European Commission

Study on an assessment methodology for the benefits of electricity storage projects for the PCI process

NAVIGANT

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July – 2019

EUROPEAN COMMISSION

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Luxembourg: Publications Office of the European Union, 2019

ISBN: 978-92-76-09810-2
Doi: 10.2833/802217

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ABBREVIATIONS

ACER	Agency for the Cooperation of Energy Regulators
aFRR	automatic Frequency Restoration Reserve
BRP	Balance Responsible Party
CA	Compressed Air
CAES	Compressed Air Energy Storage
CAPEX	Capital Expenditure
CBA	Cost Benefit Analysis
CEF	Connecting Europe Facility
DOE	US Department of Energy
DSO	Distribution System Operator
EASE	European Association for Storage of Energy
EC	European Commission
EENS	Expected Energy Not Served
EERA	European Energy Research Alliance
ENTSO-E	European Network of Transmission System Operators for Electricity
EPRG	Energy Policy Research Group
EPRI	Electric Power Research Institute
ETS	Emission Trading Scheme
FCR	Frequency Containment Reserve
JRC	Joint Research Centre
mFRR	manual Frequency Restoration Reserves
NPV	Net Present Value
OPEX	Operational Expenditure
P2X	Power-to-X
PCI	Project of Common Interest
PH	Pumped Hydro
PHES	Pumped Hydro Energy Storage
RES	Renewable Energy Sources
RG	Regional Group
SCC	Societal Cost of Carbon
SEW	Socio-Economic Welfare
SoS	Security of Supply
TEN-E	Trans-European Networks for Energy
TSO	Transmission System Operator
TYNDP	Ten-Year Network Development Plan
VOLL	Value of Lost Load
vRES	variable Renewable Energy Sources

EXECUTIVE SUMMARY

The European process of identifying and promoting Projects of Common Interest (PCIs) as foreseen by Regulation (EU) No 347/2013 ('TEN-E regulation') supports three main objectives:

- **Market integration**, inter alia through lifting the isolation of at least one Member State and reducing energy infrastructure bottlenecks; competition and system flexibility.
- **Sustainability**, inter alia through the integration of renewable energy into the grid and the transmission of renewable generation to major consumption centres and storage sites
- **Security of supply**, inter alia through interoperability, appropriate connections and secure and reliable system operation

Electricity storage projects can apply for the PCI status and specific support measures. The selection criteria set out by the TEN-E regulation target large-scale storage facilities, with an installed capacity of at least 225 MW and an annual net electricity generation of at least 250 GWh/yr.

Only storage and transmission projects that are part of ENTSO-E's TYNDP are eligible to apply for the PCI status. To be included in the TYNDP, projects are assessed by means of a socio-economic CBA, including their environmental and social impacts and their contribution to the European long-term policy goals. In 2018 ENTSO-E published the CBA 2.0 guideline, aiming at a consistent assessment of TYNDP transmission and storage projects across Europe – and is thereby the basis for the identification and selection of PCI projects. The CBA 2.0 employs a multi-criteria approach that combines a quantified and monetized assessment of some project impacts with the qualitative description of other indicators and compares it to the indicated costs of the project. Still, the current CBA 2.0 methodology has limitations in terms of the way electricity storage projects are assessed; because the CBA is focused on transmission assets, it does not completely capture all social benefits storage projects might bring to the power system and the European society. Amongst others, this includes fast and slow reserves procured by TSOs. In addition, not all impacts are quantified and monetized in the CBA. This makes it challenging to conduct a complete valuation of the storage projects, as only monetized impacts can be considered in a CBA.

This study aimed to improve the CBA approach for candidate electricity storage PCIs to better capture the benefits these potential PCIs bring to the EU society. Moreover, the improved approach was applied to the current list of 19 candidate storage PCIs.

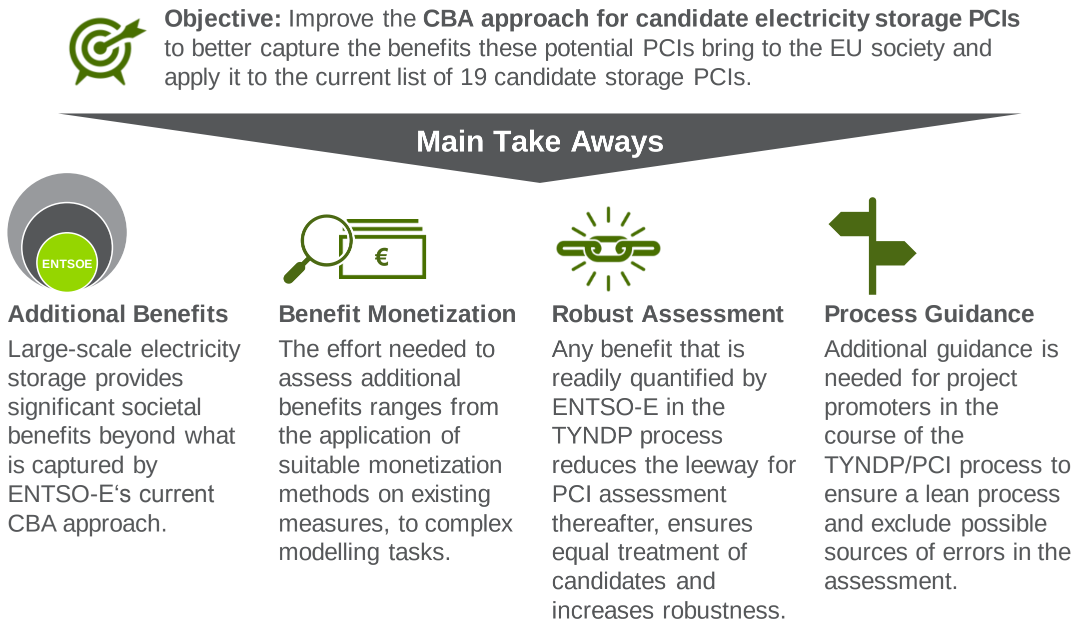

Figure 1: Objective and key take-aways of the study

The approach of this study is as follows. Firstly, we identified the benefits that typically are associated with large scale storage projects and described how they can be quantified and monetized. Thereafter, we used this set of identified benefits to assess the 19 candidate storage projects on the current fourth PCI list. Based on the monetized benefits and project costs we then established the socio-economic net present value for these PCI candidates.

To develop a suitable approach for the socioeconomic assessment of PCI candidates, we inventoried potential benefits provided by storage projects based on literature review. Starting point for the analysis is the assessment framework developed by ENTSO-E, the CBA guideline 2.0. In addition, other credible, public sources such as Agency for the Cooperation of Energy Regulators (ACER), European Association for Storage of Energy (EASE) and others are considered. Thereby, a broad set of benefit is identified, categorized in five domains: supply, ancillary services, decarbonization, transmission and other. The broad set of storage-related benefits is further reduced, disregarding benefits which are not relevant in the context of storage PCI projects. Only benefits that have a significant value contribution – in terms of societal benefit, not necessarily project promoter revenue – and are generally applicable to all projects are considered relevant. Thus, also case-specific benefits, which might have a significant effect in one or two projects but are negligible for the other projects – e.g. due to highly location-specific benefits – are neglected. We derived nine societal benefits, relevant in the context of storage PCI projects. They are summarised below, together with quantification and monetization approaches. We refer to ENTSO-E's CBA 2.0 if a monetization of the respective benefit was given in the guideline und is used by us for the assessment of PCI candidates.

- **Market-based socio-economic welfare (SEW) including RES integration and reduction of CO_2 cost:** This benefit reflects the SEW effect of integrating the storage project into the energy market. The SEW increase reflects a reduction of the system operational cost as result of the new storage unit and changed dispatch patterns of generation units with different marginal costs. In addition, the integration of storage projects into the energy market contributes to the system integration of RES by reducing their curtailment as well as a reduction of CO_2 emissions and other GHGs. The market-based SEW is quantified through modelling of the energy only market.
- **Generation capacity deferral:** Investment in energy storage projects could defer and/or reduce the need to invest in conventional, thermal generation capacity, if storage is a more cost-effective solution. The cost reduction (or avoided cost) of deferred generation investment is a societal benefit. However, we did not include this indicator into our assessment approach, since monetization requires further modelling activities beyond the scope of this study.

- **Reduced costs for ancillary services (reserve capacity, frequency regulation):** Energy storage projects can provide various ancillary services, e.g. manual Frequency Restoration Reserve (mFRR) or Frequency Containment Reserves (FCR). Operational cost savings can be realized by employing energy storage for system service provision. Since a comprehensive monetization of this benefit requires modelling of ancillary services markets we employ a benchmarking approach instead. Benchmark values are calculated by assuming a fixed ratio between the welfare generated through arbitrage on the energy-only-markets and the welfare generated through ancillary service provision.
- **Adequacy to meet demand:** A power system's adequacy to meet demand, is the ability to provide sufficient supply in order to meet the demand at any time. Storage projects can contribute to this goal by providing additional generation capacity and thereby avoiding the loss of load in case of any security of supply issues. ENTSO-E quantifies this indicator through probabilistic market and grid modelling considering contingencies such as generator or line outages. Thereby, a figure for the expected MWh-amount of energy not served (EENS) is derived. The contribution of storage to security of supply cannot only be described through avoided loss-of-load, but also through their contribution to an improved system adequacy margin. The system adequacy margin describes the surplus of available generation capacity beyond what is needed to cover the demand in situations where load shedding becomes a reasonable risk. Therefore, we use ENTSO-E's quantification of the EENS and monetize it through the value of lost load (VOLL), to reflect societal cost of energy not served.
- **Transmission capacity deferral:** Due to their flexible operation storage projects may reduce stress on the grid, alleviate congestion and thereby reduce the need for grid capacity extension. Thus, storage projects can potentially defer investment in transmission assets. Quantification and monetization require substantial modelling exercises which is out of the scope of this study, we have not been able to include this benefit in our assessment of PCI candidates.
- **Reduction in grid losses:** Energy transport in power grids causes thermal losses in the grid. Similar to a transmission project also storage projects influence generation and load flow patterns, or the power flow levels in the grid, i.e. reducing stress in the grid. Thereby, a storage project can potentially reduce but also increase grid losses. Grid losses are quantified through network studies. We use the monetized benefit by ENTSO-E and take it into account for the assessment of PCI candidates.
- **Facilitating additional RES integration (improved RES business case):** storage project may even further contribute to beneficial framework conditions for the integration of additional RES. A storage project may have a levelling effect on market prices, reduce the number of hours with low prices, and reduce curtailment of RES. Thereby, the storage project's market impact may allow for more viable business cases for RES and trigger more investments. This benefit of facilitating additional RES integration can be quantified and monetized by means of a power system model for expansion planning and unit-commitment. This modelling exercise is out of the scope of this study. Therefore, we do not take this benefit into account for the assessment of the PCI candidates.
- **Additional impact of avoided CO_2 emissions:** The additional impact of avoided CO_2 emissions captures the societal benefit of avoided GHG emissions beyond what is captured by carbon markets, such as the ETS system. the carbon price level imposed on electricity production by the EU ETS does not capture the total societal cost of carbon emissions and global warming related effects. Therefore, this benefit monetises the GHG emission reduction via the price differential between shadow carbon prices and the ETS price.
- **Reduction of non-CO_2 emissions:** The benefit reduction of non-CO_2 emissions takes into account the broad spectrum of energy related emissions beyond CO_2 and other greenhouse gases (GHGs). That is, pollutants such as SO_x, NO_x and particulate matter with a local relevance in contrast to GHGs with their global impact. A comprehensive assessment of a reduction of non-CO_2 emissions requires market modelling, similar to the assessment of a variation of CO_2 emissions. We used benchmarks for monetization by assuming a fixed ratio between CO_2-emission cost and non-CO_2-emission cost.

We employed a three-tier approach, depicted in the figure below, to assess the PCI candidate projects based on the previously identified benefits, using the three types of data sources, viz. ENTSO-E, promoters and benchmarks. The approach ensures a consistent assessment for all projects, and is described as follows:

- Starting point for the assessment of the projects is the most consistent data source – the ENTSO-E's TYNDP assessment. In tier 1, we included the benefits monetized by the ENTSO-E indicators. These are market-based socio-economic welfare including RES integration and reduction of CO_2 cost; reduction in grid losses; adequacy to meet demand.
- In tier 2, after scrutinising the information, we included data for missing benefits provided by promoters to fill the gaps of benefits not monetized in tier 1. Missing benefits declared by project promoters have been included into the assessment, if we considered data as robust and consistent. That is the case if the monetization of a benefit is the result of comprehensive modelling exercise, using a modelling methodology in line with ENTSO-E CBA guideline 2.0. Moreover, the same scenarios and underlying assumptions must have been used for the calculation as it was the case in ENTSO-E's modelling exercise.
- Lastly, in tier 3, benchmarks figures are used to monetize remaining benefits not covered in tier 1 and tier 2. Thereby, we additionally monetized the benefits reduction of costs for ancillary services, additional impact of avoided CO_2 emissions, and reduction of non-CO_2 emissions.

Nevertheless, some benefits could not be quantified or monetized within this study although they are considered potentially relevant. Quantification of these mostly grid-related benefits would require comprehensive modelling on a European system level, and generic benchmarks do not capture project specifics well enough to meet our minimum robustness requirements. These benefits are generation capacity deferral, transmission capacity deferral, and facilitating additional RES integration.

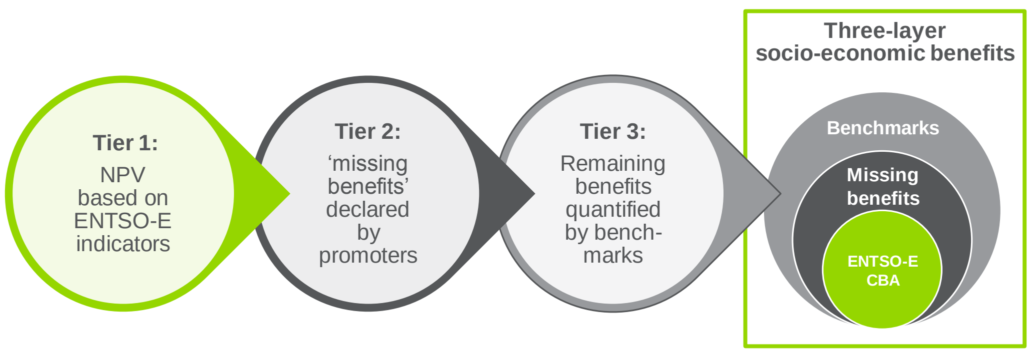

Figure 2: Methodology for the calculation of benefits to assess PCI candidates

Based on these three tiers of benefits, we calculated the societal NPV of a project through discounted cash-flow modelling. With this methodology, project costs and benefits are aggregated and brought to a comparable base. In addition to the project's benefits, we considered CAPEX and OPEX figures, taken from TYNDP 2018. The assessment is therefore focusing on monetized costs and benefits. Furthermore, we applied a social discount rate of 4% across Europe and concentrated on the ENTSO-E scenario 'Distributed Generation' for the analysis. We suggest applying a technology-specific economic lifetime beyond previously used 25 years, namely 50 years of PHEV and 35 years of CAES. Applying this methodology to the PCI storage candidates on the fourth PCI list, we arrive at a positive socio-economic NPV for most of the projects.

During this study we gained insight into the current PCI round for storage projects, through engagement with various stakeholders. We have seen certain issues in the TYNDP/PCI process which should be addressed in future rounds. In particular, a proactive outreach going beyond a publication of the TYNDP assessment results on the website to foster the timely discussion of potential errors in the data and calculations, as well as prevention of unpleasant surprises is advisable. Furthermore, we recommend that ENTSO-E and/or the EC present the CBA results more deliberate and timelier to the promoters and ask each promoter individually if the results are acceptable or need further explanation. Regarding the CBA methodology, we recommend that ENTSO-E calculates the relevant benefits we identified as much as possible. Firstly, this would result in a coherent approach for all projects. Secondly, ENTSO-E has the expertise and models in house to conduct such detailed assessments, something that is not necessarily the case for promoters, especially smaller organisations that perhaps do not have the means for such detailed assessments. Benefits that cannot be quantified and monetized by ENTSO-E – i.e. remaining missing benefits – should be clearly described, including what is expected of the promoters so that the benefits can be considered in the CBA.

1. INTRODUCTION AND STUDY OBJECTIVE

In this introductory chapter, we briefly outline the regulatory context before we describe the study objectives and our approach.

1.1 TEN-E provisions for assessment of electricity storage PCIs

The European process of identifying and promoting Projects of Common Interest (PCIs) as foreseen by Regulation (EU) No 347/2013 ('TEN-E regulation') support the objectives of market integration, sustainability and security of supply.[1] Electricity storage projects can apply for the PCI status and specific support measures. The selection criteria set out by the TEN-E regulation target large-scale storage facilities. For a project to be awarded with the PCI label, projects are assessed following the provisions of the TEN-E Regulation; the electricity storage PCIs need to contribute significantly to at least one of the following key specific criteria:

- **Market integration**, inter alia through lifting the isolation of at least one Member State and reducing energy infrastructure bottlenecks; competition and system flexibility.
- **Sustainability**, inter alia through the integration of renewable energy into the grid and the transmission of renewable generation to major consumption centres and storage sites
- **Security of supply**, inter alia through interoperability, appropriate connections and secure and reliable system operation

Moreover, only large-scale electricity storage projects are eligible to apply for the PCI status. Specific criteria are:

- a connection to the high-voltage transmission level (110kV or higher)
- an installed capacity of at least 225 MW
- an annual net electricity generation of at least 250 GWh/yr

The present (3rd) PCI list includes 14 electricity storage projects across all electricity priority corridors. For the fourth PCI list, there are 19 candidate electricity storage projects that have been included in the Ten-Year Network Development Plan (TYNDP) from ENTSO-E. The decision process for the PCI status is based on the work of the European Commission's (EC) Regional Groups (RG). For electricity transmission and storage projects the ENTSO-E TYNDP Cost Benefit Analysis (CBA) results feed into the regional assessments as well.

1.2 Current CBA approach by ENTSO-E for PCI assessment

In 2018 ENTSO-E published the CBA 2.0 guideline for grid development projects.[2] This CBA 2.0 methodology is a central tool of ENTSO-E's TYNDP process. To be included in the TYNDP, applying projects are assessed by means of a socio-economic CBA, including their environmental and social impacts and their contribution to the European long-term policy goals. Consequently, the methodology defined by ENTSO-E aims at a consistent assessment of TYNDP transmission and storage projects across Europe. Furthermore, this methodology is the basis for the identification and selection of PCI projects.

The CBA 2.0 employs a multi-criteria approach that combines a quantified and monetized assessment of some impacts with the qualitative description of other indicators and compares it to the indicated costs of the project. The CBA uses a common set of scenarios and grid models, based on which market and network simulations are performed to assess the project's impact – the so-called project-specific analysis.

[1] https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2013:115:0039:0075:en:PDF

[2] https://www.entsoe.eu/news/2018/10/12/commission-approves-2d-entso-e-guideline-for-cost-benefit-analysis-of-grid-development-projects/

The current CBA guideline 2.0 already includes some major improvements in terms of storage assessment, compared to ENTSO-E's 1st CBA guideline. Building upon a consultation process, these changes between both versions of the CBA guideline include:[3]

- Assessment of storage and transmission projects is harmonized.
- A more detailed Security of Supply indicator is considered, disaggregated into three sub-indicators, adequacy, system flexibility and system stability.
- More specific guidance is given related to the assessment of the flexibility contribution of storage projects.
- Recommendations for modelling and simulation refrain from limiting the time resolution to one-hour level (sub-hourly levels may be considered).

Still, the current CBA 2.0 methodology has limitations in terms of the way electricity storage projects are assessed; because the CBA is focused on transmission assets, it does therefore not completely capture all social benefits storage projects might bring to the power system and the European society. This includes fast and slow reserves - Frequency Containment Reserve (FCR), automatic Frequency Restoration Reserve (aFRR) and manual Frequency Restoration Reserves (mFRR) – procured by TSOs. Also, some storage projects may bring benefits to other non-electricity sectors, which require careful consideration from a CBA perspective (e.g. by comparison with partial CAPEX/OPEX). In addition, not all impacts are quantified and monetized. This makes it challenging to conduct a complete valuation of the storage projects, as only monetized impacts can be considered in a CBA. ACER delivered an opinion in March 2017 on ENTSO-E's "CBA 2.0" which still questioned the robustness and completeness of storage project assessment.[4] Raised concerns include:

- No mandatory monetization of the security of supply indicator in the guideline. In particular, flexibility benefits of storage projects are described only qualitatively.
- Beyond the indicators described in the guideline, additional benefits should be monetised, such as avoided/deferred cost for new generation investments, cost reduction for ancillary services and external costs of thermal generation.
- Missing details on the methodology for modelling of storage projects, such as handling of dispatch profiles, data needs and assumptions.

[3] https://docstore.entsoe.eu/Documents/TYNDP%20documents/TYNDP2018/consultation/Technical/Accompanying%20document%20to%202nd%20CBA.pdf

[4] https://www.acer.europa.eu/Official_documents/Acts_of_the_Agency/Opinions/Opinions/ACER%20Opinion%2005-2017.pdf

1.3 Study objectives and approach

Given this context, the goal of this study is twofold:

1. To improve the CBA approach for candidate electricity storage PCIs to better capture the benefits these potential PCIs bring to the EU society
2. To apply this approach to the current list of 19 candidate storage PCIs.

Our approach to meeting this goal consists of the following five main steps and is visualised in Figure 3:

1. We have identified the benefits that typically are associated with large scale storage projects. Benefits should contribute to at least one of the three TEN-E goals market integration, sustainability and security of supply. We focus also on the benefits that have potentially a significant impact.
2. For the selected benefits, we described how they can be quantified and monetized, and which data sources can be used for them.
3. We have then quantified and monetized the identified benefits for the 19 candidate storage projects on the current fourth PCI list. We have firstly taken the benefits calculated by ENTSO-E. Secondly, we have added missing benefits declared by promoters, after we have deemed the values robust. Finally, benefits not monetized by ENTSO-E or the promoters have been quantified by us through benchmarks from other projects and literature.
4. Then we defined the Net Present Value (NPV) approach, in which we described on which scenario we focused, which discount rate we applied and how we dealt with the economic lifetime of the technologies at hand.
5. Finally, by employing the NPV approach on the monetized benefits and the costs declared by the promoters, we calculated the individual NPVs of the 19 storage PCI candidates.

In this report, we will follow these main steps, and explain in more detail our methodology and describe the results. In the final chapter, we provide our recommendations for future TYNDP and PCI cycles.

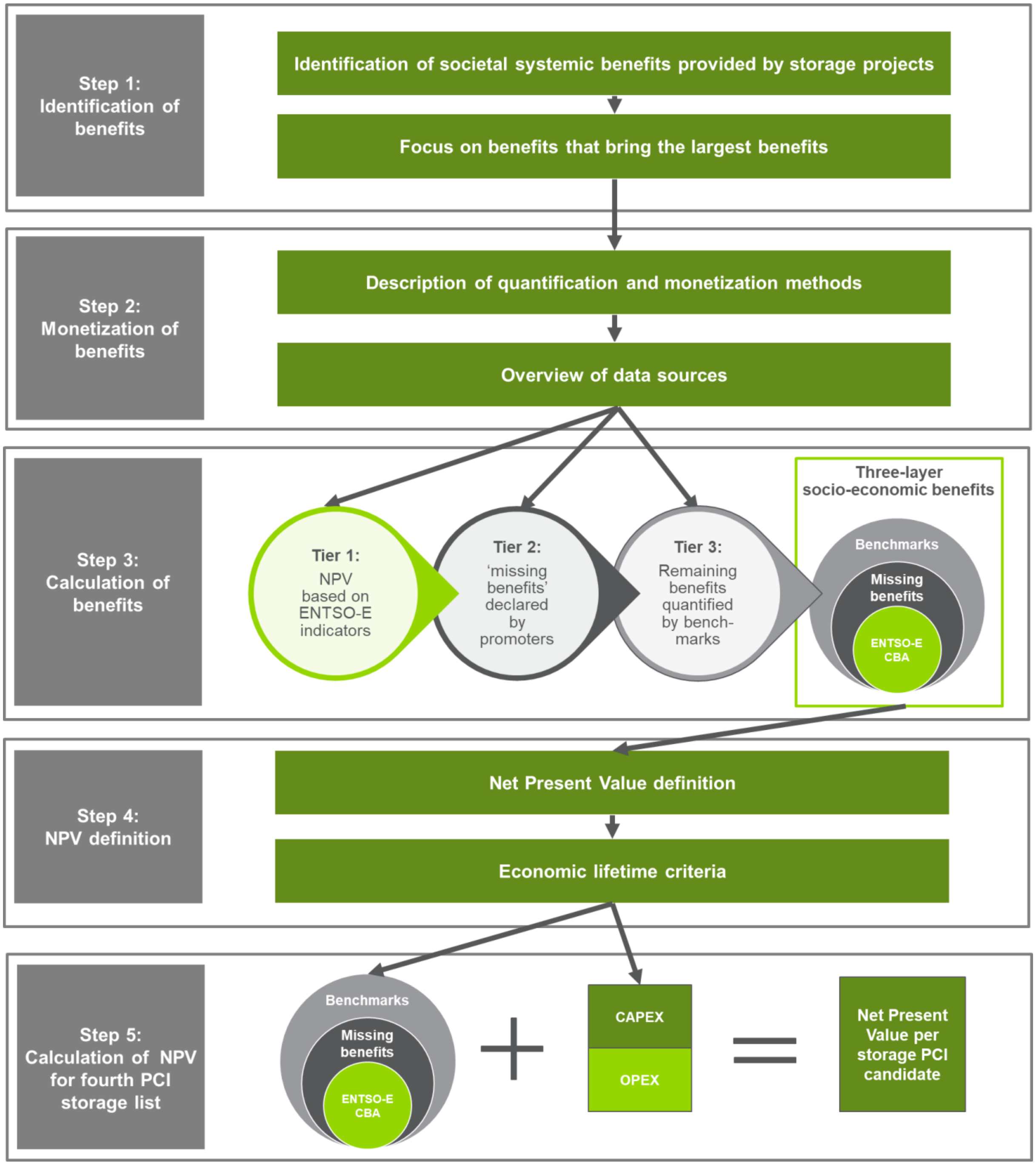

Figure 3: Methodology for the identification and monetization of storage benefits and approach to socio-economic assessment of the PCI candidate projects

2. VALUE OF LARGE-SCALE ELECTRICITY STORAGE IN THE CONTEXT OF THE PCI PROCESS

In this chapter, we describe in detail how we developed the assessment framework for storage PCI projects, illustrated in Figure 3, that is used to evaluate candidates for the 4th PCI list.

2.1 Identification of benefits

To develop a suitable approach for the socioeconomic assessment of PCI candidates, firstly, we need to inventory potential benefits provided by storage projects. Through literature review a broad set of storage-related benefits can be identified. However, only some of these benefits are of relevance in the context of storage PCI projects. Therefore, we identify the actual value drivers for large-scale electricity storage, as a subset of the previously identified benefits. This theoretical exercise, illustrated in Figure 4, leads to a better understanding which benefits are important to quantify and monetize, and which can be neglected, when conducting the socio-economic cost-benefit analysis.

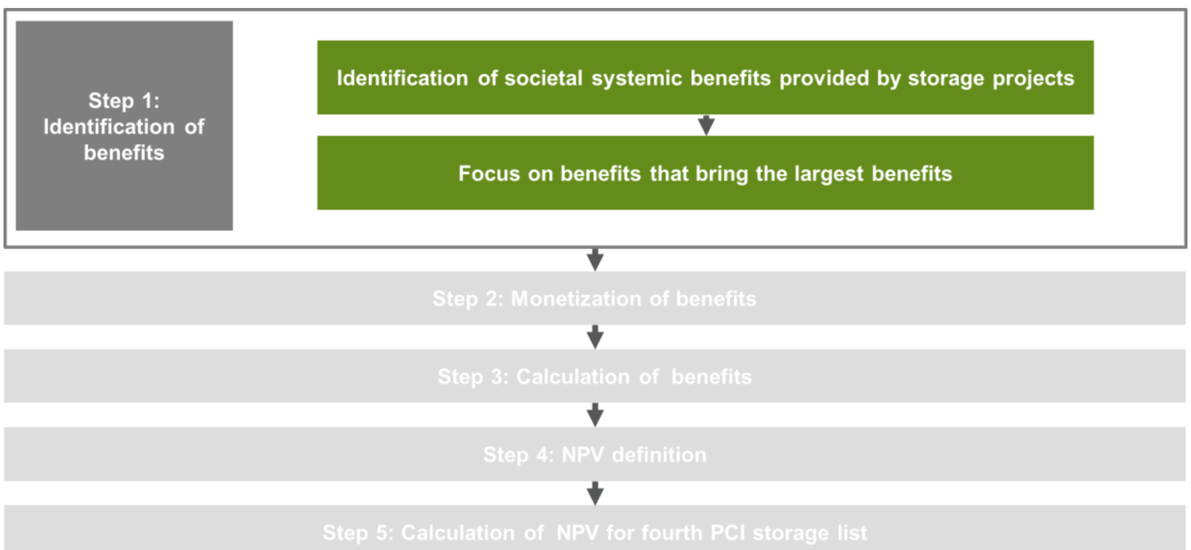

Figure 4: Methodology for analysis of existing CBA frameworks and how it feeds into the assessment methodology

The identification of benefits is based on credible public sources and we aim to capture a wide list of benefits that energy storage can provide to i.e. generation, transmission, distribution, retail and consumption. Starting point for the analysis is the assessment framework developed by ENTSO-E, the CBA guideline 2.0.[5] The guideline considers 8 different indicators, further explained in Table 1. They account for the power market impact of the storage project, environmental impact as it is reflected by the EU Emission Trading Scheme (ETS), the grid impact by means of losses, and the impact on security of supply by means of energy not served. Although the approach in principle already covers a wide variety of benefits, limitations are that the benefits are only considered at a high, aggregated level, monetization approaches are missing for various benefits, and not all potential benefits are considered, as already discussed in section 1.2.

[5] https://www.entsoe.eu/news/2018/10/12/commission-approves-2d-entso-e-guideline-for-cost-benefit-analysis-of-grid-development-projects/

Table 1: Benefit categories in ENTSO-E's CBA 2.0

ENTSO-E benefit indicators		Description	Unit	Assessment (qualitative, quantitative, monetary)
B1	Socio-economic welfare	Facilitation of market integration through reduced congestion, increased commercial exchanges, economically more efficient operation of the power system through utilization of efficient generation assets	SEW in EUR/yr	Monetized. Reflects short-run marginal costs of the power system
B2	Variation in CO_2 emissions	Change in CO_2 and other GHG emissions in the power system as a consequence of changes in generation dispatch and increased RES penetration	Emission reduction in t/yr and EUR/yr	Quantified. Monetized and included under B1. CO_2 emission cost are reflected in system's generation cost through carbon prizes (ETS)
B3	RES integration	Ability of the system to allow for the connection of new RES, unlock existing and future RES generation, minimize RES curtailment	Integrated amount of RES in GWh/yr and EUR/yr	Quantified. Monetized and included under B1. RES integration reflects in lower generation costs
B4	Variation in societal well-being as a result of variation in CO_2 emissions and RES integration	Increase in societal well-being beyond the economic effects captured by indicator B1 (SEW). E.g. this indicator reflects the full societal cost of CO_2 emissions that is not captured by carbon pricing schemes, such as EU ETS.	Not specified.	Not specified
B5	Variation in grid losses	Measure of energy efficiency. Reflects the decrease/increase of thermal losses in the transmission system due to the project.	Losses in MWh/yr and EUR/yr	Quantified and monetized. Losses are valued at average electricity prices.
B6	Security of supply: Adequacy to meet demand	Reflects the project's impact on the power system's ability to provide an adequate supply of electricity to meet the demand at any time.	Energy not served in MWh/yr Adequacy margin in MW	Quantified. Suggested, but not implemented: Energy not served can be valued at value-of-lost-load (VOLL). Adequacy margin can be valued through avoided investment cost of peaking plants.
B7	Security of supply: System flexibility	Impact of the project on the power system's ability to accommodate fast and deep changes in generation and/or load	Ordinal scale	Qualitative
B8	Only transmission projects: Security of supply: System stability	Power system's ability to provide a secure supply of electricity (regain a state of operating equilibrium after being subjected to a physical disturbance)	Project impact on ordinal scale	Qualitative

Source: ENTSO-E (2018) – Methodology: second ENTSO-E Guideline for Cost Benefit Analysis of Grid Development Projects

Therefore, we complement ENTSO-E's indicators through benefits identified in publications from the following organisations:

- Agency for the Cooperation of Energy Regulators (ACER)
- Electric Power Research Institute (EPRI)[6]
- Sandia National Laboratories[7]
- European Association for Storage of Energy (EASE)[8]
- European Energy Research Alliance (EERA)[7]
- University of Cambridge, Energy Policy Research Group (EPRG)[9]

[6] EPRI (2011) - Understanding Energy Storage Solutions and Capabilities on Utility Distribution Systems
[7] Sandia (2010) - Energy Storage for the Electricity Grid: Benefits and Market Potential Assessment Guide
Sandia (2015) - DOE/EPRI Electricity Storage Handbook in Collaboration with NRECA
[8] EASE/EERA (2017) – EUROPEAN ENERGY STORAGE TECHNOLOGY DEVELOPMENT ROADMAP

The information gathering exercise unveiled the various nuances of different methodological approaches, as different sources tend to describe similar benefits in a slightly different way. We synthetized a list of 22 benefits by removing duplicates and focused on those tangible societal impacts directly benefitting the power system. For example, wider benefits, such as the contribution of storage projects to the economic development of an area, tourism effects and job creation were considered out of scope. The 22 societal benefits are listed in Table 2 and are categorized in five domains: supply, ancillary services, decarbonization, transmission and other. The table also indicates if an individual benefit contributes to one or more of the three overarching goals of the TEN-E regulation: market integration, sustainability and security of supply.

Although all of these benefits could theoretically provide an added value for society, they can be differentiated regarding their relevance to the PCI candidate assessment. Only benefits that have a significant value contribution – in terms of societal benefit, not necessarily project promoter revenue – and are generally applicable to all projects are considered relevant. This prioritization of the benefits, given in Table 2, is based on above stated literature, the interviews (see Appendix A) with the promoters and our expert judgement. We also differentiate benefits with a case-specific relevance, meaning that these benefits could have a significant effect in one or two projects, but are negligible for the other projects, e.g. for highly location-specific benefits only applicable in a certain region.

Moreover, in Table 2 we established the link between the benefit indicators used by ENTSO-E and the further disaggregated benefits identified through literature review. Likewise, we pointed out where ENTSO-E provides a monetization of the identified benefits. After we have described the relevant benefits, including

[9] EPRG (2017) - A Social Cost Benefit Analysis of Grid-Scale Electrical Energy Storage Projects: Evaluating the Smarter Network Storage Project

Table 2: Mapping of societal storage benefits to TEN-E process

	Societal benefit	Market integration	Sustainability	Security of Supply	Relevance to CBA	In the scope of ENTSO-E indicator	Monetized ENTSO-E indicator
Supply	Market-based socio-economic welfare	✓	✓	✓	relevant	B1, B2, B3	B1
	Generation capacity deferral		✓	✓	relevant	B6, B7	
	Optimization of supply operations	✓	✓		non-relevant	B1, B2, B3	
Ancillary services	Reduced cost of reserve capacity	✓		✓	relevant	B7	
	Reduced cost of frequency regulation	✓		✓	relevant	B7	
	Voltage management			✓	non-relevant	B7	
	System restoration			✓	non-relevant	B6, B8	
	Improved frequency stability in weak grids			✓	case-specific	B7	
	Avoided loss-of-load			✓	relevant	B6	
	Improved system margin			✓	relevant	B6	
	Improved system stability			✓	non-relevant	B8	
Trans-mission	Transmission capacity deferral	✓			relevant	B6, B7	
	Minimization of intrazonal congestion	✓			non-relevant	B1	
	Reduction in grid losses		✓		relevant	B5	B5
Decarbon-ization and sustainability	Management of excess renewable electricity	✓	✓		relevant	B1, B3	B1
	Facilitating additional RES integration		✓		relevant	B4	
	Carbon abatement		✓		relevant	B1, B2	B1
	Additional impact of avoided CO_2 emissions		✓		relevant	B4	
	Reduction of non-CO_2 emissions		✓		relevant	B4	
Other	Reduction of price differentials between bidding zones	✓			non-relevant	B1	
	Support reaching interconnection target ambitions	✓	✓	✓	case-specific	B1-B8	
	Synchronization with Continental Europe of Baltic States	✓	✓	✓	case-specific	B1-B8	

The literature review results in a broad spectrum of benefits. It becomes obvious, that ENTSO-E's CBA 2.0, in principle, covers all of these benefits but only a few are actually monetized. After eliminating the non-relevant and case-specific benefits from this list, we further aggregate remaining benefits, where possible. Besides simplification of the approach, reasons are, firstly, some of the benefits can only be monetized jointly and should therefore be listed as a single indicator. This is the case for benefits reflecting in an increased market-based welfare. Secondly, benefits similar in nature, such as different types of ancillary services, should be combined to avoid double counting. The mapping of the initial 22 benefits to a resulting group of 9 benefits is given in the table below.

Table 3: Aggregation of societal benefits

	Relevant benefits aggregated
Supply	Energy-market-based socio-economic welfare (incl. RES integration and reduction of CO_2 cost)
	Generation capacity deferral
Ancillary services	Ancillary services (reserve capacity and other)
	Adequacy to meet demand
Trans-mission	Transmission capacity deferral
	Reduction in grid losses
Decarbonization and sustainability	Facilitating additional RES integration (improved RES business case)
	Additional impact of avoided CO_2 emissions
	Reduction of non-CO_2 emissions

2.2 Description of relevant benefits

The resulting 9 benefits are described in this section. We outline quantification and monetization approaches for these benefits, describe their relation to the ENTSO-E indicators and provide additional data sources.

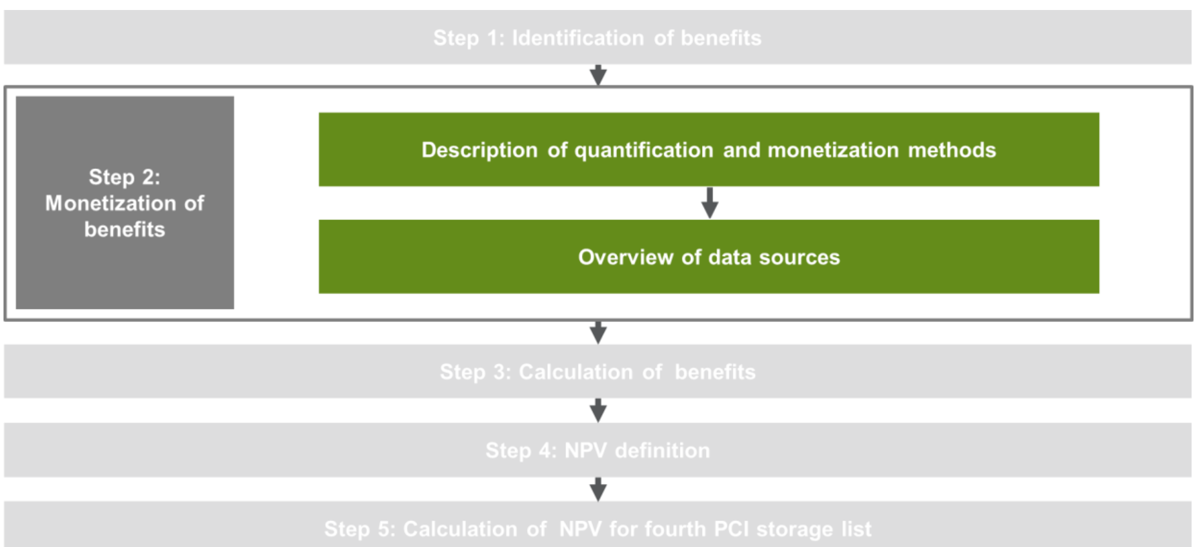

Figure 5: Methodology for the development of monetization approaches and how it feeds into the assessment methodology

General applicable principle for the quantification and monetization of benefits is, that they need to be valued from the socio-economic perspective, not to be confused with the perspective of a project promoter. This means, e.g. not only the revenues to the project promoter generated from providing a certain service need to be considered, but rather the overall cost reduction on the market for this respective service. Moreover, it should be noted, that although benefits are usually positive, they can be negative in some cases (i.e. a cost), for example if a project increases grid losses.

2.2.1 Market-based socio-economic welfare including RES integration and reduction of CO_2 cost

This benefit reflects the socio-economic welfare (SEW) effect of integrating the storage project into the energy market. The SEW is a collective benefit that captures the economic surpluses by consumers and producers originating in a reduction of the total variable generation costs. This reduction in system operational cost is a result of the new storage unit and changed dispatch patterns of generation units with different marginal costs. The market-based SEW is quantified through modelling of the energy only market. With regards to storage projects, the SEW captures the effects of arbitrage on the wholesale markets in the short and longer term, from smoothening daily price variations, to seasonal effects. Market-based SEW is the fundamental purpose of a storage project and its major contribution to market integration – and thereby the main benefit captured by the project.

In addition, the integration of storage projects into the energy market contributes to the system integration of RES by reducing their curtailment. If the infeed from RES, in particular variable RES, is higher than the instantaneous demand of the system, or higher than the transfer capacity of the grid, RES are commonly curtailed to cope with this problem. Storage contributes to managing this excess renewable electricity by adapting the load to the high feed-in and/or mitigating grid congestion. The additional share of low-marginal-cost RES result in system-wide generation cost savings. Consequently, the societal benefit of avoided spillage of RES is monetized by means of market modelling and represents a part of the overall market-based SEW.

Likewise, the market integration of storage projects contributes to a reduction of CO_2 emissions and other GHGs. That is, a changed dispatch of generation units (thermal and renewable) due to the storage unit affects system-wide GHG emissions. Since carbon pricing schemes such as carbon taxes or the EU ETS are directly imposed on carbon-based electricity production, these CO_2-costs are internalized in the production cost and do reflect directly in the system operational cost. Consequently, the benefit of avoided CO_2 emission cost is monetised as a part of the market-based SEW, calculated through market modelling and carbon prize forecasts. It needs to be emphasized that this benefit can also be a cost if the considered project increases the system's carbon emissions.

The additional RES integration and reduction in CO_2 emissions are quantified by ENTSO-E with indicators B2 and B3, respectively. However, as described, both indicators are monetized as a part of the market-based socio-economic welfare, ENTSO-E indictor B1. Therefore, we use this indicator without any changes as monetization of the market-based socio-economic welfare including RES integration and reduction of CO_2 costs.

2.2.2 Generation capacity deferral

Investment in energy storage projects could defer and/or reduce the need to invest in conventional, thermal generation capacity, if storage is a more cost-effective solution. The market-based socio-economic welfare assessment can assess how storage may out-compete other supply; if this reduces the viability to a point where the development of conventional generation can be deferred (without adequacy issues and a risk for security of supply), the resulting cost reduction (or avoided cost) is the societal benefit associated with capacity deferral. Thereby the societal benefit is monetized through avoided investments. Another possibility for ascribing a financial value to the capacity deferral is market-based, where the price is set by a capacity market – if existing.

Capacity deferral of thermal generation is within the scope of ENTSO-E indicators B6 and B7, since investment into generation capacity could be driven by the need to increase the system margin (B6) or the need for the provision of flexibility and system services (B7). ENTSO-E provides a quantification of the increased system adequacy margin within indicator B6 and suggests (but not applied) a monetization via investment costs of peaking units. We did not include this indicator into our assessment approach, since monetization requires further modelling activities that is beyond the scope of this study. That is, figures need to be derived for the investment costs of generation units in the respective region and market area, including a forecast of the future development of these figures throughout the time span considered for PCI candidate assessment.[10]

2.2.3 Reduced costs for ancillary services (reserve capacity, frequency regulation)

Energy storage projects can provide various ancillary services. For instance, non-automated or slower reserves, such as manual Frequency Restoration Reserve (mFRR) or Replacement Reserve (RR), which are part of a TSO's toolkit for frequency control. In addition, automated regulation, such as Frequency Containment Reserves (FCR) and automatic Frequency Restoration Reserve (aFRR) are used for frequency control. Technical requirements are higher for the provision of automated regulation compared to non-automated reserves, e.g. due to shorter response times. These ancillary services are commonly provided by conventional generation assets. However, PHES and other storage types are able to provide these types of reserves and are increasingly participating in ancillary services markets within Europe, given their ability to quickly adjust their output. Thereby, operational cost savings can be realized by employing energy storage for system service provision.

Reduced cost for ancillary services falls within the scope of ENTSO-E indicator B7 – system flexibility. However, it is neither quantified nor monetized by ENTSO-E. Only a qualitative assessment of a storage project's ability to provide regulation power is part of the CBA 2.0.

Since a comprehensive monetization of this benefit requires modelling of ancillary services markets we employ a benchmarking approach instead. Benchmark values are calculated by assuming a fixed ratio between the welfare generated through arbitrage on the energy-only-markets (described in section 2.2.1) and the welfare generated through ancillary service provision. Aside from market characteristics, these two benefit types are mainly determined through the technical specifications of the storage project, i.e. the capacity. Since the considered types of storage (PHES, CAES) can provide a similar range of ancillary services it is reasonable to assume that a certain per-MW-welfare can be generated on energy-only as well as ancillary-services markets.[11] This results in a monetised benefit, which represents on average 47% of the overall value (of all benefits, for all projects) for this assessment.

2.2.4 Adequacy to meet demand

A power system's adequacy to meet demand, is the ability to provide sufficient supply in order to meet the demand at any time. Storage projects can contribute to this goal by providing additional generation capacity and thereby avoiding the loss of load in case of any security of supply issues. This benefit is described by the ENTSO-E indicator B6 – adequacy to meet demand. ENTSO-E quantifies this indicator through probabilistic market and grid modelling considering contingencies such as generator or line outages.[12] Thereby, a figure for the expected MWh-amount of energy not served (EENS) can is derived. Integrating the storage project into the system is likely to reduce the EENS.

The contribution of storage to security of supply cannot only be described through avoided loss-of-load, but also through their contribution to an improved system adequacy margin. The system adequacy margin describes the surplus of available generation capacity beyond what is needed to cover the demand in situations where load shedding becomes a reasonable risk. Thereby, this benefit is able to

[10] A similar task had been performed by the regulating body of the Irish power wholesale market (SEM Committee). As a benchmark for capacity auctions, they derived an investment cost figure of 92.3 EUR/kW/yr in 2022 for the best new entrant peaking unit (open cycle gas turbine). https://www.semcommittee.com/sites/semc/files/media-files/SEM-18-156%20CRM%20T-4%20CY202223%20BNE%20Decision%20Paper%20FINAL.pdf

[11] Literature states a factor in the range of 1x to 5x for ancillary service benefits in comparison to arbitrage-based benefits for storage projects. Factor 2x is chosen as a reasonable intermediate for calculations. See: https://setis.ec.europa.eu/sites/default/files/reports/power-storage-report.pdf and https://www.nrel.gov/docs/fy10osti/47187.pdf

[12] See also https://www.entsoe.eu/outlooks/midterm/

capture the contribution of storage projects to security of supply, even if simulations show an EENS equal to zero – with and without the project.

Both approaches – system margin and avoided loss-of-load – complement each other and are covered by ENTSO-E indicator B6 – adequacy to meet demand. Although ENTSO-E quantifies both measures, no monetization had been implemented by ENTSO-E for either of them. Therefore, we use ENTSO-E's quantification of the EENS and monetize it through the value of lost load (VOLL), to reflect societal cost of energy not served. Country-specific VOLLs are given by ACER.[13] However, we employ a single VOLL-Value of 10,000 EUR/MWh for all projects as an upper estimation since it is unclear which consumer groups would be subject to the supply disruption and where they are located. A further differentiation of the VOLL is not reasonable; firstly, to guarantee equal treatment of all PCI candidates, and secondly, since VOLL estimation is uncertain in itself.

Likewise, monetization of the improved system margin, measured as MW of spare capacity, can be indirectly achieved on the basis of avoided investment costs of additional peaking generation units. However, this would result in a double-counting of a potential benefit, since we treat generation investment deferral as a separate benefit (see section 2.2.2). Therefore, we do not monetize the improved system margin.

2.2.5 Transmission capacity deferral

Due to their flexible operation storage projects may reduce stress on the grid, alleviate congestion and thereby reduce the need for grid capacity extension. Thus, storage projects can potentially defer investment in transmission assets. It should be noted though, that in some cases a storage project may increase the need for additional transmission capacity. A reduction of the grid capacity need can be quantified through network studies and a potential benefit can be monetized by estimating the avoided investment cost in transmission capacity.

The benefit of transmission investment deferral is within the scope of ENTSO-E indicator B7 – system flexibility, since flexibility can either be provided by storage or by flexible generation, connected through additional transmission capacity. ENTSO-E provides a quantification of indicator B7 only for transmission projects, using a metric that relates new, additional transmission capacity to existing cross-border capacity. However, this metric is not monetized. Conversely, possible transmission investment deferrals enabled by storage projects are only assessed qualitatively by ENTSO-E. Quantification and monetization requires substantial modelling exercises which is out of the scope of this study, we have not been able to include this benefit in our assessment of PCI candidates. For future assessments, it is advisable to develop a common metric that allows for the comparison of storage and transmission projects. Only then, the transmission capacity deferral could be monetized via transmission investment benchmarks.

2.2.6 Reduction in grid losses

Energy transport in power grids causes thermal losses in the grid. Similar to a transmission project also storage projects influence generation and load flow patterns, or the power flow levels in the grid, i.e. reducing stress in the grid. Thereby, a storage project can potentially reduce but also increase grid losses. Grid losses are quantified through network studies, in line with the methodology used for ENTSO-E indicator B5 – grid losses. The grid is modelled with and without the project and by comparison of the results, the variation in grid losses can be quantified. Monetization is achieved through additional market modelling and valuation of the losses at the system's marginal cost.

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[13] https://www.acer.europa.eu/en/Electricity/Infrastructure_and_network%20development/Infrastructure/Documents/CEPA%20study%20on%20the%20Value%20of%20Lost%20Load%20in%20the%20electricity%20supply.pdf

As described, ENTSO-E quantifies and monetizes grid losses for the TYNDP assessment. Therefore, we take the monetized benefit into account for the assessment of PCI candidates without further adjustments.

2.2.7 Facilitating additional RES integration (improved RES business case)

A storage project's contribution to the integration of RES is threefold:

1. The integration of existing RES is facilitated by reduced curtailment, as quantified by ENTSO-E indicator B3 – RES integration through the MWh-amount of avoided curtailment and monetized as a port of indicator B1 – socio-economic welfare. This is already captured in our approach, see section 2.2.1.
2. In addition, the considered project can contribute to the connection of additional RES to the power system due to new transmission/distribution lines built jointly with the storage project. ENTSO-E's CBA 2.0 describes quantification of this benefit through stating the MW-amount of RES newly connected to the main power system in indicator B3.[14] The integration of these additional RES in spatial proximity to the storage projects provides a benefit through a decrease in system operational costs. Therefore, it is monetized through indicator B1, as a part of the market-based SEW described in section 2.2.1. This is of particular importance for pumped hydro storage projects with natural inflow – since electricity production from natural inflow can be interpreted as an additional run-of-the-river hydro plant that gets connected to the power system together with the storage project. Unfortunately, ENTSO-E does not report the SEW contribution of newly connected RES separately from the SEW contribution of reduced RES curtailment. Therefore, to facilitate transparency it is advisable to report the monetized values of the two different measures within indicator B3 (reduced RES curtailment in MWh, newly connected RES in MW) separately for future assessments. The reason behind this recommendation is that we cannot consider natural inflow as a storage benefit for pumped hydro storage projects (it is rather a generation benefit), thereby enabling comparability between different storage projects. To deduct the benefit from natural inflow from the market-based SEW figures reported by ENTSO-E under indicator B1 we used the natural inflow figure of the respective project (MWh/yr) and valued it at the average marginal cost of the power system.[15]
3. Moreover, a storage project may even further contribute to beneficial framework conditions for the integration of additional RES. A storage project may have a levelling effect on market prices, reduce the number of hours with low prices, and reduce curtailment of RES. Thereby, the storage project's market impact may allow for more viable business cases for RES and trigger more investments. This benefit of facilitating additional RES integration can be quantified and monetized by means of a power system model for expansion planning and unit-commitment. Such a model can provide insight on the structural development of the power system beyond what is captured by market modelling based on scenarios of a pre-fixed mix of generation assets. This benefit contributes to ENTSO-E indicator B4, the societal well-being as a result of RES integration, although there is the possibility of overlap with various other benefits, such as RES curtailment and carbon abatement (ENTSO-E indicators B2 and B3). ENTSO-E did not provide a quantification or monetization of the indicator B4. The modelling exercise needed to quantify and monetize this benefit is out of the scope of this study. Therefore, we do not take this benefit into account for the assessment of the PCI candidates.

[14] It should be noted though, that although described in the CBA guideline, the MW-amount of newly connected RES does not appear in the project fiches of the TYNDP 2018.

[15] Marginal cost figures, differentiated per country, scenario and base year are taken from ENTSO-E – TYNDP 2018 Scenario Report Annex I: https://docstore.entsoe.eu/Documents/TYNDP%20documents/TYNDP2018/Scenario_Report_Annex_I.pdf

2.2.8 Additional impact of avoided CO_2 emissions

The additional impact of avoided CO_2 emissions captures the societal benefit of avoided GHG emissions beyond what is captured by carbon markets, such as the ETS system. Market integration of the considered project may lead to a change in the power systems carbon emissions and respective carbon cost, as described in section 2.2.1. However, the carbon price level imposed on electricity production by the EU ETS does not capture the total societal cost of carbon emissions and global warming related effects such as sea level rise. Rather, ETS market prices can be considered as distorted and shadow carbon prices need to be considered instead to better capture the complete impact on society. Therefore, this benefit monetises the GHG emission reduction via the price differential between shadow carbon prices and the ETS price. Thus, the cost of carbon up to the ETS level is monetized by ENTSO-E indicator B1 and is reflected in the market-based SEW, described in section 2.2.1. Everything on top of that is not monetized by ENTSO-E but covered within our approach under the label "additional impact of avoided CO_2 emissions". Nevertheless, this benefit is in the scope of ENTSO-E indicator B4 – variation in societal well-being as a result of variation CO_2 emissions and RES integration, for which ENTSO-E did not provide quantification and monetization methods in the CBA 2.0. Regarding monetization, it should be noted, that the additional impact of carbon emissions can be negative, in case of increased emissions due to the project, or in the case of ETS prices higher than the assumed shadow carbon prices.

For the monetization of this benefit, we used a benchmark calculated based on literature values for the societal cost of carbon (SCC), thus an estimation of the long-term effects of carbon emissions and related costs.[16] In particular, we used the kilotonne value of variation in CO_2 emissions reported by ENTSO-E (indicator B2) and valued it at the SCC, minus the scenario-specific carbon price, provided by ENTSO-E in their scenario description.[17] To account for the uncertainty in the estimation of the SCC we used a range of three different SCC values (minimum 50 EUR/t, average 150 EUR/t, maximum 300 EUR/t) reflecting the large spread of values reported in literature. The maximum and minimum values did feed into the sensitivity analysis of the candidate assessment. For future assessments it is advisable to align the SCC values with common practice used by other European institutions for CBAs, e.g. the revised versions of the EIB's CBA guideline[18] or the revised version of DG CLIMA's climate proofing guidance.[19]

2.2.9 Reduction of non-CO_2 emissions

The benefit reduction of non-CO_2 emissions takes into account the broad spectrum of energy related emissions beyond CO_2 and other greenhouse gases (GHGs). That is, pollutants such as SO_x, NO_x and particulate matter with a local relevance in contrast to GHGs with their global impact. A comprehensive assessment of a reduction of non-CO_2 emissions requires market modelling, similar to the assessment of a variation of CO_2 emissions, described in section 2.2.1. Quantification of the emission is based on standard emission factors of generation technologies and the change in generation unit dispatch, as a result of integrating the storage project into the market. Monetization of the societal cost of non-CO_2 emission is achieved through per-unit cost factors of the considered pollutants taken from literature. These cost factors consider environmental and societal impacts such as reduced life expectancy through air pollution. Similar to the monetization of a variation in GHG emissions (section 2.2.1), the reduction of non-CO_2 emissions can be a cost in case of increased emissions on the system level due to integrating the project into the power system.

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[16] Literature values for SCC are in the range of 8 to 400 USD/tCO_2 for 2030. See: IPCC – Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (2007), OECD - Cost-Benefit Analysis and the Environment (2018)

[17] See ENTSO-E – TYNDP 2018 Scenario Report

[18] The EIB's CBA guideline from 2013 considers a shadow carbon price in the range of 20 to 80 EUR/t in 2030. https://www.eib.org/attachments/thematic/economic_appraisal_of_investment_projects_en.pdf.

[19] DG CLIMA states a central estimate of 52 EUR/t in 2030 in the climate proofing guidance for the 2014-2020 programming period. https://ec.europa.eu/clima/sites/clima/files/docs/major_projects_en.pdf

This benefit is within the scope of ENTSO-E indicator B4, variation in societal well-being as a result of variation CO_2 emissions and RES integration. However, ENTSO-E did not provide any quantification or monetization for this “free form” indicator in the CBA 2.0. Therefore, we used benchmarks for quantification and monetization. The benefit of non-CO_2 emission is benchmarked by assuming a fixed ratio between CO_2-emission cost and non-CO_2-emission cost. Reasoning behind this is, that each generation unit has fixed emission factors for CO_2 and non-CO_2 emission. Consequently, a change in generation dispatch will cause not only a variation in CO_2-emissions on a system level, but also a variation in non-CO_2 emissions – the electricity production related emissions are determined through a power system’s generation mix. Moreover, CO_2 and non-CO_2 emissions are monetized through literature values for their societal per-unit cost. Consequently, a fixed cost-ratio between the two emission types is established. We calculated the benefit of non-CO_2 emission reduction as a certain percentage share of the monetized value of the variation in CO_2 emissions, reported by ENTSO-E as part of the indicator B1, thus the market-based SEW (see section 2.2.1). Since the estimation of the societal per-unit cost of non-CO_2 pollutants are highly uncertain, we employ a range of multiplicator values from 100% to 250%, with an average value of 175% (cost of non-CO_2 in relation to cost of CO_2 emissions), based on literature review. The calculation of these ratios is outlined in the appendix C. Main data source for Europe for per-unit cost of air pollutants is the EU-funded research programme ExternE (Externalities of Energy), including project NEEDS (New Energy Externalities Development for Sustainability).[20]

2.3 Three-tier approach for socio-economic assessment of storage PCI candidates

In this section we present the next step in our approach, in which we describe how the previously defined relevant benefits are calculated and where the data is coming from to evaluate the 19 candidate PCI storage projects that are on the fourth PCI list. We outline how electricity storage PCI candidates are assessed on their contribution to the TEN-E objectives. The approach has been presented to and discussed with the TEN-E Regional Groups members and was not rejected.

[20] See CE Delft (2008). External Cost of Coal – Global Estimate, EEA (2014). Costs of air pollution from European industrial facilities 2008-2012

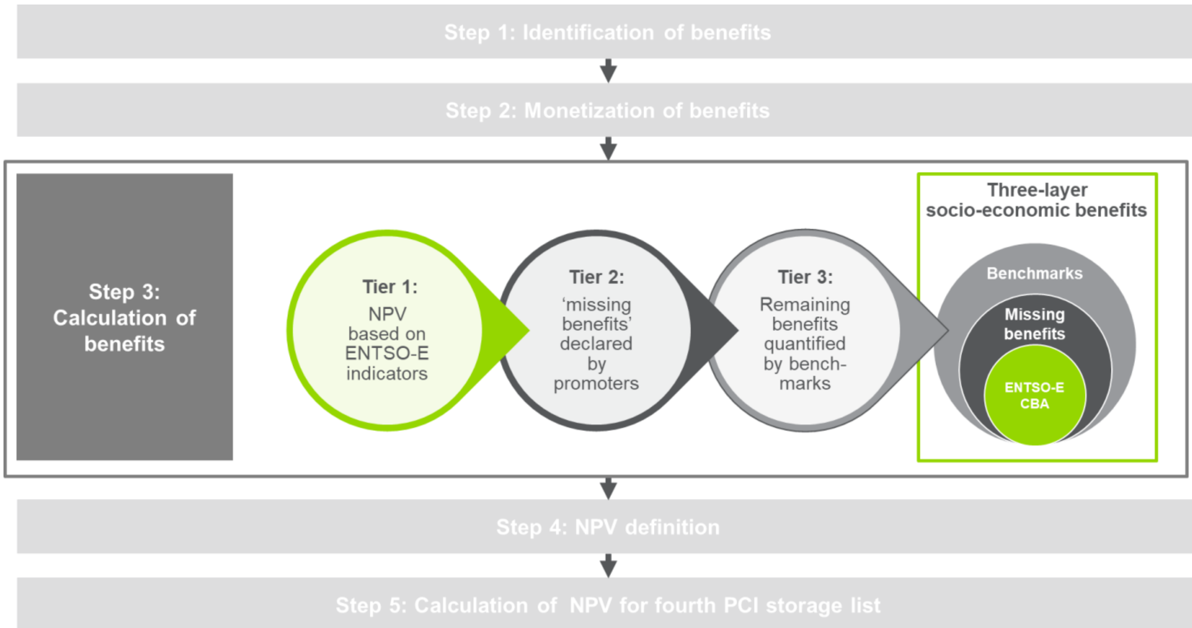


Figure 6: Methodology for the calculation of benefits to assess PCI candidates

We employ a three-tier approach, depicted in Figure 6, to assess the PCI candidate projects based on the previously identified benefits, using the three types of data sources, viz. ENTSO-E, promoters and benchmarks. The approach ensures a consistent assessment for all projects, and is described as follows:

- Starting point for the assessment of the projects is the most consistent data source – the ENTSO-E's TYNDP assessment. In tier 1, we included the benefits monetized by the ENTSO-E indicators.
- In tier 2, after scrutinising the information, we included data for missing benefits provided by promoters to fill the gaps of benefits not monetized in tier 1. Missing benefits declared by project promoters are mostly robust and consistent with the ENTSO-E methodology and scenarios, and therefore included.
- Lastly, in tier 3, benchmarks figures are used to monetize remaining benefits not covered in tier 1 and tier 2.

The mapping of the individual benefits and data sources to the three tiers is illustrated in Figure 7 and will be further explained in the following sections. We concentrate on the project benefits in this section; the cost side of the projects will be discussed in section 2.4.

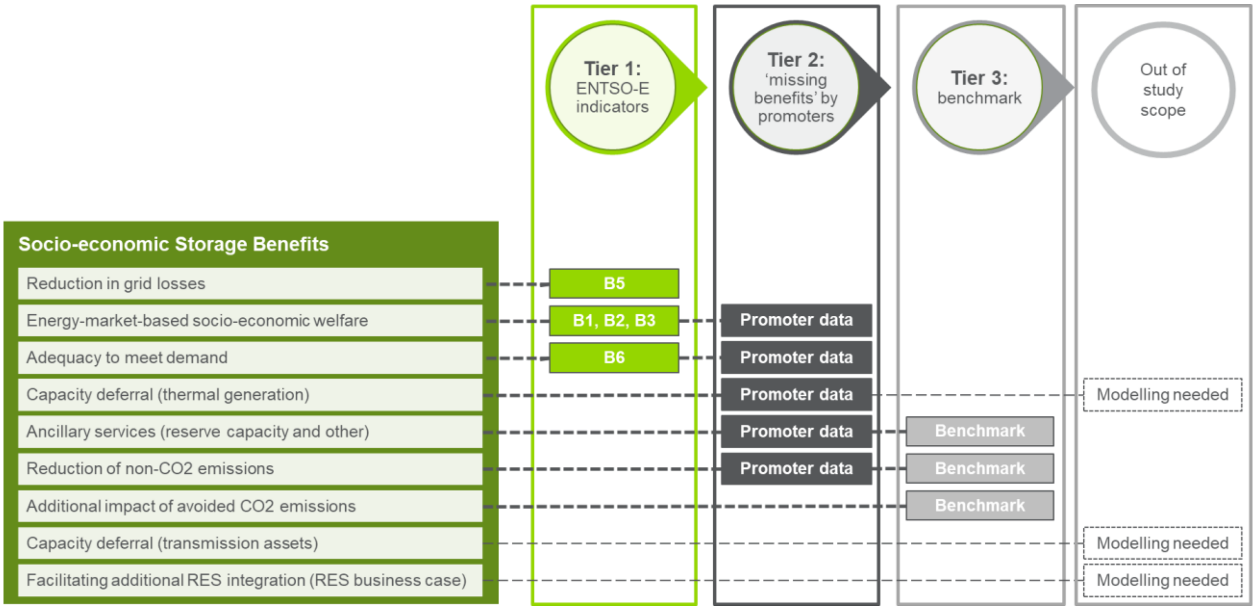


Figure 7: Mapping of the 9 benefits and data sources to the three-tier approach for NPV calculation

2.3.1 Tier 1: Monetized benefits provided by ENTSO-E indicators

The NPV is established using benefits that are readily monetised by ENTSO-E CBA indicators. These benefits and respective ENTSO-E indicators are:

- Market-based socio-economic welfare including RES integration and reduction of CO_2 cost. This benefit is monetized by ENTSO-E indicator B1 – socio-economic welfare. Nevertheless, this monetization also includes the monetisation of indicators B2 – variation in CO_2 emissions and B3 – RES integration, see section 2.2.1. If promoters reported robust and consistent values for indicator B1 themselves, we used these instead of ENTSO-E figures to better capture project-specific impacts. In addition, reasonable corrections to the B1 value are made in case of pumped hydro storage projects with natural inflow or diabatic CAES[21] with gas-fired generation to only consider benefits associated with electricity storage, and not electricity generation.
- Reduction in grid losses. This benefit is monetized by ENTSO-E indicator B5 – variation in grid losses, see section 2.2.6
- Adequacy to meet demand. This benefit is quantified by ENTSO-E indicator B6 – adequacy to meet demand through the measure of energy not served (ENS). We monetized it using the VOLL, as described in section 2.2.4.

2.3.2 Tier 2: 'Missing benefits' declared by promoters

As part of the TYNDP assessment, project promoters had the opportunity to declare so-called "missing benefits" to ENTSO-E, based on their own studies, to amend and add to ENTSO-E's analysis. ENTSO-E did not consider these benefits in the CBA 2.0, therefore, we extend the methodology here beyond what had been covered in previous PCI rounds. Based on this promoter data, we established an extended NPV by including these missing benefits.

[21] Adiabatic CAES uses only a very limited, additional energy input stream through gas and do not require a correction of the market-based SEW.

A wide variety of missing benefits have been declared by promoters. However, in some cases, promoters provided only qualitative arguments, or quantified benefits from the promoter' financial perspective instead of the societal level. E.g. promoters stated project revenues from system service provision instead of the cost reductions for procurement by the TSO. Therefore, we evaluated the declared missing benefits regarding the following criteria:

- Do the missing benefits declared by promoter fit into the nine benefit indicators outlined in Table 2?
- Did promoters provide monetized values for the missing benefits, using a societal perspective?
- Would there be a double counting of benefits if the missing benefit is included?
- Are the missing benefits declared by promoters robust and consistent? We considered data as robust and consistent, if the monetization of a benefit is the result of comprehensive modelling exercise, using a modelling methodology in line with ENTSO-E CBA guideline 2.0. Moreover, the same scenarios and underlying assumptions must have been used for the calculation as it was the case in ENTSO-E's modelling exercise.

Only declared missing benefits which met these criteria are included into our analysis. Missing benefits that have been declared by some promoters, matching above criteria, are:

- Adequacy to meet demand
- Capacity deferral (generation capacity)
- Reduction of costs for ancillary services
- Reduction of non-CO_2 emissions
- Synchronization with Continental Europe of Baltic States

However, these benefits have not been declared by the different promoters for all projects. Therefore, we further aimed at filling the remaining gaps through benchmarks in the next tier.

2.3.3 Tier 3: Benefits estimated trough benchmarks

Lastly, we estimated benefits which have not yet been monetised in tiers 1 and 2. Estimated benefits are based on benchmarking via data from public literature, according to the methodology outlined in the benefit descriptions, section 2.2:

- **Reduction of costs for ancillary services:** For some projects, which participated in the previous PCI round, we used data provided by the EC Joint Research Centre (JRC). The JRC monetised the societal benefit trough ancillary service provision for the CBA of candidates for the 3rd PCI list. For projects which had need not been part of the last PCI round, we estimated the benefit of ancillary service provision in relation to the market-based SEW provided by the project, as calculated by ENTSO-E, see section 2.2.3.
- **Additional impact of avoided CO_2 emissions:** Estimated based on the variation of CO_2 emissions calculated by ENTSO-E and the reduction of CO_2 cost already captured in the market-based SEW, see section 2.2.8.
- **Reduction of non-CO_2 emissions:** Estimated in relation to the reduction of CO_2 cost calculated by ENTSO-E, see section 2.2.9.

Nevertheless, some benefits could not be quantified or monetized within this study although they are considered relevant. Quantification of these mostly grid-related benefits would require comprehensive modelling on a European system level, and generic benchmarks do not capture project specifics well enough to meet our minimum robustness requirements. These benefits are:

- **Generation capacity deferral:** Monetization can be achieved based on the capacity contribution of a project and investment cost projections for generation units, as described in section 2.2.2.
- **Transmission capacity deferral:** This benefit can be quantified through network modelling and monetized based on the investment cost projections for transmission assets. Further discussion can be found in section 2.2.5.
- **Facilitating additional RES integration:** To assess the impact of storage projects onto the future development of RES capacity, a dispatch and investment model is needed in contrast to

the dispatch model used by ENTSO-E together with scenarios and pre-defined figures for future RES capacities. Further discussion can be found in section 2.2.7.

In addition to these three benefits that could not be considered, we also excluded case-specific benefits from our analysis. Therefore, although we have significantly improved the approach of ENTSO-E's CBA 2.0. to better capture the benefits large electricity storage projects bring to the European society, there are still impacts that could have an effect on the NPV of individual projects.

2.4 NPV definition

We calculate the societal NPV of a project through discounted cash-flow modelling, the usual approach for a CBA, also applied by ENTSO-E in the CBA 2.0. With this methodology, project costs and benefits are aggregated and brought to a comparable base. The ENTSO-E TYNDP assessment provided quantified, scenario-specific benefits for years 2025 and 2030. We calculated annual benefits based on these two years. In case the project is expected to be commissioned before 2025, we use the 2025 benefit values for the years from commissioning year to 2025, thus consider annual benefits constant. Between 2025 and 2030, we linearly interpolate the annual benefits. Benefits beyond 2030 are kept constant until the end of a project's lifetime.

In addition to the project's benefits, we considered CAPEX and OPEX, as shown in Figure 8. CAPEX and OPEX figures are taken from TYNDP 2018. Corrections are made in case of multi-usage applications of storage projects beyond the energy system. For example, if only a third of the CAPEX is related to an energy-sector investment, we reduce the CAPEX figure reported in the TYNDP 2018 to a third.

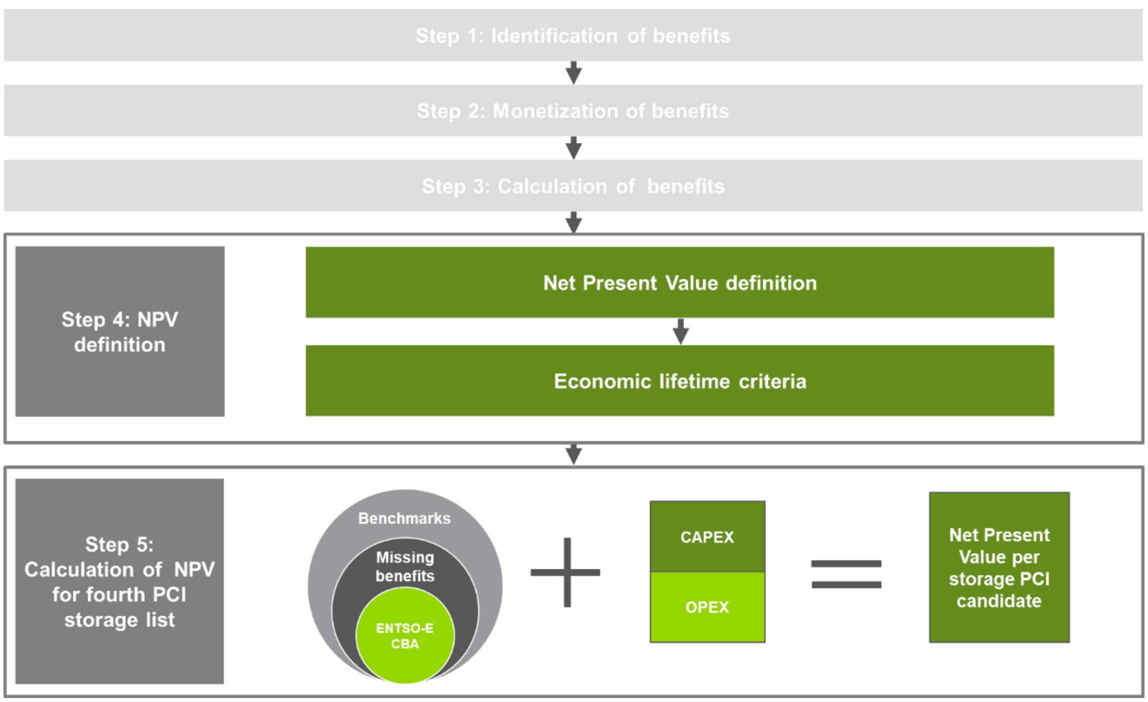


Figure 8: Methodology for the calculation of the NPV based on a project's benefits and costs

Furthermore, parameters which influence the calculation of a project's NPV are kept consistent with the transmission PCI assessment as much as possible. This includes following considerations:

- Focus is on monetized costs and benefits. This can still feed into a multi-criteria approach to cover other non-monetized aspects (not covered in this guidance).

- A social discount rate of 4% is applied across Europe. This is not to be confused with a private financial discount rate, on which the business case and financing are based, which is often higher.
- The analysis concentrates on the ENTSO-E scenario ‘Distributed Generation’, which is considered as the most appropriate scenario by the EC and is used for gas PCI project assessments as well.22
- In contrast to the transmission PCI assessment, however, we suggest applying a technology-specific lifetime beyond the 25 years, namely 50 years of PHEV and 35 years of CAES. The next section details on how we arrived at this suggestion.

2.4.1 Economic lifetime

Pumped storage plants have long technical lifetimes, sometimes more than 100 years. In fact, there are many pumped hydroelectric plants that operate for many decades with basically the same equipment as the first year they came into operation. During their technical lifetime, it is likely only minor repairs and replacement of parts is necessary, whilst continuing their operation, earning money and creating societal benefits. To a lesser extent, this is also true for compressed air systems. Similar to the discount rate, this is not to be confused with a private financial economic lifetime, on which the internal rate of return, the business case and financing is based, and typically shorter.

That means that by shortening the economic lifetime to 25 years, a significant rest value remains disregarded, leading to an unnecessarily low or negative NPV. This is especially true with low discount rates. The project promoters of pumped hydro plants and compressed air themselves calculate with longer economic lifetimes, on average 73 years and 38 years, respectively. In the table below, the economic lifetimes declared by promoters are listed.

In the following, we present in the detail how we arrived at the lifetime-figures for PHES and CAES used in this analysis. The lifetime of battery storage is discussed in Appendix D.

[22] The EC scenario does not reflect the new targets and is therefore outdated. The Sustainable Transition scenario presents an unreasonably high production from gas-fired plants and is therefore neglected.

Table 4: Economic lifetimes of the 4th PCI storage list as mentioned by the project promoters

ID	Project Name	Economic lifetime (years)
1001	Kaunertal Extension Project	90
1002	iLand	46
1011	Mont- Negre"" Power 3,300 Mw Zaragoza, Spain	75
1012	Purifying -Pumped Hydroelectric Energy Storage (P-PHES Navaleo)	75
1015	Cruachan II	80
1019	GIRONES & RAIMATS IN SPAIN	100
1025	Silvermines Hydroelectric Power Station	40
1026	Hydro pumped storage Riedl	100
1027	P-PHES CUA	75
1029	PSPP Kozjak	80
1030	MAREX Organic Power Energy Storage	100
1003	Hydro-pumped storage in Bulgaria - Yadenitsa	100
1004	Estonian PHES (pumped-hydro energy storage)	60
1006	HPS AMFILOCHIA	50
1009	Kruonis pumped storage power plant extension project	40
1014	Coire Glas	60
1013	CAES Zuidwending, NL	30
1022	CARES (Compressed Air Renewable Energy Storage)	40
1023	Cheshire Gas CAES	40

2.4.1.1 Pumped hydro energy storage

From other projects outside the EU, it becomes clear that most energy storage technology providers and project developers calculate with longer economic lifetimes for pumped hydro plants too. The table below lists some examples of pumped hydro projects outside the EU that are planned, under construction or have been recently put in operation. The shortest economic lifetime mentioned is 50 years, and the average lifetime is 76 years, similarly to what the PCI storage project promoters in Europe have declared.

Table 5: Overview of recent pumped hydro storage projects outside the EU, including their pumping capacity and economic lifetimes[23]

Project name	Pumping capacity (MW)	Country	Economic lifetime (Years)
Canyon Creek Pumped Hydro Energy Storage Project	75	Canada	50
Eldorado Pumped Storage	1000	United States	90
Silver Creek Pumped Storage Project	300	United States	50
Prineville Pumped Storage	150	United States	90
Wivenhoe Power Station	500	Australia	100
Lake Elsinore Advanced Pumped Storage	500	United States	75
Thermalito Pumping - Generating Plant	120	United States	75

From literature and scientific reports, we found similar values. The IEA for instance calculates with 60-80 years[24], similarly Agora Energiewende states 40-80 years.[25] An even broader range is mentioned by IRENA, 30-100 years, with 60 years as reference value[26]. The report on “The Economics of Power Storage”[27] mentions 75 years. And Sheffield University ranges 40-60 years as an appropriate economic lifetime.[28] After further discussion with our internal experts, the JRC and the Energy Economics department of the Technical University of Berlin, we suggest using a standard economic lifetime of 50 years for new pumped hydro storage projects. The main reason for this, still relatively conservative, approach is that it avoids making uncertain claims on post-2070 benefits. In addition, increasing the lifetime even further has only marginal effect onto the NPV, since a discount factor of 4% is used and end-of-lifetime benefits become insignificant. It also avoids the problem of projecting the future in cases where promoters indicated relative short economic lifetimes in range of 45-50 years. Although we agree there are also uncertainties between year 26 and 50 of the plant, we believe these should be covered by the sensitivity analysis of scenarios.

2.4.1.2 Compressed air energy storage

There are currently only three compressed air energy storage projects built or planned in addition to the three projects currently on the PCI list (see table below). The Huntorf and McIntosh facilities have been in operation since 1978 and 1991 respectively, according to the DOE Global Energy Storage Database. Both calculated with economic lifetimes of 30 years but are still in operation today. The Apex plant is scheduled to become operational in 2023. In literature lifetime values between 20-100 years, with a reference on value 50 years, are given by IRENA[29] and 20-60 years by TU Delft and Ecofys.[30] Taking the projected economic lifetime of these projects, literature, and the 3 PCI projects into consideration, for new compressed air energy storage projects we suggest using a standard economic lifetime of 35 years. This is also a conservative number, as it is likely the plant and its equipment will stay into operation beyond the 35 years, but we lack empirical evidence to come to an exact estimation. Moreover, a quantification of benefits is increasingly uncertain for longer lifetimes, due to the uncertain nature of energy sector developments. Similar to PHES, there are increasing uncertainties in the benefits from year 25 for CAES projects, but these should be covered with the scenarios.

[23] DOE Global Energy Storage Database (2019)

[24] https://www.iea.org/publications/freepublications/publication/ElecCost2015.pdf

[25] https://www.agora-energiewende.de/fileadmin2/Projekte/2013/speicher-in-der-energiewende/Agora_Speicherstudie_Web.pdf

[26] https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Oct/IRENA_Electricity_Storage_Costs_2017.pdf

[27] Christoph Gatzen (2008), The Economics of Power Storage - Theory and Empirical Analysis in Central Europe

[28] http://eprints.whiterose.ac.uk/98992/1/Manuscript_final.pdf

[29] https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Oct/IRENA_Electricity_Storage_Costs_2017.pdf

[30] TU Delft, Ecofys (2017). Energy Storage and intermittent Renewable Energy Sources.

Table 6: Overview of compressed air energy storage projects, including their capacity and economic lifetimes[31]

Project name	Capacity (MW)	Country	Economic lifetime (Years)
Huntorf facility	290	Germany	30
McIntosh plant	226	United States	30
Apex Bethel Energy Center	317	United States	35

2.4.1.3 Battery-based energy storage

Battery-based energy storage projects have not applied for the PCI label this round but could partake in future cycles. We propose to employ an economic lifetime of 15 years. Appendix D explains in more detail our reasoning behind this suggested lifetime.

2.4.1.4 Conclusion

In conclusion, reducing the lifetime of long-lasting pumped hydro plants to 25 years disregards a significant time in which the project still brings added value to the power system and society. That the transmission projects are currently still assessed in an economic lifetime of 25 years, and that this leads to a difference with the storage projects, is not ideal. It is our opinion, however, that also transmission projects should be considered with longer economic lifetimes, for the same reason as with projects; shortening to 25 years disregards a significant value of transmission assets, as it is very likely that the infrastructure will be in operation for many more years. We suggest a technology specific separation of the economic lifetimes for projects to be considered for the PCI label:

- 50 years for pumped hydro
- 35 years for compressed air

By employing technology specific economic lifetimes, the projects can be better compared in costs, benefits and their contribution to social welfare. This is under the assumption that all technologies operate in the same markets (which they likely will) and the same external costs are internalised (or not).

The main argument against a technology specific economic lifetime is that newer technologies such as large-scale battery-based storage still have to go through their learning curve, whereas pumped hydro is already a mature technology. Although batteries have a shorter technical lifetime now, it is very likely their costs, efficiency and longevity will dramatically increase in the future. By setting a realistic economic lifetime of for instance 15 years now, this could be outdated for new battery projects in the next few years or decades. We suggest however, to possibly prolong the economic lifetime at a later stage instead of already adopting an economic lifetime of future projects that is longer than the current technical lifetimes of batteries. We included more information on the economic lifetime of battery-based energy storage in Appendix C.

In addition to our recommendation, there are two alternative options to consider:

1. Instead of using a standard economic lifetime per technology, the economic lifetime of the projects as mentioned by the project promoters, based on the information of the technology providers or integrating companies, could be used. This would lead to the best estimated economic lifetime per project, taking all benefits into account. It is unsure, though, if this can be practically maintained by the regulators and ENTSO-E.

[31] DOE Global Energy Storage Database (2019)

2. If the technology specific economic lifetime is undesirable, the economic lifetime of battery-based and compressed air energy storage projects could both be prolonged to 50 years, but that would mean a significant periodical reinvestment in equipment to stay in operation and assuming the plants will not be decommissioned until at least 50 years after they became operational. For batteries, this is unconventional, and we therefore recommend using a technology specific lifetime.

3. INDICATIVE NPV RESULTS OF PCI PROJECT CANDIDATES

We have applied the stepwise approach outlined in the previous chapter on the 19 PCI candidate storage projects on the 4th PCI list. The table below shows the resulting societal NPV for each project. Similar information presented differently is illustrated in Figure 9 as the percentage share of the project's cost, differentiating in the different benefits, coherent with the steps in our suggested approach. If the sum of all positive benefits outweighs the sum of costs (including negative benefits), the project achieves a positive NPV, indicated as 100% in the graph. Thus, projects having a gap have a negative NPV. Benefits quantified in step 1 – data provided by ENTSO-E's TYNDP 2018 assessment – are labelled as ENTSO-E benefits. Benefits declared by promoters and included into the analysis in step 2 are labelled missing benefits. Lastly, benefits included in step 3 and quantified through employing industry benchmarks are labelled as benchmark benefits in the graph. If the sum of these three benefit types is lower than 100% of the project's cost, the NPV is negative. If one of the categories is not shown in the graph for a specific project, either data is unavailable, promoters did not declare any benefits, respective benefits are negligible, or benefits are negative and thus regarded as a cost.

Table 7: CBA results for scenario Distributed Generation Average

Project	Benefit-Cost-Ratio
1001 - Kaunertal Extension Project	1.4
1002 - iLand	5.2
1003 - Hydro-pumped storage in Bulgaria - Yadenitsa	1.2
1004 - Estonian PHES (pumped-hydro energy storage)	1.3
1006 - HPS AMFILOCHIA	1.1
1009 - Kruonis pumped storage power plant extension project	2.8
1011 – PHES Mont-Negre, Zaragoza, Spain	5.9
1012 - Purifying -Pumped Hydroelectric Energy Storage Navaleo	6.6
1013 - CAES Zuidwending, NL	4.0
1014 - Coire Glas	0.6
1015 - Cruachan II	4.9
1019 - Girones & Raimats In Spain	3.8
1022 - CARES (Compressed Air Renewable Energy Storage)	1.2
1023 - Cheshire Gas CAES	0.4
1025 - Silvermines Hydroelectric Power Station	2.2
1026 - Hydro pumped storage Riedl	2.2
1027 - P-PHES CUA	7.0
1029 - PSPP Kozjak	0.8
1030 - MAREX Organic Power Energy Storage	6.5

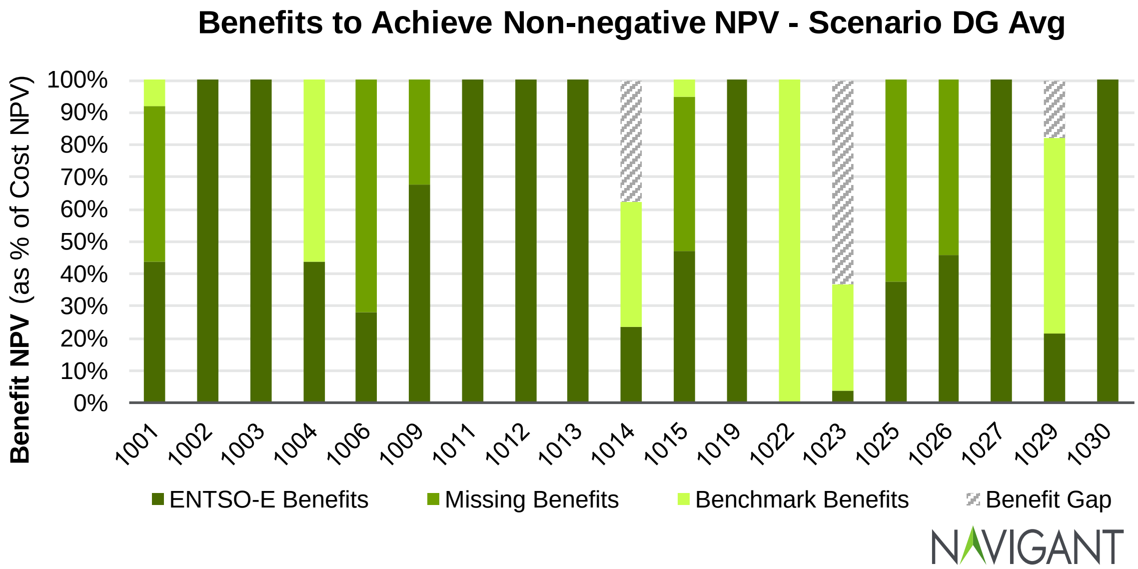


Figure 9: Benefits to achieve positive NPV (Scenario Distributed Generation - Average)

The results show that most of the projects achieve a positive NPV following our approach. Projects 1014, 1023 and 1029 did not achieve a positive NPV. Reasons differ from project to project:

- Project 1014: Promoters did not declare any monetized missing benefits so far. A study to quantify additional benefits could close the gap. The benchmark benefits for project 1014 accounting for the additional impact of avoided CO_2 emissions as well as the reduction of non-CO_2 emissions are negligible, since the emission reduction is very small in the considered scenario. The benchmark benefit for cost reduction for ancillary services alone is – although substantial – not enough to close the remaining benefit gap.
- Project 1023: Promoters did not provide monetized benefits that could be taken into account, due to inconsistencies with ENTSO-E methodology and scenarios. Furthermore, benchmark benefits are not sufficient to close the remaining benefit gap.
- Project 1029: Promoters did not provide monetized benefits, robust and consistent with ENTSO-E scenarios which could be considered as missing benefits. However, a study to quantify additional benefits of the project is under way, according to the promoters. The benchmark benefits are not sufficient to close the remaining benefit gap. In addition, benchmark benefits for CO_2 and non-CO_2 emission reductions are negative, since the project increases system emission according to ENTSO-E.

However, it could be argued that the NPV of these projects can be increased if benefits are considered which could not be quantified in the light of this study.

The split of benefit categories varies between projects. However, as the graph indicates, most projects which have a positive NPV already achieve this value based on the ENTSO-E and missing benefits. We performed this analysis in an Excel-based tool, in which we implemented the stepwise CBA approach described in section 2.3. The tool aggregates data from the various data sources and allows for a detailed analysis of the projects' NPVs. Various input parameters such as discount rate, project lifetime, considered benefits can be altered to perform a sensitivity analysis. The output is generated for all 4 scenarios, including their ranges. The Appendix E displays some examples of the tool in more detail.

4. GUIDANCE FOR FUTURE TYNDP/PCI CYCLES

During this study we gained insight into the current PCI round for storage projects, through engagement with various stakeholders and by reproducing a CBA of storage projects ourselves. Thereby, we have encountered the many challenges to conduct the CBA assessment of storage projects. In the following, we have provided some recommendations for future TYNDP and PCI cycles based on our insights.

4.1 Proactive outreach

We have seen that various promoters have made errors in the data they provided. For example, in some cases the OPEX figures provided by the promoters included the cost of buying electricity and depreciation, which are not part of the OPEX as defined by ENTSO-E, which only focuses on operations and maintenance. This results in too high cost figures, and consequently in a too low NPV. Another error we have experienced more than once related to differing decimal and thousands separators by commas and points, leading to large erroneous figures. We have also experienced that some of the data was wrongly published on the project fiches on the ENTSO-E website. We recommend therefore that ENTSO-E conducts a sanity check on the data delivered by the promoters, and the promoters on the CBA results. In addition, we experienced that promoters were surprised by certain (negative) results. A proactive outreach going beyond a publication on the website should be able to counter this, and we recommend that ENTSO-E and/or the EC present the CBA results more deliberate and timelier to the promoters and ask each promoter individually if the results are acceptable or need further explanation.

4.2 Increased guidance

We recommend that ENTSO-E calculates the relevant benefits we identified as much as possible. Firstly, this would result in a coherent approach for all projects. Secondly, ENTSO-E has the expertise and models in house to conduct such detailed assessments, something that is not necessarily the case for promoters, especially smaller organisations that perhaps do not have the means for such detailed assessments. Benefits that cannot be quantified and monetized by ENTSO-E – i.e. remaining missing benefits – should be clearly described, including what is expected of the promoters so that the benefits can be considered. The description of the benefits and ways to assess them can be exemplified with worst and best practices. For instance, a common misconception we have encountered is the difference between private financial benefits versus societal benefits. Services brought by the promoters can be remunerated, but this does not necessarily represent the value these services bring to the European society. If missing benefits that are delivered by the promoters are rejected by ACER or ENTSO-E, we recommend that this will be clearly communicated including the reasoning behind the rejection and what is needed in order to take the figures into consideration in the CBA.

4.3 Prioritize efforts

The second CBA guideline employed by ENTSO-E for the assessment of storage projects does not fully quantify all benefits provided by storage. A revision of the guideline should focus on the benefits identified and prioritized in chapter 2. We recommend to at least include the benefits of high relevance not yet fully captured by the ENTSO-E methodology to better capture the benefits of large-scale electricity storage, which are (Benefit No. according to Table 2):

- **Reduction of costs for ancillary services**: Including these benefits might be the most pressing issue, since these services can be provided by all considered storage projects. Therefore, suitable modelling approaches are needed to include ancillary services markets into the analysis. Modelling should focus balancing markets, since these provide the highest added value amongst ancillary services. Modelling these balancing markets is similar to the modelling of the energy-only-market: data about market participants is needed, including number and size of the units, as well as bidding price (marginal cost) estimations. Based on these the merit order of the balancing energy and balancing power markets can be derived and market results simulated. One of the main challenges of modelling balancing markets is to make a reasonable assumption about the future demand for balancing power, considering the long lifetime of PCI projects. Therefore, balancing market modelling needs to be based on the same scenarios assumptions as other benefit quantifications. Ancillary service market modelling requires knowledge about local market conditions and a reasonable view on the future development of these markets. Quantifying this benefit is thus best situated within the area of responsibility of ENTSO-E.

- **Additional emission related impacts** (Additional impact of avoided CO_2 emissions, Reduction of non-CO_2 emissions): Just as the quantification of a project's impact on the system's CO_2 emissions, the quantification of non-CO_2 emissions should be performed by ENTSO-E as well. Thereby, consistency of the emission figures could be ensured, building on the same market modelling results. Challenging herein is, that non-CO_2 emission are difficult to estimate since non-CO_2 emission factors are diverse, changing from plant setup to plant setup. Moreover, monetization of these two benefits is rather uncertain, since a great range of values for the social cost of carbon and the social cost of non-CO_2 emissions exists in literature. Therefore, ENTSO-E should refer to a common credible source and ensure a consistent monetization approach for all projects. For example, the same shadow cost of carbon could be aligned with the EIB or DG Clima, and non-CO_2-per-unit cost are available from the ExternE programme (see ch. 2.2).
- **Transmission grid impact and capacity deferral** (Generation capacity deferral, Transmission capacity deferral): Stronger emphasis should be given to the grid related impacts of storage projects. The second CBA guideline already considers the additional adequacy margin as a quantified measure for security of supply. Further guidance could be given on translating this measure into capacity deferral of generation and transmission assets, as well as on monetization. E.g. monetization of generation capacity deferral can be achieved by considering the investment cost of the best new entrant peaking unit, as a benchmark for generation capacity costs (see ch. 2.2). Moreover, the system flexibility indicator used by ENTSO-E should further develop to allow for quantification, not only for transmission, but also for storage projects. Thereby, a more consistent assessment of transmission and storage projects is achieved.
- **Long-term market impact** (Facilitating additional RES integration): Storage projects may have an impact on the long-term RES market development, in addition to the effect on the short-term operating cost of the power system. A suitable modelling approach to capture this long-term impact needs to go beyond the current unit commitment model used by ENTSO-E to assess the market impact of a project. To this end an expansion planning model can be used, representing the future development of generation capacities. Compared to a model for operation optimisation alone, a combined model also for investment optimization is more complex, e.g. also investment cost estimates for generation units are needed.

4.4 Recommendations for stakeholders

4.4.1 Promoters

The leeway provided by the CBA guideline for quantification and monetization of missing benefits should be used to include the most relevant benefits. However, analyses should be in line with ENTSO-E methodology and consistent to the scenarios. Furthermore, the societal perspective needs to be employed for benefit monetization, not to be confused with the private financial remuneration of certain services. However, such financial considerations can be used to estimate the benefits on a social level. For example, if ancillaries are a crucial element of a project's business case, promoters have already analysed future reserve needs, competitive positioning, etc. Thus, a reasonable opinion on societal cost savings can be formed and included into the CBA as a missing benefit. Moreover, it is advisable that project promoters liaise with their local TSO to better understand the grid impact of their projects.

4.4.2 ENTSO-E

ENTSO-E could extend the scenarios, for instance by incorporating flexibility options per market node. Thereby, uncertainty and leeway are reduced for project promoters in their own modelling efforts and quantification approaches. Consequently, better coherence and comparability of the CBA results could be achieved.

The TYNDP process could be more streamlined in terms of data gathering and avoiding several loops, actively decreasing the efforts for project promoters. A clear guideline with explicitly defining the data needs, formats, measures and units could be of used for this purpose, possibly combined with examples and best practices.

4.4.3 ACER

ACER could provide further input to strengthen the CBA by developing additional metrics with which promoters can provide additional info. Perhaps considering the option of providing unit investment costs for storage is beneficial to the process, comparable to transmission.

4.4.4 EC

The information offered by the EC during the PCI process should be tailored to different stakeholder groups. E.g. project promoters have different information needs than TSOs. Knowledge sharing amongst PCI stakeholders could be initiated by forming a dedicated platform for this purpose. In particular, an exchange between EC, ACER and ENTSO-E could be initiated, building on the experience from the CBA stakeholder expert group.

APPENDIX A: SUMMARY OF PROJECT PROMOTER CONSULTATION

Out of the total 19 projects on the fourth PCI list, we interviewed 12 promoters. The semi-structured interviews were based on a predefined set of open questions (see Appendix B) covering topics from the current PCI process to storage CBA and more technical details, such as quantification approaches. All interviews have been documented in an interview report and have been sent to and verified by the interviewees. In this section, we have summarized the main outcomes of the project promoter consultation in an anonymous, objective form. That means that we do not necessarily share the opinion of some of the promoters. We have taken the input of the promoters into consideration when developing our suggested approach for the PCI CBA process.

A.1 2018 PCI process

Overall, promoters share the opinion that the data collection work and information provision process has was significantly improved compared to the previous rounds, thanks to the supporting attitude of the ENTSO-E. Some still see shortcomings and possibilities for improvements in the process; a promoter found the process to be more difficult than two years ago and expected ACER to take a more mediating or supervising role. Also, a promoter experienced some hurdles in communication during the changeover from ENTSO-E to the EC.

On the notion of how the PCI application process could be improved, a promoter foresees a simplified process in which a project meeting all criteria and is in a beneficial location, a grant is awarded which will be used to calculate all the other CBA and technical performance data (for the TYNDP). This would then feed in its suitability for grants (for CEF and/or others). This could also be done via direct qualification.

Another proposed improvement in the process focuses on costs, which should be treated as equally important as benefits. If for instance the environmental costs are considered at the beginning of the PCI process, all the projects with a (considered) high environmental cost could be filtered out upfront.

A.2 General CBA process

Monetization is often difficult already on a private level due to the absence of a liquid or mature target model markets or the absence of a market at all, and due to insufficient or non-existent market coupling with other EU Member States. Benefits through the provision of ancillary services can be quantified through their monetization on existing markets – under the prerequisite that well-developed ancillary services markets are in place. This would then still have to be extrapolated to a social level, where the benefit could differ.

It is found challenging to separate benefits between transmission, storage and generation of storage projects. Usually, at the commercial level, these are separated to avoid complexity so each of the categories must ignore the externalities that do not affect the business case. But there are clear interdependencies between the benefits in these categories. The inclusion of the output costs and inputs for each of the three allow for an optimisation of the overall system which brings benefits to the individual project afterwards. Without a holistic view, these benefits will not be captured fully. RES penetration through curtailment avoidance and market stabilisation are benefits that are dependent on other factors in the system.

Some promoters find it problematic that the impacts and benefits of the project on distribution level or specific customer items are not as much in focus as the system wide effect (transmission level) and the cross-border relevance of PCI.

A.3 The role of ENTSO-E

The ideal role of the ENTSO-E in the decision process of the PCI has been stressed by several promoters, mentioning it should remain the central data base and enable efficient data quality management; to avoid any data differences sent to different parties, like ENTSO-E, DG Energy and ACER. In addition, it was found beneficial for ENTSO-E to become/remain the central data base that also publishes a common set of definitions for all data requested by different parties in line with the EC and ACER.

Another suggestion included an even more active role for ENTSO-E, performing a leading role in the execution of the CBA and other assessments. This would immediately solve the discontent by some promoters on the burden to gather the data and conduct the assessments. It was mentioned that this could lead to the situation that only major incumbents can deliver the mandatory studies and smaller developers are discouraged, leading to fewer projects being developed.

A.4 Missing market mechanisms

Several benefits are hard to monetize, as was confirmed by most of the promoters. One indicated the clear example of the lack of a functioning market mechanism to monetize capacity investment deferral. Likewise, the monetization of avoided capacity upgrades is not part of the considered benefits in the PCI process thus far, while it is most likely a significantly contributing benefit. Other benefits which are hardly monetized correctly are the ramping ability and presence of ancillary services, next to the security of supply. In general, the promoters agree on the need for stronger frameworks to better capture the benefits, which also support to better understand the financial feasibility of storage projects.

A.5 Discrimination between technologies

Currently, the employed CBA methodology does not take decommissioning costs, refurbishment and the project's lifetime into account (well enough). The assessment itself should be technology neutral as most promoters underline. However, some believe that long-term storage should be valued higher in the TYNDP process. Furthermore, some promoters believe a distinction should be made between technologies to gain more insight in the differences in technical lifetimes, and because batteries and pumped hydro energy storage projects target different markets.

A.6 Wider focus for benefits

The grid-oriented set of services bring benefits directly to the power system, increase efficiency and stability, and easier to quantify. A second set of benefits are more policy and macro-economic focused and come about from an integrated approach, driven by renewable energy penetration, creating more indirect benefits to society. This second set of benefits is not captured (completely) by the current process and cannot be quantified easily and can be quite different for different storage technologies. The same holds true for the environmental impact in addition to CO_2 emissions. About half of the promoters mention that the full environmental costs should be considered in the CBA.

In the wider socio-economic benefits that cannot be (easily) expressed in terms of CO_2 emissions, some PHES projects also provide benefits in terms of flood protection and traffic infrastructure improvement. Therefore, most promoters of PHES projects believe the considered benefits in PCI process should take a wider focus. Other benefits mentioned include the economic development of areas or the attractiveness of investments in the region, job creation, avoidance of curtailment of wind energy and lowering the dependence of the European market on natural gas.

A.7 Missing benefits

As mentioned above, the current PCI process does not fully cover all systemic benefits. The (partially) missing benefits that are mentioned at least twice are mentioned here.

- RES integration
- Enhanced performance of interconnectors
- Security of supply (SoS)
- Ancillary services: cost savings for procurement (thermal alternative)
- Avoided socio-economic costs of blackout
- Variation in system losses as already given by ENTSO-E
- Reduction of necessary reserve for redispatch power plants
- Provision of synchronous inertia

A.8 Dealing with uncertainty

According to several promoters, the PCI process is not adapted to the uncertainties perceived by the project promoters. A high uncertainty in market development causes high uncertainty for project developers, especially in the early phases of the project. The certainty of the financial and economic analyses is limited by the current regulatory framework and lack of roadmaps. It is difficult to quantify some benefits due to the expected changes in the regulatory framework and potential new market arrangements such as capacity markets. Project promoters can only consider current regulatory and policy frameworks, leading to an unavoidable uncertainty. One promoter mentioned that uncertainty can be captured by applying a longevity efficiency to the storage devices. Another way to look at it would be the cost-effectiveness of short-term storage investments, or to use different discount rates.

A.9 Improvement suggestions of CBA

One insight that resonated throughout most of the interviews is the need for clarity on which level and in which context the benefits are identified and evaluated. There seemed to be a general misunderstanding on private vs. social level and that the focus is on systemic and market benefits, excluding wider macro-economic and social benefits.

Another recurring remark is on the scenarios: it should be part of a process where the Member State would declare which scenario it is intending to follow before the analysis is undertaken. This would provide more certainty on the need for additional transmission, generation and storage capacity. In other words, it would create more insight in concrete infrastructure requirements, based on which ENTSO-E could run a precise data collection and modelling exercise to elucidate the projects that fit those infrastructure requirements.

A.10 PHES and natural inflow

According to some PHES project promoters, the use of natural inflow is an integral part of the project concept. Renewable energy generation using natural inflow is a by-product of the extended flexibility services, making the splitting of benefits not useful.

APPENDIX B: INTERVIEW GUIDELINE FOR PROJECT PROMOTER CONSULTATION

The following topics have been discussed in the course of the interviews:

1. Introduction. Navigant will briefly introduce the project, the goal of the interview and how we foresee to use the interview results. We hope you can provide us with some background information of your organisation and the storage projects you are working on.
2. General overview of storage benefits identified by EASE (see Figure 10 below). We would like to ask you questions related to:
    a. completeness of the set of benefits
    b. most important/significant/relevant benefits for your specific project (qualitative statement)
    c. how to quantify or monetize the benefits, in addition to what is stated in the TYNDP and/or provided in the PCI application
3. Provision of system-wide services. We would like to ask you questions related to:
    a. your frequency control abilities
    b. capacity services options
4. Local benefits, such as grid-investment deferral. We would like to know about:
    a. your role in providing these local benefits
    b. quantification of these local benefits
5. Local benefits such as black-start capability. We would like to ask you:
    a. Black-start capability of your project
    b. compliance with relevant technical requirements
    c. your view on black start capability by your storage project as a societal value driver
    d. monetization of black start capability
6. Economic lifetime of costs and benefits. We would like to discuss:
    a. size and periodicity of operational/maintenance expenditures
    b. size and periodicity of refurbishment/modernization expenditures
    c. the economic lifetime as applied in a CBA
7. In case of pumped hydro with natural inflow:
    a. a pragmatic way to decouple benefits from inflow (supply) to those of pure storage
8. Open discussion. We would like to hear which other topics need to be discussed from your perspective.
9. Wrap-up and conclusion.

Generation/Bulk Services	Ancillary Services	Transmission Infrastructure Services	Distribution Infrastructure Services	Customer Energy Management Services
Arbitrage	Primary frequency control	Transmission investment deferral	Capacity support	End-user peak shaving
Electric supply capacity	Secondary frequency control	Angular stability	Contingency grid support	Time-of-use energy cost management
Support to conventional generation	Tertiary frequency control	Transmission support	Distribution investment deferral	Particular requirements in power quality
Ancillary services RES support	Frequency stability of the system		Distribution power quality	Maximising self-production & self-consumption of electricity
Capacity firming	Black start		Dynamic, local voltage control	Demand charge management
Curtailment minimisation	Voltage support		Intentional islanding	Continuity of energy supply
Limitation of disturbances	New ancillary services		Limitation of disturbances	Limitation of upstream disturbances
			Reactive power compensation	Reactive power compensation
				EV integration

Figure 10: EASE's depiction of storage applications[32]

[32] https://eera-es.eu/wp-content/uploads/2016/03/EASE-EERA-Storage-Technology-Development-Roadmap-2017-HR.pdf

APPENDIX C: HANDLING OF NON-CO_2 EMISSIONS

Air pollution causes local damage due to a higher number of diseases (morbidity) and thereby reduced life time expectancy (mortality) in the affected population, restricted activity days, work loss days, hospital admissions, and medication use. These external costs of non-CO_2 emissions can be monetized via pollutant-specific per-unit cost. Main non-CO_2 pollutants to take into account are SO_2; NO_X; Volatile organic compounds (VOCs); particulate matter (PM).

Quantification of the per-unit cost is depending on a variety of local factors (background pollution, dispersion patterns, population affected, meteorological conditions, income, GDP). Values can be derived either by using a statistical value of live (VSL) or through stated preferences by asking people about their willingness to pay (WTP) for a longer life.

Combining the per-unit cost with EU-wide power plant emission figures for these pollutants, the total damage burden is calculated. Based on the assumption that the ratio of energy related CO_2 and non-CO_2 emissions is fixed and reflects the generation mix, these numbers can be used to calculate a rough estimate for the cost of non-CO_2 emissions in comparison to CO_2 emission cost. The difference in the estimates between the different sources reflects the uncertainty.

The costs of non-CO_2 emissions are estimated to be in the range of 1x to 2.5x of the CO_2 emission costs.

This ratio is dependent on

- CO_2 per-unit cost: carbon prices are likely to increase in the future, the TYNDP assumes 27, 50 and 84.3 EUR/t in 2030, in the EUCO, Distributed Generation and the Sustainable Transition scenario respectively;
- non-CO_2 pollutant per-unit cost: these prices are arguably going to increase since they are dependent on factors such as GDP and the affected populations income;
- and the ratio between non-CO_2 and CO_2 emissions: the ratio is likely to decrease in the future, due to shift in generation structure, i.e. coal phase out.

The cost ratio is therefore arguably going to decrease in the future.

	Source / Scenario	SO_2	NO_X	PM	CO_2	Non-CO_2
EU Power plant emissions (kT)	**CE Delft**	1.470	1.200	43	889531,52	
Per-Unit Cost (EUR/t)	**CE Delft Cost (NEEDS)**	6.830	6.291	27.470	20	
	EEA Cost low	9.792	4.419	22.990	9,5	
	EEA Cost High	28.576	11.966	66.699	38,1	
Total Cost (10E9 EUR)	**CED**	10,0	7,5	1,2	17,8	18,8
	EEA low	14,4	5,3	1,0	8,5	20,7
	EEA high	42,0	14,4	2,9	33,9	59,3
Non-CO_2 Cost as % of CO_2 Cost	**CE Delft**					**106%**
	EEA low					**245%**
	EEA high					**175%**

Sources:

- Main data source for Europe for per-unit cost of pollutants is the EU-funded research programme ExternE (Externalities of Energy), including project NEEDS (New Energy Externalities Development for Sustainability).
- CE Delft (2008). External Cost of Coal – Global Estimate
- EEA (2014). Costs of air pollution from European industrial facilities 2008-2012

APPENDIX D: LIFETIME OF BATTERY-BASED ENERGY STORAGE

In addition to the discussion and recommendations on the economic lifetime for pumped hydro and compressed air energy storage facilities, we suggest economic lifetime for battery-based energy storage projects for potential future PCI rounds. There are hardly any battery-based storage projects that meet the PCI label demand of 225 MW capacity, yet. There are, however, numerous smaller scale projects that are connected to the transmission or distribution grid, providing system services. The table below lists some of the projects ≥10 MW. The average economic lifetime of these projects is 14 years. For lithium ion batteries, the standard metric for the economic lifetime the US is 10 years.[33] The actual technical lifetime depends on how the systems are used – i.e. how many cycles and depth of discharge – and what specific type of battery cells are used. Many vendors and developers are now building projects with 15 or 20 year lives. However, these projects will typically have batteries replaced or added over time to maintain the initial capacity and offset degradation of the cells. Literature states similar ranges for the lifetime of Li-Ion-based systems, in the range of 5-15 years[8], 12-20 years[34] and 5-20 years.[7] Based on this information, for battery-based energy storage we suggest using a standard economic lifetime of 15 years. The main reason we adopt a more progressive number – i.e. more on the upper side of the range found in literature and actual projects – compared to pumped hydro, is that batteries are likely to improve technically in the coming years, improving their technical lifetimes. Also seeing there are no battery-based storage projects on the fourth PCI list, it takes at least another 2 years before a potential battery project applies for the PCI label. Moreover, many technology providers calculate with at least 15 years technical lifetime. Therefore, an economic lifetime of 15 years seems appropriate.

"Before the law sits a gatekeeper. To this gatekeeper comes a man from the country who asks to gain entry into the law. But the gatekeeper says that he cannot grant him entry at the moment. The man thinks about it and then asks if he will be allowed to come in later on. “It is possible,” says the gatekeeper, “but not now.” At the moment the gate to the law stands open, as always, and the gatekeeper walks to the side, so the man bends over in order to see through the gate into the inside. When the gatekeeper notices that, he laughs and says: “If it tempts you so much, try it in spite of my prohibition. But take note: I am powerful. And I am only the most lowly gatekeeper. But from room to room stand gatekeepers, each more powerful than the other. I can’t endure even one glimpse of the third.”

The man from the country has not expected such difficulties: the law should always be accessible for everyone, he thinks, but as he now looks more closely at the gatekeeper in his fur coat, at his large pointed nose and his long, thin, black Tartar’s beard, he decides that it would be better to wait until he gets permission to go inside. The gatekeeper gives him a stool and allows him to sit down at the side in front of the gate. There he sits for days and years. He makes many attempts to be let in, and he wears the gatekeeper out with his requests. The gatekeeper often interrogates him briefly, questioning him about his homeland and many other things, but they are indifferent questions, the kind great men put, and at the end he always tells him once more that he cannot let him inside yet. The man, who has equipped himself with many things for his journey, spends everything, no matter how valuable, to win over the gatekeeper.

The latter takes it all but, as he does so, says, “I am taking this only so that you do not think you have failed to do anything.” During the many years the man observes the gatekeeper almost continuously. He forgets the other gatekeepers, and this one seems to him the only obstacle for entry into the law. He curses the unlucky circumstance, in the first years thoughtlessly and out loud, later, as he grows old, he still mumbles to himself. He becomes childish and, since in the long years studying the gatekeeper he has come to know the fleas in his fur collar, he even asks the fleas to help him persuade the gatekeeper. Finally his eyesight grows weak, and he does not know whether things are really darker around him or

[33] Depart of Energy, 2018

[34] https://www.agora-energiewende.de/fileadmin2/Projekte/2013/speicher-in-der-energiewende/Agora_Speicherstudie_Web.pdf

whether his eyes are merely deceiving him. But he recognizes now in the darkness an illumination which breaks inextinguishably out of the gateway to the law. Now he no longer has much time to live.

Before his death he gathers in his head all his experiences of the entire time up into one question which he has not yet put to the gatekeeper. He waves to him, since he can no longer lift up his stiffening body. The gatekeeper has to bend way down to him, for the great difference has changed things to the disadvantage of the man. “What do you still want to know, then?” asks the gatekeeper. “You are insatiable.” “Everyone strives after the law,” says the man, “so how is that in these many years no one except me has requested entry?” The gatekeeper sees that the man is already dying and, in order to reach his diminishing sense of hearing, he shouts at him, “Here no one else can gain entry, since this entrance was assigned only to you. I’m going now to close it." Franz Kafka, 1915.

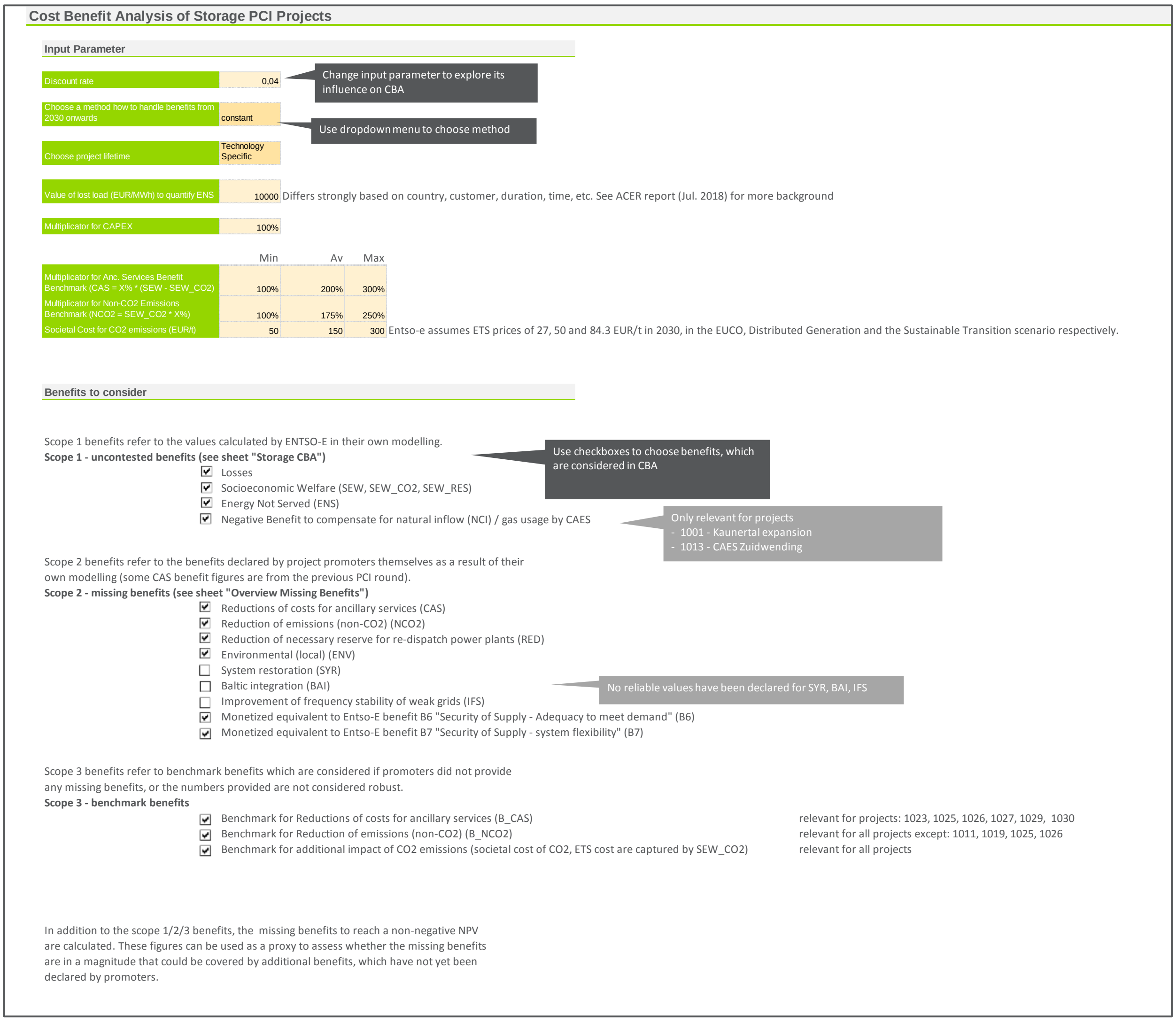
Table 8: Overview of battery-based energy storage projects, including their technology, capacity and economic lifetimes[35]

Project name	Technology	Rated Power (MW)	Country	Economic Lifetime (Years)
Hornsdale Power Reserve 100MW / 129MWh Tesla Battery	Lithium-ion Battery	100	Australia	15
Escondido Energy Storage	Lithium-ion Battery	30	United States	10
Modesto Irrigation District - Primus Power	Zinc Bromine Flow Battery	28	United States	20
Golden Valley Electric Association (GVEA) Battery Energy Storage System (BESS)	Nickel-cadmium Battery	27	United States	25
Anchorage Area Battery Energy Storage System	Lithium-ion Battery	25	United States	30
Marengo Project	Lithium-ion Battery	20	United States	10
AltaGas Pomona Energy - SCE / Greensmith Energy	Lithium-ion Battery	20	United States	10
Hecate Energy Bancroft - (San Diego, CA)	Lithium-ion Battery	20	United States	20
Terna Grid Defense Plan Phase II (1)	Lithium-ion Battery	20	Italy	12
Jake Energy Storage Center: RES Americas	Lithium Iron Phosphate Battery	19.8	United States	10
Elwood Energy Storage Center: RES Americas	Lithium Iron Phosphate Battery	19.8	United States	10
Minami Hayakita Substation Hokkaido Electric Power- Sumitomo	Vanadium Redox Flow Battery	15	Japan	3
WEMAG Schwerin Battery Park - Younicos	Lithium-ion Battery	15	Germany	20
14.8 MW / 58.8 MWh IESO Energy Storage Procurement Phase 1 - Hecate Energy (Toronto Installation)	Lithium-ion Battery	14.8	Canada	15
Daimler second Life Storage - The Mobility House	Lithium-ion Battery	13	Germany	10
Dispatchable Solar Storage - 13 MW / 52MWh - SolarCity	Lithium-ion Battery	13	United States	20
Terna SANC Project (1)	Sodium-sulfur Battery	12	Italy	12
Terna SANC Project (2)	Sodium-sulfur Battery	12	Italy	12
Auwahi Wind Farm	Lithium-ion Battery	11	United States	20
Terna SANC Project (3)	Sodium-sulfur Battery	10.8	Italy	12
SCE LM6000 Hybrid EGT - Center	Lithium-ion Battery	10	United States	10
SCE LM6000 Hybrid EGT - Grapeland	Lithium-ion Battery	10	United States	10
Tucson Electric Power (TEP) - NextEra	Lithium Nickel Manganese Battery	10	United States	10
University of Arizona Science and Technology Park / TEP - E.ON	Lithium Ion Titanate Battery	10	United States	10

[35] DOE Global Energy Storage Database (2019)

APPENDIX E: EXAMPLES OF EXCEL-BASED CBA TOOL

The following graphics are only exemplary and do not show the final results of the assessment.



Cost Benefit Analysis of Storage PCI Projects

Input Parameter

Discount rate	0,04		
Choose a method how to handle benefits from 2030 onwards	constant		
Choose project lifetime	Technology Specific		
Value of lost load (EUR/MWh) to quantify ENS	10000		
Multiplicator for CAPEX	100%		
	Min	Av	Max
Multiplicator for Anc. Services Benefit Benchmark (CAS = X% * (SEW - SEW_CO2)	100%	200%	300%
Multiplicator for Non-CO2 Emissions Benchmark (NCO2 = SEW_CO2 * X%)	100%	175%	250%
Societal Cost for CO2 emissions (EUR/t)	50	150	300

Change input parameter to explore its influence on CBA

Use dropdown menu to choose method

Differs strongly based on country, customer, duration, time, etc. See ACER report (Jul. 2018) for more background

Entso-e assumes ETS prices of 27, 50 and 84.3 EUR/t in 2030, in the EUCO, Distributed Generation and the Sustainable Transition scenario respectively.

Benefits to consider

Scope 1 benefits refer to the values calculated by ENTSO-E in their own modelling.
Scope 1 - uncontested benefits (see sheet "Storage CBA")

- [x] Losses
- [x] Socioeconomic Welfare (SEW, SEW_CO2, SEW_RES)
- [x] Energy Not Served (ENS)
- [x] Negative Benefit to compensate for natural inflow (NCI) / gas usage by CAES

Use checkboxes to choose benefits, which are considered in CBA

Only relevant for projects
- 1001 - Kaunertal expansion
- 1013 - CAES Zuidwending

Scope 2 benefits refer to the benefits declared by project promoters themselves as a result of their own modelling (some CAS benefit figures are from the previous PCI round).
Scope 2 - missing benefits (see sheet "Overview Missing Benefits")

- [x] Reductions of costs for ancillary services (CAS)
- [x] Reduction of emissions (non-CO2) (NCO2)
- [x] Reduction of necessary reserve for re-dispatch power plants (RED)
- [x] Environmental (local) (ENV)
- [ ] System restoration (SYR)
- [ ] Baltic integration (BAI)
- [ ] Improvement of frequency stability of weak grids (IFS)
- [x] Monetized equivalent to Entso-E benefit B6 "Security of Supply - Adequacy to meet demand" (B6)
- [x] Monetized equivalent to Entso-E benefit B7 "Security of Supply - system flexibility" (B7)

No reliable values have been declared for SYR, BAI, IFS

Scope 3 benefits refer to benchmark benefits which are considered if promoters did not provide any missing benefits, or the numbers provided are not considered robust.
Scope 3 - benchmark benefits

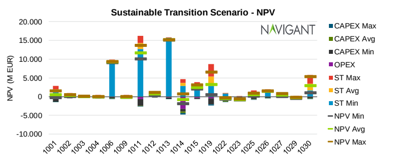
- [x] Benchmark for Reductions of costs for ancillary services (B_CAS) — relevant for projects: 1023, 1025, 1026, 1027, 1029, 1030
- [x] Benchmark for Reduction of emissions (non-CO2) (B_NCO2) — relevant for all projects except: 1011, 1019, 1025, 1026
- [x] Benchmark for additional impact of CO2 emissions (societal cost of CO2, ETS cost are captured by SEW_CO2) — relevant for all projects

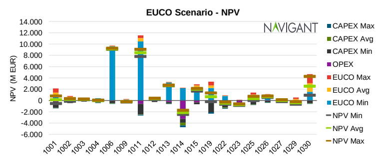
In addition to the scope 1/2/3 benefits, the missing benefits to reach a non-negative NPV are calculated. These figures can be used as a proxy to assess whether the missing benefits are in a magnitude that could be covered by additional benefits, which have not yet been declared by promoters.

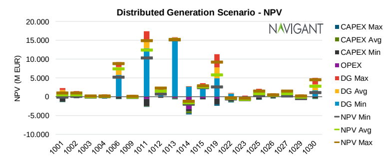
Comparison - all Projects

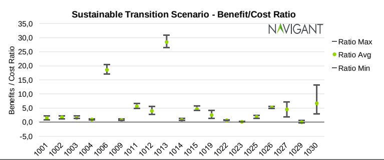
Project	Benefits NPV (2019) M EUR – Sustainable Transition Min	Max	Avg	Euco Min	Max	Avg	Distributed Generation Min	Max	Avg	Cost NPV (2019) M EUR – CAPEX Max	Min	Avg	OPEX
1001 - Kaunertal Extension Project	1143	2879	1915	852	2124	1424	1305	2261	1820	1190	1112	1123	187
1002 - iLand	462	967	752	309	795	655	581	1464	919	404	404	404	38
1003 - Hydro-pumped storage in Bul	217	377	262	280	432	343	92	408	215	139	139	139	36
1004 - Estonian PHES (pumped-hydr	351	351	351	382	359	370	459	482	470	295	197	246	118
1006 - HPS AMFILOCHIA	9699	9844	9795	9622	9735	9669	5785	9254	7937	472	386	429	96
1009 - Kruonis pumped storage pow	245	433	328	155	227	199	276	489	367	145	118	132	292
1011 - "REVERSIBLE PUMPED-STORA	12715	16205	14285	10449	11537	11049	12952	17377	14919	2019	1827	1923	627
1012 - Purifying -Pumped Hydroelec	699	1457	1049	480	670	574	984	2611	1732	182	182	182	81
1013 - CAES Zuidwending, NL	15674	15745	15723	3208	3261	3229	15746	15760	15757	318	235	276	275
1014 - Coire Glas	2858	4667	3643	2218	2231	2226	2726	2752	2737	1425	658	1096	3286
1015 - Cruachan II	2772	3841	3181	2326	2838	2656	3063	3602	3279	316	316	316	355
1019 - TWO REVERSIBLE HIDROELEC	2889	8638	5343	2171	3363	2702	4934	11281	7821	1862	1551	1551	493
1022 - CARES (Compressed Air Rene	826	898	877	792	940	885	828	944	902	596	321	458	870
1023 - Cheshire Gas CAES	40	163	93	26	131	74	89	332	152	360	194	277	544
1025 - Silvermines Hydroelectric Pov	905	1642	1310	751	1394	1076	1085	2133	1541	516	422	469	243
1026 - Hydro pumped storage Riedl	1786	1888	1855	941	1151	1058	768	865	804	320	290	305	53
1027 - P-PHES CUA	230	956	620	-67	267	154	293	1600	947	100	100	100	36
1029 - PSPP Kozjak	-95	191	30	-372	140	-71	-162	483	253	281	281	281	28
1030 - MAREX Organic Power Energy	1674	5820	3489	1546	4685	3038	1669	4972	3344	591	437	514	5

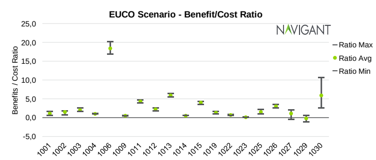
Project	Total NPV – Sustainable Transition Min	Max	Avg	Euco Min	Max	Avg	Distributed Generation Min	Max	Avg	Ratio Benefits / Cost – Sustainable Transition Min	Max	Avg	Euco Min	Max	Avg	Distributed Generation Min	Max	Avg	All Scenarios Avg
1001 - Kaunertal Extension Project	-235	1580	605	-526	825	114	-72	962	510	0,8	2,2	1,5	0,6	1,6	1,1	0,9	1,7	1,4	1,3
1002 - iLand	21	526	310	-132	353	213	140	1023	478	1,0	2,2	1,7	0,7	1,8	1,5	1,3	3,3	2,1	1,8
1003 - Hydro-pumped storage in Bul	43	203	87	105	257	169	-83	234	40	1,2	2,2	1,5	1,6	2,5	2,0	0,5	2,3	1,2	1,6
1004 - Estonian PHES (pumped-hydr	-63	36	-13	-32	44	6	45	167	106	0,8	1,1	1,0	0,9	1,1	1,0	1,1	1,5	1,3	1,1
1006 - HPS AMFILOCHIA	9131	9361	9270	9053	9252	9144	5216	8771	7412	17,1	20,4	18,6	16,9	20,2	18,4	10,2	19,2	15,1	17,4
1009 - Kruonis pumped storage pow	-191	23	-95	-281	-183	-225	-160	79	-57	0,6	1,1	0,8	0,4	0,6	0,5	0,6	1,2	0,9	0,7
1011 - "REVERSIBLE PUMPED-STORA	10069	13751	11735	7803	9083	8499	10306	14924	12369	4,8	6,6	5,6	3,9	4,7	4,3	4,9	7,1	5,9	5,3
1012 - Purifying -Pumped Hydroelec	437	1195	787	218	407	312	722	2348	1470	2,7	5,6	4,0	1,8	2,6	2,2	3,8	10,0	6,6	4,3
1013 - CAES Zuidwending, NL	15082	15236	15172	2615	2751	2678	15154	15251	15206	26,5	30,9	28,5	5,4	6,4	5,9	26,6	30,9	28,6	21,0
1014 - Coire Glas	-1853	724	-738	-2493	-1712	-2156	-1984	-1191	-1644	0,6	1,2	0,8	0,5	0,6	0,5	0,6	0,7	0,6	0,7
1015 - Cruachan II	2100	3170	2510	1654	2167	1984	2391	2931	2607	4,1	5,7	4,7	3,5	4,2	4,0	4,6	5,4	4,9	4,5
1019 - TWO REVERSIBLE HIDROELEC	535	6594	3299	-184	1319	658	2579	9237	5777	1,2	4,2	2,6	0,9	1,6	1,3	2,1	5,5	3,8	2,6
1022 - CARES (Compressed Air Rene	-640	-293	-452	-674	-251	-444	-638	-247	-427	0,6	0,8	0,7	0,5	0,8	0,7	0,6	0,8	0,7	0,7
1023 - Cheshire Gas CAES	-864	-575	-727	-877	-606	-747	-814	-406	-668	0,0	0,2	0,1	0,0	0,2	0,1	0,1	0,5	0,2	0,1
1025 - Silvermines Hydroelectric Pov	146	977	598	-8	729	364	326	1468	830	1,2	2,5	1,8	1,0	2,1	1,5	1,4	3,2	2,2	1,8
1026 - Hydro pumped storage Riedl	1413	1545	1497	568	808	700	395	522	446	4,8	5,5	5,2	2,5	3,4	3,0	2,1	2,5	2,2	3,5
1027 - P-PHES CUA	95	821	485	-202	132	19	157	1465	812	1,7	7,1	4,6	-0,5	2,0	1,1	2,2	11,8	7,0	4,2
1029 - PSPP Kozjak	-404	-118	-280	-681	-170	-380	-471	174	-56	-0,3	0,6	0,1	-1,2	0,5	-0,2	-0,5	1,6	0,8	0,2
1030 - MAREX Organic Power Energy	1078	5379	2971	951	4244	2520	1074	4531	2825	2,8	13,2	6,7	2,6	10,6	5,9	2,8	11,3	6,5	6,3

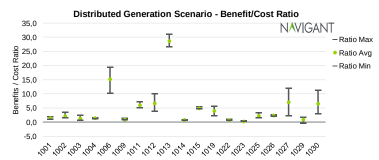


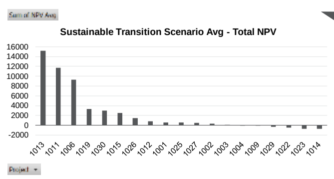




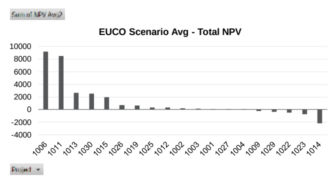


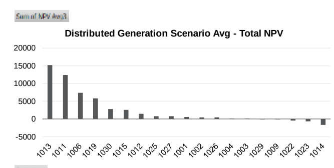






Pivot Chart: right click, "Refresh Data" to show updates after input parameters have been changed



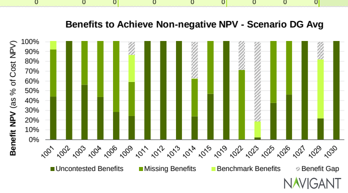


Comparison - all projects; missing benefits for non-negative NPV

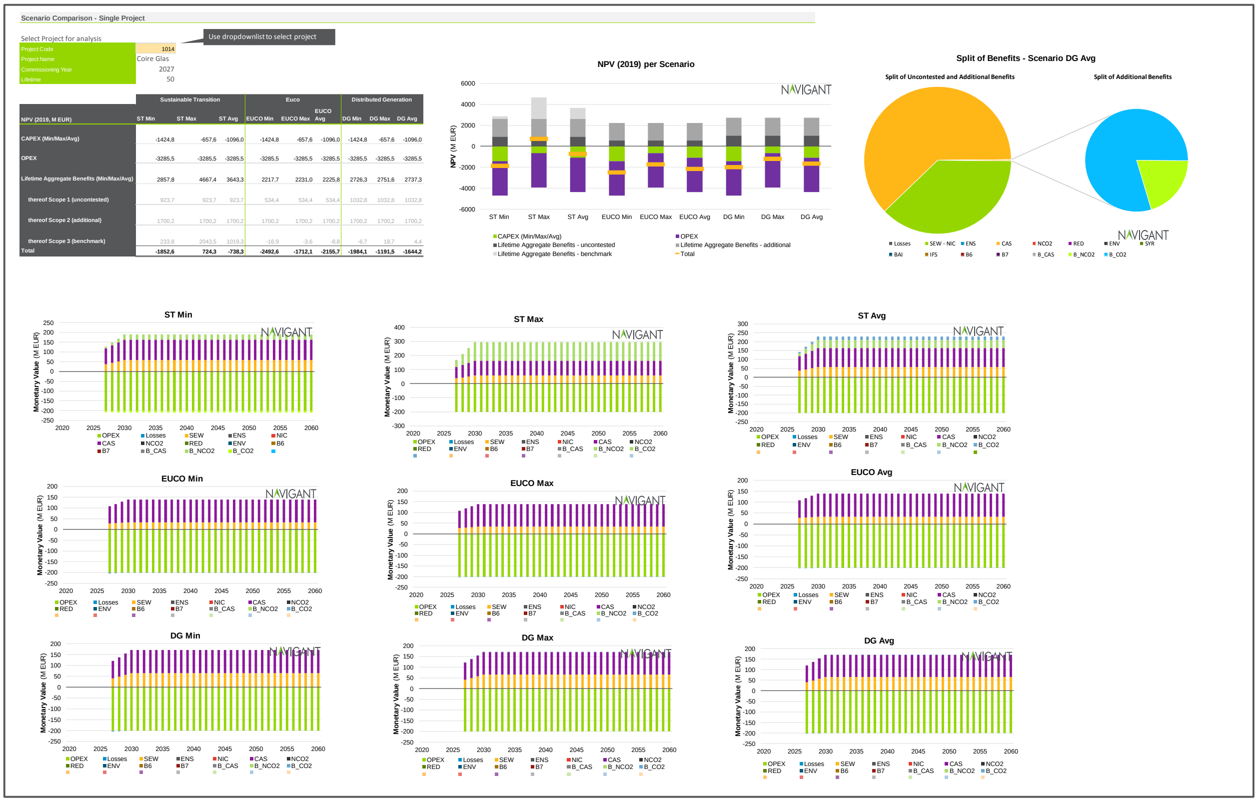
Project	Missing Lifetime Aggregate Benefits for a Non-Negative NPV (2019) M EUR – Sustainable Transition Min	Max	Avg	Euco Min	Max	Avg	Distributed Generation Min	Max	Avg
1001 - Kaunertal Extension Project	235	0	0	526	0	0	72	0	0
1002 - iLand	0	0	0	132	0	0	0	0	0
1003 - Hydro-pumped storage in Bul	0	0	0	0	0	0	83	0	0
1004 - Estonian PHES (pumped-hydr	63	0	13	32	0	0	0	0	0
1006 - HPS AMFILOCHIA	0	0	0	0	0	0	0	0	0
1009 - Kruonis pumped storage pow	191	0	95	281	183	225	160	0	57
1011 - "REVERSIBLE PUMPED-STORA	0	0	0	0	0	0	0	0	0
1012 - Purifying -Pumped Hydroelec	0	0	0	0	0	0	0	0	0
1013 - CAES Zuidwending, NL	0	0	0	0	0	0	0	0	0
1014 - Coire Glas	1853	0	738	2493	1712	2156	1984	1191	1644
1015 - Cruachan II	0	0	0	0	0	0	0	0	0
1019 - TWO REVERSIBLE HIDROELEC	0	0	0	184	0	0	0	0	0
1022 - CARES (Compressed Air Rene	640	293	452	674	251	444	638	247	427
1023 - Cheshire Gas CAES	864	575	727	877	606	747	814	406	668
1025 - Silvermines Hydroelectric Pov	0	0	0	8	0	0	0	0	0
1026 - Hydro pumped storage Riedl	0	0	0	0	0	0	0	0	0
1027 - P-PHES CUA	0	0	0	202	0	0	0	0	0
1029 - PSPP Kozjak	404	118	280	681	170	380	471	0	56
1030 - MAREX Organic Power Energy	0	0	0	0	0	0	0	0	0

Project	Missing annual benefit as % of annual scope 1+2 benefits – Sustainable Transition Min	Max	Avg	Euco Min	Max	Avg	Distributed Generation Min	Max	Avg
1001 - Kaunertal Extension Project	21%	0%	0%	62%	0%	0%	6%	0%	0%
1002 - iLand	0%	0%	0%	43%	0%	0%	0%	0%	0%
1003 - Hydro-pumped storage in Bul	0%	0%	0%	0%	0%	0%	90%	0%	0%
1004 - Estonian PHES (pumped-hydr	18%	0%	4%	8%	0%	0%	0%	0%	0%
1006 - HPS AMFILOCHIA	0%	0%	0%	0%	0%	0%	0%	0%	0%
1009 - Kruonis pumped storage pow	78%	0%	29%	181%	80%	113%	58%	0%	15%
1011 - "REVERSIBLE PUMPED-STORA	0%	0%	0%	0%	0%	0%	0%	0%	0%
1012 - Purifying -Pumped Hydroelec	0%	0%	0%	0%	0%	0%	0%	0%	0%
1013 - CAES Zuidwending, NL	0%	0%	0%	0%	0%	0%	0%	0%	0%
1014 - Coire Glas	65%	0%	20%	112%	77%	97%	73%	43%	60%
1015 - Cruachan II	0%	0%	0%	0%	0%	0%	0%	0%	0%
1019 - TWO REVERSIBLE HIDROELEC	0%	0%	0%	8%	0%	0%	0%	0%	0%
1022 - CARES (Compressed Air Rene	77%	33%	51%	85%	27%	50%	77%	26%	47%
1023 - Cheshire Gas CAES	2177%	353%	778%	3349%	462%	1009%	914%	122%	439%
1025 - Silvermines Hydroelectric Pov	0%	0%	0%	1%	0%	0%	0%	0%	0%
1026 - Hydro pumped storage Riedl	0%	0%	0%	0%	0%	0%	0%	0%	0%
1027 - P-PHES CUA	0%	0%	0%	neg.	0%	0%	0%	0%	0%
1029 - PSPP Kozjak	neg.	62%	947%		122%	neg.	neg.	0%	22%
1030 - MAREX Organic Power Energy	0%	0%	0%	0%	0%	0%	0%	0%	0%

"neg." indicates that the annuals scope 1+2 benefits are negative. Therefore, a % value can not be calculated.



If benefits are negative they are added to the cost.



	Sustainable Transition			Euco			Distributed Generation		
NPV (2019, M EUR)	ST Min	ST Max	ST Avg	EUCO Min	EUCO Max	EUCO Avg	DG Min	DG Max	DG Avg
CAPEX (Min/Max/Avg)	-1424,8	-657,6	-1096,0	-1424,8	-657,6	-1096,0	-1424,8	-657,6	-1096,0
OPEX	-3285,5	-3285,5	-3285,5	-3285,5	-3285,5	-3285,5	-3285,5	-3285,5	-3285,5
Lifetime Aggregate Benefits (Min/Max/Avg)	2857,8	4667,4	3643,3	2217,7	2231,0	2225,8	2726,3	2751,6	2737,3
thereof Scope 1 (uncontested)	923,7	923,7	923,7	534,4	534,4	534,4	1032,8	1032,8	1032,8
thereof Scope 2 (additional)	1700,2	1700,2	1700,2	1700,2	1700,2	1700,2	1700,2	1700,2	1700,2
thereof Scope 3 (benchmark)	233,8	2043,5	1019,3	-16,9	-3,6	-8,8	-6,7	18,7	4,4
Total	-1852,6	724,3	-738,3	-2492,6	-1712,1	-2155,7	-1984,1	-1191,5	-1644,2

MJ-02-19-680-EN-N

Publications Office

doi: 10.2833/802217