only in testing mode), but cannot supply electricity to the grid, their use in hybrid installations is hence limited, except at the same site. * There is no common definition of energy storage in the regulatory framework, and it was removed from the Energy Act amendment draft.
9. Best practices	

Denmark

Topic	Denmark - Policy description
1. Public Support	The NECP version refers to electricity storage: * Policies and measures adopted with the 2018 Energy Agreement includes, among many others, the energy storage fund of 2019, developing markets for flexibility and ancillary services, * Energy storage could be a useful tool to ensure sufficient supplies of energy, by levelling out demand peaks and by making use of surplus wind energy from times of high wind power generation to store for later times of shortage. Today, the technologies available for storing electricity are rather limited and expensive. Yet, the technologies will possibly continue to be developed and become profitable with time, as current trends in prices of storage technologies are indicating. This means that in the future it is not unlikely that for instance power-to-gas and the hydrogen sector could play a larger role in ensuring supply security and that batteries will become more prominent in the energy markets. * The flexibility of the energy system is expected to be facilitated largely by market-based solutions. Therefore, it is an objective to support structures that favour demand response and energy storage markets. Especially the integration with the district heating sector and its vast energy storage capacity is expected to provide a basis for increasing flexibility through increased demand response and energy storages * The Danish electricity market is open for participation from renewable energy, demand response and storage, including via aggregation * In order to accommodate future needs, the Danish Government has established a fund supporting development and demonstration projects on energy storage. The fund's size is 128 million DKK and it was in December 2019 granted to two Power-to-X-projects * Increased flexibility in energy system is crucial for the green transition and storage can contribute to that flexibility * NER (Nordic Energy Research) has identified seven key areas that could enhance joint Nordic research efforts, among which Energy Storage * While smart grids specifically address the problem of moving consumption to other times during the day and matching supply with demand, system integration is also a growing and very important area. In the future, many factors will be competing to supply this dynamic: electric cars, electric cartridges, heat pumps, etc. system integration also covers aspects relating to energy storage and smart energy * A larger share of intermittent RE leads to greater demand for energy storage solutions. In this context, battery storage, in particular, is expected to play a significant role (including small scale PV) * Furthermore, energy storage could be a useful tool to ensure sufficient supplies of energy, by levelling out demand peaks and by making use of surplus wind energy from times of high wind power generation to store for later times of shortage * Ambitious targets and plans to decarbonise the energy supply : more than 1 million green cars by 2030; a new gas strategy; a roadmap for smart energy, expected to provide increasing flexibility through demand response and energy storage
2. Permitting	
3. Energy Markets and Capacity Mechanisms	DA/ID markets: *Energy storage is able to participate in DA and ID markets Capacity mechanisms: NA * District heating companies own and operate large thermal storage facilities and are active in the electricity market to respond to short-term changes in electricity prices.
4. Ancillary Services	Balancing market: * FCR cooperation project active, allowing for provision of FCR capacity by storage. * Pumped hydro is eligible to provide also FRR services * No other information identified on storage not being eligible to participate in balancing markets *Design of some products not compliant Electricity Target Model including, max delivery period of 4 hours (mFRR), validity period (aFRR & mFRR) & settlement rule (pay as bid aFRR & mFRR) * Max/min price limits compliant with Electricity Target Model * Single pricing, single position compliant with Electricity Target Model New ancillary services: * SIR: Looking into solutions for falling inertia levels * Transmission-level voltage control provision in 2020 was mandatory and non-remunerated

Topic	Denmark - Policy description
	Mechanisms to value distributed flexibility sources: * Local flexibility platforms & other initiatives: INTERRFACE (T/DSO) * Possible to stack different balancing services from committed availability windows, however dynamic pooling is not yet allowed * District heating companies own and operate large thermal storage facilities, often equipped with electric boilers. Their fast response is offered to the balancing market.
5. Grid Aspects	* No double charging in 2020 for transmission-connected storage * Only prosumers are charged for withdrawal charges for the distribution grid * The TSO Energinet has published grid codes specifically for the connection and access of batteries * The DSO Danish Energy has recently participated in several research projects analysing the impact of batteries on distribution systems * Self-producers (companies) shall not pay the grid tariff for the part of their production covering their own consumption * Customers with their own 132 kV transformers with settlement on the 132 kV side pay a reduced grid tariff * The NECP is taken into account while developing NDP through the assumptions regarding the consumption and production provided by the Danish Energy Agency * PHS & other storage facilities (e.g. batteries) are not allowed to be included in network development plan, * Introduced public consultations of the draft NDP; Published stakeholders' comments and responses * None of the DSOs prepare a NDP (from 2023 each DSO should prepare an electricity development plan
6. Taxes & Levies	* There is no exemption of taxation and fees, storage is considered as a normal consumer
7. Other & General	* No definition of storage in the national legislation
8. Barriers	* There is still an absence of technical specifications for how batteries are expected to participate in all of the Nordic ancillary services markets. The Danish requirements for batteries are currently being revised, and a new version is expected in late 2019.
9. Best practices	* District heating companies are actively participating in energy markets. * The TSO Energinet has published grid codes specifically for the connection and access of batteries

Estonia

Topic	Estonia - Policy description
1. Public Support	The final 2019 NECP version refers to electricity storage: * Hydrogen could be one of the main options for the storage of renewable energy and more favourable options for the storage of electricity for days, weeks or even months * seasonality need for temporary storage on the part of the proprietor * Estonia's economy needs investment in the transition to cleaner energy and more sustainable jobs, including the acquisition of wind farms (including national defence aerial surveillance radars), electricity storage solutions, cogeneration plants, transport to biofuels and electricity transfer, electricity railways and modern rental housing funds, renovation of apartment buildings, demolition of buildings that fall out of use, decarbonisation of the cement and lime industries, recycling of industrial residual gases. * Chapter deals with measures to increase the flexibility of the energy system to produce renewable energy, such as smart grids, aggregation, demand response, storage, distributed generation, distribution, redispatching and curtailment mechanisms and real-time price signals, including the introduction of intraday coupling and cross-border balancing markets * As regards independent aggregators and energy storage, the regulation will be complemented by Directive 2019/944 on the EU internal electricity market * The trends of Estonia's renewable energy sector in 2040 viewpoints depend heavily on the megatrends we can see in Europe and also in the world, where carbon-neutral energy production, energy saving and storage and smart consumption are the keywords * To ensure security of electricity supply in Estonia, a combination of renewable energy production facilities and storage solutions (including seasonal storage), … may be used in the future * As regards energy storage, Estonia is already on the world map, with Skeleton Technologies, the leading European producer of super-capacitors, producing facilities in Germany and developing in Tallinn * on RD&I, be at the forefront of next generation renewable energy technologies, storage, smart grid and home solutions, smart cities, buildings neutrality, clean transport, clean carbon capture and utilisation and nuclear energy, building on Horizon 2020.
2. Permitting	* No specific permitting provisions identified.
3. Energy Markets and Capacity Mechanisms	DA/ID markets: *Energy storage is able to participate in DA and ID markets Capacity mechanisms: NA * The Electricity Market Act indicates that the regulator may oblige the TSO to tender new production, energy storage devices or energy efficiency/demand-side management measures if generation reserves fall below requirements or if this is necessary for the promotion, of new technologies * In April 2010 the Nord Pool power exchange started operations in Estonia. Nord Pool day ahead and intraday markets are open to storage. The day ahead products include hourly and block orders, while the intraday market offers 15-minute, 30-minute, hourly and block products.
4. Ancillary Services	Balancing market: * In January 2018 the Baltic common balancing market came in operation, covering mFRR. Storage is allowed to provide mFRR services. For mFRR the product duration is 15 min , the minimum bid size is 1MW. * Currently only FRR is used in the Baltic balancing market. The Russian Unified Power System (UPS) provides FCR and FRRa, while Baltic TSOs also provide RR. * Aggregated generation and loads can participate only in the FRRm market. They cannot provide other ancillary services such as black start or voltage control. * Loads use the same market mechanisms and activation procedures as generation to provide balancing services (both capacity and energy) *No other information identified on storage not being eligible to participate in balancing markets *Design of some products not compliant with Electricity Target Model including max delivery period (mFRR), validity period (mFRR), max price limit, no min limit implemented * Single pricing, single position compliant with Electricity Target Model * All power plants that are connected to the main grid must have voltage control capability. The service is partly remunerated by the TSO. * Black start service is provided by power plants which are included in the restoration plan as black start service providers. It is not a mandatory service and is remunerated by the Elering.

Topic	Estonia - Policy description
	* The Electricity Market Act indicates that the regulator may oblige the TSO to tender new production, energy storage devices or energy efficiency/demand-side management measures if generation reserves fall below requirements or if this is necessary for the promotion of new technologies Mechanisms to value distributed flexibility sources: * Local flexibility platforms & other initiatives: INTERRFACE (T/DSO)
5. Grid Aspects	* In the Electricity Market Acts it is stated that withdrawal charges for storage apply similarly to consumers (network fee + electricity excised duty + renewable energy fee). Starting from March 2022, injection of electricity into the network will be derogated from the distribution and transmission fee. * Injection charges for prosumers connected to the distribution grid, usually households, installed capacity >0,015 MW and withdrawal charges for prosumers. * According to an Elering 2015 report, a DSO was already then looking at flexibility projects such as energy storage, as it had already 'been forced to curtail the maximum output of a wind farm due to local network constraints. In the long term, the DSO is expecting overloaded substations in all types of distribution network areas (rural, suburban and urban).' * The feed-in scheme was kept for installations under 50 kW following the 2018 update of the Electricity Market Act. Net metering is not allowed. * Several power plants will have to be closed in the future due to the NECP and this has been taken into account in the assessment of production adequacy. The development of the network takes into account additional wind farms. The adequacy of externalconnections is assessed. * PHS & other storage facilities (e.g. batteries) are allowed to be included in the network development plan, however are not included. * Neither public consultations nor any specific or bilateral consultation is carried out, however upcoming amendment of the national legislation in Estonia will also include a requirement for the NDP to be publicly consulted * Not all DSOs prepare NDPs, other alignment/joint activities DSO/TSO
6. Taxes & Levies	* No specific mention of electricity storage in the tax legislation, thus assumed that storage charging pays the electricity consumption tax.
7. Other & General	* Storage is added in the updated Electricity Market Act (March, 2022). Network companies are obliged to prepare relevant network services for electricity storage.
8. Barriers	
9. Best practices	* The Baltic states implemented the Baltic common balancing market, with storage being able to provide the first product, mFRR. * Regulation specifically indicates TSO roles to tender for new flexibility resources including storage due to generation adequacy or innovation considerations

Finland

Topic	Finland - Policy description
1. Public Support	The NECP version refers to electricity storage: * The transition to a low-carbon economy will require additional investments, particularly in bioeconomy, the circular economy, clean energy solutions, energy efficiency, emissions-free forms of energy production, energy storage solutions, carbon recovery and energy utilisation, along with research, development and innovation activities and measures to bring these solutions to market * Among the three most popular proposals of the citizens' survey: Promotion of decentralised energy production (electricity, heat, transport, storage) through sustainable and cost-effective measures * As for ensuring generation adequacy in the light of the renewable energy contribution, including demand response and storage, the Finnish strategic reserve system plays a significant role. * Demand response and storage are further promoted by applying the proposals by the Smart Grid Working Group as discussed in Chapter 3.4.3 * In October 2018, the Smart Grid Working Group set up by the Ministry of Economic Affairs and Employment proposed an extensive operational programme to increase the demand-side response of electricity and the opportunities for customers to participate. The working group's key proposals were: 1/ clarifying the roles of actors in the market-based implementation of demand-side response (e.g. principles for the storage of electricity, discontinuation of the flexibility implemented by distribution networks); 2/ highlight the significance of market-based solutions for demand response and storage * Finland committed to doubling public innovation funding for clean energy by 2020. The baseline was the average of the funding granted by TEKES to projects on renewable energy sources, storage of energy, energy systems and energy networks between 2013 and 2015 * Finland is also active in Set-Plan key action no 7. "Batteries for e-Mobility and Stationary Storage", where Finland is leading the working group related to battery recycling. * Total use of electricity in the transport sector is not more than 1–2% of the total electricity demand during the assessed period. Its impact on electricity generation is small on a yearly level, but charging batteries and active use of them as two-way electricity storage can affect both the short-term electricity market and the local grid.
2. Permitting	* In Finland, there is no specific rules (legislation, procedures) for the storage permitting. * Small-scale batteries need only the city planning acceptance, but when locating battery in the existing industrial site, the permitting is typically only light notification. * Large-scale storages like pumped hydro or hot water storage (based in natural rock) need also permission according to the water body legislation when affecting water body/ground water levels or other hydro-morphological issues. The permission of the large-scale projects comprises public hearings as part of permitting procedure. Stakeholders indicate there are also rights for contestation through courts, which can lead to prolonged delays if there is no social acceptance.
3. Energy Markets and Capacity Mechanisms	DA/ID markets: *In 1998-1999, the Nord Pool power exchange started operations in Finland. Nord Pool day ahead and intraday markets are open to storage. The day ahead products include hourly and block orders, while the intraday market offers 15-minute, 30-minute, hourly and block products. *Energy storage is able to participate in DA and ID markets * Regulatory framework allows for all eligible customers to participate in all market places, including active customers (not explicitly mentioned). However, due to minimum participation thresholds of the market places aggregation is needed. Capacity mechanisms (strategic reserve): * Allows energy storage, however CM has a limited delivery period (three winter months * There is integration between district heating, cooling and electricity both in supply and demand, with extensive use of water boilers and other water heating systems as storage and an estimated 1800 MW of heat storage controllable through smart meters. Night-day-tariffs have been used to shift electricity consumption to night hours, mainly due to water heat storages. Large heat storages especially connected with combined heat and power plants supplying district heating networks are common. * For example, in Helsinki there are underground cooling storages. * Heat pumps are commonly used for heating on building level (over 1 Mio units in use) and to produce district heating and cooling.
4. Ancillary Services	Balancing market: * In 2022, batteries can participate in FRR and FCR services, while loads could provide FCR/FRRm. Dedicated rules to batteries apply to the management of the state of charge and to the restoration of full activation capacity in FCR.

Topic	Finland - Policy description
	* Regulatory framework allows for all eligible customers to participate in all market places, including active customers (not explicitly mentioned). However, due to minimum participation thresholds of the market places aggregation is needed. * Fingrid conducted a pilot from 2017 to 2019 to allow the participation of independent aggregators in the mFRR balancing market that was prolonged and the participation enlarged in 2020. * Regulatory framework for active consumers to participate in balancing markets was not in place in 2020 *Design of some products not compliant Electricity Target Model including max delivery period longer than 4 hours (mFRR), min capacity required (aFRR, mFRR), min bid size energy & capacity, validity period, activation rule * Not compliant with Electricity Target Model: Max limit, no min limit implemented New ancillary services: * SIR: Looking into solutions for falling inertia levels Mechanisms to value distributed flexibility sources * Local flexibility platforms & other initiatives: INTERRFACE, OneNet (T/DSO) * Portfolio bidding is allowed in all reserve products and markets, however same capacity cannot be sold multiple times; dynamic pooling is allowed in balancing services * Offering storage in non-frequency ancillary services procurement is allowed.
5. Grid Aspects	* MS does not apply injection charges for storage connected to distribution grid, only injection & withdrawal charges for prosumers. * There is no separate connection or access rules and/or standard terms of contract for storage. Similar to self-generation, storage is considered a consumer when charging and a producer when discharging. Grid tariff for production is in LV- and MV-networks limited to up to 0.07 €/kWh. . Most of the DSOs do not charge for LV injections below 100 kW. * Net metering within one hour will be introduced to all customers from 1.1. Self-production within a consumption site (behind a meter) is allowed. * The NDP takes into account the future changes in system needs that are guided by the NECP * PHS & other storage facilities (e.g. batteries) are allowed to be included in the network development plan. * The government's proposal for legislation follows the logic that the system operators should not be allowed to own or operate storage unless there is no market based capacity available for the need of the DSO. * Published stakeholders' comments and responses * Coordination between TSO/DSO NDPs: Other alignment/joint activities DSO/TSO
6. Taxes & Levies	* Taxation of electricity for large batteries has been eliminated in 2019. Electricity is transferred to large storages without any excise duty on electricity. The excise duty is paid when electricity is transferred to be consumed. * The government programme in early 2021 foresaw that taxation on electricity storage for pumped storage facilities and smaller batteries will be examined.
7. Other & General	* Electricity storage is defined in the law concerning electricity and fuel taxes: 'electrical storage' means a functional unit of equipment, machinery and buildings required for the short-term electrochemical storage of electricity.
8. Barriers	* Double taxation for small batteries still needs to be eliminated.
9. Best practices	* The government formed a Smart Grids working group, addressing multiple aspects related to e.g. storage, aggregation and active consumers. * The Finnish energy market is generally based on open market driven policies and competition on level playing field. This applies to electricity retail and wholesale markets as well as heating markets. * TSO pro-activity is seen as a positive aspect, as well as co-operation between TSO, DSOs and market actors. * Using storage in non-frequency ancillary services is allowed. * One of the largest virtual batteries in the EU is located in Finland. It aggregates and controls distributed energy assets (mainly water heaters) owned by customers, for grid balancing purposes.

France

Topic	France - Policy description
1. Public Support	The NECP refers to electricity storage * Power systems flexibility tools including storage must be developed on the medium-term, especially due to the penetration of renewable energy * The multi-annual energy plan should anticipate the energy system change and enable the development of energy storage377 * Storage is identified as a specific R&I need * Storage is a flexibility pillar to handle fast supply and demand fluctuations * The 2018 Low-Carbon National Strategy reference scenario includes storage, including measures to develop geothermal heat storage * Plan to confirm by 2023 the gas storage needs post-2026 * Identify sites for decommissioning in the next multi-annual energy plan * Plan to develop in the first period of the multi-annual energy plan (by 2023) the framework to develop storage as an alternative to grid expansion from 2028 * The multi-annual energy plan adopted in 2020 (programmation pluriannuelle de l'énergie, PPE) gives the objective to develop an additional 1,5 GW of PHS between 2030 and 2035. * Plan to continue R&I efforts in storage through various government mechanisms * Plan to study the reutilisation of salt caverns for hydrogen storage * Plan to review support framework to enable solar thermal heat storage * Additional storage needs to 2035 occur only in scenarios with faster decrease of nuclear power generation * "The 'Batteries and Storage action plan' intended to cover batteries, a key technology for applications involving electric mobility and fixed energy storage." * 'The French Ministry of Higher Education, Research and Innovation, through the ANR, and the German Federal Ministry of Education and Research (BMBF) launched a bilateral call for projects in 2018 with funding of €20 million on energy storage and distribution (expected to close in January 2019)' * Adoption of a regulation to allow storage specific call for tenders to increase storage development to cope with flexibility needs.
2. Permitting	* The standard permitting rules for power generation plants apply to energy storage plants e.g. planning permission (which covers environmental issues), power generation licence (at the moment, electric storage plants have not been submitted to power generation permit application, this question will be discussed in the next few months) and authorisation to construct.
3. Energy Markets and Capacity Mechanisms	DA/ID markets: * Energy storage is able to participate in DA and ID markets * In 2018 the EPEX energy exchange introduced loop block orders, where two block orders are executed or rejected together, representing for example the storage cycle. Capacity mechanisms: * Existing rules to take into account the specific contribution of storage to security of supply. A storage unit can individually participate in the CRM if its capacity is above 1MW, or through aggregation for a total of minimum 1MW, for lower capacities. * Only a few storage technologies as explicitly eligible for participation (among which batteries and pumped hydro storage) * Call for tenders complementing the CRM to incentivise the development of additional capacities: storage included and awarded (batteries) in the 2019 edition covering the 2021-2028 periods. 7 year-long fixed premium.
4. Ancillary Services	Balancing market: * Pumped hydro can provide a wide range of ancillary services (FCR, FRRm, FRRa and RR), while batteries are eligible to provide FCR and aFRR. To this end, the Frequency System Services rules are currently being reviewed in order to clarify the conditions and pre-requisites for the participation to batteries * FCR cooperation project active, allowing for provision of FCR capacity by storage * Trans European Replacement Reserves Exchange (TERRE) in place for exchange of replacement reserves, and allowing the participation of storage, at least pumped hydro * No other information identified on storage not being eligible to participate in balancing markets

[377] CRE (French regulator) has achieved a review of the regulatory issues for the development of storage. Results, including recommendations and special requests to the system operators are reported in a document available here (in French): https://www.cre.fr/Actualites/La-CRE-publie-sa-feuille-de-route-pour-le-stockage-de-l-electricite

Topic	France - Policy description
	* Some balancing products not compliant with Electricity Target Model including max delivery period 120 minute (mFRR & RR), min capacity (mFRR, RR), min bid size energy & capacity (mFRR & RR), validity period, regulated prices as settlement rule (FCR & mFRR), activation rule * Not compliant with Electricity Target model: min/max price limit * Single pricing, single position compliant with Electricity Target Model *Full valorisation of storage assets on Balancing Mechanism is not yet possible but discussions ongoing. Mechanisms to value distributed flexibility sources * The DSO Enedis launched a call for tenders for local flexibility products in dedicated areas, including storage and demand response, and REFLEX project in order to introduce market mechanisms in the frame of grid congestion management * The TSO RTE has also launched a call for flexibility products from storage in dedicated areas. * All products and markets can be offered at pool level, and dynamic pooling is possible in wholesale and CM and partially for balancing. FCR contracts for example include a penalty for non-delivery but no exclusivity clauses * Storage operators must sign the same regulated contract to provide ancillary services as other providers. * Storage not allowed in 2020 to provide transmission-level voltage control services
5. Grid Aspects	* Double charging in 2020 for pumped hydro storage * injection & withdrawal charges for distribution grid for PHS, other storage (e.g. batteries) and prosumers. * Storage operators pay 'postage stamp' transmission charges as a consumer (for their offtake) and do not pay injection charges. A discount on the transmission grid tariff up to 50% applies for energy storage plants, if their utilisation rate during off peak hours exceeds 0.53 and if their efficiency rate is higher than 70%. * There are in France no locational network tariffs. * Rules for grid connection currently applicable for 'utility scale' batteries are considered efficient and do not jeopardize the development of storage. * Network connection procedures for small network users are currently separate for demand and production. * The specific legal provisions regarding self-production also stimulate flexibility solutions including storage. * Specific tariff exists for multi-locations customers. This tariff considers a unique virtual site, summing all load of the concerned sites, and calculating an annual fee proportional to the necessary length of network to connect these sites. * Industrial customers connected to the transmission grid can benefit from a reduction of their transmission invoice from 5% to 90% depending on whether they have storage capabilities or not, their demand (annual consumption, annual usage duration, usage duration during peak period vs. usage duration during off-peak period) and on the importance of electricity in their process, and the degree of international competition * NDP aligned with NECP: A central scenario is defined to reflect the French Multiannual Energy Programme. The Programme was however not finalized at the time inducing some uncertainties on the central scenario. In this context, alternative scenarios (‘Volt’ and ‘Ampere’ designed by the TSO) were particularly useful to assess the projects. * PHS & other storage facilities (e.g. batteries) are not allowed to be included in network development plan, discussion is ongoing. * A more extensive and longer consultation of the draft NDP in France; Published stakeholders' comments * Not all DSOs prepare NDPs, other alignment/joint activities DSO/TSO
6. Taxes & Levies	* Storage charging needs to pay for taxes, levies and network tariffs for the electricity consumed (even in isolated systems, ZNI) but the electricity stored to be reinjected in the network is exempted from tax on final electricity consumption.
7. Other & General	* A definition of storage exists (order of 7th of July 2016) : 'a set of stationary electricity storage equipment allowing the storage of electric power in one form and its reconversion, while being connected to the public power grids. The technologies of these equipment are [pumped storage], hydrogen, electrochemical batteries [...]. The facility is connected to the public power grid directly or indirectly, through facilities belonging to a user of the grid.'

Topic	France - Policy description
8. Barriers	* There is a lack of a connection framework for batteries conducting to the risk that new existing constraints for other assets (non-synchronous generation) would apply to batteries, however network operators' technical regulation included specificities of non-synchronous storage assets. *Minimum size for participation on Balancing Mechanism high (10 MW)
9. Best practices	* NECP addresses storage extensively, including in R&I strategy, multi-annual energy plan, and industrial strategy. * Many task forces have been set up to discuss storage, one being co-chaired by the NRA and the ministry.

Germany

Topic	Germany - Policy description
1. Public Support	The NECP refers to electricity storage * Central strategy in renewable energy: expansion of funding programmes for heat storage systems * The Federal Government has set the goal of building a flexible electricity system consisting of well-developed electricity networks and flexible power plants and consumers. Storage facilities will be integrated into this system wherever appropriate. It has also confirmed its ambition to enhance research into storage technologies. * The market incentive programme for supporting renewable energies in the heating market provides funding for large-scale storage facilities for heat from renewables * The Seventh Energy Research Programme covers five main topics, including 'System Integration,' with a focus on networks, storage reservoirs and sector coupling as a new area of research * Plans exist to set up a new Fraunhofer Institute for Storage Technologies
2. Permitting	* Federal Battery Act (Batteriegesetz – BattG, https://www.bmu.de/en/law/batteries-act/) is transposing Directive 2006/66/EC of the European Parliament and of the Council of 6 September 2006 on batteries and accumulators and repealing Directive 91/157/EWG. The new Act (amendment) deals with the placing on the market of portable batteries containing cadmium and intended for use in cordless power tools, and of button cells with low mercury contents. * Regarding the installation of storage units, the applied legislation is the Federal Building Code (Baugesetzbuch - BauGB) and the Federal Emission Protection Act (Bundes-Imissionschutzgesetz - BImSchG) * Transposed Directive 2013/56/EU on (waste) batteries and accumulators addresses the placing on the market of portable batteries and accumulators containing cadmium intended for use in cordless power tools, and of button cells with low mercury content * Permitting of pumped hydro depends on regional and local authorities with varying levels of staff and capacity. Processes are often done on paper, with lack of digitisation * Planning and permitting procedures: renewables are categorized as “overriding public interest”, explicitly excluding hydropower and thus PHS
3. Energy Markets and Capacity Mechanisms	DA/ID markets: *Energy storage is able to participate in DA and ID markets * The general legal framework consists of three legislative pieces: the Energy Act (Energiewirtschaftsgesetz - EnWG); the Renewable Energy Act (Erneuerbare Energien Gesetz - EEG); the Framework of the prequalification and the provision of the PRL: Eckpunkte Freiheitsgrade bei der Erbringung von Primärregelleistung * There is globally non-discriminatory market access (EEX/EPEX). In 2018 the EPEX energy exchange introduced loop block orders, where two block orders are executed or rejected together, representing for example the storage cycle. * Electricity storage (pumped hydro and batteries) can individually or via aggregation participate in the electricity markets (threshold for direct participation of 1 MW) as long as storage is part of a nomination for which a balancing responsible party exists. * CHPs are using heat storage to take benefits of the electricity market price volatility; this option is in general economically more attractive than storing electricity * Network users increasingly combined PV systems with local storage, to increase self-consumption from 30% to up to 80%, also driven by the low feed-in tariff for new PV installations
4. Ancillary Services	Balancing market: * FCR cooperation project active, allowing for provision of FCR capacity by storage. (Framework of the prequalification and the provision of the PRL: Key points Degrees of freedom in the provision of primary balancing power). * Pumped hydro is eligible to provide also FRRa/FRRm services *No other information identified on storage not being eligible to participate in balancing markets *Design of some products not compliant Electricity Target Model including, max delivery period of 4 hours (mFRR), validity period (aFRR & mFRR) & settlement rule (pay as bid aFRR & mFRR) * Compliant with Electricity Target model: max/min price limits & single pricing, single position * Transmission-level voltage control provision in 2020 was mandatory and non-remunerated Mechanisms to value distributed flexibility sources: *Local flexibility platforms & other initiatives: Small-assets to CM & aFRR (TSO & third party), * Pooling is allowed to fulfil prequalification requirements, The SOGL define the Requirements. Definition and Requirements for “Pool”, “Groupe” and Units are defined by TSO

Topic	Germany - Policy description
	Value stacking of balancing products is possible;
5. Grid Aspects	* No double charging in 2020 for transmission-connected storage * Partially withdrawal charges to storage operators connected to the distribution grid. * The conditions for connection/access to the grids are regulated in: Technische Anschlussregel Mittelspannung VDE-AR-N-4110 & Technische Anschlussregel Hochspannung VDE-AR-N-4120 (Implementation Network Codes „Requirements for Generators" (RfG)). * Since stored electricity taken off from the grid is considered as final consumption, in principle all final consumer levies must be paid for this offtake (incl. EEG surcharge, grid charges, others), and the charge applies a second time when the final consumer off-takes. But some exemptions apply: * Grid charges do not have to be paid for electricity that provides upward balancing energy in the balancing market. In this special case, there are no grid fees for withdrawal from the grid (injection fees don't apply either because there are generally no injection fees in Germany. Depending on full load hours, the grid fee has to be at least 10, 15 or 20% of the 'normal' grid fee. * There are network charge reductions for customer with an exclusive usage of storage (not less than 20% of yearly power price). * Grid-connected storage facilities are exempted from the grid charges for storage for 20 years after commissioning. This applies for pumped hydro storage plants commissioned from August 2011 (or for 10 years when existing plants increased electrical capacity by at least 7,5% or storage capacity by at least 5% after August 2011 (§118 (6) EnWG). * Hydrogen electrolysis plants, like electricity storage systems, are exempted from electricity grid charges for 20 years if they are connected to the grid by 4 August 2026 * Unlike stationary electricity storage devices, storage in electric vehicles does not fall under exemption rules, full network charges are due. * There is a network tariff reduction for energy intensive customers (typically heavy industry customers) with energy consumption that exceeds 7 000 full load hours per year and 10 GWh. Depending on full load hours, the grid fee has to be at least 10, 15 or 20% of the normal grid fee * For industrial electricity users, the level of grid charges is largely determined by their peak load. To lower their peak offtake and related grid charges, electricity storage is often considered as an option. * A monthly instead of yearly capacity component is offered for final customers with a temporary peak electricity consumption * An individual tariff is available to final customers with a peak load not coinciding with system peak demand. The individual tariff must not be lower than 20% of the published regular tariff. * NDP aligned with NECP: Various input parameters are defined in the scenario definition to facilitate goals, e.g. maximum CO_2 emissions, installed renewable energy sources to meet "share of the electricity consumption" goals, number of electric vehicles. * PHS & other storage facilities (e.g. batteries) are not allowed to be included in network development plan. * From the public consultations stakeholders' comments are published * Not all DSOs prepare an NDP, data exchanges regarding scenario's and/or assumptions; consultation between the TSO and DSO
6. Taxes & Levies	* Storage is treated as final consumption and thus bears network charges, taxes and levies since 2009. The following exemptions apply: * Battery electricity storage is regarded as a network component, and therefore not subject to the electricity consumption tax (StromStG §5, Abs. 4) * Pumped hydro plants are considered generators. Generators are not subject to the electricity consumption tax (StromStG §9, Abs. 1, Nr. 2 and StromStV §12, Abs. 1, Nr. 2) * Electricity from storage fed into the network for balancing purposes (i.e. upward balancing energy) is exempt from the EEG surcharge, as the electricity is supplied to the balancing group. * A storage facility according to the EEG is treated like an EEG installation. In order for a self-supply constellation to exist, there must be personal identity between the self-supply system, the storage plant and the consumption of the electricity * Self-production plants are existing plants that have already generated electricity for self-production before 1 August 2014. These plants are currently exempt from the EEG surcharge. * Self-consumption systems are all those installed from 1 August 2014. These plants must pay the full EEG surcharge, unless they are combined heat and power plants (CHP) or renewable energy plants (RE), or are not connected to the network. Rebates exist depending on the utilisation, use of biogas for self-generation. E.g. Batteries and thermal storage which can prove with a costly measurement system that they only use renewable energy are exempted from levies for renewable energy (below 10 KWp).

Topic	Germany - Policy description
	* The electricity consumed for the generation of green hydrogen has to pay fees, levies and taxes. The long-term stored hydrogen is charged again when it is used by the next end user. However, electricity used for power-to-gas is exempted from charges and levies if hydrogen is transformed directly into electricity again. In this case no state-imposed costs have to be paid. The difference in production costs plus state-imposed costs to other forms of hydrogen can exceed total investment costs. Green hydrogen costs about 6 Ct/KWh. If levies, fees and taxes apply the costs are increasing to 28 Ct/KWh. Hence, electrolysers could be clearly defined as time buffer and facilitator for PtX in the energy law to get the state-imposed costs down and attract investments. * Electricity storage is exempt from the EEG surcharge, if the storage facility fulfil §§60, 61 l EEG 2021, EEG-surcharge ends in 2022 in generally * Electricity storage is exempt from the CHP-fee if the storage facility fulfils special restrictions of the KWKG * Electricity storage is exempt from the offshore-wind-surcharge if the storage facility fulfils special restrictions of the EnWG * Electricity storage is exempt from the industrial-switchable-surcharge if the storage facility fulfils special restrictions of the AbLaV * Electricity storage is exempt from the offshore-wind-surcharge if the storage facility fulfils special restrictions of the EnWG
7. Other & General	* The Electricity Tax Act defines stationary battery storage: 'a rechargeable storage for electrochemical-based electricity that remains exclusively at its geographical location during operation, permanently connected to the utility grid and not part of a vehicle. The geographic location is a point determined by geographic coordinates'. Charging of grid connected storage is free of electricity tax.
8. Barriers	* Network tariff exemption does not remove the obligation for storage facilities to pay some other regulatory charges not directly related to TSO activities. There is legal uncertainty as to whether the exemption from the network charges also applies to the concession fee and the levies that are charged. This concerns the CHP surcharge, the §19 surcharge and the offshore liability charge. * Delivery to a sister company in a corporation is not considered as self-supply according to the strict interpretation of § 61 EEG by the national regulator.
9. Best practices	* In the further development of the electricity market, balancing deviations will be more heavily punished, resulting in suppliers taking their customers under liability. Storage can then be part of the corporate strategy to avoid such deviations

Greece

Topic	Greece - Policy description
1. Public Support	The NECP foresees the addition of approximately 2.7 GW of electrical storage capacity by 2030, split between around 1.4 GW in pumped hydro and 1.2 GW in batteries. Two explicitly named pump storage projects (one of which is a PCI project) are to be implemented by 2025. The NECP contains furthermore the following references to storage: * To achieve high levels of penetration of uncontrollable RES plants, as set out in the NECP, in an economically rational way (sufficiently low cuts in their output), there is generally a need for energy storage. For several decades, pumped storage has been the most widespread international method for large-scale storage of electricity. Today, international developments are rapid in terms of other forms of storage, for large or small installations, especially for batteries of different kinds. The coupling of markets via interconnectors in accordance with the provisions of the new electricity market model is important for achieving high levels of penetration. There is also interest in power-to-gas (e.g. hydrogen) storage applications, in the context of which the interconnection of electricity and gas networks is also investigated. Moreover, given the international interconnections of the Greek mainland system, the investigation of the needs for storage and coverage thereof at a regional level may also prove efficient. * The full regulatory framework for the operation of storage systems in the electricity market will have been developed and it will be possible to develop these systems as part of generation units with simplified administrative procedures to authorise their operation by 2020. Already in the energy offsetting scheme, provision is made to operate storage systems exclusively for the storage of energy generated by self-generation RES systems and for its use by end consumers to meet their electricity needs at a later time. * As regards power generation in particular, RES will be the major domestic source of power as early as in the middle of the following decade, with a share exceeding 65% of the domestic power generation by 2030, by utilising in the most cost-effective manner Greece's high potential especially for wind and photovoltaic plants. A tool in this direction will be the full functioning of the new electricity market model, the simplification and speeding up of the licensing procedure, the digitisation of the energy system and the enhancement and expansion of energy infrastructures to allow for maximum RES penetration in power generation, focusing on storage systems, and in general the gradual electrification and the energy coupling of final consumption sectors to allow for maximum RES share in final energy consumption. Another priority is promoting electromobility, which will now rely heavily on RES power generation. * A further aim is to combine consumption sectors to the greatest and most efficient extent possible, placing emphasis on maximising the use of RES. The electrification of different uses in final consumption is an essential component in achieving this aim. A typical example is heat pumps which, together with the future greater use of energy storage systems and self-production schemes, will make a decisive contribution in this direction. * At a technical level, it is also critical for the following period to develop an appropriate institutional framework for storage units and have them participate in the electricity market. The participation of these units is considered to be crucial for attaining high shares of RES in the electricity market. In this context, plans have to be made immediately also for making possible the deployment of storage units within a RES plant, using simplified procedures. * The main categories of flexibility sources are dispatchable power plants, storage, interconnections and demand response. * For islands that are not expected to be interconnected, a significant reduction in the use of diesel for power generation is also being promoted, with the setup of state-of-the-art RES plants combined with storage technologies * in RD&I, Transformation of the transport sector, to be achieved by reducing the cost of small-scale electricity storage technologies and of electromobility * the development of both centralised and decentralised storage units is expected to contribute towards the attainment of the goal of optimal integration of RES in electricity networks. * Storage systems are expected to play an important role in reducing RES cuts in the system as a whole, to address local congestion problems and to ensure more adequate capacity and better system flexibility. Combining RES plants with energy storage systems, i.e. where they share a common connection point (storage system installed behind the meter or at a point in the distribution network downstream the same point of connection with the high voltage system), can mitigate the impact of RES plants on system operation, smoothing out variations in generation, provided that there are no operating problems. * Both centralised and decentralised storage units require the development of a comprehensive regulatory and statutory framework for their operation in energy markets and their integration in electricity networks. * The options for coupling the electricity and gas sectors (power-to-gas) through storage applications that include conversion of electricity into renewable gas, such as hydrogen, are equally important. The

Topic	Greece - Policy description
	gas produced by using RES energy may be fed into the existing gas network and used as fuel for heating in buildings or in transport. * A key objective of centrally distributed storage systems is the development of storage units, including existing ones (Sfikia-Thisavros ~ 700 MW) and including projects of common interest (PCIs). The precise additional required power of storage systems, capacity, and technology of storage units will result from relevant studies that will be based on both the economic benefits they provide to the operation of the system and their contribution to power adequacy and flexibility of the System. * Policy measures to promote the installation of electricity storage systems may vary depending on the technology and type (centralised, dispersed) of the storage system (such as pumped storage projects in the area of Amfilochia and Amari, Crete). In particular, the promotion of centralised electricity storage systems is possible through the implementation of an appropriate purchasing mechanism, which will motivate the construction of storage systems over other electricity generation plants. * With regard to energy storage, measures will be taken to strengthen the development of new or improved electricity or thermal energy storage technologies with higher efficiency, availability, durability, security and at the lowest cost. Support will be provided for electrochemical energy storage technologies, which relate primarily to RES applications for utilisation in non-interconnected electricity networks or in remote points in the electricity network. * The essential characteristics of the electricity generation system until 2030, in line with the objectives achievement scenario, the NECP indicates 1.4GW Power of new central storage systems (batteries)
2. Permitting	* Permitting process for hybrid facilities (cf. section 8 for hybrid facility definition) follows the same rules which apply for the renewable generation component of the station
3. Energy Markets and Capacity Mechanisms	DA/ID markets: *Energy storage is able to participate in DA and ID markets * Regulatory framework for active consumers to participate in ID & DA was not in place in 2020 Capacity mechanisms: *CM does not allow storage * The participation of front-of-the-meter storage facilities in the upcoming target model has not yet been announced
4. Ancillary Services	Balancing market: * Regulatory framework for active consumers to participate in balancing markets was not in place in 2020 * Design of some products not compliant Electricity Target Model including aggregation of load not allowed, validity period, settlement rule, activation rule * Storage not allowed in 2020 to provide transmission-level voltage control services * Electricity storage is not yet eligible to provide other ancillary services
5. Grid Aspects	* No double charging in 2020 for transmission-connected storage * Withdrawal charges for prosumers connected to the distribution grid. * Stand-alone front-of-the-meter storage is not described as a specific asset in the network code and therefore should comply to the consumer and producer's rules. * Net metering for self-producers allows behind-the-meter storage. No injection to the network is allowed, as defined by the regulatory framework (Law 4513/2018) and corresponding Ministry of Energy regulation 15084/382 (2019). * Content, targets and data of the NECP approved in December 2019 are taken into account. * PHS & other storage facilities (e.g. batteries) are allowed & included in network development plan. * From the public consultations stakeholders' comments and responses are published * Not all DSOs prepare an NDP; other alignment/joint activities DSO/TSO
6. Taxes & Levies	* No specific mention of electricity storage identified in the legislation, assumption is that charging is treated as consumption for the electricity consumption tax and levy purposes. * No information identified on absence of double taxation for energy storage, thus assume it exists
7. Other & General	* Storage is a necessary component in the definition of a hybrid installation. According to the national legislation (definition in Law 3468/2006), hybrid installation is one: - Which uses at least one form of renewable energy source. - Where the total energy which the hybrid installation consumed from the grid, should not exceed 30% of the overall energy which is stored, on a yearly basis. - The maximum capacity of the renewable energy generation does not exceed 120% the storage capacity.

Topic	Greece - Policy description
8. Barriers	
9. Best practices	* Support mechanisms for renewable electricity in islands addresses and remunerates hybrid installations

Hungary

Topic	Hungary - Policy description
1. Public Support	The NECP refers to electricity storage * The construction of a new gas turbine power plant at the Mátra power plant site, which is particularly important for the security of supply in the Eastern part, is under investigation, is the construction of a new photovoltaic (PV) power plant and industrial energy storage unit, as well as the energy recovery of non-recoverable waste (RDF).The Mátra power plant site and/or the Northern Hungary region hosting it offers a good opportunity to carry out low carbon energy production and storage projects that can relieve other areas of pressure * Short-term fluctuations in weather-dependent production can be offset today mainly by gas-fired power plants, but there should also be scope for the spread of new innovative solutions such as energy storage and demand response * The Energy Innovation Council (EIT) composed by the Minister for Innovation and Technology, the Hungarian energy and industrial companies, universities, research institutes, professional organisations, the Energy Regulator (MEKH) and several Ministers identified, among the options for intervention areas: Innovative System Balance (Flexibility Storage and Demand Management). * regarding the electricity market, it is essential that the domestic electricity system (including consumers) has controllable capacities guaranteeing safe operation and balancing. (E.g.: generation capacities providing flexibility; new types of flexibility services, DSR solutions, energy storage) * As regards energy storage, Hungary intends to encourage the use of energy storage systems to integrate renewable energy production. In order to ensure cost-effective integration of renewables, it will also be necessary to encourage the uptake of innovative technologies (energy storage, capacity building of existing network elements) and modes of operation (demand response). * The spread of seasonal electricity storage and battery storage, as well as grid developments and grids, will be supported from OPs and Modernisation Fund grants as of 2021 * Investment in energy storage and micro-grid solutions (facilitating single-site operation of renewables and energy storage facilities with regulatory tools) should be encouraged. It is necessary to simplify the authorisation process and regulatory market accreditation of energy storages, to develop regulatory products making better use of the technical potential of storages (e.g. the introduction of artificial inertia-type products), to promote innovative solutions in seasonal storage and to encourage the storage of heat by cogeneration producers. * In order to support the use of the necessary innovative solutions in seasonal energy storage, Hungary is also planning pilot projects: Converting excess electricity into heat and storing it in district heating systems using electric boilers; Development of optimal storage and use of electricity generated hydrogen * It is proposed to launch pilot projects on the distribution and transmission (DSO and TSO) side for energy storage systems * The creation of a complex pilot-sized research and development centre to test the systemic interconnection of different renewable energy sources and energy storage technologies is desirable * The aim is to develop complex price regulation that encourages the use of innovative smart solutions and the market procurement of flexibility services (e.g. energy storage, demand response). * Sector coupling is accentuating when the processes of producing different forms of energy (electricity and heat as well as fuels) are interlinked. The gas market and the electricity market are already interlinked on a number of points. However, in the near future, sector coupling could also cover new areas, e.g. replacing gas-based heating/cooling with renewable-based electricity or heat pumps in regions with low-use infrastructure or not connected to the gas network. The convergence of energy systems is also facilitated by the development of energy storage technologies (e.g. battery, heat storage, power-to-gas). * In digitised energy systems, communication between generation, demand, storage and grid is becoming faster * Priority is to improve innovation, with sub-focus on development of household and industrial scale energy storage technologies * Planned measure to develop household-scale small power plants combined with smart metering and electricity storage * The upcoming Energy Strategy will define the regulatory framework for among others electricity storage in batteries
2. Permitting	* The regulator is the competent authority responsible for licensing of all generation facilities. In case of any future development e.g. pumped hydro, it would act as the licensing body. * The Hungarian Act 86/2007 on Electric Energy requires the authorisation for the operation of an electricity storage facility with a nominal output capacity of 0.5 MW or more * The Hungarian Act 86/2007 on Electric Energy indicates the provisions (including in secondary legislation) for the authorisation of power plants shall apply to electricity storage facilities, mutatis mutandis

Topic	Hungary - Policy description
3. Energy Markets and Capacity Mechanisms	DA/ID markets: *Energy storage is able to participate in DA and ID markets * Legally, all markets are open for large and aggregated consumers, however participation is currently still limited. * Large consumers, retailers and aggregated consumers are allowed to participate in the Hungarian Energy Exchange HUPX. However, in 2016 entrance was difficult, expensive and with liquidity problems. The combination of over-the-counter contracts and participation at the exchange was then common. Capacity mechanisms: NAP
4. Ancillary Services	Balancing market: * Design of some products not compliant Electricity Target Model including min capacity (aFRR, mFRR), validity period, procurement lead time (88% month ahead), settlement rule * Aggregators are allowed to provide balancing services, as there is no special restriction or rules for aggregation. * Storage not allowed in 2020 to provide transmission-level voltage control services * Black start is remunerated by the TSO. If the gross installed capacity is more than 500 MW and the power plant is connected to the transmission grid, the service is mandatory. Some of the power plants are able to provide black start capability, but their gross installed capacities are less than 500 MW.
5. Grid Aspects	* No double charging in 2020 for transmission-connected storage * withdrawal charges for other storage facilities (e.g. batteries) and prosumers connected to the distribution grid. * There is no specific legislation about tariff discounts, transformation losses, or other grid aspects. * The assumptions and targets of the NECP are important inputs for the NDP. * PHS & other storage facilities (e.g. batteries) are allowed to be included, however are not included in network development plan. * From the public consultations a summary of stakeholders' comments is published. * A single high voltage NDP; each DSO prepares a plan that is part of the all network development plan > 132 kV.
6. Taxes & Levies	* There is no specific taxation regulation for energy storage in Hungary. If energy storage is interpreted as consumption, it could be subject to electricity consumption taxes.
7. Other & General	* There is no specific electricity storage regulatory regime in Hungary * Hungarian Act 86/2007 on Electric Energy: 'Electricity storage facility' shall mean an equipment used for storing electricity by way of physical or chemical means, meaning that it converts and stores in-put electricity, then releases it back to the electricity system minus technical waste; * In essence, the current legal situation is that energy storage shares the legal role of generators and are handled by the regulator as such.
8. Barriers	* The National Energy Strategy 2030 provides negative signals as pumped hydro is deemed as not an adequate option. * All potential pumped hydro sites are located close to the River Danube and other environmentally sensitive locations, which are Natura 2000 territories. On one such site the competent authority refused the necessary environmental license, later confirmed in court. * Storage is subject to double charging and to the electricity consumption tax. * Hungary requires the development of a regulatory regime for the participation of storage in energy, capacity and ancillary service markets. * The participation of storage in ancillary service markets is very limited, restricting the available revenue streams for storage projects.
9. Best practices	* Electrical energy act contains a definition of storage. * The government, regulator and system operators are actively exploring storage technologies, pilots and system integration.

Ireland

Topic	Ireland - Policy description
1. Public Support	* The Climate Action Plan 2021 recognises the important role of electricity storage, in supporting the transformation of the electricity sector. Under Climate Action Plan 2021, the Department of the Environment, Climate and Communications has committed to developing a national electricity storage policy framework, which is due for publication in Q1 2023. * To help inform this work, the Department will launch a public consultation in summer 2022. In addition, the Commission for Regulation of Utilities has committed to reviewing the regulatory treatment of storage in late 2023. * The Climate Action Plan 2021 also committed to increasing the share of renewables electricity up to 80% by 2030. * In Climate Action Plan 2021, the Department committed to completing the second auction under the Renewable Electricity Support Scheme (RESS) in summer 2022. The final results of the auction were published on 15th June 2022. The scheme has been adapted to support increased technological diversity, with provision to couple renewable generation with storage capability at project sites. Ireland also has a target of installing 5GW of offshore wind by 2030. The Climate Action Plan 2021 also commits to holding Ireland's first ever Offshore Renewable Electricity Support Scheme auction in Q4 2022. This will help to broaden the energy mix and enhance security of supply. * Addressing the challenges associated with the integration of large-scale storage technology will also be key as we move ever closer to full decarbonisation of the electricity sector. Building on our Climate Action Plan 2021 commitments, the Department of the Environment, Climate and Communications is currently finalising preparations for a public consultation on a Green Hydrogen Strategy. The strategy is due for delivery in Q3 this year and will outline the pathways towards the production of green hydrogen and its use in Ireland's energy mix. * Ireland is a leader in terms of the level of BESS it is accommodating. We have 0.4 GW of BESS already connected to the grid, with an additional 0.5 GW contracted to connect, and a further 0.5 GW due to be contracted over the next 12 months. This totals 1.4 GW in comparison to our system peak of around 5.5 GW, meaning BESS generation could meet 25% of our system peak within a few years. * In 2021 the Irish TSO published their roadmap for changes to the transmission network, the operation of the power system, and the power market, to make the grid ready to meet the 2030 targets. In their analysis to determine this roadmap we assumed up to 1700 MW of Battery Energy Storage would be installed in Ireland by 2030. Battery energy storage technologies are required in 2030 for reserve provision, capacity adequacy and to assist with congestion management. They assumed that the energy-to-power ratio of the battery fleet will increase over the period to 2030, with up to 550 MW of the installed battery storage having a long duration capability, i.e. an average duration of six hours Relevant references in the NECP * New efficient energy storage systems should be incentivised * R&I to focus on technologies at advanced readiness levels, prioritising energy storage technologies and solutions * Policies related to small scale battery storage should be developed to facilitate self-production; moreover a regional approach to strategically located battery storage facilities is suggested to alleviate pressure on national grid * R&I to focus on technologies at advanced readiness levels, prioritising energy storage technologies and solutions * At the present only one large scale pumped hydro station energy storage facility is in operation (Turlough Hill), however a large number of battery projects are in the process of connecting. Ireland has also supported the inclusion of the Silvermines Hydroelectric Pumped Storage facility on the EU's Project of Common Interest List. The proposed development will provide 1.8GWh of storage with 360MW export capacity and 360MW of pumping load. Projects of Common Interest are key cross border infrastructure projects that link the energy systems of EU countries but can also include storage projects such as Silvermines. The project is on the 5th PCI list which was published last November. * "Construction of energy storage shall help the island sustainability."
2. Permitting	* The standard permitting rules for power generation plants apply to energy storage plants e.g. planning permission (which covers environmental issues), power generation licence and authorisation to construct. The legislation does not differentiate between generation and storage technologies.
3. Energy Markets and Capacity Mechanisms	DA/ID markets: *Energy storage is able to participate in DA and ID markets Capacity mechanisms: * Multi-year capacity contracts in place, annual delivery period

Topic	Ireland - Policy description
	* Energy storage are allowed to participate in the Irish Capacity Remuneration Mechanism; the derating factors depend on the duration of storage being provided. The CRM offers additional revenues, which may have to be partly reimbursed if the market price exceeds the strike price in the contract (€500/MWh). * Developments in the area of sector coupling are at an early stage. Some companies provide a solution combining heating, cooling, electricity and energy storage
4. Ancillary Services	Balancing market: *BESS can participate in the balancing market to some extent, and work is being undertaken to fully integrate them. *Design of some products not compliant with Electricity Target Model for settlement rule (hybrid = system services are regulated and balancing services marginal prices) (FCR, aFRR, mFRR, RR) * Max/min price limits not compliant with Electricity Target Model * Storage technologies can qualify to provide voltage support (the SSRP service), as listed in the DS3-System-Services-Proven-Technology-Types.pdf (eirgridgroup.com). The SSRP service can be provided on either transmission or distribution level. This has been the case since the inception of the system services arrangements. New ancillary services: * FFR: Ireland & Northern Ireland by using conventional generators, CH, biomass, windfarms, batteries, flywheels, PHES, CAES, HVDC, AGU, DSUs, full activation time is 2s, required duration 8 s. Ireland (Eirgrid) & Northern Ireland (SONI) defined and procured inertial response products. Ireland & Northern Ireland use fast ramping products (1, 3 and 8 hours time horizon), sustained for durations of 2, 5 and 8 hours respectively. * Some ancillary services are currently a grid code requirement in terms of capability. Units can also contract under the DS3 System Service programme for availability payments for provision of these services, and also for the provision of non-obligatory services. The DS3 programme led by EirGrid (TSO) includes the development of an enhanced market for system services, System Services exist which cover both frequency and voltage services, and are open to all technology providers. A separate DS3 fixed 6 years contract for provision of 5 services (fast reserves with response provision within 300ms for a duration of 20 mins) is also in place with a limited number of providers (110MW). The fixed 6 year contracts require a response within 300 ms and there is an incentive to respond within 150 ms. * Current DS3 arrangements are due to end in April 2024. The high level design decision for System Services Future Arrangements (SSFA) was published by the SEM Committee in April 2022.
5. Grid Aspects	* An Enduring Connection Policy (ECP) was published under which generators (including storage) can apply for a connection through annual batches (for all types of applications). * In addition, successful participation in the CRM has entitled BESS projects to a grid connection in specific circumstances. * Through ECP and the CRM, 0.9 GW of BESS capacity has been contracted for a grid connection, with 0.4 GW already connected. An additional 0.5 GW is expected to be contracted over the next 12 months. * Currently, storage only pays ToU tariffs associated with its demand(MIC)/imported energy and not its export/MEC.Some of the transmission-connected pumped hydro storages are fully or partially exempted from withdrawal charges. Also, the Public Service Obligation charge (applied to all energy consumers in Ireland) which is based on Maximum Import Capacity (MIC) will only apply to the portion of the MIC related to house load when it is offline (i.e. neither importing or exporting) and not to the full MIC related to energy injection and absorption to/from the grid. * withdrawal charges for other storage facilities (e.g. batteries) and prosumers connected to the distribution grid. * PHS & other storage facilities (e.g. batteries) are allowed & included in network development plan. * The aspect of the network codes which currently applies to energy storage is a generic Power Park Module (PPM) code which was originally elaborated for wind generators. As with any new technology being incorporated onto the transmission system, it takes some time to gain operational experience, to enable understanding of the capability of the technology to comply with Grid Code and exactly what system services this new technology can offer, for the benefit of all users. With this in mind the TSO (EirGrid) has published a number of versions of the Battery Implementation Note; Grid Code modifications are expected to follow before the end of 2022. In the interim storage can seek temporary derogations from Grid Code, if required. * There is no net metering

Topic	Ireland - Policy description
6. Taxes & Levies	* Public service obligation levies are charged only based on the house load consumption. The levy is calculated on the basis of the Maximum Import Capacity (MIC). The Commission for Regulation of Utilities (CRU) determined in 2019 that the MIC for calculation of the PSO for energy storage plants was based on the MIC when importing at 'house load' (i.e. when neither importing or exporting).
7. Other & General	* Energy Storage has recently been defined in Irish legislation under statutory instrument 76 of 2022. “energy storage” means, in the electricity system, deferring the final use of electricity to a moment later than when it was generated, or the conversion of electrical energy into a form of energy which can be stored, the storing of such energy, and the subsequent reconversion of such energy into electrical energy or use as another energy carrier;”
8. Barriers	* Currently Energy Storage providers that are over 0.5MW are required to pay Demand Transmission use of system charges (D-TUoS). In addition, plants connected at distribution level will be subject to Distribution use of system charges (DUoS * The Use of System Charges rule places energy storage plants at competitive disadvantage to generation or distribution technologies. * As with any new technology being incorporated onto the transmission system, it takes some time to gain operational experience, to enable understanding of the capability of the technology to comply with Grid Code and exactly what system services this new technology can offer, for the benefit of all users. With this in mind the TSO (EirGrid) has published a number of versions of the Battery Implementation Note; Grid Code modifications are expected to follow before the end of 2022. In the interim storage can seek temporary derogations from Grid Code, if required * There is currently no market mechanism– on utilisation of storage devices to assist in congestion management/grid investment deferral. Congestion management is being considered for the future in the context of all technologies.
9. Best practices	* Public service obligation levy applies only to on-site consumption for storage.

Italy

Topic	Italy - Policy description
1. Public Support	The NECP refers to electricity storage * With regard to the safety and flexibility of the electricity system, the promotion of a broad participation of all available resources — including accumulations, renewables and demand — will need to be taken into account for the transformation of the system induced by the increasing role of renewables and distributed generation, testing new architectures and management modes, including with the active role of TSOs. Similarly, it is necessary to take account of the essential need for storage systems, to avoid overgeneration from installations for the production of electricity from renewable sources * Support to the deployment of distributed storage systems * Bundling of generating facilities including together with storage systems, and demand units for access to services markets * It also aims to promote the deployment and use of energy storage systems, including electric vehicles, including long-term accumulation, and the integration of the electricity system with gas and water systems * Among the most stressed topics in the sections on electric RES include positions expressed in favour of self-consumption, including in a collective form by enabling multi-user configurations within energy communities; the main arguments highlighted are the promotion of demand and supply aggregators in the PPPs and the development of an enabling environment for the full development of storage technologies, especially through pumped storage and batteries, but without neglecting the new borders of power to gas * The realisation of a large storage capacity, and storage solutions involving the use of alternative energy carriers (synthetic hydrogen/methane), is concentrated in the service of the network, is also indispensable in order to mitigate some problems and have appropriate flexibility resources * A further objective relates to the important development of the storage capacity, which will be gradually but increasingly addressed to "energy intensive" solutions, in order to limit the phenomenon of overgeneration and to support the achievement of the targets for the consumption of renewable energy. In this regard, Italy adopted a new legal framework through the legislative n. 210/2021, transposing the directive UE 2019/944, in order to promote, according to a specific market mechanism, investments in new storage capacity to be allocated to market operators. * For the coming years, it is also necessary to pursue a significant development of electrochemical storage * it has been estimated that in the medium term (around 2023) new storage systems for almost 1.000 MW in production are in production, between hydro and electrochemical * It is of particular interest to be the synthesis of hydrogen from excess renewable electricity to be used for the purposes of storage or entry in gas networks * The potential for thermal energy storage technologies, especially high-efficiency cogeneration systems and district heating networks, will also be considered * In summary, the objectives for the energy security of the electricity system and its quantification are: new storage systems installed for at least 6 GW by 2030 * Increasing the flexibility of the system is certainly one of the national targets for the internal energy market. It will be pursued both by making the existing thermoelectric power park more flexible and, above all, by extending market participation to new, flexible resources. These identify aggregation and demand response, the better involvement of distributed and renewable generation not programmable to services markets and the development of new storage systems * Development of storage systems, including thermal, electrochemical and power to gas, and their interfaces with networks, to ensure high levels of penetration of non-programmable renewables * Where self-consumed energy exceeds 40% of output, a specific premium is provided, which can also drive the deployment of storage systems * Legislative Decree No 102/2014 introduced the possibility to create aggregates of demand response, generating installations, including together with storage systems and vehicle-to-grids applications, allowed to participate to ancillary services markets; to this regards several pilot projects have been implemented so far with the aim to establish a more organic regulatory framework. * The sector on which Italy was relatively more active in electrical power in 2016, from an innovative perspective, is energy storage (one fifth of the total), but also photovoltaics and wind, which together attract 37% of the innovations produced in Italy, mainly from Lombardy and Lazio.
2. Permitting	* Specific permitting rules for electrochemical storage have been introduced in 2020 (as from the Law Decree No. 76/2020), also providing for significant simplification. Storage systems are subject to different authorisation procedures depending on the location of the storage system (e.g., non-industrial area or quarry areas), the power and type of plants to which the storage is connected. For pumped hydro storage permitting rule as for RES are applicable.

Topic	Italy - Policy description
3. Energy Markets and Capacity Mechanisms	DA/ID markets: * Energy storage is able to participate in DA and ID markets * The Italian energy markets do not specify the system actors which are able to participate, thus not blocking storage. However, the Italian wholesale energy markets do not have specific linked or loop block orders to allow tailored bids by storage. Capacity mechanisms: * The Italian Capacity Market (CM) is open to all technologies (Thermal Plants, RES, DSR, storage systems). Both existing and new capacity can take part to the auctions: contracted capacity will receive an annual premium (€/MW/year) and it will have to be offered to the market (either spot energy markets or ancillary service markets). However, whilst existing capacity can only sign a 1-year contract, new capacity (i.e. new or heavily-refurbished facilities) can opt for a 15-year contract, provided that investment costs are above a threshold defined by the NRA. * The legislative decree n. 210/2021 has called for the Regulator to strengthen and promote the development of aggregations, including ones independent from the suppliers. * As previously stated, storage systems can participate in the Italian CM. In the latest auction (delivery period 2024), 1.12GW of available capacity (i.e. Capacità Disponibile in Probabilità, CDP) was provided by new storage systems, with an average duration (i.e. an energy-to-power ratio) of around 4 hours. * The legislative decree n. 199/2021, transposing the directive EU 2018/2001, introduced a process for the phase out of the « scambio sul posto » mechanism and to promote the development of storage systems in combination with the RES plants * Most behind-the-meter storage installed in Italy (and concentrated in the Lombardy region) is for increasing self-consumption of renewables.
4. Ancillary Services	Scheduling phase and Balancing market: * Storage units of at least 10 MW and with specified technical performances are required to participate in the Italian Ancillary Services Market (both scheduling phase and balancing market) as single production unit *Storage units participating in the Ancillary Services Market participate also in the RR Platform as referred to in Trans European Replacement Reserves Exchange (TERRE) in place for exchange of balancing energy from replacement reserves. * Storage units participate in the ancillary services market (secondary reserve, tertiary reserve, relief of intra-zonal congestions, real-time balancing) as UVAM (mixed aggregated virtual power plants) if they are smaller than 10 MW. * The Fast Reserve project for the procurement of rapid FCR (under 1 s) by production and non-conventional resources was approved in 2020, with a first delivery period for 2023-2027. The size of each FRU must be over 5 MW. * The UPI project has been implemented by the TSO Terna, allowing the procurement of primary frequency regulation services from power plants above 10 MW with storage systems. * Max price limit compliant with Electricity Target Model Mechanisms to value distributed flexibility sources: *UVAM *Local flexibility platforms & other initiatives: EQUIGY ; Platone
5. Grid Aspects	* No double charging in 2020 for transmission-connected storage * Withdrawal charges applied to prosumers connected to the distribution grid, however, not to other storage providers. * ARERA regulation 574/2014/R/eel updated the connection and access rules to include energy storage. Tariff discounts for withdrawal from pumped hydro are extended to all electricity storage technologies, as long as energy is not intended for final consumption. This means that hybrid configurations of storage system also combining consumption assets are not eligible for the discount. Hybrid generation + storage assets are classified as generation, and energy offtakes by these hybrid assets are differentiated between withdrawals intended for powering storage (treated as negative energy input) and withdrawal intended for powering the auxiliary generation (treated as withdrawals). In either case, consumption by hybrid generation + storage assets for ultimately providing system services is exempt from grid charges. * ARERA regulation 109/2021/R eel defines the rules for the extension of the exemption on transmission and distribution grid charges to complex configurations such as the combination of consumption and

Topic	Italy - Policy description
	storage. The ARERA scheme is that all electricity drawn from the grid and intended to power the storage systems for subsequent re-injection in the network and / or the auxiliary generation services should be treated as negative electricity input for determining tariffs. This would apply also to cases such as aggregated assets or vehicle-to-grid. * ARERA, on August 4, 2021, issued a further resolution 352/2021/R/eel proposing the launch of pilot projects for the procurement and remuneration of local ancillary services, with the aim of assessing the most appropriate negotiating solutions for all Italian DSOs. The services could be provided by any kind of DER, including energy storage facility operators and aggregators, on the basis of non-discriminatory clauses allowing the widest possible participation, with a view to technological neutrality. The resolution was then confirmed by new legal provisions with the legislative decree n. 210/2021 providing for new functions and responsibilities by the DSOs that comprise procedures in cooperation with the TSO to facilitate the participation to the ancillary service markets of all resources connected to the distribution grid and to procure local services for the security of their networks. * According to art. 38-ter of the connection network code (TICA), when storage has the same economic conditions and procedures as for high efficiency combined-heat-and-power plants, it still has to pay the connection charge. * The Italian NECP was partly taken into account when preparing the draft NDP 2020. One scenario was developed (although only for the study years 2025 and 2030, not 2040) with assumptions coming from the NECP. * PHS not allowed to be included in network development plan & other energy storage facilities (e.g. batteries) are allowed, however are not included. * Introduction of additional public consultations in the process of scenario preparation in Italy and introduction of two additional public consultations (which are completed) regarding the infrastructure needs assessment (target capacity methodology and target capacity report); Published stakeholders' comments and responses * Currently, not all DSOs prepare an NDP, data exchanges regarding scenario's and/or assumptions. In this regard, the legislative decree n. 210/2019, transposing the directive (UE) 2019/944, introduced an obligation on DSOs to prepare a specific NDP also accounting for the flexibility needs of its network.
6. Taxes & Levies	* The Italian tax authority confirms the installation of a storage system with residential PV does allow deducting the appropriate costs for tax purposes, irrespective of whether the storage system was installed together or after the PV system (Circular Letter No. 7/E of 2018). In addition, in the 2019 the Italian tax authority published the circular n. 13/E which forbids the detaxation for residential storage device if PV plant receives subsidies in the Conto Energia. * The 2020 Italian Budget Law 160/2019 includes tax credits for new high-tech assets, qualifying under the Industry 4.0 Plan. Credits amount to 40% for investments up to €2.5 million and 20% for investments from €2.5 to €10 million. * Self-consumed stored energy is exempt from taxes. No other specific mention of electricity storage identified in the legislation, thus other storage is treated as consumption for the electricity consumption tax and other levy purposes.
7. Other & General	* Regulatory decision 574/2014/R/eel: A storage system is a set of devices able to absorb and release electric energy, foreseen to work continuously in parallel to the grid or able to modify the energy exchange with the electricity grid. The storage system may or may not be integrated with a generating plant. Systems that enter into function only in emergency conditions like during a black out are not considered to be a storage system.
8. Barriers	* Further information is needed on ancillary services are needed to develop a storage business plan based not only on the energy market.
9. Best practices	* The Italian tax authority clarified tax rules, confirming the installation of a storage system with residential PV does allow deducting the appropriate costs for tax purposes, if the residential PV plant does not receive subsidies in Conto Energia. * GSE (the authority managing the payment of incentives) confirmed and regulated the installation of a storage system in an existing PV power plant receiving subsidies, in order to remove uncertainties.

Latvia

Topic	Latvia - Policy description
1. Public Support	The NECP refers to electricity storage * The NECP indicates the Latvian Innovation Fund should cover a wide range of projects beginning in 2020, including innovative renewable energy and energy storage technology projects.
2. Permitting	* There are no specific requirements for permitting of storage facilities in national policies. Access permits are issued by the Ministry of Economics, while access to the grid is subject to technical regulations issued by TSOs or DSOs. Requirements in regulations are the same as for other infrastructure.
3. Energy Markets and Capacity Mechanisms	DA/ID markets: *Energy storage is able to participate in DA and ID markets * Regulatory framework for active consumers to participate in ID & DA was not in place in 2020 Capacity mechanisms: *NAP * In 2013, the Nord Pool power exchange started operations in Latvia. Nord Pool day ahead and intraday markets are open to storage. The day ahead products include hourly and block orders, while the intraday market offers 15-minute, 30-minute, hourly and block products. * Storage for consumer energy management (e.g. peak shaving) and from electric vehicle integration is not developed in Latvia. * Planned heat storage within Riga CHP-2 plant will increase flexibility provision significantly.
4. Ancillary Services	Balancing market: * The Latvian Regulatory Authority approved amendments to the National Network Code in line with EU Regulation 2017/2195, stating that energy storage companies may participate in the provision of a balancing service. * In 2018, the Baltic common balancing market came in operation, covering mFRR. Storage is allowed to provide mFRR services. For mFRR the product duration is 15 min, the minimum bid size is 1MW. * Currently, only FRR is used in the Baltic balancing market. The Russian Unified Power System (UPS) provides FCR and FRRa, while Baltic TSOs also provide RR * Regulatory framework for active consumers to participate in balancing markets was not in place in 2020 * Not open for independent aggregators in 2020 * Design of some products not compliant with Electricity Target Model including: max delivery period (mFRR), validity period, length of balancing contracts * Not compliant with Electricity Target Model: max price limit, no min price limit implemented * Single pricing, single position compliant with Electricity Target model * Storage not allowed in 2020 to provide transmission-level voltage control services Mechanisms to value distributed flexibility sources: *Local flexibility platforms & other initiatives: INTERRFACE (T/DSO)
5. Grid Aspects	* No double charging in 2020 for transmission-connected storage * Withdrawal charges for prosumers connected to the distribution grid. * Net metering for renewable energy installations with a small-scale connection (under 3*16A amperage) was instituted in 2017 in the Electricity Market Law. * There are no specific rules for energy storage facilities to connect and access electricity grid. Storage facilities are considered as generators when supplying power to the grid and as consumers when consuming power from the grid. * The NDP was set taking into account the NECP. In addition to the assessment of the progress in the implementation of the plan, twice during the planning period (in 2024 and 2028), an environmental monitoring report will be prepared and submitted to the State Environmental Monitoring Bureau. * PHS not allowed to be included in network development plan, other energy storage facilities (e.g. batteries) are allowed & included. * From the public consultations the stakeholders' comments and responses are published.
6. Taxes & Levies	* No specific mention of electricity storage identified in the legislation, assumption is that charging is treated as consumption for the electricity consumption tax and levy purposes.
7. Other & General	* Energy storage is not defined in the national regulatory framework.
8. Barriers	* There is no regulatory framework for storage in Latvia.

Topic	Latvia - Policy description
	* Grid and taxation aspects (double charging of network tariffs, net metering for renewable energy producers with small connections) limit the business case for storage, front- and behind-the-meter.
9. Best practices	* The Baltic states implemented the Baltic common balancing market, with storage being able to provide the first product, mFRR.

Lithuania

Topic	Lithuania - Policy description
1. Public Support	The NECP refers to electricity storage: * Lithuania plans to reach by 2030 45%.RES target in final energy consumption. Therefore, investments in smart energy systems, including transmission, distribution and storage infrastructure, and in increasing the required balancing capacity are envisaged in order to successfully integrate larger volumes of renewable energy and a large number of electricity-generating customers * In addition, Lithuania's 2021-2027 operational programme for investments from the European Union funds is directly linked to the implementation of the Commission's recommendations, with a view to allocating EU funds investments to such tasks, such as: developing smart energy systems and grids, as well as local energy storage solutions * The planned capacity mechanism will be technologically neutral, as it will be open not only to electricity generation but also to existing and future electricity installations to be installed (built) by the participants in the capacity auction before the start of the capacity delivery period, but also to installations managed by storage and independent electricity demand aggregators. * Objectives set out in the National Energy Independence Strategy, with, among the priority axes for energy research and experimental development: Development and integration into the grid of new technologies for low greenhouse gas emissions and ambient air pollutants that are resilient to climate change changes in energy production and storage; and integration into the EU's strategic value chains * Promote the production of electricity storage technologies by attracting investment in the production of these technologies in Lithuania * Financing the deployment and storage of RES energy generation solutions * The generating customer shall be given the opportunity to 'store' the electricity produced by him and not consumed by him for his own use in the electricity networks between 1 April of the current year and 31 March of the following year. The producer shall pay a network access charge for the amount of electricity that he has 'stored' and recovered from the electricity networks[378]. The amount of electricity supplied to the electricity grid in excess of the electricity consumed by the customer during the storage period shall not be carried forward to the next storage period * It is envisaged that the 'prosumer' scheme will continue until April 2040 by granting the right to "storage" electricity produced and not consumed by the economy in the electricity networks * In addition to the smart meter, it is also planned to introduce a smart metering system for meter management; reliable data collection, storage and analysis * Financing of energy security projects (with CEF): Field and infrastructure studies for the Kruonis pumped storage plant (Kruoni HAE) * Litgrid is currently carrying out a pilot battery project to check the availability of battery storage systems under realistic operating conditions of the Lithuanian electricity system. Battery storage systems can contribute to maintaining the required level of inertia (synthetic inertia function) and to ensuring very rapid reserves of regulatory powers, which would contribute to improving system adequacy in preparation for synchronous work with continental European networks * Promote the integration of electricity storage facilities and services into the electricity market * Consumers will be able to consume, store and sell self-generated electricity to the market and participate in all electricity markets and contribute to increasing the flexibility of the electricity system through energy storage. * The Action Plan for the implementation of the National Energy Independence Strategy includes policy measures in the research, innovation and competitiveness sector up to 2030: Develop and implement a common data storage and exchange platform * The funds allocated to Lithuania in the Modernisation Fund would be used for the modernisation of energy systems, the deployment of energy storage solutions in both district heating and electricity transmission and distribution networks in order to integrate the planned ambitious RES levels

[378] https://www.vert.lt/atsinaujinantys-istekliai/Puslapiai/elektros-energija-gaminanciu-vartotoju-naudojimosi-elektros-tinklais-Service-prices.aspx

Topic	Lithuania - Policy description
	* Planned policy measures for RES in the electricity sector up to 2030: AEI8. Financing of RES energy deployment and storage solutions, including prosumers, RES Communities (EU support) ; AEI19. Promote the use of RES for CHP heat generation by assessing the potential of solar technologies, heat pumps and heat storage in CHP systems; * Planned market integration policies up to 2030: ERC26. Promote market integration of energy storage facilities and services; ERC28. Kruoni pump-storage plants (KHAE) implementation of the construction project for Unit 5 * The Ministry of energy actions on 'improvement of power generation infrastructure, energy distribution networks and energy storage' forecast as a cross-cutting adaptation policy for 2021-2030 with EU funds, but no budget is indicated.
2. Permitting	* No specific measures or requirements for permitting of storage facilities identified in national legislation.
3. Energy Markets and Capacity Mechanisms	DA/ID markets: *Energy storage is able to participate in DA and ID markets * Regulatory framework for active consumers to participate in ID & DA was not in place in 2020 Capacity mechanisms: *NAP * In 2012-2013, the Nord Pool power exchange started operations in Lithuania. Nord Pool day ahead and intraday markets are open to storage. The day ahead products include hourly and block orders, while the intraday market offers 15-minute, 30-minute, hourly and block products. * The 2017 Law on Necessary Measures against the Threats Posed by Unsafe Nuclear Power Plants in Third Countries stipulates that the Lithuanian electricity storage facilities (Kruonis Pumped Storage Hydroelectric Plant) cannot be used for storing electricity generated by unsafe nuclear power plants in third countries. * The Lithuanian CRM is technology-neutral and thus allows for the participation of storage and DSM. A consultation was closed in February 2019 and the first auction is forecasted to take place by March 2020. * The Kruonis pumped hydro plant has a significant role in the Lithuanian power system.
4. Ancillary Services	Balancing market: * In January 2018, the Baltic common balancing market came in operation, covering mFRR. Storage is allowed to provide mFRR services. For mFRR the product duration is 15 min, the minimum bid size is 1MW. The ENTSO-E ancillary systems survey of 2018 however indicates only pumped hydro is eligible to provide FRRm to TSOs, while batteries are not yet eligible to provide AS. * Currently only FRR is used in the Baltic balancing market. The Russian Unified Power System (UPS) provides FCR and FRRa, while Baltic TSOs also provide RR. * Energy Cells (a publicly-owned subsidiary) contracted 200 MW of battery storage to provide islanded operation in phase I of the project (until 2025) until the Baltic countries are synchronised with the Continental Europe Area and also balancing and synthetic inertia in phase II (post-2025). * Regulatory framework for active consumers to participate in balancing markets was not in place in 2020 * Design of some products not compliant with Electricity Target Model including max delivery period 60 minutes (mFRR), validity period, length balancing contract, max/min price limits * Single pricing, single position compliant with Electricity Target Model * Storage not allowed in 2020 to provide transmission-level voltage control services
5. Grid Aspects	* No double charging in 2020 for transmission-connected storage * injection & withdrawal charges for prosumers connected to the distribution grid. * Baltic synchronisation project * The political roadmap on the synchronisation of the Baltic States to the Continental Europe electricity network is from 2019. Studies performed by the Baltic and Polish TSOs decide on how to provide regulating power from HVDC links, where battery systems were identified as a viable alternative to frequency regulation by HVDC systems. Final investment decisions are not due in the next years while the technical capabilities of large battery systems are not proven, but preparatory steps are being taken. * The Connection Agreement foresees additional studies with battery system suppliers regarding several technical and economic analysis on such a battery system. * The NDP took into account the NECP. For example, it considered future development of renewable energy resources. The TSO also planned to introduce new environmentally friendly technologies and equipment, leading to energy savings. * PHS and energy storage facilities (e.g. batteries) are allowed to be included in the network development plan, however are not included.

Topic	Lithuania - Policy description
6. Taxes & Levies	* No specific mention of electricity storage identified in the legislation, assumption is that charging is treated as consumption for the electricity consumption tax and levy purposes.
7. Other & General	
8. Barriers	
9. Best practices	* The Baltic states implemented the Baltic common balancing market, with storage being able to provide the first product, mFRR.

Luxembourg

Topic	Luxembourg - Policy description
1. Public Support	There are mentions to storage in the NECP: * Luxembourg intends to become a pioneer for the successful implementation of a large-scale nation-wide energy transition. Sustainable and energy efficient buildings with local flexibility options and/or energy storage capacity, as well as sustainable mobility components (smart grids) will form the main pillars of this system * Lists decentralised storage and flexibility options as cornerstone for future developments.
2. Permitting	* There are currently no specific permitting rules applied to storage devices. The draft revision of the law on the organisation of the electricity market authorises all end users to own and operate energy storage devices within certain technical limits.
3. Energy Markets and Capacity Mechanisms	DA/ID markets: *Energy storage is able to participate in DA and ID markets * Regulatory framework for active consumers to participate in ID & DA was not in place in 2020 Capacity mechanisms: *NAP * For the time being, the role of energy storage in consumer energy management is negligible. The new legal provisions on self-consumption and energy communities might lead to an accelerated development. * The "Vianden Pumped Storage Plant", one of the largest in its kind in Europe, is located in the Grand-Duchy of Luxembourg with a capacity of 1,3 GW and approx. 5.000 MWh. Owned and operated by the Société Electrique de l'Our S.A., it contributes significantly to the flexibility and reliability of the electricity system in the greater region. * Heat storage capacities used for the operation e.g. district heating systems do not play an important role in Luxembourg and none of those contributes to the flexibility needs in the electricity sector.
4. Ancillary Services	Balancing market: * Ancillary services for the Luxembourg grid area are procured by the German TSO Amprion on behalf of the Luxembourg TSO Creos due to the fact that they are in the same LFC area. Conditions are settled in a service contract. Mechanisms were being developed to fully enable assets in Luxembourg to participate in these procurement processes. * No information identified on storage not being eligible to participate in balancing markets * Regulatory framework for active consumers to participate in balancing markets was not in place in 2020 * Design of some products not compliant with Electricity Target Model including aggregation of load not allowed, procurement lead times * Compliant with Electricity Target Model: max/min price limits
5. Grid Aspects	* No double charging in 2020 for transmission-connected storage * injection & withdrawal charges for other storage facilities (e.g. batteries) & prosumers connected to the distribution grid. * There are no specific provisions that apply to the grid connection and access rules of energy storage facilities. * Consumption of self-produced electricity from renewable energies involving storage devices is exempt from the variable grid tariff, however, a fixed capacity fee is still due * The NDP takes into account the NECP. * PHS and other energy storage facilities (e.g. batteries) are not allowed to be included in network development plan. * Regarding public consultations; only the scenario development part of the NDP is consulted by the TSO * Regarding TSO/DSO coordination NDPs: other alignment/joint activities DSO/TSO
6. Taxes & Levies	* According to the legislative framework, 'the energy consumption used for storage purposes' and 'the energy consumption used to produce electricity or used to maintain the capacity to produce electricity' is exempt of the electricity consumption tax. * Self-consumption - with or without storage devices - is exempt from the renewable levies
7. Other & General	
8. Barriers	* Full market access of assets to all ancillary service procurements, also see 4.
9. Best practices	

Malta

Topic	Malta - Policy description
1. Public Support	The NECP refers to electricity storage: * key policies and measures regarding Energy Security in the context of the long-term objective of decarbonisation of the energy system and increased deployment of RES, will address Energy storage solutions and demand management * The importance of utility battery storage systems for security of supply reasons was also raised during the public consultation process * Ensuring system stability will either require significant spinning capacity, utility scale battery storage or flexible balancing services over the electricity interconnector with Sicily. However, the latter is limited to 200MW (the capacity of the interconnector) and would in practice be lower if already meeting part of the load * Currently, Malta has no utility scale battery storage facilities, and keeping large spinning capacity is highly inefficient and may not be technically viable at all times * Increasing the flexibility of the national energy system, including through the roll-out of cost-effective, innovative solutions such as storage * The Government will continue to assess innovative, viable and cost-effective solutions tailored to the specificities of Malta's energy system, such as the deployment of energy storage solutions, which would incorporate aspects related to increased RES generation * RES electricity in Malta is almost exclusively generated from photovoltaic systems with no storage capability and significant intermittency caused by highly variable and localized cloud cover. * Support for additional PV capacity shall also be aligned with the exigencies of a stable grid and shall consider options which facilitate the integration of battery storage. This promises to provide several benefits, including mitigation of overvoltage on the LV network, peak shaving, increased self-consumption and demand management. However, this depends significantly on the availability of storage solutions at an appropriate price point, such that any Government intervention can yield the desired results. * Battery storage. As of 2020, a pilot scheme supporting the integration of battery storage with PV systems will be launched. Early adopters of solar PVs whose feed-in-tariff has expired will be eligible to receive a 25% grant (capped at €1,000) against the purchase of a battery system for the storage of renewable energy and therefore increase the share of self-consumption. A preliminary study was conducted in 2019 to assess the feasibility of such a measure; the pilot project will feed into this continuing assessment. It is likely that a large-scale roll-out of battery storage systems for households, PV-integrated or stand-alone, would require a significantly higher level of support or lower cost of storage than at present. In this regards Malta shall be seeking EU funds (including Cohesion funds) to bridge the gap * The Government is closely monitoring the development of the energy storage market considered essential for further deployment of photovoltaic capacity and for optimisation of the power system by providing for demand management and peak demand shaving * It's important to note that the range of storage solutions which could be successfully implemented in Malta is also limited. For instance, the predominant large-scale energy storage solutions, such as pumped-storage hydropower are not available in the Maltese context * Enemalta is required to apply economic dispatch which would also include aggregation, demand response and storage subject to technical requirements * Utility scale battery storage is being studied not only for security of supply reasons, but also with respect to grid stability considerations, which is currently one of the barriers limiting Malta's renewable energy potential post-2020. Investments in storage infrastructure will facilitate further deployment of renewable energy * Enemalta will monitor the development of the energy storage market.
2. Permitting	* There are no specific permitting requirements for storage nor clarity on whether it would be considered as generation. This was one of the reasons for a project not to connect to the grid while testing. In terms of the Electricity Regulations (S.L.545.34) which transpose Directive 2019/944, energy storage must be notified to the Regulator. The notification of storage is required after connection to the grid.
3. Energy Markets and Capacity Mechanisms	DA/ID markets: * There is no liquid wholesale market in Malta. Capacity mechanisms: *NAP
4. Ancillary Services	Balancing market: * Balancing in Malta is conducted by the DSO in coordination with the Italian TSO. Only the DSO has balancing responsibility in Malta
5. Grid Aspects	* no injection charges for prosumers connected to the distribution grid, however, MS does apply withdrawal charges for prosumers.

Topic	Malta - Policy description
	* Since 2010 there is no net metering scheme in Malta, as it was substituted by a feed-in tariff. *Network tariffs are partly covered through all inclusive retail tariffs which are charged only on units consumed from the grid. Consumers pay a fixed charge as consumption point and not related to existence of storage or otherwise
6. Taxes & Levies	* No specific mention of electricity storage identified in the legislation, and thus charging from the grid is treated as consumption for the electricity consumption tax and levy purposes.
7. Other & General	* Energy storage is defined in the Electricity Regulation (S.L.545.34)
8. Barriers	* There is currently no regulatory framework for electricity storage in Malta, which overall represents an important barrier and requires a case-by-case approach, resulting in significant uncertainty. * The absence of a liquid wholesale market in Malta generally forecloses the participation of storage in energy markets. * Technical requirements to connect storage to the grid are catered for by the Electrical Installations Regulations (S.L.545.24)
9. Best practices	* R&I policies already address energy storage projects/technologies.

Netherlands

Topic	Netherlands - Policy description
1. Public Support	The NECP provides insights about the order of magnitude of needed controllable capacity, an estimated 15-17 GW in 2030 and 17-27TWh a year. It furthermore refers to electricity storage as follows: * Typical issues that may arise at regional or local level include, for example, the spatial integration of renewable energy options, as well as the storage and infrastructure of heat and electricity * The Netherlands already has a lot of flexibility to deal with the loss of supply or demand in line with market conditions. The Netherlands does not have separate targets for increasing the flexibility in the system. Flexibility in the form of demand response, storage or controllability is interconnected in the electricity market and is traded through the different markets without the precise identifiable element of flexibility * The growth of the number of smart meters will also enable consumers, if they so wish, to react to real time prices, with or without aggregators. In addition, any barriers to storage will be removed. The transition to electric driving can contribute to this. * New opportunities such as the deployment of flexibility, energy storage, demand and orientation and congestion management will also look at how to maximise the available space on the grid with the lowest social costs * Flexibility is further unlocked by [further] introducing dynamic tariffs in the retail market. There is a great deal of flexibility in the system, such as large scale users, which are flexible and responsive to real time prices by switching up, up- or down, and parties with storage assets dealing with different markets. Where necessary, barriers to storage will be removed * In general, the Dutch authorities pursue electricity market frameworks that promote fair competition between market players and therefore do not discriminate against any party. These include those providing renewable energy, demand response and storage, including aggregation. No separate national targets have been set for this purpose * Energy tax and energy bill: There are a number of changes in energy taxation and in the Sustainable Energy Storage (ODE) with an impact on energy bills. The gas tax is increased. Additional funds raised in this way will be refunded by a higher tax reduction and a lower taxation of electricity * The Netherlands has great potential for producing renewable electricity. An important part of energy security for the Netherlands is the potential for large-scale and long-term storage of renewable electricity. The development of power to gas is crucial to continue to supply a large part of its own energy needs and the storage of renewable electricity in the form of a gas entails flexibility for the electricity tourism system and a renewable energy carrier for the sustainability of transport and mobility, the industry and the built environment the Netherlands do not do so * Dynamic tariffs are also more and more entering the retail market. There is a great deal of flexibility in the system, such as large scale users, which are flexible and responsive to real time prices by ramping ups, up- or downstream storage, and parties with storage assets dealing with the different markets. In the area of Energy (TSE), systems integration and flexibility are becoming increasingly common and financial support for research (innovation).In addition, the TSO also runs several pilots with pooled/aggregated storage of small-scale storage devices such as home and electric cars
2. Permitting	* No specific permitting rules are defined, and storage characteristics are not suited for the current permitting regulations. This gives municipalities autonomy to determine their own requirements, which increases the permitting complexity. * For aquifer thermal energy storage (ATES) specifically, multiple legislation addresses the use of underground resources, environmental protection, permitting and monitoring, as well as accompanying manuals and other tools. * Businesses indicate the lack of standards (regarding storage safety such as prevention of fire and heat dissipation) is a reason to be reluctant to invest on a large scale in lines for products and services based on storage, and that it will be necessary especially for underground energy storage to obtain social acceptance.
3. Energy Markets and Capacity Mechanisms	DA/ID markets: *Energy storage is able to participate in DA and ID markets * Regulatory framework for active consumers to participate in ID & DA was not in place in 2020 Capacity mechanisms: * There is no Dutch capacity mechanism. * The National Energy and Climate Plan indicates dynamic retail rates will be further expanded, beyond current practices. Several electricity suppliers already provide dynamic (hourly) retail prices. * In 2018 the EPEX energy exchange introduced loop block orders, where two block orders are executed or rejected together, representing for example the storage cycle.

Topic	Netherlands - Policy description
	* There are over 2500 aquifer thermal energy storage systems in the Netherlands, with a total capacity above 1 GW and reducing both total and peak energy demand. Strong growth is forecasted to 2020. In August 2018 the total battery capacity of EVs was 2532 MW.
4. Ancillary Services	Balancing market: * FCR cooperation project active, allowing for provision of FCR capacity by storage. Storage balance service providers in the FCR market are considered generation, but there is a differentiation made between energy-limited sources (e.g. batteries) and unconstrained sources (large gas or coal-fired production units). It is also possible to pool various storage assets under a single balancing service provider (BSP), facilitating the satisfy the FCR market requirements. * Batteries could provide also FRRa services. There is no pumped hydro in the Netherlands. * No other information identified on storage not being eligible to participate in balancing markets * Regulatory framework for active consumers to participate in balancing markets was not in place in 2020 * Not open for independent aggregators in 2020 * Design of some products not compliant with Electricity Target Model including min delivery period (mFRR), min capacity required (mFRR), min bid size capacity (mFRR) * For all balancing products pooling is allowed; dynamic pooling for mFRR and aFRR is allowed * Storage not allowed in 2020 to provide transmission-level voltage control services Mechanisms to value distributed flexibility sources * Local flexibility platforms & other initiatives: Enervalis (DSO & third party), ETPA (power exchange, TSO/DSO); main driver of flexibility is HV congestion (Source: Accenture); GOPACS (T/DSO); Dynamo flexmarkt Nijmegen-Noord * The National Energy and Climate Plan indicates several pilot projects offering on flexible markets resources from bundled/aggregate storage, and small-scale storage equipment (including home batteries and electric cars)
5. Grid Aspects	* No double charging in 2020 for transmission-connected storage * injection & withdrawal charges for prosumers connected to the distribution grid. * Transmission access tariffs in the Netherlands are mostly capacity-based, thus avoiding double charging of access tariffs for storage. * Storage systems providing ancillary services do not benefit from grid tariff exemptions. * There are no temporal signals for network tariffs. Experiments and discussions are ongoing for more dynamic network tariffs. * The net metering will be phased out, starting in 2023. It is expected that with this phase out it will make it increasingly attractive to develop storage. * TenneT identifies the need to further develop the market model and processes for congestion management in cooperation between TSO and DSOs. The GOPACS platform is launched were grid operators, both TSO and DSOs, can prevent congestion by redispatching generation/consumption to areas outside the possible congested area. * The NDP 2020 has explicitly taken into account the Dutch Climate Agreement which is the basis for the CO2 reduction plans of the Dutch government and which also forms the basis of the NECP. It had one scenario based on the Climate Agreement that is used by the TSO and all DSOs. The NDP 2020 scenarios data-freeze happened before the adoption of the NECP. The NRA is currently not certain how the 2022 scenarios will relate to the NECP. * PHS and other energy storage facilities (e.g. batteries) are not allowed to be included in network development plan. * Introduced public consultations of the draft NDP. * Data exchanges regarding scenario's and/or assumptions and other alignment TSO/DSOs NDPs
6. Taxes & Levies	* Since 2022, double taxation of energy storage has been eliminated * A tax advantage can be obtained by companies that invest in storage systems. The Energy Investment Allowance (EIA) fiscal scheme provides fiscal advantages by allowing deduction of up to 45% of the investment costs from the taxable profit.
7. Other & General	
8. Barriers	* The lack of guidelines on permitting of storage leaves the responsibility for municipalities to determine the requirements. This can lead to incoherent requirements in the Netherlands. A stakeholder indicates guidelines are necessary to orient municipalities in the permitting of storage. * The lack of temporal signals in network tariffs reduces the incentives for load management by users.

Topic	Netherlands - Policy description
9. Best practices	* There is advanced participation of storage and aggregators in balancing markets, recognized by studies. * Capacity-based access tariffs eliminate the possibility of double charging of access fees to storage. * Local governments (e.g. municipalities and provinces) need to create a Regional Energy Strategy (RES) as defined in the National Climate Agreement, with attention also to energy infrastructure (and thus storage) aspects. * A policy instrument facilitates experiments allowing a specified exemption under the Electricity Act, for example for experimentation with energy storage. Within 4 years the government evaluates the outcome and lessons learned, to see whether a legislative change is warranted. * During the last years a number of (de facto, international) standards have been developed with the input from Dutch parties, such as USEF (Universal Smart Energy Framework, USEF foundation) for flexibility on the marketplace, the OCPP protocol for flexibility from electric vehicles (Open Charge Alliance) and the protocol EFI to connect flexibility devices virtually to a marketplace (Foundation Flexiblepower Alliance Network, FAN). Other projects worked on a basis for a standard for smart distribution stations and the employment of direct current (DC).

Poland

Topic	Poland - Policy description
1. Public Support	The NECP refers to electricity storage: * it is important to develop technologies for energy storage, the roll-out of smart grids, the development of electromobility, the introduction of energy-efficient and highly efficient technologies * Technological progress will have a significant impact on the scale of RES use, both in terms of the current generation of energy and in radically new technologies, but also in energy storage technologies * The small elasticity of the Polish energy market (on the supply side and the supply side) is mainly due to the fact that there are practically no regulatory sources (except for pumped storage) which would be in a state * Investments in gas generation and transmission infrastructure are a key element in ensuring the flexibility of the system in view of the increasing role of RES. The participation of active audiences and aggregators, also through the deployment of smart grids, will be able to respond to situations of scarcity. In the long term, the development of demand side management (DSR), energy storage, as well as energy clusters, which should have the potential to be self-balanced can also be taken into account in the long term * The existing potential for the offshore wind sector (offshore sector) in the Baltic, in view of the need to ensure adequate storage capacity and the transmission of such energy generated after 2025, offers opportunities for the development and use of this technology beyond * In the context of R & D & I, it will be important to support the area of innovation in infrastructure (including technologies) for generation, storage and use of hydrogen, … * The development of storage technologies is a prerequisite for the development of RES and for the development of storage technologies * The capacity market is technologically neutral, thereby creating a level playing field for all electricity, electricity storage and DSR (Demand Side Response) technologies of, taking into account the degree to which individual technologies contribute to security of supply and provided that the requirements of the Power *Market Act of 8 December 2017* are met * Particular attention should be paid to the capacity market that allows DSR auctions and energy storage facilities. In the auctions held in 2018 and 2019, strong contracts were awarded to close to 3 200 MW of DSR units and to energy storage facilities * Measures will be taken to increase the flexibility of the energy system in relation to the generation of energy from renewable sources, e.g. smart grids, aggregation, DSR, storage, distributed generation, mechanisms control, re-dispatching and curtailment as well as real-time price signals, including the introduction of intraday coupling * Energy storage facilities, including cells and batteries for electric vehicles: the development of electromobility is in line with the EU's strategic direction * Another way is production based on hydrogen (P2L), which can be CO2 neutral and can contribute to a significant reduction in greenhouse gas emissions while maintaining the liquid form. The maintenance of a liquid form is greatly facilitated by the transport and storage of energy
2. Permitting	* The 2021 Energy Law amendment require facilities above 10 MW requiring licensing by the NRA, while facilities above 50 kW need to register with the respective TSO or DSO. Time limits are established for * In April 2022 an important amendment to the small prosumers energy market was introduced, with a transition from net-metering to the net-billing type * In 2024, it is planned to transit into dynamic prices even for small prosumers.
3. Energy Markets and Capacity Mechanisms	DA/ID markets: *Energy storage is able to participate in DA and ID markets * Regulatory framework for active consumers to participate in ID & DA was not in place in 2020 Capacity mechanisms: * Multi-year capacity contracts in place, annual delivery period * The capacity market design in the Capacity Market Act of 2017 prioritizes low-emission technologies, including storage, with the minimum required provision period being shortened to 4 hours.
4. Ancillary Services	* Storage may contribute to ancillary services. Balancing market: * No information identified on storage not being eligible to participate in balancing markets * Regulatory framework for active consumers to participate in balancing markets was not in place in 2020 * Design of some products not compliant with Electricity Target Model for aggregation of load not allowed, validity period, asymmetrical balancing products * Not compliant with Electricity Target Model: max/min price limits

Topic	Poland - Policy description
	* Single pricing, single position compliant with Electricity Target Model * Storage not allowed in 2020 to provide transmission-level voltage control services
5. Grid Aspects	* Double charging has been eliminated with the 2021 Energy Law amendment * The 2021 Energy Law amendment introduced a discount of 50% of connection costs * March 2022 net metering was changed to net billing. * The state energy policy contains guidelines in the field of CO2 emissions through goals to be achieved for each year. In this way, it determines the future structure of the generation system (depending on the amount of power demand and the allowed level of CO2 emissions). This influences the reconstruction of the energy system and sets tasks for the TSO in terms of ensuring continuity and stability of the energy supply to industry and customers. * "Energy storage facilities shall be included in network development plan under special conditions". Pursuant to Article 16/7/8 of Energy Law: "7. The plan referred to in paragraph 1, includes in particular: 8) projects related to the use of electricity storage facilities, as far as the distribution, transmission or interconnected system operator deems it technically justified to ensure electricity supply, and it will show in a cost-benefit analysis that the use of electricity storage will be beneficial, and it will not be associated with disproportionately high costs - in the case of plans prepared by energy companies involved in transmission or distribution of electricity. "
6. Taxes & Levies	* There is no exemption to other surcharges such as for RES or cogeneration support. * There is no exemption for the electricity consumption tax in Poland.
7. Other & General	* The 2021 Energy Law amendment introduced harmonised definitions on energy storage and energy storage facilities
8. Barriers	* Due to huge popularity of small PV installations, before the rules changed in April 2022, there are household areas with a problem of overvoltage due to the high small PV density in some area
9. Best practices	* The capacity market design in the Capacity Market Act of 2017 prioritizes low-emission technologies, including storage, with the minimum required provision period being shortened to 4 hours.

Portugal

Topic	Portugal - Policy description
1. Public Support	The NECP refers to electricity storage. * It forecasts an increase in storage capacity, first through pumped hydro and, closer to 2030, with a more relevant contribution of hydrogen and batteries. A large part of this capacity should be related with solar and wind renewable generation, and the remaining with stand-alone storage. The NECP also considers that, to increase the role of demand response in the electricity sector and incentives to behind-the-meter storage in buildings and industry will be very relevant, along with the increase of smart charging in EVs. * Smart grids, management support systems, producer and/or consumer aggregators, smart meters, storage systems, local energy generation, active consumers, flexibility of offer/demand, electric vehicle, among others, are the variables to be taken into account in constructing the grid model of the future * The development of new technologies and the improvement of existing low carbon technologies requires a significant effort in research and innovation that will be achieved through the adoption of an ambitious and comprehensive agenda covering all stages of the technological development until their commercialisation. This will greatly contribute to national support frameworks that will be oriented towards research and technological development in line with the country's priorities, such as hydrogen, storage, smart grids, advanced biofuels, deep geothermal, concentration thermal, energy from the oceans, energy integration, energy conversion and storage, low carbon processes, circular economy, precision farming, among others * For the electricity sector, a strong impulse is given to the electrification of the consumption associated with the decarbonisation of production by enhancing the exploitation of the renewable energy potential with a particular focus on onshore/offshore wind and solar technologies, in parallel with the promotion of distributed generation, promotion of storage, strengthening and optimisation of the transmission and distribution networks and by promoting pilot projects * Pilot projects based on Concentrated Solar Thermal Technologies will be promoted as a technology enabling energy storage * National objectives with regard to increasing the flexibility of the national energy system, in particular by means of deploying domestic energy sources, demand response and energy storage * A significant part of the new storage capacity should be directly linked to the renewable electricity generating centres * By 2030, storage capacity is expected to increase, mainly via reversible pumping hydro, and at a later stage of the decade a contribution of batteries and hydrogen technologies. A significant part of this capacity should be linked to the production sites themselves via wind and solar technologies, with the remaining dedicated storage * In the electricity sector, industrial installations and storage incentives behind-the- meter in the building and industry sectors, so as to make changes in the daily load profile in the public service electricity grid less marked, as well as the generalisation of "smart" charging strategies on electric vehicles * new hydroelectric plants with storage and reversibility (pumping operation) that are expected to be placed in service until 2026 (reversibility, Daivões, already commissioned – 2nd quarter of 2022, and Alto Tâmega, expected commissioning date by the beginning of 2024) ensure an important contribution to increasing the flexibility of the system * Hydrogen has a huge potential as an energy carrier, which could serve as energy storage or fuel for the various sectors of the economy * Ensuring security of supply should be ensured by adopting appropriate measures addressing an imbalance between supply and demand, including those related to the overall technical management of the system, which encourage the diversification of supply sources and which contribute to the planning, construction and maintenance of the necessary infrastructure. The increase in interconnection capacity, storage systems (key in an essentially renewable energy system), the adoption of new network planning mechanisms, the dissemination of smart grids, etc * To promote storage systems, the following action measures are envisaged: 1/ Create the legal framework for the implementation of storage systems 2/ Promote the implementation of storage projects associated with renewable electricity generation centres; 3/ Promote storage on islands. * The demand aggregator will aim to bring together different actors/entities, such as final consumers, small producers, storage, recharging points for electric vehicles, or any combination of them, and act as a single entity and participate in the electricity market and provide system services. * The development of activities associated with renewable energy, storage, hydrogen, advanced biofuels and other 100% renewable fuels will require the provision of specialised training needs covering various levels of training * The Innovation Fund is one of the largest funding programmes for low-carbon innovative technology demonstration projects and focuses on, among others, energy storage.

Topic	Portugal - Policy description
	* InnovFin Energy Demo Projects: This financing arrangement consists of loans, loan guarantees or financing of property type, normally between EUR 7,5 and EUR 75 million for innovative energy system transformation projects, including but not limited to: renewable energy technologies, smart energy systems, energy storage, carbon capture and storage or carbon capture and use. This financing mechanism is complemented by the European Investment Bank * The challenge of the adequacy of network infrastructure enabling an effective energy transition arises in particular to the Low Voltage Network (LV) that will no longer be a passive network to integrate a whole set of new concepts, from network intelligence, management support systems, smart meters, storage, energy management, local production, energy communities, electric vehicles, among others, are variable to be taken into account in the construction of the future network Portugal has made a bet on capacity auction processes. In particular, the auctions that took place in 2020 (solar), in 2021 for the attribution of the connection capacity of the Pego coal plant, which ceased operations in the last quarter of 2021 and, more recently, the floating solar auction. These auctions include the possibility of associating the production of electricity with the installation of storage solutions, making it possible to maximise the potential of grid connection capacity in hourly terms, as well as increasing the contribution of renewable energy to grid stability. The RMSA-E 2021 (Security of Supply Monitoring Report for the national electricity system), assumes in the ambition scenario a target of 200 MW of installed storage capacity in PT for 2030 (taking into account the results of the 2020's Solar auction). Regarding transport sector, in particular electric vehicles, the RMSA-E 2021, in line with NECP modelling for transport sector ("ambition scenario"), it is assumed, for 2030 (considering smart-charging): 1.250.000 BEV light vehicles; 2.147 BEV Heavy vehicles for passages and 690 BEV vehicles for goods.
2. Permitting	* Legislation indicates the generation and storage license shall include the conditions for storage (not impacting storage for self-production). * Autonomous storage units require a license, depending on the installed capacity. Above 1 MW a production and operation license are needed. Autonomous storage below 1 MW requires prior registration and operating certificate. Rules are set in the new Decree-Law no. 15/2022 (which repealed the Decree-law no. 76/2019). Permitting rules apply equally to generation and storage units. * Decree-Law no. 15/2022 also introduces the Technological Free Zones (art. 216), which can be used for the development of solutions associated with renewable energies. Its operation, in terms of licensing, is simplified, enabling the creation of pilot projects that may be scaled up. * Decree-law no. 30-A/2022 provides exceptional measures to ensure the simplification of procedures for the production of electricity from renewable sources.
3. Energy Markets and Capacity Mechanisms	DA/ID markets: *Energy storage is able to participate in DA and ID markets * In the 2nd semester of 2021, Portugal established a Regulation Reserve Band Market, with the objective of complementing the operational reserve of the electricity system with a regulation reserve band. This market is open to very high, high and medium voltage consumers, and is carried out through a competitive auction. The consumers which have been contracted, following the auction, are obliged to provide the Regulatory Reserve Band that has been awarded to them, with a corresponding consumption decrease potential. storage not being eligible to participate in this mechanism.
4. Ancillary Services	Balancing market: * Trans European Replacement Reserves Exchange (TERRE) in place for exchange of replacement reserves, and allowing the participation of storage * No other information identified on storage not being eligible to participate in balancing markets *Design of some products not compliant with Electricity Target Model for min delivery period (mFRR), max delivery period (mFRR), aggregation of load not allowed, validity period * Compliant with Electricity Target Model: max/min price limits * Dual pricing, dual position not compliant with Electricity Target Model, recently addresses in public consultation from the NRA, yet to be resolved. * Storage is clarified in the new Decree-Law (DL) 15/2022, 14th January 2022, but needs to be implemented through further regulation by the TSO and NRA. The DL includes the possibility foreseen in the article 36 and 54 of the IEM directive for grid operators to own and operate storage facilities upon the NRA approval. * The RES self-production and energy communities framework in the Decree-Law 162/2019, repealed by Decree-law no. 15/2022 requires storage units to have a meter it those are directly connected to the public grid as an electric facility apart from the consumption and generation units. EVs are considered storage only if they have bidirectional chargers.

Topic	Portugal - Policy description
	* Only conventional generators provide (mandatory and non-remunerated) voltage control in Portugal. * Black-start is not mandatory. A CCGT and a hydro plant provide the service in Portugal.
5. Grid Aspects	* No double charging in 2020 for transmission-connected storage * no withdrawal charges for PHS connected to the transmission and distribution grid, however does apply withdrawal charges to prosumers connected to the distribution grid. * Self-consumers and small producers (including with storage) must pay the connection costs to the grid. In what concerns self-consumed energy, they only pay for grid charges concerning the connection voltage level (and not for the costs of higher voltage networks). When there is reverse flows to higher voltage levels, the exemption is partial following a methodology set by the national regulator. * A governmental entity aided by the TSO shall issue a Monitoring Report on Security of Supply and take into consideration the NECP and the new ERAA by ENTSO-E. When preparing the NDP, the TSO shall take into consideration the NECP and the Security of Supply report (e.g. new renewable generation capacity expected in the next 10 years) and propose or schedule investments accordingly. * PHS and other energy storage facilities (e.g. batteries) are allowed to be included in the network development plan, PHS, batteries & hydrogen included as well. * The DSO for High Voltage and Medium Voltage networks are obliged to prepare a NDP (for 5 years planning). No obligation to prepare NDP for Low Voltage operators. Consultation between TSO and the DSO regarding DSO/TSO coordination NDPs.
6. Taxes & Levies	* There is no exemption for storage from the electricity consumption tax set by the Law-Decree n.º 73/2010. * No other indications of tax & levy exemptions for storage in Portugal.
7. Other & General	* The regulatory framework for the electric mobility is defined in Decree-Law no. 39/2010, as amended by Decree-Law no. 90/2014. In 2016, Resolution of the Council of Ministers No. 49/2016 of 1st of September, was published and approved the end of the first phase of the MOBI.E pilot network and launch the second phase of the pilot network, in order to cover municipalities not served in the first phase. In 2017, the National Action Framework for the creation of an infrastructure for alternative fuels (QAN) was approved, through Resolution of the Council of Ministers no. 88/2017 of 26 of June, complying with Directive 2014/94/EU, of the European Parliament and of the Council of 22 October, transposed to the internal order by Decree-Law no. 60/2017, of 9 June. This framework established objectives and targets, as well as measures to promote the use of alternative fuels and the development of their supply infrastructure, having established, for the charging infrastructure of electric road vehicles, a public network, in 2020, composed of a minimum number 2,394 charging points, including the pilot network points.
8. Barriers	* The prohibition for renewable energy generators with storage from withdrawing energy impedes the use of the storage assets for multiple applications.
9. Best practices	* Regulation on permitting requirements for autonomous storage forecasted in legislation. * Permitting of batteries in generation facilities are considered retrofitting and went well in the past.

Romania

Topic	Romania - Policy description
1. Public Support	The NECP refers to electricity storage: * "The storage capacities will contribute to the reduction of gaps between the demand and offer of electricity in the decarbonisation process and energy security" * "the area Energy storage is represented in the research group C4 of the National Electricity Transmission Operator" * "plans to clearly define the concept of energy storage in the primary law and to lay down the conditions for release of energy storage licences and for connection to the network" * The government plans to integrate over 400 MW of battery storage capacity to flatten the load curve and provide balancing reserves. * The development of small storage capacities to foster the integration of RES is one of the main policies of the operational objective 'Ensure energy storage and backup systems capacities'. This comprises the development of pumped hydro, including the construction of the Tarnita-Lapustesti station. * Hybrid technologies for the storage of energy is a main research direction of the National Hydrogen and Fuel Cell Centre, in the form of the Lithium-Ion program. * The possibilities for storage and aggregated production of multiple consumers/producers should be considered.
2. Permitting	* There are no specific permitting rules for storage in Romania * For small scale, the active consumer permitting rules will be applied. * Permitting duration is long (2-5 years for greenfield storage projects) , but is not seen as a central barrier.
3. Energy Markets and Capacity Mechanisms	DA/ID markets: *Energy storage is able to participate in DA and ID markets Capacity mechanisms: * NAP * As of 2016 demand response was already allowed in the Romanian electricity wholesale market, but was not active. The legal framework is well-established, but due to a number of key barriers, is has not taken off the ground due to the lack of secondary legislation, the lack of smart meters and the electricity system is supply-driven.
4. Ancillary Services	Balancing market: * No information identified on storage not being eligible to participate in balancing markets * Design of some products not compliant with Electricity Target Model for several aspects, including maximum delivery period (RR & mFRR), minimum capacity (FCR, aFRR, mFRR &RR) and minimum bid size (FCR, aFRR, mFRR &RR), no load aggregation allowed, validity period, symmetric balancing capacity products (aFRR) * Compliant with Electricity Target Model: max/min price limits * Single pricing, single position compliant with Electricity Target Model * Storage not allowed in 2020 to provide transmission-level voltage control services
5. Grid Aspects	* Double charging in 2020 for pumped hydro storage * withdrawal charges for PHS, other storage facilities (e.g. batteries) & prosumers connected to the distribution grid. * Law 121/2014 on energy efficiency lists energy storage services as one of the criteria for assessing energy efficiency for network operators. * Further Government Emergency Ordinance (GEO) 143/2021 for the full transposition of the contents of the Electricity Directive 2019/944 issuing the need for the NRA (ANRE) to adjust secondary legislation, if necessary, within 6 months of the effective date of this Emergency Order to include the development of the regulatory framework through which DSOs are encouraged to purchase energy storage and other flexibility services. * Net metering for renewable energy installations of up to 100 kW was introduced in 2018 through an amendment to Law 220/2008. * A feed-in support scheme for renewables is in place where the price is set to the last year's average from the day-ahead market. The price that the consumer is buying energy from the grid is almost double due to fees (distribution fee, transmission fee, extraction fee). * The NDP contains scenarios that include the assumptions and targets set out in the NECP. * PHS and other energy storage facilities (e.g. batteries) are allowed to be included in the network development plan, however are not included * Regarding DSO/TSO coordination NDPs: other alignment/joint activities DSO/TSO

Topic	Romania - Policy description
6. Taxes & Levies	* No specific mention of electricity storage identified in the legislation, assumption is that charging is treated as consumption for the electricity consumption tax and levy purposes.
7. Other & General	
8. Barriers	* The high hydropower installed capacity in Romania (6.4 GW) including pumped hydro (200 MW) may act as a disincentive to further development of energy storage and related policies * In practice demand response is not active in the Romanian electricity and balancing markets.
9. Best practices	* The NECP provides a target to integrate over 400 MW of battery storage capacity * EDPR has inaugurated in 2018 a 1MW battery system in its Cobadin wind farm * Research laboratories specialising in the development of energy storage technologies are forecasted.

Slovakia

Topic	Slovakia - Policy description
1. Public Support	* Notified construction of battery storage facilities in the Slovak Republic: -ELSEA - Energy storage facility of a cumulative installed capacity of 384 MW; The ELSEA project is a candidate for the PCI list -SE Integrator 70 MW; SE integrator project is a candidate for the PCI list * The amendment to Act 251/2012 contains legal regulation of new participants in electricity market and gas market with positive impact on flexibility provision, which include in particular active customer, energy community, operator of the electricity storage facility and aggregator. It also contains legal regulation of electricity sharing and storage. * In the new energy law No 251 (to take effect on 1.10.2022) and the Market Rules Decree (to enter into force by 31.3.2023), the energy storage specified in the energy law as the equipment, which allows the postponement of electricity consumption or the conversion into a form of energy that can be stored, in the form of controlled charging and discharging processes of such equipment. The energy storage will have the right to be connected to TSO/DSO system, to participate on ancillary services, to provide flexibility and to provide flexibility for aggregation. * The recovery and resilience plan includes energy storage as an important part of managing energy system flexibility after increasing penetration of renewable sources. The NECP refers to electricity storage * The deployment of intelligent energy systems and electricity storage systems is particularly important. * In line with the overarching European legislation, to create conditions for the provision of support services allowing the aggregation of demand facilities, energy storage facilities and power generation facilities for the purpose of offering balancing services * The development of energy storage will ensure the integration of variable RES into the grid * The integration of the local storage of energy in storage appliances, energy storage devices and electric vehicles or in the gas distribution network with their storage capacities is therefore an important element of the smart grid. * The maintenance and support of the existing capacity and operation of pumped storage power plants and, where appropriate, to assess the potential increase in storage capacity by building a new pumped-storage hydroelectric power plant * State R&I programme (SRDP) Energy Security includes storage * Conditions for the provision of support services from among others storage, including balancing services should be created * Indicates support to shortening of the currently used trading intervals on daily, intraday and balancing markets. * Conditions are currently being created for the provision of support services from storage (LER, BESS), effective from 1.9.2022. * Highlights the Ipeľ Pumped Hydropower Project (proposed capacity of 560 MW), which depends however on the development of the EU electricity market and interest from a strategic investor
2. Permitting	* Energy storage units go through the standard permitting process (environmental, construction, access and connection to the power system location, others), and there are no specific rules for energy storage. * Large scale energy storage (pumped hydro) has to fulfil standard technical specification of TSO/ DSO for connection. The specific permitting rules for other types of energy storage (LER e.g. batteries) are included in the technical conditions of the power system.
3. Energy Markets and Capacity Mechanisms	DA/ID markets: *Energy storage is able to participate in DA and ID markets * Regulatory framework for active consumers to participate in ID & DA was not in place in 2020 Capacity mechanisms: *The adequacy issues have not been identified in Slovakia so the Capacity mechanism is not needed to be implemented in the Slovak Power System at this point. * Due to competitiveness, the typical utilisation of storage is limited to back-up power supply, provision of ancillary services (pumped hydro) or peak shaving. * Limited battery energy storages are installed in behind the meter installation combined with PV installation. In small business for 'peak shaving', to a limited extent. * There are some applications of CHP systems storing heat to provide electricity system products to the markets but mainly balancing services to the TSO. * CZT allows for the provision of support balancing services in electricity systems and the storage of energy in the form of heat.

Topic	Slovakia - Policy description
4. Ancillary Services	Balancing market: * Under the Slovak rules, pumped hydro is eligible to provide specific products (Tertiary 3 min+/-) and also standard products of aFRR, mFRR+/- services * Batteries are eligible to provide only FCR. * Regulatory framework for aggregators, active consumers and operator of the electricity storage facility to allow their participation in balancing markets is being prepared * Design of all the products is compliant with Electricity Target Model for max delivery period (mFRR), min capacity required (mFRR), min bid size energy & capacity (aFRR, mFRR), procurement lead times, but not compliant with settlement rules (pay as bid aFRR, mFRR) and 15 min time of purchase availability. These inconsistencies will be resolved before accession to the PICASSO and MARI platforms in 2024. * Not compliant with Electricity Target Model: max/min price limits * Single pricing, single position compliant with Electricity Target Model
5. Grid Aspects	* No double charging in 2020 for transmission-connected storage * No injection charges for PHS connected to the distribution grid, but applies withdrawal charges for PHS & prosumers connected to the distribution grid. Prosumers in case their injection capacity is higher than their withdrawal capacity are charged for injection charges. * The TSO takes the NECP into account when designing the generation mix. * PHS and other energy storage facilities (e.g. batteries) are allowed to be included in the network development plan. NDP includes new storage technologies. * Regarding DSO/TSO coordination NDPs: other alignment/joint activities DSO/TSO
6. Taxes & Levies	* Charging for storage is treated as consumption for the electricity consumption tax and levy purposes
7. Other & General	
8. Barriers	* Regulatory: Energy storage (except hydro pumps) is burdened by capacity and injection fee that over-charges its usage.
9. Best practices	* National R&I programme includes storage in the energy security category * Second life energy storage is one of the IPCEI project

Slovenia

Topic	Slovenia - Policy description
1. Public Support	The NECP refers to electricity storage * "Development of energy storage technologies, infrastructure and services as energy security and internal energy market target for 2030" * "Providing conditions for further integration of markets and construction of necessary infrastructure as an economic instrument to reinforce participation in European research projects in the area of energy storage (p. 108), increase R&D funding to the transition to a low-carbon society and other low carbon technologies" (p.117) * Part of the NEPN Scenario * Technological development and commercial breakthrough of storage technologies is listed as a key challenge for Slovenia. * Slovenia's Smart Specialisation Strategy (S4) includes a pillar on mobility including related energy storage systems.
2. Permitting	* Depending on the technology (for example pumped storage) storage of electricity might be considered as production, so construction of such projects of more than 1 MW connected to public grid requires a permission issued by the Minister for Infrastructure.
3. Energy Markets and Capacity Mechanisms	DA/ID markets: *Energy storage is able to participate in DA and ID markets Capacity mechanisms: * NAP * Behind-the-meter storage is already allowed. Besides larger projects, there have been some smaller projects including the vanadium-flow batteries installed at a restaurant in the Slovenian Alps.
4. Ancillary Services	Balancing market: * FCR cooperation project active, allowing for provision of FCR capacity by storage. * No other information identified on storage not being eligible to participate in balancing markets * Design of some products not compliant with Electricity Target Model for max delivery period (mFRR), min capacity required (aFRR), min bid size capacity (mFRR), validity period, procurement lead time, length of balancing contracts (FCR, aFRR, mFRR), settlement rule (pay as bid, aFRR, mFRR) *Not compliant with Electricity Target Model: max/min price limits & dual pricing, single position * The Slovenian regulator has launched in July 2019 a public consultation regarding the establishment of a flexibility market in Slovenia, that deals with the role of storage as well. It explores the possible roles of storage in providing flexibility services and seeks input from stakeholders regarding dynamic tariffs and possible flexibility products. It identifies several barriers on market design, measurement, validation, support systems and technical solutions. * There is also a reference in the Energy Act regarding facilitating the inclusion of advanced technologies for the provision of ancillary services.
5. Grid Aspects	* Storage facilities are exempt from the network charges under certain conditions as defined by the 'Act determining the methodology for setting the network charge, the criteria for establishing eligible costs for electricity networks, and the methodology for charging for the network charge' adopted every 3 years by the regulator, which poses regulatory uncertainty (exemptions not determined by law). - Between April and June regulator opened a public consultation on the new Act. Under the new proposal, storage facilities are no longer exempt from network charges, except for the time they provide ancillary services. The new Act should enter into force in 2023 for the period of 3 years. New proposal poses risks to viable economic operation of existing pumped storage hydro power plants, as well as to new investments. * In Slovenia, specific incentives for smart grid investments exist: If the network operator realizes investments in smart grids that meet the requirements set out in the methodology, a one-off incentive is acknowledged amounting to 3% of the current value of the asset in the year in which the asset was put into service. Yet, these incentives were considered to be too low and will be increased in the next regulatory period. * The PCI smart grid project, SINCRO.GRID, is under implementation as a cooperation between TSOs and DSOs from Slovenia and Croatia, with a 10MW/50MWh battery energy storage system (BESS) being trialled in Slovenia * To access the network, storage facilities must contract with the TSO (ELES) or the DSO SODO and/or the sub-contracted distribution companies * Slovenia applies net metering for small consumers

Topic	Slovenia - Policy description
	* Scenarios of development NDP must be in line with the NECP. * No public consultations are carried out by other entities, however TSO has specific (bilateral) consultations * Regarding DSO/TSO coordination NDPs: other alignment/joint activities DSO/TSO
6. Taxes & Levies	* No specific mention of electricity storage identified in the legislation, storage facilities are a separate category and they do not pay consumption taxes and levies in charging mode.
7. Other & General	
8. Barriers	
9. Best practices	

Spain

Topic	Spain - Policy description
1. Public Support	The NECP refers to electricity storage * Listed in the measure of Demand management, storage and flexibility (p.83) * "It is necessary to determine the technical requirements for participants offering energy from renewable sources, energy storage managers and those providing demand response services, to participate in existing and developing markets" (p.84) *Listed in the measure of Plan for the technological upgrading of existing electricity generation projects with renewable energies (p.97) * Listed in the measure of Planning for safe operation of a decarbonised energy system (p.172) *Listed in the measure of Adaptation of electricity grids to integrate renewables (p.86) *Listed in the measure of Unique projects and strategy for sustainable energy on the islands (p.101) *Listed in the measure of Local energy communities (p. 102) * Listed in the measure of Integration of the electricity market (p.180); funding of research (pp. 280) * The Storage Strategy was adopted in 2021 and contains varied measures for incentivising and promoting a level playing field for storage. * Component 8 of RRP (Resilience and Recovery Plan) for Spain, includes a specific investment, C8.I1 amounting to 654M€ of support, that comprises both BTM and FTM storage. Additionally, the regulated retribution scheme of the RD 960/2020 introduces a premium coefficient of market exposure for hybrid facilities including energy storage. In line with C8.I1, two grants were developed : 1) RD 447/2021 and RD 377/2022 to support BTM energy storage. 2) Ministerial Order 1447/2021 to support FTM projects for FTM energy storage in R&D.
2. Permitting	* Permitted behind-the-meter storage is explicitly allowed to consume electricity. * The Royal Decree 1183/2020 exempts self-consumption installations with a power under 15 kW * Batteries co-located with renewable energy plants supported by the support scheme "régimen económico" may store only the on-site generated electricity and not withdraw energy from the grid for storage. * The RD-Law 6/2022 equates energy storage to generators in regards of permits, authorisation and registry, in order to provide regulatory certainty for stakeholders. Several regulation schemes have been developed during the last years, RD-law 23/2020, RD 1183/2020 and RD-Law 6/2022 to facilitate the development, deployment and authorisation of stand-alone and hybrid storage installations. * A stakeholder indicates the permitting process is lengthy with different administrations involved. * Climate Change and Energy Transition Law indicates new hydropower concessions in the public domain will have as a priority to support the integration of renewable energy in the electricity system, promoting in particular pumped hydro storage when this is compatible with environmental objectives. It also foresees the regulation of the pumping, storage and generation for the objective of maximising the integration of renewables.
3. Energy Markets and Capacity Mechanisms	DA/ID markets: *Energy storage is able to participate in DA and ID markets * Regulatory framework for active consumers to participate in ID & DA was not in place in 2020 Capacity mechanisms: * Draft proposal for CM has been published and includes energy storage, both in stand-alone installations and as part of hybrid installations. * There is no capacity remuneration mechanism in Spain, central actors are studying the matter. * There is no specific regulation adapted to allow vehicle-to-grid applications.
4. Ancillary Services	Mechanisms to value distributed flexibility sources *Local flexibility platforms & other initiatives: SmartNet Spain (DSO) Balancing market: * NRA resolution of 10 December 2020 updating the operating procedures regulates, among others, the non-discriminatory access of storage to balancing markets * Trans European Replacement Reserves Exchange (TERRE) in place for exchange of replacement reserves, and allowing the participation of storage * Not open for independent aggregators in 2020. However, the Storage Strategy foresaw the creation of the independent aggregator figure. * Not compliant with Electricity Target Model including: minimum delivery period (mFRR &RR), max delivery period (mFRR), min bid size energy (RR), validity period, length balancing contracts (FCR) * Compliant with Electricity Target Model: min/max price limits

Topic	Spain - Policy description
	* Dual pricing, single position not compliant with Electricity Target Model * Resolution of 10 December 2020 (Circular Informativa 8/2021) regulated the participation of energy storage facilities in the provision of ancillary services * MITECO call for proposals issued in March 2022, through opening of a public consultation for the establishment of rules for regulatory sandboxes (in addition to the one opened in July 2021). Decision process ongoing. * IDAE and the market operator OMIE are exploring local electricity market models, with possible pilots starting. * Black start and voltage control services are regulated, without remuneration. Currently, voltage control and non-frequency services are in the regulatory pipeline of the System Operator (REE). Some operating procedures have included the participation of energy storage in the provision of this services.
5. Grid Aspects	* No withdrawal toll charges (peajes) for PHS & batteries connected to the transmission or distribution grid, as specified in NRA CNMC decision 3/2020. Also no policy-related charges (cargos) for all storage according to Royal Decree 148/2021, from 9 of March. * The Royal Decree 1183/2020 regulated access to the grid for storage facilities, and Circular 1/2021 by the NRA established the methodology and conditions for access to and connection to the transmission and distribution networks of electricity generation facilities * Net metering is simplified for active consumers with less than 100 kW in law-decree 15/2018. * Self-consumed energy from renewables, co-generation or waste is exempt from network tariffs and other tariffs in law-decree 15/2018. * No information available that state that NDP is aligned with NECP. *Royal Decree-Law 29/2021 of 22 December, sets storage as a component that can be fully integrated into the electricity grid, so that it contributes to guaranteeing the safe operation of the transmission grid. The 2021-2026 planning of the transmission grid includes actions to guarantee the connection of storage systems, as well as drawing relevance to the importance of integrated storage or synchronous compensators. * Regarding public consultations: summary of stakeholders' comments are published. * Regarding DSO/TSO coordination NDPs: other alignment/joint activities DSO/TSO
6. Taxes & Levies	* There is no specific mention of electricity storage in the taxation legislation, thus storage discharge is subject to the electricity production tax (Impuesto sobre el valor de la producción de la energía eléctrica, IVPEE). Self-consumption installations under 100 kW are exempt. * The Energy Strategy indicates the government aims to develop time-differentiated network tariffs * The government aims to recover renewable support costs from the general budget instead from network users
7. Other & General	* The Law-decree 23/2020 defines the figure of the holder of storage installations
8. Barriers	* While specific rules for RES+storage are in place for RES tenders in Spain, this does not necessarily value the greater dispatchability of the projects, as greater market exposure may increase the risks to the project * The lack of markets for the provision of black start and voltage control services and the impossibility for TSOs to procure ancillary services reduces the revenue streams available for storage.
9. Best practices	* Indicative development of storage to 2030 in the NECP, separated between pumped hydro and batteries. * In the support auction for renewable generation in the Balearic Islands, generation facilities with batteries received extra points versus facilities without batteries. * Potential inclusion of renewables combined with storage in the next support auctions, intended for thermal solar but open to all technologies due to technology-neutral approach. Inclusion of energy storage as a priority in the Resilience and Recovery Plan, specifically in Component 8, which includes several reforms and investments related to energy storage.

Sweden

Topic	Sweden - Policy description
1. Public Support	The NECP refers to electricity storage * In the Government Budget Bill for 2020 (prop.2019/20: 1(21) The Government notes that a future electricity system with a higher proportion of variable wind and solar production increases the need for flexibility in programmable generation, demand response in user sectors, energy storage and system services to support and stabilise the electricity system * In the direction of the Energy Policy Bill[379], the Government considers that the network owner's role may need to be given a broader content to fully exploit the benefits of smart grids, energy storage and demand response to the electricity system
2. Permitting	* in Sweden, permits for water utilisation (incl hydro storage plants) will be revised according to new legislation incorporated in the Swedish Environmental Code so that no permit is older than 40 years or other time frame stated in the revised permit.
3. Energy Markets and Capacity Mechanisms	DA/ID markets: *Energy storage is able to participate in DA and ID markets * Regulatory framework for active consumers to participate in ID & DA was not in place in 2020 Capacity mechanisms: *CM does not allow storage, min bid size > 5 MW * Heat and electricity systems are integrated in several ways, e.g. in co-generation of electricity and heat, or when DH is produced with electric boilers or heat pumps. Heat can also be stored more easily than electricity, and thermal storages are used to improve the system balancing of variable power generation. By utilising co-generation, heat pumps and thermal storages, a DH supplier can respond to price signals on the electricity market. In times of high electricity prices, DH production can be adjusted to maximise the power generation and thermal storage used to cover heat demand, and in times of excess power, DH suppliers can utilise more heat pumps. There is a number of heat storage projects ongoing based on storage on the DH systems.
4. Ancillary Services	Balancing market: * No information identified on storage not being eligible to participate in balancing markets * Regulatory framework for active consumers to participate in balancing markets was not in place in 2020 *Design of some products not compliant with Electricity Target Model for max delivery period, min capacity required (aFRR, mFRR), min bid size capacity (aFRR, mFRR), aggregation of load not allowed, validity period, settlement rule (pay as bid FCR), activation rule. * Not compliant with Electricity Target Model: max price limit, no min price limit implemented * Storage not allowed in 2020 to provide transmission-level voltage control services New ancillary services: * The Swedish TSO, Svenska Kraftnät, states that the requirements on ancillary services will generally increase and will much more clearly reflect and be adapted to the system's needs. In 2019, Svenska Kraftnät started to establish a market for FFR (Fast Frequency Reserve), where electricity storage could be an important part. *SIR: Looking into solutions for falling inertia levels Mechanisms to value distributed flexibility sources *Local flexibility platforms & other initiatives: INTERRFACE (T/DSO)
5. Grid Aspects	* injection & withdrawal charges for PHS, other storage facilities (e.g. batteries) & prosumers connected to the distribution grid. Only prosumers with installed capacity > 0.0435 MW are charged for injection charges. * An owner of a grid connected electricity storage is obliged to pay a grid tariffs and tax for electricity supplies to the storage from the grid. Storage owners are also formally obliged to pay a feed-in-tariff for electricity feed into the grid from the storage, however storage units with a capacity less than 1500 kW are excepted. * No information available that state that NDP is aligned with NECP.

[379] prop.2017/18: 228 The direction of energy policy.

Topic	Sweden - Policy description
	* PHS and other energy storage facilities (e.g. batteries) are allowed to be included in the network development plan, however are not included. * Regarding public consultations: neither public consultations nor any specific or bilateral consultation is carried out * Regarding DSO/TSO coordination NDPs: no alignment DSO/TSO NDPs.
6. Taxes & Levies	* There is tax deduction for the excess electricity injected into electricity network from renewable energy (residential solar PV, wind etc.), equal to SEK 0.60/kWh * Recovery of energy tax on electricity after storage of batteries: as of 1 January 2019, Chapter 11, Section 13 of the Energy Tax Act (1994: 1776) provides for the possibility to apply for a refund of energy tax on electricity consumed from a network subject to a concession, stored and then fed back to the same electricity network subject to a concession. This is to avoid unintended double taxation
7. Other & General	
8. Barriers	The Swedish Energy regulator conducts an annual investigation on the Swedish flexibility market. The 2019 investigation showed that there are not technical or legal barriers for flexibility measures, such as electricity storage. A general problem though is the lack of access to metering data of sufficient resolution for creating more real-time markets for flexibility and the time for the market actors to access such data. The main obstacle for electricity storage in Sweden is the lack of economic incentives due to the lack of price volatility on the Nordic electricity market.
9. Best practices	

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