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Harmonised system-wide cost-benefit analysis for candidate smart electricity grid projects

[DRAFT FOR PUBLIC CONSULTATION]

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Executive summary

Projects of common interest (PCIs) are key energy infrastructure projects essential for completing the European internal energy market and for reaching the EU's energy policy objectives of affordable, secure and sustainable energy. This Methodology for the cost-benefit analysis of smart electricity grid candidate PCIs supports the implementation of the EU Regulation on trans-European energy infrastructure (Regulation (EU) 2022/869, the 'TEN-E Regulation'), defining the cost-benefit analysis (CBA) methodology pursuant to TEN-E Regulation Article 11(8) to be followed by project promoters proposing candidate projects of common interest in the field of smart electricity grids. It presents a thorough revision of the 'Guidelines for conducting a cost-benefit analysis of smart grid projects'[1] applied during the time of applicability of the repealed TEN-E Regulation (EU) 2013/347.

While the CBA methodological approach remains the same as in the previous guidelines, this present methodology contains a profound revision ensuring compatibility with the new provisions of the revised TEN-E Regulation compatible, as well as improvements based on lessons learnt and best practices collected during the decade between 2012, when the first CBA guidelines for smart electricity grids were drafted, and 2022, when the revised TEN-E Regulation entered into force.

When preparing their project applications, project promoters should clearly and convincingly build the case for their project. They shall demonstrate how the smart electricity grid project proposal is compliant with and supports the objectives of the TEN-E Regulation criteria. This CBA methodology intends to guide project promoters in performing the cost-benefit analysis for their project.

Project promoters should in particular argue convincingly the project's contribution to the relevant TEN-E criteria, by monetising the related benefits of the project as much as possible, and making reference to the KPIs proposed in this methodology as relevant considering the specific scope of the project. Project promoters should also clearly assess the economic viability of the project, analysing whether the benefits to be achieved by the project outweighs its costs.

Therefore, arguments should be credibly supported by numerical quantifications, expressing the benefits in monetary values and clarifying any assumptions made in such calculations. Only when monetisation is not feasible to a sufficient level of confidence given a substantial number of assumptions needed, or because the monetisation requires complex modelling that may be disproportionate to the capabilities of the project promoter, quantification without monetisation may be pursued. As a last resort, qualitative appraisals of benefits are possible for those benefits that cannot be reliably monetised nor quantified. This CBA methodology makes KPI proposals for the monetisation, quantification and/or qualitative appraisal of benefits.

It should be noted that, when proposing a smart electricity grid project, project promoters may have decided to come together to solve a substantial combination of possible cross-border challenges, and may count at their disposal an even larger number of available options to address such challenges, with different smart electricity grid project possible solutions with various configurations, technology choices and possible processes to be established between the project promoters. Therefore, the KPIs

[1] https://publications.jrc.ec.europa.eu/repository/handle/JRC67964

proposed in this CBA methodology are not exhaustive and project promoters may, if duly justified, propose other evaluation methods for monetising, quantifying and qualitatively assessing benefits. In any case, project promoters should always clearly and transparently demonstrate and explain the rationale of their assumptions and calculations.

1 Introduction and scope

The entry into force of the revised regulation on guidelines for trans-European energy infrastructure (the 'TEN-E Regulation', Regulation (EU) 2022/869, repealing Regulation (EU) 2013/347), now aligned with the European Green Deal[2], calls for an update of the previous smart electricity grid Cost-Benefit Analysis (CBA) methodology[3] that had been employed in the previous five rounds of selection of Smart Electricity Grids candidate projects for the status of Project of Common Interest (PCI).

When considering the possibility to develop a project, firstly, it is essential to consider that **a smart electricity grid project is not an end in itself**, but rather a means to an end. Thus, the proposed methodology aims at rewarding those EU projects that contribute the most to the objectives set by the TEN-E Regulation. Project promoters would therefore normally decide to come together and partner to consider a smart electricity grid project in order to solve a concrete challenge of cross-border relevance impacting their grids and/or systems, in support of policy objectives.

Secondly, it is important to consider **what the TEN-E Regulation foresees from smart electricity grid projects of common interest**. As for all categories of the TEN-E Regulation, having a significant **cross-border impact** remains a minimum requirement for becoming a PCI. Moreover, smart electricity grid projects shall contribute significantly to **sustainability** through the integration of renewable energy into the grid. The revised TEN-E Regulation further expands on what purposes should a smart electricity projects strive for, informing of four specific criteria, at least two of which the project shall contribute to.

As established in the Regulation, a smart electricity grid projects should always facilitate the integration of the behaviour and actions of all connected users and the uptake of large amounts of renewables, and should provide support in areas in line with the specific criteria, such as the integration of distributed energy resources, enabling demand response by conventional and new flexibilities including electric vehicles or energy storage; the facilitation of new business models including renewable energy communities and aggregators; the facilitation of new market structures such as market-based congestion management or V2G flexibility provision in balancing markets; the inclusion of innovative technologies that provide for a more efficient system operation and increase cross-zonal capacity; smart sector integration such as the interlink between smart electricity grids and heat systems based on heat pumps or district heating; the inclusion of cybersecurity systems and technologies… The opportunities to imagine, design and develop relevant smart electricity grid projects that provide a benefit to the EU are therefore enormous, with the criteria and requirements set in the TEN-E Regulation providing for the direction to be followed by project promoters wishing to propose a candidate Project of Common Interest.

Smart electricity grid PCIs can therefore support TSOs and DSOs in creating the framework, enabling the opportunities and addressing the cross-border challenges surging as the energy system moves towards a more digitalised environment with more variable and distributed energy sources. In particular, the need for real-time visibility of the grid, and the development of adequate arrangements to manage energy flows with

[2] https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1576150542719&uri=COM%3A2019%3A640%3AFIN
[3] https://ec.europa.eu/jrc/en/publication/reference-reports/guidelines-conducting-cost-benefit-analysis-smart-grid-projects

market participants — including better coordination with TSOs — are key issues for DSOs to overcome. Typical barriers for DSOs to achieve this include[4] the lack of data and control system configuration in real time, inadequate IT systems, lack of commercial frameworks for contracting with DER and aggregators, poor data quality on customer demand, lack of coordination of balancing actions with the DSO, lack of open standards and protocols enabling interoperability with DER, no localised platforms for the purchase of balancing and congestion management services, insufficient protection against physical and cybersecurity threats, etc. A smart electricity grid project may provide benefits in a number of these areas.

Ultimately, the benefits of smart electricity grid PCIs are to be perceived by EU consumers in the forms applicable to the scope of the project, such as energy savings and lower average electricity prices, reduction of outages, more frequent and transparent billing information, the possibility to participate in the electricity market via aggregators, etc.

1.1 TEN-E Regulation (EU) 2022/869: smart electricity grids

The TEN-E Regulation in its Article 4(1) establishes the general criteria that smart electricity grid candidate PCIs shall comply with, namely:

- the project shall **prove necessary** for the smart electricity grid thematic priority area;
- the **potential benefits** of the project, assessed according to the respective smart electricity grid specific criteria, **shall outweigh its costs**, including in the longer term; and
- the project shall meet any of the following criteria: a) it involves **at least two Member States** by directly or indirectly, via interconnection through a third country, crossing the border of two or more Member States; b) it is located on the territory of one Member State, either inland or offshore, including islands, and has a **significant cross-border impact** as set out in point (1) of Annex IV to the Regulation.

All smart electricity grid candidate projects shall therefore be necessary for the smart electricity grid priority thematic area in accordance with Annex I(12), it must present net positive benefits in accordance with this methodology, and it must either involve and cross the border of at least two Member States or be located in the territory of one Member State while demonstrating significant cross-border impact.

Regarding the requirement set in Article 4(1)(a), Annex I(12) sets two main goals to be attained by the priority thematic area:

- ***efficiently integrate the behaviour and actions of all users*** *connected to the electricity network, in particular the* ***generation of large amounts of electricity from renewable*** *or* ***distributed energy*** *sources and* ***demand response*** *by consumers, energy storage, electric vehicles and other* ***flexibility*** *sources, and*

[4] https://cdn.eurelectric.org/media/3637/ey-report-future-of-dsos-h-5D683D61.pdf

- *in addition, as regards* ***islands*** *and island systems,* ***decreasing energy isolation****, supporting* ***innovative*** *and other solutions involving* ***at least two Member States*** *with a* ***significant positive impact*** *on the Union's 2030 targets for energy and climate and its 2050 climate neutrality objective, and contributing significantly to the* ***sustainability of the island*** *energy system* ***and that of the Union***.

The revised TEN-E Regulation is therefore clear that all smart electricity grid candidate PCIs shall efficiently integrate the behaviour and action of all users connected to the network covered by the project, supporting the integration of large amounts of renewables or DER and demand response by consumers and flexibility sources. Project promoters shall demonstrate that the proposed candidate projects indeed serve such purposes.

Moreover, a smart electricity grid PCI candidate will have significant of cross-border impact when it fulfils the following conditions in accordance with Annex IV(1)(c):

> *The project is designed for* ***equipment and installations at high-voltage and medium-voltage level****, and involves TSOs, TSOs and DSOs, or DSOs from* ***at least two Member States****. The project may involve only DSOs provided that they are from at least two Member States and provided that* ***interoperability is ensured****.*
>
> *The project shall satisfy* ***at least two of the following criteria****: it involves 50 000 users, generators, consumers or prosumers of electricity, it captures a consumption area of at least 300 GW hours/year, at least 20 % of the electricity consumption linked to the project originates from variable renewable resources, or it decreases energy isolation of non-interconnected systems in one or more Member States. The project does not need to involve a physical common border.*
>
> *For projects related to* ***small isolated systems*** *as defined in Article 2, point (42), of Directive (EU) 2019/944, including islands, those voltage levels shall be equal to the highest voltage level in the relevant electricity system;*

When project promoters consist of only DSOs, **interoperability** must be ensured. The DSOs of the project should therefore clearly demonstrate that the DSOs' systems and applications are already interoperable or that the smart electricity grid project effectively establishes such interoperability. Interoperability relates to the seamless integration of inter-related assets and processes, including through reliable communication and functionality. This may involve, for example:

- enhanced and standardised information and (real-time) data exchange processes that enable achieving an objective of the smart electricity grid project (e.g. the establishment of a flexibility market for procuring congestion management services);

- the establishment of mutual processes that enable achieving an objective of the project (e.g. integrated modelling procedures, optimised system operation that increases the cross-zonal capacity available in an interconnector, the establishment of a common IT architecture or interface for exchanging real-time information on the activation of flexibility bids, etc.).

An important **simplification** for project promoters of smart electricity grid projects applying for PCI with regard to the requirements set in Regulation (EU) 2013/347 is the reduction of required **specific criteria** to be demonstrated: from six criteria to sustainability plus at least two out of four criteria. Such simplification eases the burden on project promoters and enables them to propose projects that target in detail some of the possible criteria.

Another substantial **simplification** comes on the clarification of the **possible arrangements of project promoters** among TSOs, DSOs and/or a combination thereof. The TEN-E Regulation clarifies that, where the promoters contain a list of DSOs only, interoperability shall be particularly demonstrated.

This CBA methodology addresses only those TEN-E Regulation provisions relating to the cost-benefit analysis of smart electricity grid candidate projects of common interest. The CBA methodology builds on previous guidelines, considering the new requirements laid down in Regulation (EU) 2022/869 as well as best practices and lessons learnt from previous experiences. Project promoters should clearly and convincingly build a case for their project following the TEN-E Regulation requirements and the indications in this CBA methodology.

2 Assumptions

Main variables and assumptions need to be clearly set, substantiating their validity and clearly indicating the data sources used for making assumptions and for selecting the parameters. Some of the critical values to be considered by the project promoter are:

- Social discount rate
- Reference period
- Implementation schedule
- Impact of the regulatory framework on assumptions, parameters and benefits
- Macroeconomic factors
- Implemented technologies
- Peak load forecast
- Electricity demand forecast

a) Discount rate

Project promoters should use a discount rate representing the lowest rate at which 'society' can borrow money in the long-term, excluding short-term volatilities. A discount rate allows to convert benefits and costs that extend over the long economic life of energy infrastructure projects to present value. The discount rate reflects the long-term opportunity cost of resources for society as a whole.

The discount rate has a significant impact on the assessment of the smart electricity grid project, since costs are incurred predominantly at the beginning of the project, while benefits from the project often come only in the long-term. The discount rate thus affects the final judgement on the efficiency of the investment project.

As a general assumption, a 4% discount rate should be assumed, in agreement with the current value assumed for other PCI energy infrastructure categories. The discount rate should in any case be consistent with the same value defined in the harmonised energy system-wide cost-benefit analysis methodology for projects on the Union list falling under the energy infrastructure categories set out in point (1)(a), (b), (d) and (f) and point (3) of Annex II to TEN-E Regulation.

b) Duration of the CBA horizon

The number of years for which cost and benefit forecasts are provided corresponds to the project's reference period. The reference period should correspond to the project's economic life to allow its likely long-term impacts to unfold.

The project's economic life is defined as the expected time during which the project remains useful (i.e. capable of providing goods/services) to the project promoter and does not necessarily correspond to the actual physical life of the project's assets (e.g. if the assets are in good condition but not economically useful anymore).

When a project includes assets with different economic lives, a good practice is to set the reference period as the value-weighted average lifetime of these assets. This, however, should generally be restricted to a reasonable time limit of future forecastability of the net future economic cash flows.

The project promoter shall transparently calculate (i.e. explaining assumptions) the reference period as the value-weighted average lifetime of these assets, indicating the assumed economic lifetime of each (substantial) type of asset. The reference period should include the years of both investment and operations (and decommissioning, when relevant). Some individual assets may have a longer economic life, which shall be capped at a maximum of 50 years for individual assets.

Likewise, the reference period of the whole project shall be capped at a maximum average economic life of 25 years[5]. The reference period shall be calculated and an assumption of it being 25 years cannot be made (it can only be considered of 25 years if such is the result of the calculation).

The project promoters are encouraged to refer to standard benchmarks that are internationally (or nationally) accepted that justify the propose lifetime of the different assets of the project. The weighting should be done proportionally to the costs of the assets, with the value of such assets all measured at a common reference year.

c) Implementation schedule

The implementation schedule of the project may have a great impact on the CBA, in particular on the time distribution of costs.

One possible case is that net benefits decrease as the implementation rate increases. This may be the case when a particular choice of the discount rate values earlier initial costs much higher than the benefits that are reaped at a later point in time. Alternatively, different variables such as 'estimated inflation', 'evolution of energy prices', 'decrease in costs due to technology maturity' or applied 'discount rate' may lead to higher net benefits with a fast installation rate.

The implementation schedule should be summarised in a GANTT chart.

d) Impact of the regulatory framework on assumptions, parameters and benefits

Providing information about the regulatory framework in the Member States where the smart electricity grid project implementation is taking place is required, specifying the impact of regulations on the assumptions and on the benefit calculations of the CBA.

In particular, it is important to highlight the impact of the regulatory framework on the level of certainty that stated benefits will realise. Developments complementing the regulatory framework may be helpful in determining the level of certainty; for example,

[5] As per EIB practice: https://www.eib.org/attachments/thematic/economic_appraisal_of_investment_projects_en.pdf

the existence of national tenders, plans or strategies for the deployment of renewables or electric vehicles in the area of the project would provide a higher degree of certainty that the benefits of the smart electricity grid project on RES uptake and EV demand response service provision will materialise.

The regulatory framework should include clarity, per involved Member State, on all the relevant areas that relate to the benefits analysed for the project. For example, if the smart electricity grid project is said to facilitate the establishment of a flexibility congestion management market for demand response to be provided by electric vehicles, the regulatory framework should clarify the context in each Member State for the establishment of aggregators, demand response, EV participation in electricity markets, sharing of EV data with TSOs and DSOs, etc.

Moreover, project promoters are required to explain the regulatory framework impacting the financeability of the project, including the network tariff methodology applicable to smart electricity grid projects in the respective Member States, e.g. their inclusion in the Remunerated Asset Based, the existence of a premium for innovation or digitalisation over traditional investments, etc.

e) Macroeconomic factors

Macroeconomic factors such as the inflation rate, gas prices, electricity price, raw material prices… need to be taken into account to make estimates as accurate as possible. Project promoters should explain made assumptions.

f) Shadow cost of carbon

Values for the shadow cost of carbon within the CBA horizon should be aligned, where applicable, to shadow cost of carbon values in Tables 5 and 6 of Commission Notice 2021/C 373/01[6].

g) Implemented technologies

Design parameters, system architecture and technology, as well as the adoption of public standards and protocols, can greatly affect the CBA outcome. Project promoters are requested to list the main assets of the project, splitting between transmission and distribution levels, and briefly explaining the functionality of each asset.

Project developers are encouraged to explain what alternative projects or assets have been assessed to solve the cross-border challenge that the smart electricity grid project aims to address, and why such alternative projects and assets were disregarded.

Expected cost reduction associated with technology maturity of innovative assets included in the smart electricity grid project should also be detailed where relevant.

[6] Technical guidance on the climate proofing of infrastructure in the period 2021-2027 https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:C:2021:373:FULL&from=EN

h) Peak load forecast

The peak load forecast has substantial implications in the design of the smart electricity grid project, influencing the need for infrastructure reinforcement or deployment, conditioning the design parameters such as capacity that the infrastructure shall be ready to cope with, and impacting some of the possible benefits of the smart electricity grid project such as on load shifting and peak shaving. Project promoters should specify peak load forecasts in the area of the project.

i) Electricity demand forecast

The electricity demand depends on the development of other factors, such as population growth, domestic consumption, implementation of energy efficiency and savings measures, non-domestic consumption and electricity losses.

Estimated for each Member State and for each year within the duration of the CBA horizon, this assumption should be consistent with the most updated TYNDP scenarios.

3 Project assessment

The cost-benefit analysis for smart electricity grid projects is based on a framework consisting of seven steps divided into three categories:

a) Characterising the project

1. Description of goal of the project and selected assets
2. Mapping assets into functionalities

b) Estimating the benefits

3. Mapping functionalities into benefits
4. Establishing the baseline
5. Monetising benefits and identifying beneficiaries

c) Comparing costs and benefits

6. Identifying and quantifying the costs
7. Economic analysis

The relevance of these mapping exercises rests on two factors: they assist in thinking of sources of benefits, making a complete set of estimated benefits more likely, and they facilitate a thorough evaluation of the impact of a project.

Project promoters may find additional information on how to build appropriate CBAs in general (not specific to smart electricity grids) in the European Commission's Guide to cost-benefit analysis of investment projects[7] and the following Economic Appraisal Vademecum 2021-2027[8], as well as the EIB's Economic appraisal of investment projects[9], which includes a case study on a regional electricity distribution network (while not a smart electricity grid).

a) Step 1: Description of goal of the project and selected assets

The first step is to provide a main summary of the project and to describe its goals.

The summary of the project should contain:

- The list of project promoters and involved Member States
- The current situation in the area of the project: number of users, consumption in the area of the project (GWh/year) and renewable penetration in electricity consumption.
- The scale and dimension of the project, including users to be served and annual

[7] https://ec.europa.eu/regional_policy/sources/docgener/studies/pdf/cba_guide.pdf
[8] https://ec.europa.eu/regional_policy/sources/docgener/guides/vademecum_2127/vademecum_2127_en.pdf
[9] https://www.eib.org/attachments/thematic/economic_appraisal_of_investment_projects_en.pdf

energy consumption and renewable penetration in electricity consumption to be handled.

Then, a description of the technologies and assets centric to the smart electricity grid project should be presented with a brief description of their purpose and characteristics. ENTSO-E's Technopedia[10] may support project promoters in utilising standard vocabulary and descriptions of assets.

Particular attention should be taken to two types of assets: recharging points for EVs and energy storage facilities such as batteries. The smart electricity grid project may provide the network and ICT needed for communicating with the relevant parties such as the relevant aggregators, demand-response operators, prosumers and energy storage facility operators, and thereby facilitating the establishment of new market frameworks and the provision of new services by such parties and their assets. Typically, DSOs would not own, develop, manage or operate such assets, thus these assets would normally either not be part of the PCI candidate proposal (while the benefits from enabling new services provided by such assets should be covered in the determination of the project's benefits), or it should be appropriately justified by explaining why the inclusion of the assets is essential for the success of the smart electricity grid project and how the necessary conditions are fulfilled:

- DSOs shall not own, develop, manage or operate **recharging points for electric vehicles**, except where DSOs own private recharging points solely for their own use. By way of derogation, Member States may allow DSOs to own, develop, manage or operate recharging points for EVs provided that a number of conditions set in the Electricity Directive Article 33(3) are fulfilled. If the project promoter decides to include any recharging points for EVs in the smart electricity grid PCI candidate, the promoter should justify whether it is for its own use or the promoter should demonstrate the consent given by the Member State(s).

- Likewise, DSOs shall not own, develop, manage or operate **energy storage facilities**. By way of derogation, Member States may allow DSOs to own, develop, manage or operate such facilities, where they are fully integrated network components and the NRA has granted its approval, or where a number of conditions set in the Electricity Directive Article 36(2) are fulfilled. If the project promoter decides to include any energy storage facilities in the smart electricity grid PCI candidate, the promoter should demonstrate the consent given by the Member State(s) and clarify the purposes of the energy storage facility as part of the smart electricity grid project, in particular which services the storage is expected to provide (e.g. voltage control or aFRR balancing energy).

Where batteries or other energy storage facilities are included in the smart electricity grid PCI candidate and the promoter owing the storage assets is not a DSO but a non-regulated company, in addition to justifying the need for including such assets in the smart electricity grid project, the economic assessment of the project should be done both for the whole smart electricity grid project in line with this CBA methodology, as well as explicitly separating the commercial assets with a dedicated CBA.

Moreover, where the energy storage facility is in line with the energy infrastructure category established in the TEN-E Regulation Annex II(1)(c) – such as being directly

[10] https://www.entsoe.eu/Technopedia/

connected to HV transmission lines and distribution lines designed for a voltage of 110 kV or more (or the highest voltage level of a Member State or a small isolated system) –, or any equipment or installation essential for such system including protection, monitoring and control systems in accordance with Annex II(1)(d), the battery or relevant storage facility should be included in the respective energy infrastructure category.

The assets and technologies utilised should be clearly described, explaining their functionality, purpose, relevance in the whole smart electricity grid project and justification for the selected geographical location.

b) Step 2: Mapping assets into functionalities and location

The second step is to determine which smart electricity functionalities are activated by the assets proposed for the project.

An example[11] of mapping assets into functionalities is shown for illustration.

In addition to the functionalities of the assets, the number (or range) of assets to be deployed and the justification for the proposed location of such assets required for the success of the smart electricity grid project should be included. The description of the number of assets and location should be as granular as possible, indicating levels of uncertainty where needed.

Table 1. Example based on the list of assets deployed in the InovGrid project.

Type of asset	Asset	Description of asset	Number of assets	Location of asset(s)
Infrastructure	EDP Box (EB)	Device that includes a measurement module, control module and communication module and which is installed at the consumer/producer site.	1	Village A
	HAN Module	Communication and control module that allows reading of the records of the local EB (e.g. consumption, power consumption profile, historical events, quality of service) by connecting	1	Town B

[11] Guidelines for conducting a cost-benefit analysis of smart grid projects https://publications.jrc.ec.europa.eu/repository/handle/JRC67964

		to other devices.		
	Distribution Transformer Controller (DTC)	Local control equipment will be installed in distribution transformer stations, the main components being a measurement module, a control module and a communication module. Its main functions are: collecting data from the EB and MV/LV substation, data analysis functions and grid monitoring.	6-7, depending on…	Distributed transformer stations located in A, B and C
	DTC Cell Module (Distribution Automation)	Module that enables the turning on and off remotely or locally of the various independent circuits of the MV/LV substation. This is a critical component for Distribution Automation for providing new functionalities like remote management and automatic network reconfiguration.	6-8	…
	DTC Power Quality Module	Module that allows the recording and reporting of the quality characteristic values of the wave voltage (root mean square value, flicker, voltage dips, harmonics), providing information and generating alarm events.	…	…
Information systems	InovGrid Infrastructure Management	Includes all features related to the execution of commands and data collections of the InovGrid infrastructure, with the possibility of being integrated into commercial systems, management of communication and InovGrid network	…	…

		settings.		
	Meter Data Management (MDM)	Repository of data collected from InovGrid infrastructure, including consumption, readings, events, status and data network quality. It also includes the main functions of the data validation received, management of InovGrid equipment (DTCs and EBs).	…	…
	Energy Data Management (EDM)	Includes the features related to the treatment of consumption figures collected, including the estimation of missing or invalid data, aggregation data functions and publication of data. Also includes features related to the profiling of added value based on the rules and profile type in force.	…	…
	DSO Web Portal	DSO web page that offers access to remote commercial services and to data consumption/production, with the possibility of using functions of data analysis.	…	…
	Supervision Module	Comprises components directly related to the supervision of InovGrid solutions, including the treatment of events/ incidents, the overall performance management solution (InovGrid equipment and systems) and the management of the service provided by the solution.	…	…

	Meter Asset Management (MAM)	Repository for registration of features and configurations of the equipment-based infrastructure InovGrid (DTC and EB), including the management of their history.	…	…
	Distribution Management System (DMS)	Comprises a monitoring and control system, remote data collection devices and sensors. It enables real-time communication with the infrastructure, with the possibility of remote control actions on the network.	…	…
	DPlan	A simulation and analysis system that optimises investment and operations planning	…	…

FUNCTIONALITIES

ASSETS	Integrate users with new requirements				Enhancing efficiency in day-to-day grid operation						Ensuring network security, system control and quality of supply						Better planning of future network investment			Improving market functioning and customer service								More direct involvement of consumers in their energy usage					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
EDP Box	•	•	•	•	•	•	•			•	•	•	•			•	•		•	•		•	•		•	•	•	•	•	•	•		•
HAN Module																						•			•			•		•	•		•
Distribution Transformer Controller (DTC)	•	•	•	•	•	•	•		•	•	•	•	•		•	•	•		•	•	•	•	•					•	•				
DTC Cell Module			•		•																												
DTC Power Quality Module		•	•			•	•	•		•									•														
InovGrid Infrastructure Management	•	•	•	•			•	•	•	•	•	•	•	•	•	•		•	•	•		•	•	•	•	•	•	•	•	•			•
Meter Data Management (MDM)		•		•	•	•	•	•	•	•	•	•	•		•	•	•	•	•		•			•				•	•	•			•
Energy Data Management (EDM)							•		•											•	•			•									
DSO Web Portal	•	•																		•	•	•	•	•	•			•	•	•	•	•	•
Supervision Module		•	•	•	•	•	•	•		•					•			•	•														
Meter Asset Management (MAM)								•										•											•				
Distribution Management System (DMS)		•	•	•	•	•	•	•		•	•	•		•	•				•														

Figure 1. Map of each asset into the functionalities it provides

c) Step 3: Mapping functionalities into benefits

A second mapping should be done to link the functionalities identified in step 2 into the benefits they are expected to provide.

The identified benefits should be consistent with those later monetised, quantified or qualitatively assessed.

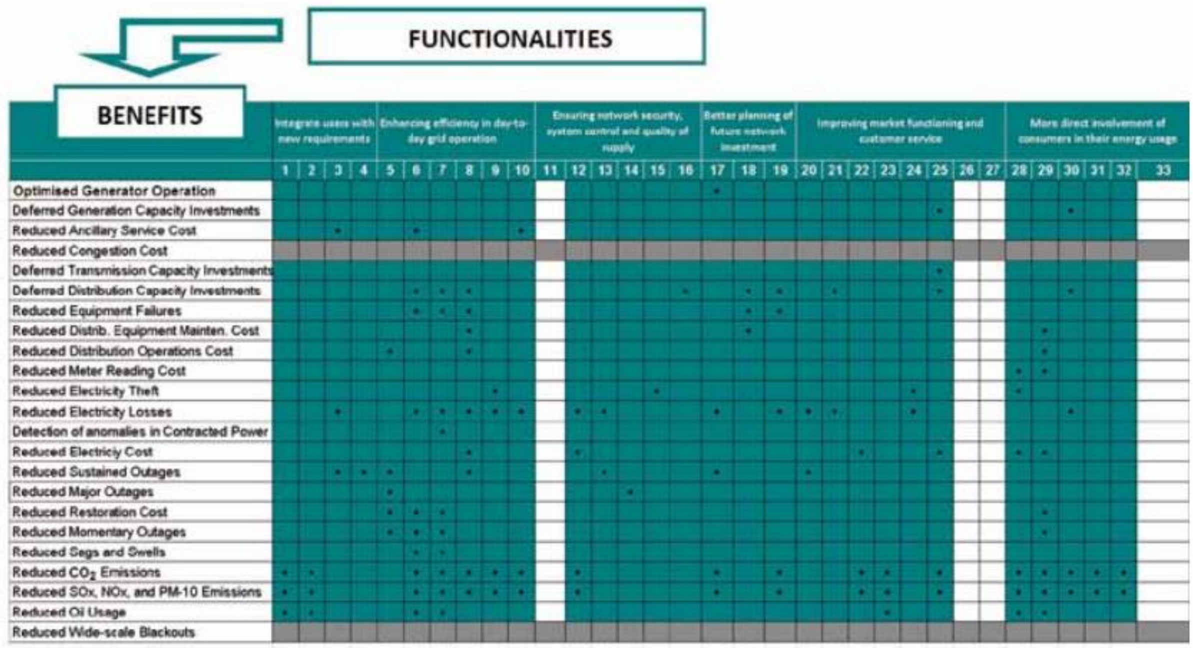

Figure 2. Map of each functionality into a benefit

d) Step 4: Establishing the baseline

The objective of establishing the project baseline is to formally define the system condition which will occur if the project does not take place. This is the baseline situation against which all other scenarios of the analysis are compared.

The CBA should consider the following two scenarios:

- Business As Usual (BAU) scenario (without smart electricity grid project deployment). This is the reference scenario to assess the impact of the smart electricity grid project. It should consider not the status quo at the time when project promoters submit their project application, but the expected developments to occur in the geographical area and for the time period to which the scenario with the smart electricity grid project relates to. For example, the electricity consumption and peak demand in the area of the project should refer to that long-term forecasts, and not to the current patterns. Project promoters should clarify any assumptions made.

- Smart electricity grid project implementation (SG) scenario. This is the scenario with the smart electricity grid project in place. Particular attention should be devoted to clearly defining the portion of the grid that will be affected by the smart electricity grid project and that will thus be considered in the analysis. The choice of the boundary of the analysis should be clearly illustrated and motivated.

Table 2. Example of the definition of the baseline conditions

Benefit	Baseline condition	Metric used	Estimated or planned condition	Metric used
Reduced outages	Losses relating to power outages (BAU)	- Estimated number of non-supplied minutes/year - Value of lost load	Reduced losses linked to reduced outages due to real-time monitoring and new TSO-DSO data exchange process	- Estimated number of non-supplied minutes/year

e) Step 5: Monetising benefits and identifying beneficiaries

Once the baseline and project scenarios have been defined, projects need to identify, collect and report the data required for the quantification and monetisation of the benefits. This data might be raw data, such as hourly load data, or data that is already analysed, such as line losses.

When performing the CBA, project promoters should always strive to **monetise** the different benefits of the project. Arguments regarding benefits of the project should be credibly supported by numerical quantifications, expressing the benefits in monetary values.

Only when such monetisation is not feasible to a sufficient level of confidence given a substantial number of assumptions needed, or because the monetisation requires complex modelling that may be disproportionate to the capabilities of the project promoter, quantification without monetisation may be pursued. As a last resort, qualitative appraisals of benefits are possible for those benefits that cannot be reliably quantified and monetised. This CBA methodology makes KPI proposals for monetisation, quantification and/or qualitative appraisals as relevant depending on the concrete benefit under analysis.

The qualitative demonstration of impacts shall continue to be a last resort mechanism where monetisation or other quantifiable approaches are not possible. This might be the case for example in assessing certain benefits such as the usage of technological innovation or the implementation of certain cybersecurity elements.

When monetisation is not possible, the benefits will be analysed outside the CBA, complementing the whole assessment of the project.

A dedicated chapter in this methodology informs project promoters of the determination of benefits in accordance with the TEN-E Regulation. Project promoters may have decided to get together to solve a substantial combination of possible cross-border challenges, and may count at their disposal an even larger number of available options to address such challenges, with different smart electricity grid project possible solutions with different configurations, technologies and processes established between the project promoters. Therefore, the KPIs proposed in this CBA Methodology are not exhaustive and project promoters may, if duly justified, propose other evaluation methods for monetising, quantifying and qualitatively assessing benefits. In any case, project promoters should always clearly and transparently demonstrate and explain the rationale of their assumptions and calculations.

Once all benefits have been determined, the **beneficiaries** of the benefits should be identified, splitting per Member State and/or project promoter partners where relevant.

Lastly, the level of **uncertainty** (high, moderate, low) indicating the likelihood that the benefit will realise shall be included for each benefit, justifying the response:

- High: the estimate is very uncertain and difficult to quantify. The implicit precision level is viewed as ±100% with a 95% level of confidence.
- Moderate: the estimate is viewed to be ±40% with at least an 80% level of confidence, i.e. there is an 80% probability that the actual value is within ±40% of the estimate in quantitative metrics and/or in how to monetise.
- Low: the estimate is viewed to be ±20% with at least an 80% level of confidence, i.e. there is an 80% probability that the actual value is within ±20% of the estimate.

Figure 3. Example of benefits breakdown (%) with indication of uncertainty levels (red: high, green: low)

f) Step 6: Identify and quantify the costs

The costs of a project are those costs incurred in implementing and operating the project, relative to the baseline. Some costs can be measured directly by the investing companies, while others are typically easy to estimate since their prices, or good proxies, can be obtained in the marketplace. Cost data is a combination of estimated costs obtained through dialogue with suppliers and of data coming directly from the project and tracked by the project promoters.

Taxes (energy taxes, VAT) should not be incorporated into the CBA.

Only assets and costs necessary to achieve the implementation of the smart electricity grid project should be incorporated. As such, the number of assets considered should be proportional to the goal and benefits of the smart electricity grid project. Project promoters should provide clarity on the (range of) number of assets necessary, and provide adequate justifications as relevant.

Costs should be split into CAPEX and OPEX.

Some assets may have an economic life longer than the reference period. In cases in which, at the end of the reference period, some assets and technologies are still economically useful or there is a market for their resale, a residual value should be calculated and demonstrated.

If relevant to the project, such remaining value of certain assets/components may be calculated based on a standard accounting depreciation formula (book value).

Collecting information on the project's costs allows the calculation of a project's return on investment.

g) Step 7: Project value calculation

Once costs and benefits have been estimated, they should be compared to evaluate the cost-effectiveness of the project. Project promoters are required to demonstrate whether the expected project (monetised) benefits outweigh its costs. The potential overall benefits of the project should outweigh its costs, including in the longer term.

The aggregation of discounted benefits and costs determines the economic net present value of the smart electricity grid project, which project promoters should determine for the whole project (global) as well as per participating Member State (national).

Any residual value of project's assets may be included in the last year of analysis.

The project's overall socioeconomic performance should be measured by the economic net present value (NPV) indicator, which expresses the difference between discounted total social benefits and social costs, valued at shadow prices, and is expressed in monetary values. The project is economically viable when the NPV is positive.

Another indicator to be calculated is the benefit-cost ratio (BCR), which is the ratio between the present value of all monetised benefits divided by the present value of all costs[12].

[12] More detailed information on the project value calculation can be found in the latest CBA methodology developed by ENTSO-E.

4 Transparency and confidentiality

In submitting their CBA application, project promoters for smart electricity grid candidate PCIs must provide all the necessary information with the appropriate level of transparency and detail, also taking into consideration the provisions of the TEN-E Regulation, to allow the Commission to be able to rebuild the NPV and BCR calculations.

5 Benefits

Specific criteria

The TEN-E Regulations establishes in Article 4(3)(b) the specific criteria that shall apply to smart electricity grid projects falling under the energy infrastructure category of smart electricity grids as set out in Annex II(1)(e).

The project shall contribute *significantly to sustainability through the integration of renewable energy into the grid, and contributes to at least two of the following specific criteria:*

(i) *security of supply, including through efficiency and interoperability of electricity transmission and distribution in day-to-day network operation, avoidance of congestion, and integration and involvement of network users;*

(ii) *market integration, including through efficient system operation and use of interconnectors;*

(iii) *network security, flexibility and quality of supply, including through higher uptake of innovation in balancing, flexibility markets, cybersecurity, monitoring, system control and error correction;*

(iv) *smart sector integration, either in the energy system through linking various energy carriers and sectors, or in a wider way, favouring synergies and coordination between the energy, transport and telecommunication sectors*.

Table 3. Benefits, specific criterion and TEN-E references

Benefit code - name	Specific criterion	TEN-E Article 4 paragraph
B1 - Increase of electricity generated from new renewable sources	Sustainability	3(b)
B2 - Integration of renewables in the system		
B3 - Reduction of greenhouse emissions		
B4 - Level of losses in transmission and distribution networks	Security of supply	3(b)(i)
B5 - Percentage utilisation (i.e. average loading) of electricity network components		
B6 - Availability of network components (related to planned and unplanned maintenance) and its impact on network performances		
B7 - Duration and frequency of interruptions, including climate-related disruptions		
B8 - Efficient and innovative system operation	Market integration	3(b)(ii)
B9 - Decrease of energy isolation and (increased) interconnection		
B10 - Level of integrating other sectors and facilitating new business models and market structures		
B11 - Innovation	Network security, flexibility and quality	3(b)(iii)
B12 - Flexibility, balancing, demand response		

and storage	of supply	
B13 - Peak demand reduction		
B14 - Cybersecurity		
B15 - Efficient operability between TSO and DSO levels		
B16 - Energy efficiency		
B17 - Cost-efficient use of digital tools and ICT for monitoring and control purposes		
B18 - Stability of the electricity system		
B19 - Voltage quality performance		
B20 – Linking of energy carriers and sectors and favouring synergies and coordination between sectors	Smart sector integration	3(b)(iv)

5.1 Sustainability

The project contributes significantly to sustainability through the integration of renewable energy into the grid

Annex IV(4)(a) further details how to evaluate the criterion: *the level of sustainability* [shall be] *measured by assessing the extent of the ability of the grids to connect and transport variable renewable energy*.

Therefore, *sustainability* is to be measured by assessing the extent of the ability of the grids to connect and transport additional renewable energy into the system thanks to the smart electricity grid project. The integration is thus measured by assessing the amount of new renewables that can be incorporated into the system, and the ability to integrate them without increasing levels of curtailment of renewable sources in the area of presence of the smart electricity grid project. Moreover, the TEN-E Regulation stresses the need to assess climate proofing of energy transmission projects. In addition, supplementing these, the reduction in CO_2 equivalent emissions expected thanks to the project may support the assessment of its climate impact.

5.1.1 B1 - Increase of electricity generated from new renewable sources

The project promoter should clarify the increment of renewable capacity that can be incorporated in the system thanks to the smart electricity grid project. For the avoidance of doubt, this means the change (Δ) in renewable capacity uptake that the project enables further to what would have been incorporated anyhow without the smart electricity grid project, and not the absolute / total amount of renewables expected in the geographical area of the project neither the change in uptake with respect to the current amount of renewables at the time of submission of the PCI candidate application.

This KPI is quantified as requested in terms of percentage variation of the share of electricity generated from renewables that can be safely integrated in the system between the SEG and the BAU scenarios (over a defined period of time), assuming the same total amount of electricity consumed in both scenarios:

$$B_1\,[\%] = \frac{E\_RES_{\,SEG} - E\_RES_{\,BAU}}{E_{total}} \cdot 100$$

Where:

- $E\_RES_{\,SEG}$ and $E\_RES_{\,BAU}$ represent the amount of electricity generated from renewable sources in the SEG and BAU scenarios respectively [MWh];
- E_{total} is the total energy consumption in the geographical area corresponding to the area where the smart electricity grid project is deployed, in a defined period (it is assumed constant before and after the project realisation) [MWh].

The calculation of RES energy requires the estimation of the installed capacity [MW] and of the equivalent running hours of the different types of RES units considered [h/year]. Project promoters should demonstrate clearly and transparently how the estimations were carried out.

This benefit does not need to be monetised, although project promoters are welcome to propose a monetisation approach that they find reliable.

5.1.2 B2 - Integration of renewables in the system

The notion of integration of renewables in the system may be captured by determining the allowable maximum injection of electricity without congestion risks in the networks.

As specified by CEER[13], "this index can be considered as the transmission system equivalent of the hosting capacity. It can also be seen as the net transfer capacity from a (hypothetical) production unit to the rest of the grid. The condition 'without congestion risks' should be interpreted as obeying the prescribed rules on operational security."

This indicator can be calculated on an hourly basis, considering the actual availability of network components and the actual power flows through the network. This would result in an indicator whose value changes with time.

The indicator may be calculated as a fixed value under pre-defined worst-case power flows and a pre-defined outage level (e.g. n-1). The resulting value would give the largest size of production unit that can be connected without risking curtailment. The KPI is calculated through the equation below:

$$B_2\,[\%] = \frac{P_{RES\ imax(SEG)} - P_{RES\ imax(BAU)}}{P_{ref}} \cdot 100$$

Where:

- $P_{RES\ Max(i)}$ represents the largest size of the renewable production unit (or equivalent) that can be connected without risking curtailment in the pre-defined worst case scenario [MW];

- P_{ref} is the power load in the grid under consideration in the pre-defined worst-case scenario (it is assumed constant before and after the project) [MW].

The choice of P_{ref} as a normalisation factor rewards projects having, for the same power load, a higher increase of the allowable maximum injection of power in absolute terms.

Project promoters should clearly state the assumptions and calculations made to obtain the values of the different variables contained in the KPI. As per the determination of the share of electricity generated from new renewable sources, the BAU scenario shall refer to the expected situation for the same time period in the future to which the SEG

[13] CEER (Council of European Energy Regulators), 2011. CEER status review of regulatory approaches to smart electricity grids. CEER Report. Ref: C11-EQS-45-04.

scenario is estimated, and not to the situation at the time of submission of the PCI candidate application.

This benefit does not need to be monetised, although project promoters are welcome to propose a monetisation approach that they find reliable.

5.1.3 B3 - Reduction of greenhouse emissions

The estimation of the reduction of GHG emissions achieved thanks to the smart electricity grid project is not required, but welcome. It may be difficult for the project promoter to make a realistic estimation of the respective benefits of the project without making a complex and granular modelling to forecast the impact of the smart electricity grid project on clearing prices, the determination of the generation assets that a more flexible management of the system thanks to the project is going to replace, etc.

Nonetheless, depending on the benefits and purpose of the specific smart electricity grid project, such estimation of GHG emissions reduction may not entail substantial complexity to determine it.

If the project promoter is capable of making such determination (i.e. if the promoter has the means to make a detailed modelling, or the estimation of GHG emission reduction does not require complex models), the following indications guide the quantification of the reduction.

Moreover, once quantified, the reduction of GHG emissions can be easily monetised. The European Commission's Vademecum[14] provides guidance on appropriate shadow costs of carbon for 2020-2050 as best available evidence on the cost of meeting the temperature goal of the Paris Agreement.

The quantification of the reduction of GHG emissions requires the identification of all possible means of GHGs reduction brought by the project, for instance:

- Reduction due to lower energy losses;
- Reduction due to energy efficiency;
- Reduction due to peak load reduction and displacement of fossil-based peak generation;
- Reduction due to higher integration of renewables with consequent displacement of fossil-based generation to cover base load;

Project promoters may then calculate the estimated variation of GHG emissions normalised to total energy demand in the portion of the grid affected by the project:

$$B_3\ [EUR] = [GHG\ emissions_{\ BAU} - GHG\ emissions_{\ SEG}] \cdot SCC$$

[14] https://ec.europa.eu/regional_policy/sources/docgener/guides/vademecum_2127/vademecum_2127_en.pdf

The avoided GHG emissions can be calculated as follows:

$$GHG\ emissions\ _{BAU} - GHG\ emissions\ _{SEG} = \frac{r\ _{emission}}{\eta_g} \times \Delta Energy$$

Where:

- $r\ _{emission} \left[\frac{kg}{MWh_{Thermal}}\right]$ is the average GHG emission rate of the fossil-based energy mix in the region/country under consideration;
- $\eta_g \left[\frac{MWh}{MWh_{Thermal}}\right]$ is the average efficiency of the thermal power plants in the region/country under consideration (ratio between electricity produced per unit of thermal energy);
- $\Delta Energy\ [MWh]$ represents the amount of fossil-based energy displaced via fewer losses, energy efficiency, replacement of fossil-based energy with renewable energy sources, or others as relevant;
- SCC is the shadow cost of carbon as expressed in the European Commission's Vademecum or following updated shadow cost of carbon figures published by the European Commission.

If feasible, a more precise calculation should be carried out by estimating the emission rate of different fossil-based power plants (coal, gas etc.) instead of using average values, and modelling the amount of displaced fossil-base generation for each fossil fuel.

As per the other KPIs, the BAU scenario shall refer to the expected situation for the same time period in the future to which the SEG scenario is estimated, and not to the situation at the time of submission of the PCI candidate application.

5.2 Security of supply

Security of supply, including through efficiency and interoperability of electricity transmission and distribution in day-to-day network operation, avoidance of congestion, and integration and involvement of network users

Annex IV(4)(b) further details how to evaluate the criterion: *security of supply* [shall be] *measured by assessing:*

- *the **level of losses** in distribution, transmission networks, or both,*
- *the **percentage utilisation** (i.e. average loading) of electricity network components,*
- *the **availability of network components** (related to planned and unplanned maintenance) **and its impact** on network performances, and*
- *on the **duration and frequency of interruptions**, including climate related disruptions*.

When a smart electricity grid project is meant to increase security of supply, the project promoters should demonstrate how the project provides an added value, including at least the level of losses, percentage utilisation, availability of network components and on interruptions.

Additional benefits relating to security of supply may be justified where relevant. This may be the case for example if the smart electricity grid project is design to support certain system adequacy risks in the area, e.g. by reducing **outage** risks in the area of the project. In such case, the expected energy not supplied (EENS) may be calculated by the project promoters, while this may require a certain amount of modelling.

EENS can be monetised for a project by using a reliable figure for the value of lost load (VOLL) [EUR/kWh], a measure of the cost for consumers associated with unserved energy. It represents the loss that is incurred by customers in case of electricity service interruption. Estimates for VOLL vary significantly depending on geographic factors, differences in the nature of load composition, the type of consumers that are affected and their level of dependency on electricity, differences in reliability standards, the time of year and the duration of the outage [ENTSO-E]. Given such significant dependencies, project promoters are requested to justify the reliability of the used VOLL values applicable to the area of the project (such as values validated by an NRA or calculated based on a methodology validated by an NRA); where such VOLL estimates to not exist, project promoters are not required to monetise.

5.2.1 B4 - Level of losses in transmission and distribution networks

While network losses are an inevitable consequence of transporting and distributing power across the network, smart electricity grids can help reducing the level of losses through improvements efficiency of the system and in grid reliability.

This KPI is expressed as:

$$B_4 \text{ [EUR]} = \left[\frac{EL_{BAU} - EL_{\text{SEG}}}{E_{tot}}\right] \cdot MC$$

Where:

- EL_{BAU} represents the yearly level of energy losses [MWh/year] in the portion of the grid under consideration in the BAU scenario. Where project promoters perform a network model, energy losses may be calculated with a relatively high degree of certainty following the approach followed by ENTSO-E in TYNDP.

  Where project promoters will not perform a network and market model of the project, they should indicate the assumptions and estimated value of this parameter, where possible based on actual data for the area where the smart electricity grid project is proposed. Where the project promoters do not have access to such data, or require the preparation of network models that create disproportionate burdens on the promoter, simplifications can be made for example by using national averages, such as from CEER's reports on power losses[15], which contain detailed information on power losses at transmission and distribution levels in electrical grids for all European countries;

- EL_{SEG} represent the yearly level of energy losses [MWh/year] in the portion of the grid under consideration in the scenario with the smart electricity grid project;

- E_{tot} represents the total yearly energy consumption in the geographical area corresponding to the portion of the grid under consideration [MWh/year]. For the sake of simplicity, it is assumed to be the same in the BAU and SEG scenarios;

- *MC* represents the marginal costs of generation needed to cover the difference in losses between the BAU and SEG scenarios [EUR/MWh]. This may be estimated with a market model complementing a network model. Where project promoters will not perform a network and market model of the project, they should indicate the assumptions and estimated value of this parameter, where possible based on actual data for the area where the smart electricity grid project is proposed.

In addition to the KPI calculation, project promoters shall explain which local structural parameters are affecting the value of the KPI (e.g. the presence of distributed generation in distribution grids and their production pattern). The smart electricity grid project may reduce losses by impacting load-flow patterns when decreasing the distance between production and consumption. Alternatively, it is possible that energy losses might

[15] E.g. 2020 edition: https://www.ceer.eu/documents/104400/-/-/fd4178b4-ed00-6d06-5f4b-8b87d630b060

actually increase in absolute value in the SG scenario due to higher penetration of DER. If applicable, project promoters could analyse the ratio between energy losses and the amount of energy injected from DER in the SEG and BAU scenarios and demonstrate whether, even if the absolute value of losses has increased, a relative improvement with respect to the amount of injected DER energy is observed.

Where project promoters are able to produce the relevant models, marginal costs with and without the smart electricity grid project can be calculated and, by multiplying by the respective amounts of losses, monetise the estimation of losses.

5.2.2 B5 - Percentage utilisation (i.e. average loading) of electricity network components

Smart electricity grid projects should normally facilitate a better use of grid assets in terms of capacity utilisation. Project promoters shall demonstrate how the proposed smart electricity grid project, by affecting the average loading of the network components, is providing security of supply benefits (e.g. via increasing available capacity thanks to the optimisation of average loading).

Project promoters should explain which national and local factors affect the analysis.

Project promoters should strive at quantifying and monetising these justifications; qualitative justifications may be provided where necessary.

5.2.3 B6 - Availability of network components (related to planned and unplanned maintenance) and its impact on network performances

The smart electricity grid implementation can have positive effects on the availability of network components. The implementation of smart electricity grid capabilities potentially allows for condition-based maintenance and reduces the stress of grid components. This might reduce the mean time between failures (MTBF), as components are operated at their optimal working point, and the mean time to repair (MTTR), thanks to faster identification of faults and to condition-based/proactive maintenance.

For example, the possibility of remote control of MV devices and the integration of computational intelligence, with the continuous monitoring of relevant parameters (e.g. temperature, dissolved gas, insulating oil quality, etc.[16]) reduces the need of intervention of work field teams.

The availability of components is defined as:

$$Availability = \frac{MTBF}{MTBF + MTTR}$$

Where:

[16] https://www.sciencedirect.com/science/article/pii/S2773032822000013?via%3Dihub

- *MTBF* is the mean time between failures
- *MTTR* is the mean time to repair

For a given component, the benefit is expressed as the percentage variation of its availability in the SEG and BAU scenarios:

$$B_6\ [\%] = \frac{Availability_{SEG} - Availability_{BAU}}{Availability_{BAU}} \cdot 100$$

The indicator should be applied only to those components whose availability is indispensable for optimal grid performance and have a direct impact on output-based indicators like SAIDI and SAIFI. An alternative way to measure the impact of increased availability on network performances is to measure the increase in the network equipment lifespan in the SEG scenario. The project promoters may also quantify the comparison between the number of unplanned maintenance interruptions before and after the smart electricity grid project implementation.

5.2.4 B7 - Duration and frequency of interruptions, including climate-related disruptions

Continuity of supply refers to the availability of electricity to the grid user. The duration and frequency of electricity supply interruptions, as measured by **SAIDI** (System Average Interruption Duration Index) and **SAIFI** (System Average Interruption Frequency Index) are widely used indicators[17]. Overall, the average power interruption duration and frequency of power distribution networks in EU-27 is low, averaging only 1.01 and 0.92 for SAIDI (2020) and SAIFI (2020) respectively[18].

These KPIs are expressed by calculating the variations of reliability indices in the SEG and BAU scenarios.

$$B_{7a}\ [\%] = \frac{SAIDI_{SEG} - SAIDI_{BAU}}{SAIDI_{BAU}} \cdot 100$$

$$B_{7b}\ [\%] = \frac{SAIFI_{SEG} - SAIFI_{BAU}}{SAIFI_{BAU}} \cdot 100$$

Where:

- SAIDI is the System Average Interruption Duration Index [minutes] and represents the sum of customer-sustained outage minutes per year divided by the total customers served.

[17] 'Identification of appropriate generation and system adequacy standards for the Internal Electricity Market' report: https://ec.europa.eu/energy/sites/ener/files/documents/Generation%20adequacy%20Final%20Report_for%20publication.pdf

[18] Source Eurelectric's DSO Facts and Figures, based on the Wold Bank's Getting Electricity methodology: https://documents1.worldbank.org/curated/en/546831513855840819/pdf/122197-WP-DB17-CS-Getting-electricity.pdf

- SAIFI is the System Average Interruption Frequency Index [units of interruptions per customer] and represents the number of customer interruptions divided by the total customers served.

In addition, as much as possible, the project promoter should quantify the expected impacts on the duration and frequency of interruptions caused by climate-related disruptions, in consistency with the related information provided in accordance with the sustainability criteria elements related to climate change, including the climate vulnerability and risk assessment.

5.3 Market integration

Market integration, including through efficient system operation and use of interconnectors

Annex IV(4)(c) further details how to evaluate the criterion: *market integration* [shall be] *measured by assessing the innovative uptake in system operation, the decrease of energy isolation and interconnection, as well as the level of integrating other sectors and facilitating new business models and market structures*.

An integrated EU energy market is the most cost-effective way to ensure secure and affordable energy supplies to EU citizens. Through common energy market rules and cross-border infrastructure, energy can be produced in one EU Member State and delivered to consumers in another. This keeps prices in check by creating competition and allowing consumers to choose energy suppliers.

Smart electricity grid projects can support the process of market integration in many ways. For example, the project may be installing technologies and processes that increase the average flow-based domains made available to the market, increasing the average cross-zonal capacity made available at the border between two Member States; or it may be technically enabling the participation of distributed flexibility resources in a coordinated TSO-DSO congestion management market-based procurement process.

5.3.1 B8 - Efficient and innovative system operation

An efficient system operation optimises the usage of resources available while ensuring secure and quality supply to consumers. Many approaches to increase the efficiency of system operation can be explored. For example, DSOs and TSOs may better coordinate the activation of resources in balancing markets, they may optimise their processes to increase the available cross-zonal capacity at transmission level, or they may create a joint platform and process for the joint market-based procurement of congestion management services at both TSO and DSO levels.

Project promoters should demonstrate how innovative uptake will support the efficient system operation, including how such action or process to which the innovative aspects of the smart electricity grid project is contributing to will effectively support in the operation of the system.

KPIs in other sections of this CBA methodology may also be relevant to complement the demonstration of the project's benefits in market integration (e.g. the KPI on peak demand reduction).

a) Enabled DER capacity uptake and market benefits

Some market integration benefits of the smart electricity grid project may relate to its capability to enable a higher uptake of distributed energy resources than what the system would have integrated without the project. Such higher DER uptake may, for example:

- increase liquidity in the procurement of balancing or non-frequency ancillary services;
- it may be complemented with other elements of the project that promote the appearance of aggregators and demand-side response operators;
- it may reduce market power in congestion management services;
- etc.

As a first step, before demonstrating, quantifying and monetising the enabled market benefits, the **uptake of DER capacity enabled by the smart electricity grid project**, further to what would have been enabled without the project, should be quantified.

A KPI on installed capacity of distributed energy resources in distribution networks can capture the amount of additional capacity of distributed energy resources that can be safely integrated in the distribution grid thanks to the smart electricity grid project.

CEER defines 'hosting capacity' as "the amount of electricity production that can be connected to the distribution network without endangering the voltage quality and reliability for other grid users"[19].

The calculation of this indicator might depend on specific national or local conditions or regulatory framework (e.g. technical and economic conditions of curtailment of power/generation during periods of overproduction). The project promoter should clearly state the relevant local and national conditions affecting the calculation of this KPI.

The contribution of a smart electricity grid project to integrate DERs can be assessed by estimating, over a defined period of time (e.g. a year), the increase of DER energy injected in the distribution grid in safe conditions as a result of the smart electricity grid implementation (e.g. through active management of distribution networks: control of transformer taps, innovative voltage regulation algorithms, reactive power management, innovative grid protection/monitoring, etc.).

$$B_8\ [\%] = \frac{EI_{SEG} - EI_{BAU}}{E_{total}} \cdot 100$$

Where:

- $EI_{SEG}\ [MWh]$ is the DER energy input (over a defined period, e.g. yearly) that can be safely integrated into the portion of the distribution grid under consideration in the SEG scenario;

[19] CEER (Council of European Energy Regulators), 2011. CEER status review of regulatory approaches to smart electricity grids. CEER Report. Ref: C11-EQS-45-04.

- EI_{BAU} $[MWh]$ is the DER energy input (over the same defined period as in the SEG scenario) that can be safely integrated into the same portion of the distribution grid under consideration in the SG scenario;

- E_{total} $[MWh]$ is the total energy consumption in the portion of the grid under consideration and is used as a normalisation factor to keep into account the size of the smart electricity grid project.

The installed DER capacity is affected by the short-circuit level increase of the line, the voltage stability and the nominal current before and after the new installation. The (electrical) protection of the equipment is always taken in to account. Most of these values can be calculated by a power flow and short-circuit analysis. Calculation hypothesis should be clearly explained and documented.

As highlighted by Lo Schiavo[20], both EI_{SG} and EI_{BAU} should be calculated with respect to the network structure, based on the 'hosting capacity' approach discussed in Deuse et al.[21], regardless of the DER units actually connected to the network before and after the project. In this sense, this KPI can be calculated referring to the hosting capacity in the SG and BAU scenarios. The BAU scenario should not refer to the situation at the time of submission of the PCI candidate application, but to the expected situation at the same time period as considered for the SG scenario.

It should be noted that the contribution of DER in terms of energy should be assessed cautiously and in accordance to local conditions. In fact, distributed energy resources can positively contribute to the system operation by providing ancillary services, which in some cases may result in less energy generated. If that is the case, project promoters can include this analysis in their evaluation of this KPI.

Once the DER capacity uptake enabled by the smart electricity grid project has been quantified, the **related market benefits** can be determined. For example, the impact of incorporating such DER may be assessed in relation to the decrease of market power in a congestion management market existing in the area of application of the project. In such example, the project promoters may perform a market power analysis.

5.3.2 B9 - Decrease of energy isolation and (increased) interconnection

A smart electricity grid project may decrease energy isolation (e.g. Malta, Cyprus) and increase interconnection by directly or indirectly increasing the interconnection capacity between Member States (e.g. via a new cross-border line or by increasing system operation and thereby further maximising cross-border capacity). The smart electricity

[20] Lo Schiavo L., Delfanti M., Fumagalli E., Olivieri V., 2011. "Changing the regulation for regulating the change Innovation-driven regulatory developments in Italy: smart electricity grids, smart metering and e-mobility". Working paper 46, IEFE - The Center for Research on Energy and Environmental Economics and Policy at Bocconi University, available from http://www.iefe.unibocconi.it/wps/wcm/connect/Centro_IEFEen/Home/Working+Papers/WP_ 46_CdR_iefe

[21] Deuse J., Grenard S., Bollen M.H.J., 2008. "EU-DEEP integrated project – Technical Implications of the "hosting-capacity" of the system for DER", International Journal of Distributed Energy Resources, vol. 4, no.1, pp. 17-34

grid project may increase hosting capacity at transmission level, distribution level or both.

This may be measured by assessing the ratio between interconnection capacity of a Member State and its electricity demand, which can be calculated on yearly data as follows:

$$r_j = \frac{r * \sum \mu_i(NTC_i)}{E_{tot}} \times 100$$

Where:

- r: number of hours in a year
- $\sum \mu_i(NTC_i)$: sum of average NTC values on all relevant borders
- E_{tot}: total energy demand in a country in a year

It should be noted that this indicator is mostly significant for interconnections between bidding zones where capacity calculation is based on NTC (Net Transfer Capacity). According to the guideline on capacity allocation and congestion management[22], capacity in highly meshed networks should instead be calculated through the flow-based (FB) calculation method, therefore in case the project is in an area that already operates under FB, a correct estimation of SEG benefits should be assessed through a simulation of power flow change in the selected network branch. In case of little historical FB experience in the area, hampering the possibility of the project promoter to make reliable assessments on the impact of the project on capacities, simplifications may be done (e.g. by estimating under an NTC approach).

In any event, the KPI should express the percentage variation of the aforementioned ratio in the SEG and BAU scenarios.

$$B_9\ [\%] = \frac{r_{SEG} - r_{BAU}}{r_{BAU}} \cdot 100$$

5.3.3 B10 - Level of integrating other sectors and facilitating new business models and market structures

The level of integrating other sectors and facilitating new business and market structures may refer to many different aspects:

- When it comes to integrating other sectors (see also section on the 'smart sector integration' criterion), project promoters may assess the level of new integration enabled by the smart electricity grid project and its relevance for market integration.

[22] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32015R1222&from=EN

- With regard to the facilitation of new business models and market structures, numerous examples may be thought. For example, the Member States where the smart electricity grid project is proposed may be trying to foster the participation of demand response through aggregation as a tool to provide efficient market-based services and, by so, reducing electricity prices and increasing the efficiency of the energy system. While the Member States are in charge of ensuring that the relevant regulatory framework exists, the smart electricity grid project may provide the necessary technical capabilities. Likewise, similar examples can be imaging for enabling citizen energy communities, procurement of DER such as EVs, joint TSO-DSO market-based congestion management, etc.

In fact, as digitalisation takes a more prominent role in the energy sector, new business models and market structures not under consideration today are likely to emerge.

Project promoters should demonstrate, quantify and, where possible, monetise the market integration benefits stemming from sector integration and new business models and market structures.

5.4 Network security, flexibility and quality of supply

Network security, flexibility and quality of supply, including through higher uptake of innovation in balancing, flexibility markets, cybersecurity, monitoring, system control and error correction

Annex IV(4)(d) further details how to evaluate the criterion: *network security, flexibility and quality of supply* [shall be] *measured by assessing the innovative approach to system flexibility, cybersecurity, efficient operability between TSO and DSO level, the capacity to include demand response, storage, energy efficiency measures, the cost-efficient use of digital tools and ICT for monitoring and control purposes, the stability of the electricity system and the voltage quality performance*.

5.4.1 B11 - Innovation

While possibly difficult to justify quantitatively in some instances, the project promoter should strive for it and demonstrate at least qualitatively how the higher uptake of innovation in all or some of the mentioned services and actions (*balancing, flexibility markets, cybersecurity, monitoring, system control and error correction*) is attained. Such innovation in services or actions such be consistent with, and where relevant support the implementation of, the applicable EU legislation and policy priorities.

In this regard, project promoters are encouraged to consider whether technologies, business models, ITC architectures or other aspects investigated in previous calls of Horizon Europe[23] (or its predecessor) can be utilised for the benefit of the proposed PCI candidate. When this is the case, the project promoter should justify why the specific Horizon Europe technology was selected, in which assets it will be implemented, what are the expected benefits and how they compare to other conventional alternatives. The project promoters may also refer to other innovation programme projects conducted at national or regional level, or by the own research of (some of) the partners of the PCI candidate cooperation.

For example, the smart electricity grid project may include certain innovative uptake[24] that addresses the increasing voltage violations and worsened voltage quality near the border of two Member States caused by the large amounts of DER being installed in the area. The project promoters should strive to demonstrate, quantify and monetise the impact on voltage violations and increase in voltage quality performance (below), and the respective innovative uptake (e.g. via referring to the usage of a technology developed via a Horizon Europe call).

[23] https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/cluster-5-climate-energy-and-mobility_en

[24] For example: https://cordis.europa.eu/article/id/442103-smart-grid-tools-on-the-eu-s-innovation-radar

5.4.2 B12 - Flexibility, balancing, demand response and storage

To integrate the growing share of renewable energy, the future electricity system should make use of all available sources of flexibility, particularly demand side solutions and energy storage[25].

a) System flexibility

The establishment of a regulatory framework enabling and encouraging the use of flexibility is responsibility of the Member States. Project promoters should describe if and how such regulatory framework and plans or programmes make it possible (or will by a certain time) to attain the system flexibility benefits that the smart electricity grid project aims to facilitate. For example, it one of the project's objective is to enable the procurement of congestion management from flexibility providers in the area of the project, the promoters should explain whether the regulatory framework is in place for DER, demand response or energy storage to provide the flexibility services that the project will enable (for example, whether dynamic electricity pricing for households and companies has been established, or whether the role of aggregator exists).

b) Balancing

The Electricity Directive[26] establishes in its Article 31(9) that DSOs shall cooperate with TSOs for the effective participation of market participants connected to their grid in retail, wholesale and balancing markets. The delivery of balancing services stemming from resources located in the distribution system shall be agreed with the relevant TSO. Project promoters should clarify how such cooperation will take place in the areas relevant to the scope of the project. Promoters should also clarify whether the smart electricity grid project enables the users connected to it to offer standard balancing energy product bids in accordance with the guideline on electricity balancing[27] and its methodologies (e.g. if the smart electricity grid project enables the transmission of real-time information with the required granularity and frequency).

c) Capacity to include demand response

Demand response is key to integrate the growing share of renewable energy and new electricity loads (e.g. resulting from heat pumps and electric vehicles) in a cost-efficient way.

When adopted and where relevant, the project promoter should demonstrate whether the smart electricity grid project is in line with the network code for demand-side flexibility[28] in the areas relevant to the project, for example in enabling and supporting the necessary requirements for measurement, validation and settlement of flexibility

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[25] Regulation (EU) 2019/943: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32019R0943

[26] Directive (EU) 2019/955: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32019L0944

[27] Commission Regulation (EU) 2017/2195: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02017R2195-20210315

[28] Network code in relation to demand response, including rules on aggregation, energy storage and demand curtailment rules, pursuant to Article 59(1)(e) of the Electricity Market Regulation, being drafted at the time of preparation of this CBA methodology.

services, in having the sufficient ITC capabilities to handle the requirements on market processes and transmission and distribution coordination, procurement or giving access to aggregation.

d) Energy storage

The smart electricity grid project may enable the usage of energy storage flexibility in the procurement balancing, congestion management, voltage control or other services.

Whereas the energy storage facility projects should normally be a separate project not covered within the smart electricity grid project under consideration – for example, a commercial project outside of the PCI process scope, or a separate PCI candidate project falling under the energy infrastructure category set in the TEN-E Regulation Annex II(1)(c) –, the equipment, digital ICT components or other elements relevant to the smart electricity grid energy infrastructure category increasing the capacity to integrate energy storage may be part of the smart electricity grid project. Where relevant for the smart electricity grid project, project promoters may consider whether the benefit determination and KPIs proposed in the CBA methodology developed for the energy infrastructure category on energy storage facilities are relevant for their project.

5.4.3 B13 - Peak demand reduction

The smart electricity grid project may facilitate a reduction of peak electricity demand in the area where it is installed if demand-side response is to be expected if the project is realised. For example, the Member States where the project is proposed may have established an ambitious regulatory framework for the appearance of flexibility markets, supporting a market-based *peak shaving* by temporarily scaling down production, activating an on-site power generation system, or relying on a battery. Or an aggregator may be installing a large battery energy storage system (BESS) near an industrial site in the area of the smart electricity grid project and plans to take advantage of the dynamic electricity pricing enabled by the national regulatory framework and, technically, by the smart electricity grid project's capabilities, to do *load shifting* when economically sensible.

Such benefits from reducing peak demand may be quantified through a ratio between minimum and maximum electricity demand within a defined time period. Provided that a sufficiently granular modelling of the expected marginal prices is done, such quantification can also be monetised.

The following KPI can be used to calculate the variation in the ratio between minimum (P_{min}) and maximum (P_{max}) electricity demand, within a pre-defined time period, as a consequence of the implementation of the smart electricity grid project:

$$B_{13\mathrm{a}}\,[\%] = \frac{\left[\frac{P_{min}}{P_{max}}\right]_{SEG} - \left[\frac{P_{min}}{P_{max}}\right]_{BAU}}{\left[\frac{P_{min}}{P_{max}}\right]_{BAU}} \cdot 100$$

Or alternatively:

$$B_{13b}\ [\%] = \frac{\Delta P_{BAU} - \Delta P_{SEG}}{P_{Peak\,BAU}} \cdot 100$$

Where:

- ΔP_{BAU} represents the difference between maximum and minimum electricity demand (within a predefined period of time) in the BAU scenario.
- ΔP_{SEG} represents the difference between maximum and minimum electricity demand (within the same predefined period of time as under BAU) in the SEG scenario.
- P_{Peak} represents the peak electricity demand in the BAU over the predefined period of time.

The choice of P_{Peak} as normalisation factor is intended to reward projects for which the reduction between maximum and minimum electricity demand represents a higher share of the peak power load in the BAU.

A structural difference in the indicator should be taken into account when running comparisons, due to for example electrical heating and weather conditions, shares of industrial and domestic loads[29].

The BAU scenario should consider the elements that are foreseen to take place regardless of the possible realisation of the smart electricity grid project. For example, it may be the case that peak demand will be larger at the time during when the project would be realised than today's peak demand. The future's expected peak demand, with a detail justification on what this is expected to be, would be the one against which the peak demand for the project should be compared with, assessing whether the project will support in peak shaving and quantify it.

5.4.4 B14 - Cybersecurity

Smart electricity grids bring enormous opportunities to enable the energy transition – flexibility, efficient system operation, sector coupling… Along with such new possibilities, also come new risks that need to be carefully addressed. The number of cyber-vulnerabilities in an increasingly electrified and digitalised energy sector is growing, and that means that cybersecurity needs to play a more centric role in energy infrastructure projects, no less in smart electricity grid projects.

Cybersecurity action can take many forms. Challenges in different areas are to be addressed, such as ensuring data protection for the large volume of sensitive customer information that the smart electricity grid will transmit, the protection of control devices (including physical security), the adoption of IT communication standards…

[29] ERGEG (European Regulators Group for Electricity and Gas) (2010). Position Paper on Smart electricity grids. An ERGEG Conclusions Paper, 10 June 2010.

Particular attention should be given by project promoters and system operators to the *Network Code on sector-specific rules for cybersecurity aspects of cross-border electricity flows*[30], approved by ACER on 13 July 2022, in their design and implementation of the smart electricity grid project.

Given the broad nature of ICT products, services and processes that may be implemented for cybersecurity purposes, a qualitative assessment might be appropriate for describing and demonstrating the uptake of cybersecurity elements in the project.

The project promoters should strive to clearly justify the proposed cybersecurity actions; the consistency with the requirements of the network code, the justification of the proposed technologies, services or processes; the coverage of the proposed cybersecurity elements over the total scope of the project; and the benefits that it will provide, quantified where possible. The explanations should be high-level, clear and understandable for non-cybersecurity experts, while additional technical details can be provided where relevant for experts.

5.4.5 B15 - Efficient operability between TSO and DSO levels

a) Communication

A minimum requisite to have an efficient operability between TSOs and DSOs is to have adequate communication and data exchange, both for long-term aspects such as the planning of network investments, as well as in daily operations and real-time actions, such as exchanges on the observability, forecasts and interacting capabilities with DER and demand response providers connected to the respective grids; the coordinated activation of resources, including the impact of assets activated for congestion management on the system frequency and therefore balancing needs, or vice versa; the application of common procedures to manage unforeseen circumstances; the coordination in metering and settlement procedures; etc.

Moreover, as established in the Electricity Directive Article 32(2), DSOs shall exchange all necessary information and shall coordinate with TSOs to ensure the optimal utilisation of resources, to ensure the secure and efficient operation of the system and to facilitate market development. Likewise, according to Article 40(6), TSOs have the same obligation to exchange all necessary information and coordinate with DSOs to ensure the optimal utilisation of resources, to ensure the secure and efficient operation of the system and to facilitate market development.

The guideline on electricity transmission system operation's[31] Part II on Operational security, Title 2 on Data exchange, provides relevant information on data exchange between TSOs, between TSOs and DSOs, between SOs and distribution-connected power generating modules, and between TSOs and demand facilities, that may help project promoters' structuring their explanations.

Project promoters should explain in detail the current levels of communication between the different parties and the new communication features and impact on business

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30 https://www.acer.europa.eu/sites/default/files/documents/Recommendations/Revised%20Network%20Code%20on%20Cybersecurity%20%28NCCS%29_1.pdf

31 Commission Regulation (EU) 2017/1485 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02017R1485-20210315

processes that the smart electricity grid project will enable in support of network security, flexibility and quality of supply, distinguishing where applicable between the different levels: TSO-TSO, TSO-DSO and DSO-DSO communication.

b) TSO-DSO interoperability

After explaining the communication and data exchanges between the TSOs and DSOs relevant to the smart electricity grid project, project promoters may justify TSO-DSO interoperability using a similar KPI to the one proposed under the section on general criteria, adapted to aspects relevant to network security, flexibility and quality of supply, such as the following.

The following interoperability KPI enables the assessment of the interoperability of transmission and distribution system operators in aspects relevant to network security, flexibility and quality of supply:

$$B_{18}\ [\,] = \sum_{i=1}^{3}(KI\ 0.i \cdot w_{coord\,(i)})_{SEG} - \sum_{i=1}^{3}(KI\ 0.i \cdot w_{coord\,(i)})_{BAU}$$

Where:

- BAU refers to the scenario, in the same time horizon as the SG scenario, indicating the expected future situation regardless of the actual deployment of the smart electricity grid project (e.g. if two DSOs are already planning to cooperate in certain areas and will do so with or without the project, such foreseen level of cooperation should be accounted for in the BAU scenario).
- $w_{coord(i)}$ are values between 0 and 1 that express the weights associated to each of the *key indicators* considered. The weights should be either equal per indicator or, when appropriately justified and where one indicator clearly reflects the purpose of the smart electricity grid project, the project promoter may propose a weight proportional to the relevance of the key indicator in attaining the objectives specified for the project (e.g. a smart electricity grid project that is commissioned to enable a flexibility market may account for a larger weight on market coordination). The sum of all $w_{coord(i)}$ shall equal 1. The weight given to the key indicators shall be the same in the BAU and SG scenarios.
- $KI\ 0.i$ go for the key indicators expressing coordination between system operators:
    - KI 0.1 – network security
    - KI 0.2 – flexibility
    - KI 0.3 – quality of supply

System operators should clearly justify the values given to both the weights and the key indicators. While this is a qualitative estimation, the explanations given by the project promoters should give enough visibility on the interoperability cooperation between the TSOs and DSOs.

System operators should clearly justify the values given to both the weights and the key indicators. While this is a qualitative estimation, the explanations given by the project promoters should give enough visibility on the interoperability cooperation between the parties.

5.4.6 B16 - Energy efficiency

In certain circumstances, energy efficiency measures may have additional added values (complementing the actual increase of energy efficiency of the system, needing less resources to achieve the same output) such as an increase in network security, flexibility and quality of supply. For example, this may be the case if by incorporating certain innovative technologies, the operation of the electricity system is made more energy efficient and has positive impacts on grid congestion, allowing more flexible capacity to be made available to the market.

In case of energy efficiency measures, project promoters are encouraged to quantify and monetise the respective savings. Depending on the technology installed, there may be different ways to do such demonstrations.

For example, the project promoter may quantify and monetise the benefits by determining the **capacity and avoided costs** linked to the reutilisation of residual heat for district heating.

In a different example, the project promoters may estimate the benefits of **deferred investments** in transmission or distribution networks thanks to the capabilities provided by the smart electricity grid project, such as the reduction of peak load, enabling the postponement of the reinforcement of existing grids by a number of years, or the construction of new grid projects; or by postponing grid reinforcements thanks to the utilisation of technologies that optimise the operation of grids (e.g. increased capacities using DLR). Project promoters should detail the number of years that the investments are deferred and assumptions for marginal costs when demonstrating these benefits.

Project promoters should monetise the benefits by calculating the difference between discounted cash flows if the deferred investment (e.g. grid reinforcement) would have been built in year 1 and the year when it will be actually built thanks to the smart electricity grid project. The discount should be done applying the approach indicated in the respective section of this CBA methodology, including the social discount rate.

5.4.7 B17 - Cost-efficient use of digital tools and ICT for monitoring and control purposes

To integrate the growing share of renewable energy, the future electricity system should make use of digitalisation through the integration of innovative technologies with the electricity system.

Advanced digital tools and ICT for monitoring and control have always been the key enabler of smart electricity grids, for instance, by installing intelligent protection devices to improve the controllability of flows in the distribution network.

The role of digital tools and ICT is indeed so pervasive that singling out any one general indicator may be complicated. Project promoters should demonstrate how they are incorporating innovative approaches on digital tools and ICT in their project. Promoters should also demonstrate how the proposed solutions are cost-efficient, quantifying and monetising as possible, for example by comparing them with the alternative options available in the market to achieve the same result.

5.4.8 B18 - Stability of the electricity system

TSOs and DSOs keep the electricity system stable within acceptable stability limits, performing stability monitoring and assessments and operational security analyses, and acting accordingly after a violation of such limits is detected, such as activating remedial actions or initiating an outage coordination process. For example, system operators may require services providing inertia for local grid stability.

At transmission level, the guideline on electricity transmission system operation[32] groups three categories of stability: frequency stability, voltage stability and rotor angle stability.

At distribution level, the integration of large amounts of (renewable) DER may have significant effects on the voltage profile, network losses and fault level [Mahmud, N., Zahedi, A.].

TSOs and/or DSOs may have detected regular constraints affecting the stability of the electricity system (e.g. in several consecutive year-head operational security analyses), which could be addressed structurally via services enabled by a smart electricity grid project (instead of via remedial actions).

In case one of the reasons why project promoters propose the project is for the stability of the electricity system, they should demonstrate in detail which issue it aims to solve, how the smart electricity grid project would solve the problem and to what extent. They should also accompany their demonstrations with relevant quantifications, monetised as much as possible, and using where relevant KPIs included in other parts of this CBA methodology.

For example, two system operators with a common border may see regular frequency stability issues in the area near the border and consider that load shifting and peak shaving load control would be useful tools to ensure stability of the electricity system, which may be enabled if a cross-border smart electricity grid project is commissioned. In such case, project promoters may additionally refer to the KPI on 'peak demand reduction' when demonstrating the stability benefits.

Where the assessment of system stability would require a disproportionate modelling by project promoters in order to quantify it, they may instead produce a qualitative assessment of the relevant stability types. Project promoters may take ENTSO-E's approach in TYNDP as source of inspiration:

[32] Commission Regulation (EU) 2017/1485
https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02017R1485-20210315

Table 3. Example of system stability indicator, given as qualitative indicator related to the different technologies (Source: ENTSO-E[33])

Element	Transient stability	Voltage stability	Frequency stability
New AC line	++	++	0
New HVDC	++	++	+
AC line series compensation	+	+	0
AC line high temperature conductor / conductor replacement (e.g. duplex to triplex)	-	-	0
AC line Dynamic Line Rating	-	-	0
MSC/MSR (Mechanically switched capacitors / reactors)	0	+	0
SVC	+	+	0
STATCOM	+	++	0
Synchronous condenser	+	++	++

Where:

-	Adverse effect: the technology/project has a negative impact on the respective indicator
0	No change: the technology/project has no (or just marginal) impact on the respective indicator
+	Small to moderate improvement: the technology/project has only a small impact on the respective indicator
++	Significant improvement: the technology/project has a large impact on the respective indicator
N/A	Not relevant: if a particular project is located in a region where the respective indicator is seen as not relevant, this should also be highlighted by reporting as N/A

[33] https://eepublicdownloads.entsoe.eu/clean-documents/tyndp-documents/Cost%20Benefit%20Analysis/200128_3rd_CBA_Guideline_Draft.pdf

5.4.9 B19 - Voltage quality performance

Voltage quality is an increasingly important issue due to the growing susceptibility of end-user equipment, industrial installations and distributed generation to voltage disturbances. Adequate voltage quality prevents the automatic shut-down of automated industrial machines and damage to sensitive assets such as computers and high-end electrical devices.

To function efficiently, distribution grids require good quality electrical power with a number of characteristics, such as stable continuity of service, low harmonic content, low variation in voltage magnitude and low transient voltages and currents[34]. Transient voltage variation and harmonic distortion of the network voltage are two important aspects of power supply, where large amounts of distributed renewable generation may cause power quality problems in a weak distribution network, particularly during starts and stops[35]. Smart electricity grid projects may play a role in increasing quality of supply by addressing these challenges.

Due to the naturally intermittent renewable distributed generation's varying output as well as the dynamic behaviour of loads, voltage variations can occur very rapidly. Voltage regulation issues due to high penetration of distributed renewable resources are one of the key issues that limit their integration in the network.

Traditional methods for voltage regulation in distribution systems are on load tap changer (OLTC), switched capacitors (SC) and step voltage regulators (SVR). Several more advanced methods also exist, such as reactive power control (VAR compensation) by a reactive compensator, area-based OLTC coordinated voltage control, inverters at distributed renewable generation sites, consumption shifting or energy storage [Mahmud, N., Zahedi, A.].

The impact of the smart electricity grid project on voltage quality performance can be assessed by assessing short interruptions, voltage dips, flicker, supply voltage variation and harmonic distortions. It is useful to group the different voltage disturbances into continuous phenomena and voltage events. For each quality parameter to be regulated, it is important that it can be observed, quantified and verified.

Continuous phenomena are voltage variations that occur continuously over time. Continuous phenomena are mainly due to load patterns, changes of load or non-linear loads. They can often be satisfactorily monitored during measurement over a limited period of time, e.g. one week.

Voltage events are sudden and significant deviations from normal or desired wave shape or RMS value. Voltage events are typically due to unpredictable events (e.g. faults) or to external causes. Normally, voltage events occur only once in a while. To be able to measure voltage events, continuous monitoring and the use of predefined trigger values are necessary.

In order to assess the impact of the smart electricity grid project over voltage quality

[34] https://cdn.eurelectric.org/media/5089/dso-facts-and-figures-11122020-compressed-2020-030-0721-01-e-h-57999D1D.pdf

[35] 'Review of control strategies for voltage regulation of the smart distribution network with high penetration of renewable distributed generation'; Mahmud, N., Zahedi, A.
https://www.sciencedirect.com/science/article/pii/S136403211630243X

performance, KPIs on voltage line violation and total harmonic distortion improvements may be used.

a) Voltage line violations reduction

Defined in accordance with the EN 50160 standard. The resulting KPI could be expressed in terms of number of voltage line violations over a predefined period of time:

$$KPI_{22a}\ [\%] = \frac{(Voltage\ violations)_{SEG} - (Voltage\ violations)_{BAU}}{(Voltage\ violations)_{BAU}} \cdot 100$$

If feasible, the duration of voltage line violations in the BAU and SG scenarios should also be considered in this analysis.

Violations are calculated with reference to the following requirements:

- Variations in the stationary voltage RMS value are within an interval of +/-10% of the nominal voltage (in steady state)
- Number of micro-interruptions, sages, and surges, assessing the number of events (MV-LV violations) recorded over a given time period (one year for example). Dips and surges are recorded when the voltage exceeds the threshold of +/-10% of its nominal value (in transient state).

b) Total harmonic distortion factor

The total harmonic distortion (THD) factor can be measured as defined in EN 50160. The KPI could be expressed as the percentage variation between the BAU and the SRG scenarios.

$$KPI_{22b}\ [\%] = \frac{THD_{SEG} - THD_{BAU}}{THD_{BAU}} \cdot 100$$

5.5 Smart sector integration

Smart sector integration, either in the energy system through linking various energy carriers and sectors, or in a wider way, favouring synergies and coordination between the energy, transport and telecommunication sectors

Annex IV does not further details how to evaluate the criterion.

5.5.1 B20 – Linking of energy carriers and sectors and favouring synergies and coordination between sectors

Sector integration means linking the various energy carriers - electricity, heat, cold, gas, solid and liquid fuels - with each other and with the end-use sectors, such as transport or industry. Linking sectors will allow the optimisation of the energy system as a whole, rather than decarbonising and making separate efficiency gains in each sector independently. Smart electricity grid PCIs can play a key role in smart sector integration.

Given the expected significant increase in power demand from the transport sector, in particular for **electric vehicles** along highways and in urban areas, smart electricity grid projects could help **improving energy network-related support** for cross-border high-capacity recharging. Network services could include, for example, via smart charging (V1G) to provide frequency support in system defence strategies or to provide peak shaving, or via vehicle-to-grid (V2G) where a bidirectional converter may be used to inject power into distribution or transmission networks via markets for balancing, given the fast response of the EV batteries, as well as congestion management or others.

EV charges could interact with several aspects of the electricity sector: hourly dispatch and supply–demand adequacy, grid flows and sizing of transformers, intraday balancing markets, coupling with other distributed energy resources and frequency regulation[36].

KPIs in other sections of this CBA methodology may be relevant for demonstrating certain characteristics of smart sector integration, such as those for peak demand reduction or installed DER capacity.

Smart sector integration is also possible between the **power and heat** sectors, for example by smartening demand response provided by electric heat technologies following real-time energy prices, such as district heating based on heat pumps.

Other synergies between these sectors can be imagined, such as the establishment of a district heating network based on the reutilisation of residual heat produced in substations of a smart electricity grid project, which would additionally support the

[36] 'Integration of electric vehicles into transmission grids: A case study on generation adequacy in Europe in 2040'. R. Lauvergne, Y. Perez, M. Françon, A. Tejeda De La Cruz. 2022 https://www.sciencedirect.com/science/article/pii/S0306261922012879

'**energy efficiency** first' principle, or on the residual heat of a data centre connected to a smart electricity grid project that provides demand response market services.

The opportunities for smart sector integration and synergies and coordination between sectors are ample. Thus, it is likely that KPIs will need to be tailored to the characteristics of the specific project. Project promoters are highly recommended to propose KPIs to measure the benefits in sector integration that the project provides. Promoters may refer to KPI proposals in scientific papers, other existing CBA methodologies or propose their own indicator.

At the very least, project promoters are expected to clearly justify and demonstrate that there will actually be sector integration after the smart electricity grid project is realised, for example via demonstrating the existence of a project for establishing a EV fast charging V2G system in the area, a firm plan by a municipality to establish such EV system, a district heating company setting a network, a contract or memorandum of cooperation with a company providing a certain smart sector integration service, etc.

List of abbreviations

ACER	Agency for Cooperation of Energy Regulators
aFRR	frequency restoration reserves with automatic activation
AMM	advanced meter management
BAU	business as usual
B/C	benefit/cost ratio
BESS	battery energy storage system
CBA	cost–benefit analysis
DER	distributed energy sources
DHC	district heating and cooling
DSF	demand-side flexibility
DSR	demand-side response
DSO	distribution system operator
DLR	dynamic line rating
EMS	energy management system
ENTSO-E	European Network of Transmission System Operators for Electricity
EU DSO Entity	association of DSOs in the Union
FFR	fast frequency response
FCR	frequency containment reserves
FRR	frequency restoration reserves
GDPR	General Data Protection Regulation
HV	high voltage
HVDC	High voltage direct current
ICT	information and communication technology
IRR	internal rate of return
KPI	key performance indicator
mFRR	frequency restoration reserves with manual activation
MV	medium voltage
NTC	net transfer capacity
NPV	net present value
NRA	national regulatory authority
OLTC	on load tap changer
PLC	power line carrier
PCI	project of common interest

RES	renewable energy sources
RMS	root mean square
RR	replacement reserves
SCADA	supervisory control and data acquisition
SEG	smart electricity grid
STATCOM	static synchronous compensator
SVC	static VAR compensator
TSO	transmission system operator
VVC	voltage-VAR control

JRC Mission

As the science and knowledge service of the European Commission, the Joint Research Centre's mission is to support EU policies with independent evidence throughout the whole policy cycle.

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