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Projects of common interest in the priority thematic area of smart grids deployment

Evaluation of candidate projects under EU Regulation 347/2013 on trans-European energy infrastructure

Vasiljevska, J., Flego, G.

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Contact information

Name: Tilemahos Efthimiadis
Address: European Commission, Joint Research Centre, P.O. box 2, 1755 ZG, Petten, Netherlands
Email: tilemahos.efthimiadis@ec.europa.eu
Tel.: +31 224565141

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Contents

Abstract

The document presents the outcome of the evaluation process of candidate projects of common interest in the priority thematic area of smart grids deployment, as set out in Regulation (EU) No 347/2013. The evaluation follows the guidelines of the *Assessment framework for projects of common interest in the field of smart grids — 2017 update* developed by the Joint Research Centre (JRC) and adopted within the smart grid priority thematic group.

The report aims to assist the smart grid priority thematic group in proposing projects of common interest in the thematic area of smart grids deployment to be included in the fifth Union list of projects of common interest.

Authors

Julija Vasiljevska, Gianluca Flego

Executive summary

Policy context

This report supports the implementation of the European Union (EU) regulation on guidelines for trans-European energy infrastructure (Regulation (EU) No 347/2013). More specifically, it aims to support the smart grid thematic area group in proposing projects of common interest in the priority thematic area of smart grids deployment by providing an assessment of candidate projects in this thematic area. Projects of common interest are energy infrastructure projects, which are essential to complete the European internal energy market and to meet the EU's energy policy objectives of affordable, secure, and sustainable energy.

Projects of common interest may benefit from accelerated planning and permit granting, a single national authority for obtaining permits, improved regulatory conditions, lower administrative costs owing to streamlined environmental assessment processes, increased public participation through consultations and increased visibility to investors.

To obtain the status of a PCI, a project must have a significant impact on the energy markets and market integration in at least two EU countries (or an EU and EEA[1] country), increase energy market competition and contribute to the EU's energy security, competitiveness and climate goals by diversifying energy sources and integrating renewables. The selection process gives preference to projects in priority corridors and areas, as identified in the Trans-European Networks for Energy (TEN-E) strategy, in which smart grids deployment is identified as one of the 12 priority infrastructure corridors and thematic areas.

Once a project is assigned the status of a PCI, it is also eligible for Union financial assistance in the form of grants for works or grants for studies. Such assistance could be granted if the project promoters can clearly demonstrate the significant positive externalities generated by the projects and their lack of commercial viability, according to the business plan and other assessments carried out, notably by possible investors or creditors or, where applicable, a national regulatory authority.

This report is intended to assist the smart grid priority thematic group in selecting projects of common interest in the priority thematic area of smart grids deployment to be included in the fifth Union list of projects of common interest.

Key conclusions

The report presents the outcome of the evaluation process of candidate projects of common interest in the area of smart grids deployment based on the *Assessment framework for projects of common interest in the field of smart grids — 2017 update* (Vasiljevska and Gras, 2017) developed by the European Commission's Joint Research Centre (JRC) and adopted within the smart grid priority thematic group of the European Commission.

Five candidate projects have been submitted to the Commission and evaluated accordingly. These are (in alphabetical order): **ACON** (Again COnnected Networks) – Member States: Czech Republic and Slovakia, **CARMEN** (Carpathian Modernisation of Energy Network) – Member States involved: Romania and Hungary, **Danube InGrid** — Member States involved: Hungary and Slovakia, **Gabreta** – Member States involved: Czech Republic and Germany, and **Green Switch** – Member States involved: Slovenia, Croatia and Austria.

All project proposals were analysed and assessed based on the information provided by the project promoters and in reference to both the project's compliance with the general criteria laid out in Article 4(1) of regulation (EU) No 347/2013, and the evaluation of the project's contribution to the smart grid specific criteria of Article 4(2) of the same regulation. More specifically, all project proposals were evaluated in accordance with the following steps: *(1) Project's necessity for the priority thematic area of smart grids deployment by referring to the energy infrastructure category of Annex II(1)(e) to the regulation, (2) verification of a project's cross-border impact (compliance with any of the criteria of Article 4. 1. (c)); (3); (4) Project contribution to the smart grid specific criteria (Article 4(2)(c) of the regulation) – energy system-wide cost-benefit analysis*

The **ACON** project builds its idea on the need to significantly improve the efficiency of the distribution networks in the project area while increasing the cross-border capacity at the DSO level. It capitalises on existing cross-border distribution network interconnections (currently used only for non-standard operational activities) and proposes further enhancement of these interconnections by deployment of smart grid solutions. Notwithstanding the conventional elements proposed in the project, the project includes technologies and solutions necessary for the priority thematic area of smart grids deployment (point 4(10) of Annex I to the regulation). It demonstrates a significant cross-border dimension by directly involving DSOs and TSOs from two Member States, where the TSOs also stand to benefit from more efficient and reliable operation of the distribution networks in the project area. In this respect, the project

[1] European Economic Area.

complies with Article 4(1)(c)(i) of the regulation. The ACON project demonstrates a significant contribution to the six smart grid specific criteria outlined in Article 4(2) of the regulation and a positive outcome in the project's societal cost-benefit analysis.

The **CARMEN** project builds its scope and objectives on the system needs in the project area to improve the efficiency of distribution network operation and the service quality provided to the network users using smart grid technologies and functionalities, while at the same time contribute to the national and European climate and energy targets. More specifically, it aims to integrate massive penetration of wind power into the distribution network near the Romanian-Moldovan border and solar power near the Romanian-Bulgarian border, which will lead to increase of power flows in the east-west direction. Such increase will impact the transmission grid as well and ask for increased cooperation with the Romanian DSO involved in the project, as well as between the TSOs of the two Member States. Given the general deficit of power generation in Hungary, the project is expected to enable secure and efficient flow of this increased generation power on the east-west corridor in the long run, which will impact the transmission grids of both Member States. The project envisages modernisation and digitisation of key HV and MV infrastructure, such as modernisation and capacity increase of HV overhead lines, modernisation of HV/MV transformer stations and modernisation of MV/LV transformer substations. Additionally, deployment of communication devices and optical fibres mounted to selected HV overhead lines, together with installation of smart metering devices and SCADA upgrade, will facilitate better coordination in the power supply management of the affected areas.

Therefore, the project includes investments in the energy infrastructure category of Annex II(1)(e) to the Regulation, which will enable integration of behaviour and actions of all grid users – in particular, the generation of large amounts of electricity from renewable or distributed energy sources and demand response by consumers. This way, the project also proves necessary for the priority thematic area of smart grids deployment (point 4(10) of Annex I to the regulation). The CARMEN project is located on the territory of one Member State (Romania) and it demonstrates cross-border impact by complying with Article 4(1)(c)(ii) of the regulation and Annex IV(1)(e) to the Regulation. In particular, the project is designed for equipment and installations at 20 kV and 110 kV network level; it involves 1 517 922 consumers; consumption area of 10 296 487 GWh/year and 37 % of energy supplied comes from renewable energy variable in nature. The project involves distribution system operator (Delgaz, Romania) and transmission system operators of two Member States (Transelectrica, Romania and MAVIR, Hungary). In addition, the project demonstrates a significant contribution to the six smart grid specific criteria outlined in Article 4(2) of the Regulation and a positive outcome in the project's societal CBA.

The **Danube InGrid** project aims to significantly improve the efficiency of (especially distribution) system operation services through increased availability of flexibility resources to allow better balancing, safer grid management, higher voltage quality, shorter and less frequent interruptions, lower RES curtailment and lower line congestion, all while increasing the network's hosting capacity with respect to intermittent renewable energy sources (RES) and distributed generation (DG). This is obtained through the installation of new smart facilities, especially the construction of two new smart substations (400/110 kV and 110/22 kV, respectively), multiple micro substations, automatic tap changer MV/LV transformers and remote fault detection systems. This allows radical improvement of the observability and remote controllability of the system. This wealth of new and detailed system state information made available to each DSO is to be shared across borders in real time, or close to real time, through modern optical fibre communication technology also installed as part of the project, enabling much closer coordination in the operation of distribution systems. TSOs also stand to benefit from more efficient network management and clearly need to be well involved to fully tap into the project's potential. This will also build a shared data repository to be exploited for analysis of typical system conditions and their efficient management. Customers will also be incentivised towards more active participation through facilitated demand response and DG installation, potentially also through enabled dynamic pricing developments. Therefore, the Danube InGrid project both complies with Article 4(1)(c)(i) of the Regulation and proves necessary for the priority thematic area of smart grids deployment (point 4(10) of Annex I to the Regulation). The Danube InGrid project demonstrates a significant contribution to the six smart grid specific criteria outlined in Article 4(2) of the Regulation and a positive outcome in the project's societal CBA. Remarkably, this holds even in the worst-case scenario, with 40 % lower benefits constructed for sensitivity analysis purposes.

Gabreta project demonstrates impact on variety of power system operation dimensions, ranging from improved metering and monitoring of the grid, higher flexibility and easier balancing, enhanced capabilities for frequency and voltage control, larger hosting capacity for integration of renewable generation (especially for distributed energy), smoothing of consumption profiles within an increase in overall demand levels, avoided line congestion and lower RES curtailment, easier fault detection and reparations for shorter and less frequent interruptions. These results are provided by an overall smartening of the equipment at the LV and MV level, with special regard to substations, meters, algorithms, and monitoring, control, and communication technology, as well as by an 8 MW expansion in energy exchange capacity at the distribution level. All this is expected to bring about a profound change in grid management patterns, bringing about truly regional coordination in the operation of the electricity network.

These enhancements in the ability to retrieve and exchange system state information in real time, also obtained through the adoption of fibre, broadband over power lines (BPL), and 5G communication technology, will create a substantial flow of data brought to the service of system optimisation, both in short-run management and in deeper long-run analysis of system patterns. It will be made available through the creation of data storage facilities shared by the region's network operators. Active end-customer participation, both as distributed energy generators and as potential providers of flexible demand, will be enabled through smart appliances, potentially through the adoption of dynamic pricing setups. The project complies with Article 4(1)(c)(i) of the Regulation, as well as for the priority thematic area of smart grids deployment (point 4(10) of Annex I to the Regulation).

The project promoters clearly demonstrate the project's contribution to the six smart grid specific criteria outlined in Article 4(2) of the Regulation, and its positive expected impact on social welfare within a societal cost-benefit analysis. This carries over to when stress tests are performed, such as through the computation of positive cost-benefit measures within a worst-case scenario where key benefits parameters are decreased by 40%. Consequently, the project proves remarkably stable even through the application of sensitivity analysis methodologies.

The **Green Switch** project aims is to optimise the utilisation of existing infrastructure and efficiently integrate new technologies and advanced functionalities to allow for higher hosting capacity, efficient integration of new loads and new type of loads (e.g. electric vehicles), optimise future investments and improve the security and the quality of operation and supply. The project involves partners from Slovenia, Croatia and Austria, and more specifically, TSOs, DSOs, retailer and a generation company. The project promoters have recognised the value of cooperation among partners facing similar challenges in their grid areas and proposes cost-effective solutions by responding to common challenges to the complex management of power flows at transmission and distribution network levels.

Main project investments include installation of smart grid equipment at 10 kV level or higher which will enable implementation of advanced functionalities to integrate new distributed generation and loads as well as increase reliability and quality of supply. Therefore, the project includes investments in the energy infrastructure category of Annex II(1)(e) to the Regulation, which will enable integration of behaviour and actions of all grid users – in particular, the generation of large amounts of electricity from renewable or distributed energy sources and demand response by consumers. This way, the project also proves necessary for the priority thematic area of smart grids deployment (point 4(10) of Annex I to the Rregulation). The project demonstrates cross-border dimension both at transmission and distribution network level (compliance with Article 4(1)(c)(i) of the Regulation). At transmission network level, TSOs from Slovenia and Croatia aim to increase the capacity of existing cross-border lines by installing high temperature low sag conductor wire technology (HTLS), Dynamic Thermal Rating (DTR) and install Power Control Systems to better control the cross-border flows, thereby increasing the safety and reliability of the electricity system in the project area as well as demonstrating positive impact on the neighbouring power systems. Moreover, the project aims to increase the cross-border capacity at the DSO level in the project area by installing a MV cross-border emergency electrical connection between Austria (KAERNTEN NETZ) and Slovenia (Elektro Gorenjska) and upgrading another existent MV cross-border interconnection in the area of Seebergsattel (Jezersko), both with the aim to increase security of supply in the bordering area of both DSOs. In addition, the project demonstrates a significant contribution to the six smart grid specific criteria outlined in Article 4(2) of the Regulation and a positive outcome in the project's societal CBA.

Related and future JRC work

The JRC aims to support the European Commission's Energy Union (2) strategy and the European Green Deal (3) to make energy more secure, affordable, and sustainable, as well as foster efficient and sustainable transport in Europe. A modern energy infrastructure is crucial for an integrated energy market and to enable the EU to meet its broader climate and energy goals. This requires considerable investment in the existing gas and electricity networks, with rapid development of their interconnections. To face these challenges, JRC research includes desktop and experimental studies on ways to integrate renewable energy sources and demand side participation into the power grid. It also investigates the grid interoperability with, for example, information and communication technology (ICT) and transport systems. Since the establishment of the first Union list of projects of common interest in 2013, and every second year, the JRC supports the implementation of the EU Regulation on guidelines for trans-European energy infrastructure in the priority thematic area of smart grids deployment. Since 2015, the JRC has also supported the implementation of the Regulation in the energy infrastructure priority corridors of electricity and gas and, since 2020, also in the priority thematic area of cross-border carbon dioxide networks.

(2) https://ec.europa.eu/energy/topics/energy-strategy/energy-union_en
(3) https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

Quick guide

To assist the development of an integrated EU energy market and ensure fulfilment of the EU's policy objectives of affordable, secure, and sustainable energy, every two years the European Commission adopts a list of key energy infrastructure projects known as Projects of Common Interest (PCIs). This report presents the outcome of the evaluation process of candidate PCIs in the priority thematic area of smart grids deployment of the Regulation (EU) No 347/2013 to be included in the 2021 Union list of projects of common interest. The evaluation process relies on a thorough analysis of the information provided by the project promoters in the submitted project proposals and follow-up interactions with the promoters, and it closely follows the *Assessment framework for projects of common interest in the field of smart grids — 2017 update* (Vasiljevska and Gras, 2017).

1. Introduction

1.1. Objectives

European Union (EU) Regulation on guidelines for trans-European energy infrastructure (Regulation (EU) No 347/2013) addresses the identification of projects of common interest necessary to implement priority corridors and areas falling under the energy infrastructure categories in electricity, gas, oil and carbon dioxide set out in Annex II ('energy infrastructure categories').

Regulation (EU) No 347/2013 recognises 'smart grids deployment' as one of the twelve priority infrastructure corridors and thematic areas, with the objective to adopt smart grid technologies across the Union to 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 (DER) and demand response by consumers. In this context, Article 2(7) of the Regulation defines a smart grid as '*a network efficiently integrating the behaviour and actions of all users connected to it — generators, consumers and those that do both — in order to ensure an economically efficient, sustainable electricity system with low losses and high quality and security of supply and safety'. In addition, point (1)(e) of Annex II to the regulation identifies a smart grid infrastructure as 'any equipment or installation, both at transmission and medium voltage (MV) distribution level, aiming at two-way digital communication, real-time or close to real-time, interactive and intelligent monitoring and management of electricity generation, transmission, distribution, and consumption within an electricity network'.*

On 12 January 2021, the Commission launched a call for candidate projects in the smart grids thematic area falling under the energy infrastructure category set out in Annex II.1(e) to be included in the fifth list of EU projects of common interest (PCIs). Submitted projects were prepared in line with the *Assessment framework for projects of common interest in the field of smart grids — 2017 update* (Vasiljevska and Gras, 2017) and followed specific template for project proposals (Annex I, JRC assessment framework). The JRC assessment framework builds on the requirements put forward in the existing Regulation (EU) No 347/2013 on guidelines for trans-European energy infrastructure [4], hereinafter referred to as 'the regulation'. It presents a methodological approach for verification of a project's compliance with the general criteria laid out in the regulation (Article 4) and in the evaluation of the project's contribution to the smart grid specific criteria of Article 4 of the regulation and in line with Annex IV (4) to the regulation. The Commission tabled a legislative proposal for revising the regulation before the end of 2020 [5], and the new rules are expected to be adopted by the European Parliament and the Council in time for the sixth PCI list.

Candidate projects in the thematic area of smart grids deployment have been also subject to a twelve-week public consultation [6] - launched by Commission on 24 March 2021. In this way, the Commission seeks to obtain views from the public, from stakeholders, and from public authorities on the specific candidate projects in smart grid infrastructure and their merits for the fifth list of projects of common interest.

The report presents the outcome of the evaluation of smart grid project proposals and, as such, it aims to assist the smart grids priority thematic group [7] in proposing projects of common interest (PCIs) in the priority area of smart grids deployment for inclusion in the fifth list of PCIs. The list will then be adopted by the European Commission by the end of 2021 and published in the Official Journal by early 2022.

1.2. Policy context

To facilitate the development of an integrated European Union (EU) energy market, since 2013 and every other year, the European Commission draws up a list of key energy infrastructure projects, known as projects of common interest, essential for meeting the EU's energy policy objectives of affordable, secure, and sustainable energy.

Projects of common interest must meet the following general criteria, according to Article 4(1) of the regulation.

a) The project must be necessary for at least one of the energy infrastructure priority corridors and areas (Annex I to the regulation).

b) The potential overall benefits – assessed according to the six specific criteria outlined in Article 4(2)(c) of the regulation – outweigh its costs, including in the longer term. Each specific criterion is to be assessed against a set of indicators set out in point (4) of Annex IV to the regulation.

c) The project shall either involve at least two Member States by directly crossing the border of two or more

(4) http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2013:115:0039:0075:en:PDF.
(5) https://ec.europa.eu/energy/sites/ener/files/revised_ten-e_regulation_.pdf
(6) https://ec.europa.eu/energy/consultations/consultation-list-candidate-projects-common-interest-smart-grids-0_en
(7) https://ec.europa.eu/energy/topics/infrastructure/projects-common-interest/regional-groups-and-their-role/smart-grid-regional-group_en

Member States or cross the border of at least one Member State and a European Economic Area country; alternatively, it shall be in the territory of one Member State and have a significant cross-border impact ([8]).

In the context of point b) above, the project's overall benefits shall be assessed according to the six specific policy criteria outlined in Article 4(2)(c) and the overall benefits shall outweigh the project's costs by conducting a societal cost-benefit analysis (energy system-wide cost-benefit analysis, Annex V (8) to the regulation). The six specific criteria of Article4 (2) (c) are the following ones:

- integration and involvement of network users with new technical requirements with regard to their electricity supply and demand
- efficiency and interoperability of electricity transmission and distribution in day-to-day network operation
- network security, system control and quality of supply
- optimised planning of future cost-efficient network investments
- market functioning and customer services
- involvement of users in management of their energy usage.

Annex IV (4) to the regulation further specifies that each specific criteria of Article 4 (2) (c) shall be evaluated using a set of indicators (hereafter referred as 'key performance indicators - KPIs') ([9]), namely:

- **KPI_1** – reduction of greenhouse emissions
- **KPI_2** – environmental impact of electricity grid infrastructure
- **KPI_3** – installed capacity of distributed energy resources in distribution networks
- **KPI_4** – allowable maximum injection of electricity without congestion risks in transmission networks
- **KPI_5** – energy not withdrawn from renewable sources due to congestion or security risks
- **KPI_6** – methods adopted to calculate charges and tariffs, as well as their structure, for generators, consumers and those that do both
- **KPI_7** – operational flexibility provided for dynamic balancing of electricity in the network
- **KPI_8** – ratio of reliably available generation capacity and peak demand
- **KPI_9** – share of electricity generated from renewable sources
- **KPI_{10}** – stability of the electricity system
- **KPI_{11}** – duration and frequency of interruptions per customer, including climate-related disruptions
- **KPI_{12}** – voltage quality performance
- **KPI_{13}** – level of losses in transmission and distribution networks
- **KPI_{14}** – ratio between minimum and maximum electricity demand within a defined time period
- **KPI_{15}** – demand side participation in electricity markets and in energy efficiency measures
- **KPI_{16}** – percentage utilisation (i.e. average loading) of electricity network components
- **KPI_{17}** – availability of network components (related to planned and unplanned maintenance) and its impact on network performances
- **KPI_{18}** – actual availability of network capacity with respect to its standard value
- **KPI_{19}** – ratio between interconnection capacity of a Member State and its electricity demand
- **KPI_{20}** – exploitation of interconnection capacities

([8]) Cross-border impact as set out in point (1)(e) of Annex IV to the regulation.

([9]) The KPIs are derived from the criteria of point (4) of Annex IV: level of sustainability; capacity of transmission and distribution grids; network connectivity; security and quality of supply; efficiency and service quality; and contribution to cross-border electricity markets.

- **KPI_{21}** – congestion rents across interconnections.

To facilitate the assessment of all projects that could be eligible as projects of common interest and that could be included in a regional list, each regional and thematic group shall assess each project's contribution to the implementation of the same priority corridor or area in a transparent and objective manner. This assessment shall lead to ranking of projects for internal use of the group only (Article 4 (4) to the regulation). Nevertheless, for smart grid projects falling under the energy infrastructure category set out in point 1(e) of Annex II, '*ranking shall be carried out only for those projects that affect the same two Member States, and due consideration must also be given to the number of users affected by the project, the annual energy consumption, and the proportion of generation from non-dispatchable resources in the area covered by these users*' (Article 4 (4) to the regulation).

Once a project is assigned the status of project of common interest, it may benefit from accelerated planning and permit granting, a single national authority for obtaining permits, improved regulatory conditions, lower administrative costs owing to streamlined environmental assessment processes, increased public participation through consultations and increased visibility to investors. Project of common interest will also be eligible for Union financial assistance in the form of grants for works or grants for studies. Such assistance can be granted if the project promoters can clearly demonstrate the significant positive externalities generated by the project and its lack of commercial viability, according to the business plan and other assessments carried out, notably by possible investors or creditors or, where applicable, a national regulatory authority.

Recent policy developments in view of the upgraded 2030 EU targets and 2050 climate neutrality objective under the European Green Deal have paved the way for increased role of smart grid investments in fulfilling the EU climate objectives. Smart grid solutions, including demand response have considerably developed in the last years, also facilitated by the digital transformation of the electricity sector. System integration, both between the power and gas, but also with other end-use sectors, such as transport and industry, offers additional opportunities to both the power and gas sector and increases system efficiencies. Furthermore, smart grid technologies are key elements in providing high-capacity recharging to support the decarbonisation of the transport sector. Finally, distribution system operators will play essential role in the energy infrastructure planning also because large part of renewable energy generation capacity is connected to the low and medium voltage grid. Some of these trends are already visible in the smart grid projects presented in this report.

Smart grid projects of common interest appear vital with a view to reaching the EU energy and climate targets and even more in view of the 2050 climate objectives under the EU Green Deal. Large differences between national energy infrastructures would prevent businesses and consumers from reaping the full benefits of integrated markets and smart grids and would threaten cross-border trade and cooperation across national borders. For that reason, the regulation on the trans-European energy infrastructure remains an essential instrument in supporting the development of cross-border smart grid infrastructure to enable EU interconnection targets, energy market integration and security of supply, as well as to contribute to EU climate objectives by facilitating integration of increasing amounts of renewable energy.

2. Evaluation of project proposals

On 12 January 2021, the Commission launched a call for candidate projects in the smart grids thematic area[10] to be included in the fifth list of EU projects of common interest (PCIs). All project applications were prepared in line with the JRC assessment framework and followed specific template for project proposals (Annex I, JRC assessment framework) Five (5) projects were submitted to the Commission by 8 March 2021:

- ACON (Again COnnected Networks) — Member States involved: Czech Republic and Slovakia.
- CARMEN (Carpathian Modernisation of Energy Network) – Member States involved: Romania and Hungary.
- Danube InGrid — Member States involved: Hungary and Slovakia.
- Gabreta – Member States involved: Czech Republic and Germany.
- Green Switch – Member States involved: Slovenia, Croatia and Austria.

These projects were then assessed against the criteria set out in the regulation to identify their contribution to the smart grids thematic area. Once positively assessed these projects will then be proposed for inclusion in the fifth list of PCIs.

This chapter demonstrates the projects' contribution to the criteria of the regulation corresponding to the criteria of Article 4 and the requirements of Annex II(1)(e), as presented in Figure 1.

Figure 1. Criteria for the projects' evaluation

Source: Own elaboration, 2021.

Projects submitted to the call for the priority thematic area of smart grids deployment shall include investments under the energy infrastructure category of Annex II(1)(e), namely *'any equipment or installation, both at transmission and medium voltage distribution level, aiming at two-way digital communication, real-time or close to real-time, interactive and intelligent monitoring and management of electricity generation, transmission, distribution and consumption within an electricity network in view of developing a network efficiently integrating the behaviour and actions of all users connected to it — generators, consumers and those that do both — in order to ensure an economically efficient, sustainable electricity system with low losses and high quality and security of supply and safety;'*

Additionally, each project shall comply with the general and specific criteria of Article 4(1) of the regulation. Namely, each submitted project needs to:

- prove necessary for the priority thematic area of smart grids deployment (Annex I(10) to the regulation) – by referring to the smart grid elements and the trans-European dimension of the project, and its compliance with the energy infrastructure category Annex II(1)(e).
- demonstrate a cross-border impact by complying to any of the criteria of Article 4(1)(c).
- demonstrate contribution to the smart grid specific criteria (Article 4(2)(c) of the regulation) by performing energy system-wide cost-benefit analysis (CBA).

[10] falling under the energy infrastructure category set out in Annex II(1)(e)

2.1. Again COnnected Networks (**Czech Republic and Slovakia**)

2.1.1. General overview

The idea of the ACON project, already included in the previous PCI list, revolves around the regional needs of both Member States to significantly improve the efficiency of the distribution networks in the project area while strengthening cooperation between Czechia and Slovakia and contributing to the territorial cohesion of the region of eastern Europe. More specifically, the smart grid solutions proposed in the project aim to: 1) leverage the use of existing cross-border connections at distribution network level (at 110 kV and 22 kV) and further enhance network security by strengthening these interconnections and developing new ones and 2) development and deployment of smart metering and control functionalities, mainly installed at medium-voltage (MV) and high-voltage (HV) distribution network levels. In other words, the project combines smart grid and conventional infrastructure investments, both necessary for strengthening the network operational security. Current 110 kV and 22 kV cross-border connections at distribution network level are mainly used in non-standard operational situations, whereas future regional needs of growing RES integration would lead to increased inter-regional flows in the distribution networks and thus challenge network security and quality of supply.

The ACON project brings together a total of four entities: E.ON Distribuce (DSO in Czechia), Západoslovenská distribučná (DSO in Slovakia), ČEPS (TSO in Czechia) and Slovenská elektrizačná prenosová sústava (SEPS) (TSO in Slovakia). The two DSOs take the primary responsibility for the project activities and act as project promoters, whereas the TSOs play a supporting role by making use of the information flow and associated impact on their networks.

Main project goals:

- improvement of distribution and transmission network operational efficiency
- enhancement of network security and quality of supply
- enablement of growing penetration levels of RES in the region
- leverage of the benefits of increased cross-border cooperation and connectivity.

Expected impacts:

- increased market competition in the project area
- increased distribution network reliability and quality of supply
- greater energy input (increased number of consumers and RES grid connections)
- strengthened connection at DSO level between the two Member States.

The ACON project was included in the fourth Union list of projects of common interest and has also been granted financial support from the Connecting Europe Facility (CEF) after the second call for submissions, in September 2018.

2.1.2. Compliance with the general and specific criteria of Article 4(1) of the regulation

Project's necessity for the priority thematic area of smart grids deployment (compliance with the energy infrastructure category of Annex II(1)(e) to the regulation)

The ACON project mainly involves investments at HV and MV distribution network levels, aiming to support integration of all users connected to the grid and facilitate growing penetration of RES. This entails adoption of smart grid technologies to efficiently integrate the behaviour and actions of all users connected to the electricity network and, as a result, increase the generation of renewable and distributed energy sources as well as facilitate demand response. Smart grid technologies addressed in the project allow improved network observability and control, and ultimately lead to enhanced network operational efficiency and higher quality and security of supply.

The ACON project is mainly driven by the current and future needs of the distribution networks in the project area, and therefore the DSOs of both Member States are the main project promoters. Nevertheless, the project is expected to have a positive impact on the transmission networks of both Member States, as increased network observability and control enabled by the ACON project would lead to better management of the power flows in the distribution networks and consequently power flows coming from the distribution into the transmission networks. In addition, demand-side management (DSM) solutions enabled by the ACON project, as well as future use of dynamic tariffs, could lead to a new type of ancillary services provided to the TSOs.

Some of the main infrastructure investments addressed by the ACON project are the following:

- Smart grid technologies, including a new substation dispatching control and protection system — installation of new local advanced supervisory control and data acquisition (SCADA), voltage regulation, remotely controlled transformation stations, installation of smart switches (reclosers) and fault locators on the MV power lines, intelligent algorithms for automation, etc.
- Smart communication and control technologies, including smart metering devices — optic wires, high-speed power line carrier (PLC) communication, new network dispatching model, etc.
- Modernisation of current cross-border MV and HV power lines — installation of automated remote controls for MV power lines and distribution transformer stations, deployment of optic wires for real-time (or close to real-time) data communication on the current network status, looping and cabling of MV power lines, etc.
- Construction of new cross-border distribution network interconnections and a 110/22 kV transformer station with the aim of improving network operational efficiency, security and quality of supply, and increasing network capacity while accommodating future needs of all network users.

In this regard, the project complies with the energy infrastructure category of Annex II(1)(e) to the regulation and therefore, it proves necessary for the priority thematic area of smart grids deployment (point 4(10) of Annex I to the regulation).

Project's demonstration of a cross-border impact (compliance with any of the criteria of Article 4(1)(c))

The ACON project involves two Member States by directly crossing the border of the Member States involved in the project. More specifically, the project aims to leverage the use of existing cross-border connections at distribution network level (at 110 kV and 22 kV) and further enhance network security by strengthening these interconnections and developing new ones. This will result in increase of interconnection operational capacity as well as increase of system stability and reliability.

Additionally, the project includes deployment of two-way digital communication also across the border, which will allow better involvement of consumption and distributed electricity generation into the management of the system operation. This will facilitate the development of market for ancillary services and provide increased opportunity for market players to provide such services.

Project contribution to the smart grid specific criteria (Article 4(2)(c) of the regulation) – energy system-wide cost-benefit analysis

This section illustrates the project contribution to the policy specific criteria as a way of assessing the benefits in the energy system-wide cost-benefit analysis (Article 4(1)(b)). Additionally, for projects falling into the priority thematic area of smart grids deployment, '*the cost-benefit analysis shall take into account the impacts on the indicators defined in Annex IV*' (Annex V (8) to the regulation).

The ACON project promoters elaborate on the project's impact on each of the six specific criteria, selecting a set of indicators defined in Annex IV (hereafter referred as 'KPIs') to better capture this impact against a specific criterion.

Tables 1-6 below depict the selected KPIs for capturing the project's impact against each specific criterion and the estimation approach used. Depending on the present uncertainties in the information provided by the promoters and the assumptions made, the JRC has used a colour-coded approach to evaluate the project's contribution to each specific criterion (Vasiljevska and Gras, 2017). In addition, each project's impact has been assessed in view of the following two scenarios: business as usual (BaU), i.e. without implementation of the project; and a smart grid (SG) scenario, i.e. with implementation of the project.

Policy criterion 1: integration and involvement of network users with new technical requirements with regard to their electricity supply and demand

The project is expected to effectively accommodate growing integration of distributed RES and involve controllable load in the provision of more efficient distribution network operation. To this end, the promoters selected the following KPIs in addressing the project's impact on this criterion (Table 1).

Table 1. ACON: evaluation of project's impact against the first specific criterion

Selected KPIs	Calculation approach and impact evaluation

KPI_7: operational flexibility provided for dynamic balancing of electricity in the network	The project is expected to significantly increase the operational flexibility of the electricity network for dynamic balancing as a result of effective integration and involvement of network users in managing their load. This could lead to an increase in integration of distributed RES. The ACON promoters report and demonstrate a significant increase in the operational flexibility of the network and therefore positively quantify this KPI.	
KPI_{14}: ratio between minimum and maximum electricity demand within a defined time period	The ratio between the minimum and maximum electricity demand within a defined time period is expected to decrease as a result of better involvement of network users (and their controllable load) in network management. In terms of data information and promotion of dynamic tariffs, the proposed project solution is expected to facilitate demand-side management and reduce the difference between P_{max} and P_{min}. Based on this expectation, this KPI is positively assessed for the whole project area	

Source: Own elaboration, 2021.

Policy criterion 2: efficiency and interoperability of electricity transmission and distribution in day-to-day network operation

The promoters report an increase in distribution and transmission network efficiency (and consequently a reduced level of network losses) due to increased network monitoring and control and demand-side participation enabled by the project, which in turn would lead to a reduced environmental impact.

In this respect, the promoters selected the KPIs presented in Table 1 to capture the project's impact on this specific criterion.

Table 1. ACON: evaluation of project's impact against the second specific criterion

Selected KPIs	Calculation approach and impact evaluation	
KPI_1: reduction of greenhouse gas emissions	The project is expected to increase distribution and transmission network efficiency (e.g. reduced network losses) owing to increased network observability and controllability, increased RES and effective demand-side management enabled by the project' solutions. The ACON promoters positively quantify this KPI and report a reduction of greenhouse gas (GHG) emissions owing to the project's deployment.	
KPI_2: environmental impact of electricity grid infrastructure	Enhanced network management and control enabled by the implementation of the project could lead to a reduced need to build overhead lines and, as a result, reduce the environmental impact of such grid infrastructure. Furthermore, the ACON project proposes replacement of certain overhead power lines with underground cables, thus reducing the long-term environmental impact in terms of visual impact, soil occupation, threat to endangered animal species, etc.	
KPI_3: installed capacity of distributed energy resources in distribution networks	Enhanced network management and control capabilities (e.g. innovative voltage regulation algorithms, reactive power management, innovative grid protection/monitoring) enabled by the ACON project would allow increased DER capacity that can be safely integrated in the distribution grids. The ACON promoters report an increase in the network hosting capacity for DER and positively assess this KPI.	
KPI_{13}: level of losses in transmission and distribution networks	The ACON promoters acknowledge the challenges in estimating the future value of losses owing to the smart grid elements deployed in the project; nevertheless, the promoters expect a reduction in network losses due to	

	the enhanced network management introduced by the project. As the ACON project is developed mainly at the DSO level, this KPI is evaluated with respect to the level of distribution network losses. The promoters demonstrate a positive impact of the project on this KPI by calculating the relative difference in distribution network losses between the BaU and SG scenarios.	

Source: Own elaboration, 2021.

Policy criterion 3: network security, system control and quality of supply

The promoters expect a positive project's impact on this policy criterion due to enhanced network management and control using advanced network reconfigurations and voltage regulation at the substations and provision of new types of ancillary services enabled by the project. In addition, extension of the 110 kV cross-border interconnection line and deployment of a new 22 kV line would allow enhanced network control and management and ultimately growing levels of DER.

The following KPIs (Table 2) are selected by the promoters to address the project's contribution to the third specific criterion.

Table 2. ACON: evaluation of project's impact against the third specific criterion

Selected KPIs	Calculation approach and impact evaluation	
KPI_4: allowable maximum injection of power into transmission networks without congestion risks	The ACON project mainly addresses the distribution network and, in this case, the KPI indicates the increased distribution network hosting capacity in the project area, thus allowing an increase of DER in the region without compromising the operation of the transmission network. The ACON promoters positively quantify this KPI as a result of an increase in the distribution network hosting capacity due to extension of the 110 kV line and deployment of a new 22 kV line. Moreover, the smart grid elements deployed within the project would allow enhanced network control and management and ultimately growing levels of DER.	
KPI_8: ratio of reliably available generation capacity and peak demand	The ACON project is expected to increase the reliably available generation capacity owing to enhanced network management and control, and lower peak demand as a result of demand-side management and introduction of dynamic tariffs. The reliably available capacity is the part of net generating capacity available to cover the peak load (ENTSO-E, 2009) and is, as such, an indicator of the system's adequacy. As the ACON project mainly addresses the distribution network level, the promoters use an alternative approach and positively quantify this KPI as network capability to accommodate more renewable energy, owing to better operational management and consequently lower the difference between the P_{min} and P_{max}.	
KPI_{10}: stability of the electricity system	The promoters report a positive impact on this KPI in terms of quality of supply, as the ACON project can better deal with possible under-/over-voltage situations using advanced network reconfigurations and voltage regulation at the substations and provision of new types of ancillary services (e.g. DSM) while enabling the connection of more new network users. The KPI is, however, not quantified at this stage of the project's development.	

KPI_{11}: duration and frequency of interruptions per customer, including climate-related disruptions	The ACON project is expected to increase network reliability via various smart grid elements deployed in the project (voltage regulation, remotely controlled transformation stations, installation of smart switchers and locators on the MV power lines, etc.) The promoters positively quantify the project's impact on both reliability indices, the System Average Interruption Duration Index (SAIDI) and System Average Interruption Frequency Index (SAIFI), thus bringing significant benefits to both the customers and the DSOs (in terms of avoided costs for repairs and service interventions).	
KPI_{12}: voltage quality performance	The promoters report a positive impact on this KPI in terms of voltage line violations (over a pre-defined period of time) defined in accordance with the EN 50160 standard. The KPI is quantified as a reduced number of voltage line violations over a period of one year owing to project deployment.	
KPI_{20}: exploitation of interconnection	As the project mainly addresses the distribution network level, the promoters estimate this KPI as an increase in the MV cross-border capacity due to modernisation and installation of new MV cross-border lines along with deployment of smart grid elements in the project area. As a result, the exploitation of the distribution interconnection will increase as well; however, the promoters cannot quantify this KPI at the present stage of the project's development.	

Source: Own elaboration, 2021.

Policy criterion 4: optimised planning of future cost-efficient network investments

The promoters expect a positive impact of the project on this specific criterion as increased data availability related to network operation and maintenance enabled by the project would lead to optimised planning of network investments. Moreover, a higher-percentage utilisation of electricity network components would potentially lower the cost of distribution network management and ultimately enhance planning of future cost-efficient network investments.

In this respect, the promoters capture the project's impact on this criterion using the following KPIs (Table 3).

Table 3. ACON: evaluation of project's impact against the fourth specific criterion

Selected KPIs	Calculation approach and impact evaluation	
KPI_{16}: percentage utilisation (i.e. average loading) of electricity network components	The promoters expect a positive impact on this KPI due to increased distribution network capacity and improved network stability enabled by the project. This would ultimately lead to enhanced utilisation of the TSO-DSO interface in terms of power flows coming from the transmission network and an increase in the lifetime and reliability of network components and equipment at the TSO-DSO interface. The KPI is not quantified at the current stage of the project's deployment.	
KPI_{17}: availability of network components (related to planned and unplanned maintenance) and its impact on network performance	The project is expected to have a positive impact on this KPI, as the increased data availability related to network operation and maintenance enabled by the project will lead to optimised planning of network investments. The implementation of smart grid capabilities will allow condition-based maintenance and ultimately increase the mean time between network failures (as a result of optimal loading conditions of network components) and the mean time to repair (as a result of faster fault identification). The KPI is positively quantified using existing network failure reports from both DSOs and expected improvements based on similar pilot projects.	

KPI$_{18}$: actual availability of network capacity with respect to its standard value	The promoters select the actual availability of network capacity to address the project's impact on future cost-efficient investment. In this context, the ACON project is expected to increase the network capacity with respect to its nominal value as a result of the extension and enhancement of the 110 kV line and deployment of a new 22 kV cross-border interconnection. As the ACON SG project is developed mainly at the DSO level, the project's impact on this KPI is positively assessed owing to the installation of a new cross-border interconnection line at the distribution network level, new substations and smart grid elements.	

Source: Own elaboration, 2021.

Policy criterion 5: market functioning and customer services

The project would enable increased involvement of end-users (both consumers and prosumers) in effective management of grid operation, which is critical for market functioning and the introduction of new customer services. In addition, increased physical cross-border interconnection is expected to have a positive impact on the market development in the project area.

Table 4 illustrates the KPIs selected to address the project's impact on the fifth specific criterion.

Table 4. ACON: evaluation of project's impact against the fifth specific criterion

Selected KPIs	Calculation approach and impact evaluation	
KPI$_5$: energy not withdrawn from renewable sources due congestion or security risks	The promoters use this KPI to capture the project's impact on this specific criterion, as involvement of end-users (both consumers and prosumers) in effective management of the grid operation is critical for the functioning of the retail market and the introduction of different customer services. In this regard, the ACON project is expected to reduce the amount of renewable energy not withdrawn owing to network congestion or security risks as a result of the increase in controllable load subject to demand-side management. At this stage of the project's development, promoters do not expect RES curtailment; therefore, the KPI is quantified as potential increase in RES without congestion/security risks, as a result of growing controllable load, subject to demand-side participation.	
KPI$_6$: methods adopted to calculate charges and tariffs, as well as their structure, for generators, consumers and those that do both	The ACON project is expected to make available a more granular array of information, which will allow better allocation of electricity costs between different network users. Such information typically includes automatic and (close to) real-time energy consumption and/or generation data and detailed analysis of consumer/prosumer data in the form of clear tables and graphs used for customer energy bills. Furthermore, this amount of information and detail would further promote the introduction of dynamic tariffs and potentially engage end-users in more effective management of their energy consumption. Finally, more detailed information flows would allow regulators to assess RES contribution in provision of ancillary services to both DSOs and TSOs and move the market forward for new customer services.	
KPI$_{19}$: ratio between interconnection capacity of a Member State and its electricity demand	The promoters use this KPI to capture the project's impact on the fifth specific criterion, as cross-border interconnections and cross-border cooperation have a critical impact on market functioning. An increase in the physical cross-border interconnection enabled by the ACON project is expected to have a positive impact on market development in the project area. Since the ACON project is mainly developed at the distribution network level, this positive impact is quantified as an increase in the distribution network exchange capacity resulting from modernisation of the existing cross-border lines and installation of new 110 kV and 22 kV	

	lines. In addition, deployment of smart grid elements on both sides of the border would allow integration of additional DER and enable ancillary services available to the DSO. This KPI is positively quantified as the increase in the ratio of interconnection capacity at distribution network level and energy demand in the project area. However, the impact on the ratio of total interconnection capacity in each Member State and their energy demand is expected to be limited.	
KPI_{21}: congestion rents across interconnections	A well-interconnected energy market must provide sufficient capacity to all market participants and, in this regard, the level of congestion rents strongly affects the functioning of the market itself. This KPI cannot be assessed at this stage of the project's development, as currently no congestion rents apply across the interconnection at the DSO level. Nevertheless, the promoters expect a lower probability/frequency of distribution network congestion owing to the project deployment. Moreover, the project is also expected to contribute to reduced congestion at transmission network level due to the possibility of more efficient use and production of energy at distribution network level.	

Source: Own elaboration, 2021.

Policy criterion 6: involvement of users in management of their energy usage

The ACON project is expected to increase the involvement of end-users in more effective management of their energy usage (through demand-side participation and energy efficiency measures) and consequently enable an increase in the proportion of electricity generated from RES.

Table 5 presents the KPIs, selected by the promoters, for addressing the ACON project's contribution to this specific criterion.

Table 5. ACON: evaluation of project's impact against the sixth specific criterion

Selected KPIs	Calculation approach and impact evaluation	
KPI_{9}: share of electricity generated from renewable sources	The promoters choose this KPI to address the project contribution to the sixth specific criterion, as the proportion of electricity generated from RES is expected to increase owing to more effective involvement of end-users in the management of their energy usage. The promoters positively quantify this KPI owing to increased RES connections in the project area enabled by the smart grid elements introduced by the project.	
KPI_{15}: demand-side participation in electricity markets and in energy efficiency measures	This KPI is closely linked to the involvement of users in effective management of their energy usage. In this respect, the ACON project is expected to increase the load participating in demand-side management and energy efficiency measures in comparison with the BaU scenario. The KPI is therefore positively quantified using available data from the dispatch centres of both DSOs for the BaU scenario and an expected increase in additional sources subject to DSM coming from similar pilot projects in the region.	

Source: Own elaboration, 2021.

The following section presents the societal benefits of the ACON project in monetary terms along with the total cost (capital and operational expenditure), as communicated by the promoters. Furthermore, economic indicators such as the net present value (NPV), the internal rate of return (IRR) and the benefit/cost (B/C) ratio are used to verify whether the overall project's benefits outweigh the project's costs and therefore the project complies with the second general criteria of the regulation (Article 4(b)).

The promoters assumed the following values as variables used in the societal CBA:

- **demand growth**: an average annual demand growth of 0.82 % (CZ) and 0.68 % (SK).
- **discount rate**: a value of 4 % has been used as societal discount rate (Vasiljevska and Gras, 2017).

- **time horizon**: 20 years has been chosen as time horizon (owing to the lifespan of most of the investment assets included in the project).
- **peak demand reduction**: 226.82 MW has been assumed for the project area owing to expected energy savings and peak load shift.
- **electricity price for losses**: 27 €/MWh and 32 €/MWh for Czech Republic and Slovakia, respectively.
- **electricity market price**: 40.3 €/MWh ([11]).
- **Value of lost load**: 3 970 €/MWh and 4730 €/MWh for Czech Republic and Slovakia, respectively ([12]).
- **carbon prices**: 34.5 €/t (European Commission, 2011);
- **fuel prices**: 1.043€/l and 1.1 €/l for Czech Republic and Slovakia, respectively.

The main monetary benefits and costs are listed below.

Main monetary benefits

The ACON project is expected to deliver a set of positive impacts and in that respect the following monetised benefits are communicated by the project promoters (starting from the highest to the lowest):

- electricity cost savings due to consumption reduction and peak load shift
- prevention of blackouts
- reduced CO_2 emissions and fossil fuel usage
- deferred distribution capacity investments due to consumption reduction and peak load shift
- reduced outage times
- prevention of brownouts
- reduction in electricity interruption costs for households
- reduced electricity technical losses
- reduced cost of equipment breakdowns and maintenance of assets.

Main costs

The main costs associated with the project deployment are as follows (in descending order):

CAPEX:

- Distribution grid communication elements
- Management of distribution system under new conditions
- Automated metering management technology
- Smart grids IT solutions
- Border area and cross-border connections improvement.

OPEX:

- Maintenance costs (for all activities during the project time frame)
- IT systems (operation cost of IT devices for data analysis, secure grid operation, etc.)
- Project team (labour costs for management and operation of the grid, preparation of all project's activities, etc.)
- Communication systems for monitoring the grid and data collection.

([11]) http://www.eex.com/.
([7]) https://www.sciencedirect.com/science/article/pii/S2214629617301184.

The overall project's benefits outlined above outweigh the project's costs and the project reports the following economic indicators: ENPV: 60.4 mil. €, IRR: 9.6 %, B/C: 1.18.

Sensitivity analysis

Critical variables in the project, which have been also subject to sensitivity analyses are the following:

- consumption reduction: lowering the benefit of consumption reduction by 20 % diminishes the project's NPV by EUR by 17. 9 million.
- decrease in electricity price: lowering the electricity price by 20 % diminishes the project's NPV by EUR 7.2 million.
- decrease in outage time: lowering the benefit of reduced outage time by 20 % reduces the project's NPV by EUR 3.9 million.
- peak demand reduction: lowering the value of assumed peak demand reduction owing to both energy savings and peak load shifting by 20 % diminishes the project's NPV by EUR 3.8 million.

The promoters report that even in the constructed worst-case scenario, where most salient benefits and variables (e.g. consumption reduction, decrease in outage time, reduced equipment breakdown, peak demand reduction, energy market price, wholesale margin difference between peak and non-peak generation and CO_2 price) are reduced by 20 % at once, the expected NPV is still positive (12.2 mil. €), while the B/C ratio is still marginally above 1 (1.04).

Additional non-monetary benefits

The project proposal also includes a set of non-monetary impacts, such as:

- reduced air pollutant emissions (dust particles, SO_x, NO_x and CO) due to reduced line losses
- reduced air pollutant emissions (dust particles, SO_x, NO_x and CO) due to wider diffusion of low-carbon generation sources
- reduced soil occupation
- lower threat to animal species
- reduced visual impact.

2.1.3. Summary of the ACON project's evaluation

The ACON project builds its idea on the need to significantly improve the efficiency of the distribution networks in the project area while increasing the cross-border capacity at the DSO level. It capitalises on existing cross-border distribution network interconnections (currently used only for non-standard operational activities) and proposes further enhancement of these interconnections by deployment of smart grid solutions. In addition, the project includes installation of additional 22 kV and 110 kV cross-border lines necessary for addressing current and future grid stability and reliability issues owing to growing levels of RES in the region. Notwithstanding these conventional investments necessary to support the energy needs in the project area, ACON project mainly involves smart grid technology and solutions. As a result, it proves necessary for the priority thematic area of smart grids deployment (point 4(10) of Annex I to the regulation).

The project mainly addresses a geographical region covering the electricity distribution network of both countries. Therefore, it directly involves DSOs from two Member States; the two TSOs involved in the project are also expected to benefit from more efficient and reliable operation of the distribution networks in the project area. The cross-border dimension also includes deployment of cross-border connection of two-way real-time or close to real-time digital communication to allow for interactive and intelligent monitoring and management of the electricity network through better involvement of network users in the management of their energy usage. This would create favourable conditions for utilisation of demand-side flexibility and development of innovative customer services. In this respect, the project complies with Article 4(1)(c)(i) of the regulation. In addition, the project demonstrates a significant contribution to the six smart grid specific criteria outlined in Article 4(2) of the regulation and a positive outcome in the project's societal CBA.

2.2. CARMEN — Carpathian Modernisation of Energy Network (Romania and Hungary)

2.2.1. General overview

Carmen project proposal builds on the principal need to improve the quality of service and efficiency of the electricity distribution network in one of the Member States (Delgaz, Romania) in light of growing requests for connection of renewable energy sources (RES) on the east side of Romania (mainly at distribution network level), which can ultimately result in increased power flows from the east to the west of the country. Such increase of power flows will impact the transmission grid as well and ask for increased cooperation with the DSO (Delgaz). Additionally, 500 MW of RES connection requests are recorded by the Romanian TSO (Transelectrica) on the 400 kV network connection between Moldova and the border with Hungary, of which 30% are expected to also have impact across border. Given the general deficit of power generation in Hungary, the project is expected to enable secure and efficient flow of this increased generation power on the east-west corridor in the long run, which will impact the transmission grids of both Member States.

To this end, CARMEN project largely focuses on modernisation of the HV and MV distribution network, by way of deploying smart grid investments as critical infrastructure necessary to connect large amount of RES but also enable flexibility and demand side management. On the other hand, the Romanian DSO as leading participant in the project recognises the need to improve the coordination between TSO and DSO to be able to deliver on the renewable energy targets of the EU and the Member States involved in the project and gain maximum system flexibility.

CARMEN project brings together one of the Romanian DSOs (Delgaz), the Romanian TSO (Transelectrica) and the Hungarian TSO (MAVIR) to all benefit from more intense <u>cooperation</u> primarily in the field of data exchange and know-how, expected to facilitate the management of emergency situations associated with increased deployment of variable RES in the future.

Main project goals:

- improved transmission and distribution grid stability while increasing its capacity to integrate growing amount of RES, also through deployment of demand management mechanisms
- improved quality of supply and cost-efficiency of the electricity distribution network
- digitisation and streamlining of the electricity network infrastructure to optimise network management by enabling data exchange and implementation of smart grid functionalities.

Expected impacts:

- increased observability of distribution network leading to increased efficiency of network operation
- improved quality and security of supply
- increased network hosting capacity for efficient connection of renewable energy sources to the distribution network
- improved power flow management at TSO-DSO interface which could also result in more efficient operation of the Romanian-Hungarian interconnection and lead to increase of NTC.

2.2.2. Compliance with the general and specific criteria of Article 4(1) of the regulation

Project's necessity for the priority thematic area of smart grids deployment (compliance with the energy infrastructure category of Annex II(1)(e) to the regulation)

The CARMEN project mainly involves investments at HV and MV distribution network levels, aiming to support integration of all users connected to the grid and facilitate growing penetration of RES. This entails adoption of smart grid technologies to efficiently integrate the behaviour and actions of all users connected to the electricity network and, as a result, increase the generation of renewable and distributed energy sources as well as facilitate demand response. Smart grid technologies addressed in the project allow for improved network observability and control, and ultimately lead to enhanced network operational efficiency and higher quality and security of supply.

The CARMEN project is mainly driven by the current and future needs of the distribution network in the project area. Nevertheless, the smart grids investments taking place in the distribution network are expected to have a positive impact on the transmission networks of both TSOs involved in the project. More specifically, the modernisation of 40 HV/MV substations would lead to significant decrease in voltage fluctuations and other potential events related to substation failures, which have direct impact on the transmission grid. In other words, increased network observability and control enabled by the CARMEN project would lead to better management of the power flows in the distribution networks and consequently power flows coming from the distribution into the transmission networks. The modernisation of 99 MV/LV substations and the establishment of a bidirectional digital communication system will result in increased efficiency of the distribution network operation and higher level of system security and quality of supply. This will enable deeper integration of the behaviour and actions of all grids users – in particular the generation of large amounts of electricity from renewable or distributed energy sources, and demand response by consumers.

More specifically, the CARMEN project includes the following infrastructure investments, in line with of Annex II(1)(e) to the regulation:

- Two-way digital communication owing installation of optical fibres on HV overhead lines, and smart metering system at MV and LV network level.
- Real-time and intelligent monitoring of the grid by implementing various data sharing solutions and monitoring systems, such as SCADA, data storage system for Advance Meter Management (AMM) and new grid control systems, automation voltage regulation at HV/MV substations and optical ground wire (OPGW).
- Intelligent management of electricity generation, distribution, and consumption by installing various smart solutions, such as modernised HV overhead lines, modernised HV/MV transformer stations, modernised MV/ LV transformer substations, and smart metering devices.

Finally, the promoters highlight the value of their joint approach to the regional infrastructure needs as an effective way to accelerate the know-how sharing process and for further development of smart grid infrastructure and solutions in other regions of Romania as well as in other neighbouring countries.

Based on these arguments, the project includes investments in the energy infrastructure category of Annex II(1)(e) to the regulation and it proves necessary for the priority thematic area of smart grids deployment (point 4(10) of Annex I to the regulation).

Project's demonstration of a cross-border impact (compliance with any of the criteria of Article 4(1)(c))

The CARMEN project includes investments taking place in the HV and MV distribution network of one Member State (Romania). This means that the project is located on the territory of one Member State and as such, it needs to '*demonstrate a significant cross-border impact, as set out in Annex IV.1 to the regulation'* (Article 4(1)(c)(ii)).

Furthermore, projects falling into this category, need to comply with additional technical requirements of Annex IV(1)(e), namely '*A project with significant cross-border impact is a project on the territory of a Member State, which fulfils the following conditions: the project is designed for equipments and installations at high-voltage and medium-voltage level designed for a voltage of 10 kV or more; it involves transmission and distribution system operators from at least two Member States, which cover at least 50 000 users that generate or consume electricity or do both in a consumption area of at least 300 Gigawatthours/year, of which at least 20 % originate from renewable resources that are variable in nature.*'

The distribution system operator involved in the project expects massive deployment of wind farm connections near the Romanian-Moldovan border and higher deployment of PV generation near the Romanian-Bulgarian border (the current request for the connection of PV to the Romanian transmission system operator amounts to 500 MW, of which 30% is expected to add to the increased power flows in the east-west direction). More specifically and given the position of Hungary as a net importer of power, as well as a system characterised by high transit of power flows, power flows from east Romania to the west of the country, including at the interconnectors from Romania to Hungary, can be expected to increase. The smart grid investments taking place at the distribution network in Romania would facilitate the integration of RES deployment and ultimately contribute to increase of power flows to the west, including across the border with Hungary.

The CARMEN project demonstrates cross-border impact by complying with Annex IV(1)(e) to the regulation. In particular, the project is designed for equipment and installations at 20 kV and 110 kV network level; it involves 1 517 922 consumers; consumption area of 10 296 487 GWh/year and 37 % of energy supplied comes from renewable energy variable in nature. The project involves distribution system operator (Delgaz, Romania) and transmission system operators of two Member states (Transelectrica, Romania and MAVIR, Hungary).

Finally, cooperation between the DSO and the TSO as well as between the TSOs of both Member States as part of the project is expected to contribute to increase data exchange and accelerated know-how sharing, necessary to better address emergency network operations, such as power outages, network hosting capacity for RES, power production deficit situations in the neighbouring area (e.g. hydropower in the Balkans), etc.

Based on the arguments above, the project complies with Article 4(1)(c)(ii) of the regulation.

Project contribution to the smart grid specific criteria (Article 4(2)(c) of the Regulation) – energy system-wide cost-benefit analysis

This section illustrates the project contribution to the policy specific criteria as a way of assessing the benefits in the energy system-wide cost-benefit analysis (Article 4(1)(b)). Additionally, for projects falling into the priority thematic area of smart grids deployment, '*the cost-benefit analysis shall take into account the impacts on the indicators defined in Annex IV*' (Annex V(8) to the regulation).

The CARMEN project promoters elaborate on the project's impact on each of the six specific criteria, selecting a set of indicators defined in Annex IV (hereafter referred as 'KPIs') to better capture this impact against a specific criterion.

Table 6-12 below depicts the selected KPIs for capturing the project's impact against each specific criterion and the estimation approach used. Depending on the present uncertainties in the information provided by the promoters and the assumptions made, the JRC has used a colour-coded approach (Vasiljevska and Gras, 2017) to evaluate the project's contribution to each specific criterion. In addition, each project's impact has been assessed in view of the following two scenarios: a BaU scenario, i.e. without deployment of the project, and an SG scenario, i.e. with implementation of the project.

Policy criterion 1: integration and involvement of network users with new technical requirements with regard to their electricity supply and demand

The project is expected to contribute to higher interoperability of the distribution networks and better grid management, which will facilitate better integration of DER and involve controllable load in the provision of more efficient distribution network operation and increase network operational flexibility. To this end, the promoters demonstrate the project's contribution to the first policy criterion by making reference to a set of chosen KPIs as listed in Table 6.

Table 6. CARMEN: evaluation of project's impact against the first specific criterion

Selected KPIs	Calculation approach and impact evaluation	
KPI_3: installed capacity of distributed energy resources in distribution networks	The CARMEN project is expected to provide additional grid capacity for safely integrating DER into the distribution grid, mainly owing to the installation of smart grid technologies in the distribution grid. Using the formula proposed in the JRC assessment framework, the promoters are able to quantify the project's positive impact on the increase of distribution network hosting capacity for DER.	
KPI_7: operational flexibility provided for dynamic balancing of electricity in the network	The promoters address positive project's impact on this KPI by calculating the increase in available distribution network capacity which can be utilised for grid balancing, mainly associated with involvement of network users with controllable load. This will ultimately allow for increase in variable RES. Smart grid solutions included in the project will also allow for better involvement of variable RES owing to the possibility of remote disconnection and reconnection of such power sources whilst securing the stability of both the distribution and transmission grid.	
KPI_9: share of electricity generated from renewable sources	The promoters demonstrate the project's positive impact on this KPI by quantifying the difference between the SG and BaU scenario in the share of electricity generated from RES that can be safely integrated into both, the distribution and transmission networks in the project area (as % of total energy consumption in the project area).	

Source: Own elaboration, 2021.

Policy criterion 2: efficiency and interoperability of electricity transmission and distribution in day-to-day network operation

The project is expected to have positive impact on the interoperability and efficiency of both distribution and transmission network operation (and consequently reduced network losses) due to increased network monitoring and control and demand-side participation enabled by the project, which in turn would lead to reduced environmental impact. More efficient operation of the distribution grid would also positively impact the TSO-DSO interface, which could lead to possible reduction of the exploitation rate of existing interconnections, including elimination of possible congestions.

The promoters demonstrate the project's contribution to the second policy criterion by referring to a set of chosen KPIs, as listed in Table 7.

Table 7. CARMEN: evaluation of project's impact against the second specific criterion

Selected KPIs	Calculation approach and impact evaluation	
KPI_1: reduction of greenhouse gas emissions	The promoters demonstrate the project's positive impact on this KPI, mainly owing to increased efficiency in the management and operation of the distribution electricity grid as well as increased grid flexibility. As a result, increased ratios of RES coupled with more effective demand-side management in the project area contribute to the displacement of fossil fuel-based energy and, consequently, to GHG emissions reduction.	
KPI_4: allowable maximum injection of power into transmission networks without congestion risks	The CARMEN project mainly focuses on development of smart grid solutions at distribution network level. To this end, the promoters use a modified approach for this KPI and quantify the project's positive impact on the increase of distributed energy resources (DER) capacity in the distribution grid of the project area without any congestion risk. Such capacity increase is mainly owed to modernisation of transformer stations and substations, joint with better monitoring and control of network assets.	
KPI_{13}: level of losses in transmission and distribution networks	The promoters demonstrate the positive impact of the CARMEN project on the level of distribution network losses by quantifying the difference in the level of network losses between the SG and BaU scenario, in part of the distribution grid where smart grid investments are planned to take place (HV/MV transformer stations).	
KPI_{14}: ratio between minimum and maximum electricity demand within a defined time period	The CARMEN project is expected to improve the ratio between minimum and maximum electricity demand within a defined time period owing to smart grid solutions addressed by the project, such as automatic meter management, remote control of network assets and production/load of network users, etc. As a result, the promoters demonstrate positive impact on this KPI due to better usage of both, the energy and distribution network assets and thus, more significant increase in the value of P_{min}.	
KPI_{19}: ratio between interconnection capacity of a Member State and its electricity demand	The CARMEN project involves solely investments in the distribution grid in one Member State (Romania) and therefore may only indirectly impact the NTC on Romania-Hungary interconnections. The promoters claim that the project will enable enhanced utilisation of the distribution grid, which will lead to less usage of the TSO-DSO interface. The promoters calculate the project's positive impact on this KPI, owing to the smart grid investments included in the project and also by referring to other TSO investments (outside the CARMEN project) planned to take place in near future, which will have direct impact on the NTC increase of the whole western part of Romanian interconnectors. The Carmen project will enable integration of large-scale penetration of wind power into the distribution network near the Romanian-Moldovan border and solar power near the Romanian-Bulgarian border, which will lead to increase of power flows in the east-west direction. Given the general deficit of power generation in Hungary, the promoters argue about the project's impact in enabling secure and efficient flow of this increased generation power on the east-west corridor (Transelectrica	

	400 kv axis), also across border in the long-run, which will ultimately impact the transmission grids of both Member states.	
KPI_{20}: exploitation of interconnection	The CARMEN project will not impact the interconnection capacity directly, but mainly focus on increased and better utilisation of the distribution grid and as a result possibly lead to reduced exploitation of the interconnectors. The promoters report positive project's impact on this KPI owing to the smart grid investments included in the CARMEN project together with several investments – not part of CARMEN – planned at TSO level in Romania, which will have direct impact on the NTC increase of all interconnectors in the western part of Romania.	

Source: Own elaboration, 2021.

Policy criterion 3: network security, system control and quality of supply

The promoters expect the project to show a positive impact on this policy criterion, due to enhanced network management and control and modernisation of selected primary and secondary substations as well as provision of new types of ancillary services enabled by the project. The distribution network of Delgaz (RO) included in the project is interfaced only with the transmission system of Transelectrica (RO), mostly through radial overhead lines. The promoters demonstrate positive project's impact on the stability of the electricity system by referring to increased quality and security of supply, which on the other hand will increase the network hosting capacity and ability to connect new power resources without any congestions. Better distribution grid management would also support the TSOs in guaranteeing the stability of their networks.

The promoters demonstrate the project's contribution to the third policy criterion by making reference to a set of chosen KPIs as listed in Table 8.

Table 8. CARMEN: evaluation of project's impact against the third specific criterion

Selected KPIs	Calculation approach and impact evaluation	
KPI_2: environmental impact of electricity grid infrastructure	The CARMEN project demonstrates positive environmental impact owing to reduced need of overhead lines as a result of better grid management. Additionally, smart grid technologies included in the project, such as remote monitoring and control of overhead lines and smart primary and secondary substations allow for better utilisation of existing grid assets. The promoters further calculate the project's impact on reduction of other GHG emissions (dust particles, SO_x, NO_x, and CO), which are produced alongside CO_2 emissions.	
KPI_5: energy not withdrawn from renewable sources due to congestion or security risks	The CARMEN project demonstrates its positive impact on lowering the energy not withdrawn from RES due to congestion or security risks, which leads to enhanced grid stability. The project mainly focuses on the distribution network whose solutions will facilitate integration of RES at the distribution network level and facilitate larger-scale integration of demand-side management (DSM). The promoters calculate this KPI by referring to the curtailed renewable energy based on 2019 real data from the Delgaz distribution grid and the increase of load capacity participating in DSM due to the project implementation.	

KPI_{10}: stability of the electricity system	The CARMEN project mainly addresses smart grid solutions deployed in the distribution network of Delgaz. Delgaz distribution network is only interfaced with transmission network of Transelectrica, mostly through radial overhead lines. The promoters argue about the project's impact on this KPI by referring to the quality of supply and more specifically by making a reference to other three KPIs, namely: - KPI_{11} (duration and frequency of interruptions per customer, including climate-related disruptions), KPI_{12} (voltage quality performance), and KPI_{17} (availability of network components - related to planned and unplanned maintenance. and its impact on network performance). However, this KPI is not quantified at this stage of the projects' development.	
KPI_{11}: duration and frequency of interruptions per customer, including climate-related disruptions	The CARMEN project demonstrates its positive impact on the duration and frequency of interruptions (assessed by SAIDI and SAIFI indicators). The promoters quantify this KPI by referring to the smart grid solutions addressed in the project (better monitoring and remote control of network assets, smart substations, easier location, remote disconnection of faulty network sections, etc.)	
KPI_{12}: voltage quality performance	The CARMEN project demonstrates positive impact on the voltage quality performance and, as a result, on the quality and security of supply. The promoters quantify this KPI with reference to the number of voltage line violations over a predefined period of time and based on the statistics of the DSO's dispatching centres.	

Source: Own elaboration, 2021.

Policy criterion 4: optimised planning of future cost-efficient network investments

The promoters expect a positive impact of the project on this specific criterion as increased data availability related to network operation and maintenance enabled by the project would lead to optimised planning of network investments. Moreover, better utilisation of electricity network components would lead to improved and more efficient asset management, which will directly impact the reliability of assets. This will potentially lower the cost of distribution network management and ultimately enhance planning of future cost-efficient network investments.

The promoters demonstrate the project's contribution to the fourth policy criterion by referring to a set of chosen KPIs as listed in Table 9.

Table 9. CARMEN: evaluation of project's impact against the fourth specific criterion

Selected KPIs	Calculation approach and impact evaluation	
KPI_{16}: percentage utilisation (i.e. average loading) of electricity network components	The promoters expect the project to have a positive impact on this KPI by consenting better utilisation of the distribution grid, which will potentially result in lower and more stable power flows at both distribution and transmission network level. This will lead to improved and efficient asset management in terms of asset lifecycle with a direct impact on the reliability of network assets. However, the promoters do not provide quantification of this impact at the present stage of the project development.	
KPI_{17}: availability of network components (related to planned and unplanned maintenance) and its impact on network performance	The CARMEN project demonstrates positive impact on the availability of distribution network components and its impact on the distribution network performance by allowing for condition-based maintenance thanks to faster identification of faults. Deployment of smart grid solutions in the project would lead to optimisation of investment planning and grid maintenance and consequently to longer mean time between failures and shorter mean time to repair the failures. Although the project's impact is mainly demonstrated and positively quantified at distribution network level, smart grid investments, such as	

	modernisation of 40 HV/MV substations is expected to lead to significant decrease in voltage fluctuations, network line congestion and other events associated with substation failures with direct impact on the transmission network. Moreover, smart grid investments at DSO level will result in better utilisation of the distribution grid and reduced need of transmission backbone grid for supply of specific nodal points.	
KPI_{18}: actual availability of network capacity with respect to its standard value	The CARMEN project is expected to increase the actual availability of network capacity with respect to its standard value owing to smart grid investments entirely deployed in the distribution network of the project area. The promoters positively quantify this KPI by referring to the modernisation of 40 HV/MV substations and consequently the expected increase in transformer capacity of these substations, which will ultimately lead to increased security of supply and power grid stability.	

Source: Own elaboration, 2021.

Policy criterion 5: market functioning and customer services

The project would enable increased involvement of end-users (both consumers and prosumers) in effective management of grid operation, which is critical for market functioning and the introduction of new customer services. Furthermore, the project will lead to better usage of all grid elements, including alignment of power flows at the TSO-DSO interface, which could potentially have a positive impact on the exploitation of the interconnections and increase of NTC. Finally, these measures could lead to the alignment of prices between the region and market development in the project area.

The promoters demonstrate the project's contribution to the fifth policy criterion by referring to a set of chosen KPIs as listed in Table 10.

Table 10. CARMEN: evaluation of project's impact against the fifth specific criterion

Selected KPIs	Calculation approach and impact evaluation	
KPI_6: methods adopted to calculate charges and tariffs, as well as their structure, for generators, consumers and those that do both	The promoters demonstrate the project's positive impact on this KPI mainly owed to the implementation of smart metering in the distribution grid (MV and LV) in the project area. The DSO involved in the project (Delgaz) expects to deploy smart meters to 45 % of the total customers by the end of 2028, of which less than 4.5 % are envisaged to be installed as part of the CARMEN project. This will allow for introduction of dynamic tariffs, better prediction of consumption, and other services such as accurate and automatic billing, etc. Moreover, cost related to manual data logging, fault handling, and non-technical losses will be also reduced. The project enables integration of several new information and communication technologies in distribution grids that can be used for transfer and distribution of recorded customer data, which would enable the development of a market for ancillary services.	
KPI_{21}: congestion rents across interconnections	The CARMEN project is entirely developed at the distribution network level and as such does not have direct impact on the interconnectors and their congestion rents. Nevertheless, the promoters expect positive project's impact on reducing current congestions on RO-HU interconnector together with some future investment in the transmission network (not part of CARMEN). In particular, CARMEN project is expected to facilitate larger-scale integration of RES in Moldova area and transporting this power to the east using the east-west transmission network corridor between Transelectrica and MAVIR. Additionally, CARMEN project leads to better utilisation of distribution grid assets and	

	lower and more stable flows to the transmission grid as well. This could ultimately lead to less congestion on the interconnectors and better alignment of prices between regions. Nevertheless, this KPI cannot be quantified at this stage of the project's development.	

Source: Own elaboration, 2021.

Policy criterion 6: involvement of users in management of their energy usage

The CARMEN project is expected to increase the involvement of end-users in more effective management of their energy usage (through demand-side participation and energy efficiency measures) and consequently enable increase in the proportion of electricity generated from RES.

The promoters demonstrate the project's contribution to the sixth policy criterion by making reference to a set of chosen KPIs as listed in Table 11.

Table 11. CARMEN: evaluation of project's impact against the sixth specific criterion

Selected KPIs	Calculation approach and impact evaluation	
KPI_8: ratio of reliably available generation capacity and peak demand	The CARMEN project demonstrates positive impact on this KPI as a result of increase of reliably available generation capacity and decrease of peak power demand. Smart grid investments included in the project will facilitate dynamic pricing of electricity which can ultimately lead to reduction in peak demand. The promoters adopt a modified approach to calculating this KPI, reflecting the fact that the project is entirely developed at the distribution network level. They demonstrate the project's positive impact on this KPI, owing to better integration of RES into the distribution grid due to better grid operational management and increased demand response.	
KPI_{15}: demand-side participation in electricity markets and in energy efficiency measures	The promoters demonstrate the project's positive impact on this KPI, owing to increased demand side participation facilitated by deployment of smart metering systems.	

Source: Own elaboration, 2021.

The following section presents the societal benefits of the CARMEN project in monetary terms along with the total cost (capital and operational expenditure), as communicated by the promoters. Furthermore, economic indicators such as the net present value (NPV), the internal rate of return (IRR) and the benefit/cost (B/C) ratio are used to verify whether the overall project's benefits outweigh the project's costs and therefore the project complies with the second general criteria of the regulation (Article 4(b)).

The promoters assumed the following values as variables used in the societal CBA:

- **demand growth**: an average annual demand growth of 1%.
- **discount rate**: a value of 4 % has been used as societal discount rate (Vasiljevska and Gras, 2017).
- **time horizon**: 20 years has been chosen as time horizon (owing to the lifespan of most of the investment assets included in the project).
- **peak demand reduction**: 122 MW has been assumed for the project area owing to expected peak load shift.
- **electricity price for losses**: 65 €/MWh.
- **electricity market price**: 54 €/MWh ([13]).

([13]) http://www.eex.com/.

- **Value of lost load**: 4 520 €/MWh ([14]).
- **carbon prices**: 40 €/t ([15]).
- **fuel prices**: 1 €/l.

The main monetary benefits and costs of the project are listed below.

Main monetary benefits

The main benefits associated with the project deployment are as follows (in descending order):

- Electricity cost savings
- Reduced outage times
- Estimated reduction in electricity interruption costs for households
- Prevention of blackout
- Reduced CO2 emissions and reduced fossil fuel usage
- Reduced maintenance costs of assets
- Deferred distribution capacity investment
- Reduced electricity technical losses
- Prevention of brownout
- Total savings from nudging
- Reduced cost of equipment breakdowns.

Main costs

The main costs associated with the project deployment are as follows (in descending order):

CAPEX:

- Modernisation of primary transformer substations (40 HV/MV 110/20/6 kV)
- Modernisation and capacity increase of High-Voltage overhead lines (OHL)
- Modernisation of secondary transformer substations (99 LV/MV transformer substations)
- Communication devices and optical fibres
- IT smart grids backbone and smart metering.

OPEX:

- Maintenance costs (for all activities during the project time frame)
- IT systems (operation cost of IT devices for data analysis, secure grid operation, etc.)
- Project team (labour costs for management and operation of the grid, preparation of all project's activities, etc.)
- Communication systems for monitoring the grid and data collection.

The overall project's benefits outlined above outweigh the project's costs and the project reports the following economic indicators: ENPV: 79.2 mil. €, IRR: 12.24%, B/C: 1.38.

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

(15) based on current price of carbon price on the stock market www.eex.com

Sensitivity analysis

Critical variables in the project, which have been also subject to sensitivity analyses are the following:

- Estimated % of consumption reduction in Smart Grid scenario (decrease in ENPV by 17.1 mil. €)
- Financial Market Energy Rate (decrease in ENPV by 7.9 mil. €)
- Decrease in outage time (decrease in ENPV by 8.3 mil. €)
- Monetary value of CO2 (decrease in ENPV by 2.9 mil. €)
- Wholesale margin difference between peak and non-peak generation (decrease in ENPV by 2 mil. €).

The project proposal also includes a set of non-monetary impacts, such as the following:

- Reduction of air pollution (particular matters, NO_x, SO_2)
- Reduced soil occupation
- Lower threat to animal species
- Reduced visual impact.

2.2.3. Summary of the CARMEN project's evaluation

The main aim of the CARMEN project is to improve the efficiency of distribution network operation and the service quality provided to the network users using smart grid technologies and functionalities, while at the same time contribute to the national and European climate and energy targets. The project builds its scope on the need to integrate massive penetration of wind power into the distribution network near the Romanian-Moldovan border and solar power near the Romanian-Bulgarian border, which will lead to intensification of power flows in the east-west direction. By also impacting the transmission grid, this increase will call for stronger cooperation both with the DSO and between the TSOs of the two Member States. Given the general deficit of power generation in Hungary, the project is expected to enable secure and efficient long-run management of these larger power flows on the east-west corridor, which will impact the transmission grids of both Member states. Possible areas of increased cooperation would include data sharing – possibly using cloud solutions or data sharing platforms – with focus on network operation data, weather forecast data and advanced data regarding emergency situations – outages, shortage of RES capacity, power generation deficit in the Balkans, etc.

The project envisages modernisation and digitalisation of key HV and MV infrastructure, such as modernisation and capacity increase of HV overhead lines, modernisation of HV/MV transformer stations and modernisation of MV/LV transformer substations. Additionally, deployment of communication devices and optical fibres mounted to selected HV overhead lines, together with installation of smart metering devices and SCADA upgrade, will facilitate better coordination in supply management of the affected areas. Optical fibres networks will facilitate the transfer of data for communication over the wire. IT solutions will also improve data sharing capabilities. Therefore, the project includes investments in the energy infrastructure category of Annex II(1)(e) to the regulation, which will enable integration of behaviour and actions of all grid users – in particular, the generation of large amounts of electricity from renewable or distributed energy sources and demand response by consumers. This way, the project also proves necessary for the priority thematic area of smart grids deployment (point 4(10) of Annex I to the regulation).

The CARMEN project is located on the territory of one Member State (Romania) and it demonstrates cross-border impact by complying with Annex IV(1)(e) to the regulation. In particular, the project is designed for equipment and installations at 20 kV and 110 kV network level; it involves 1 517 922 consumers; consumption area of 10 296 487 GWh/year and 37 % of energy supplied comes from renewable energy variable in nature. The project involves distribution system operator (Delgaz, Romania) and transmission system operators of two Member states (Transelectrica, Romania and MAVIR, Hungary). The project is expected to have direct positive impact on the Delgaz region, in terms of integration of behaviour of all market participants, improved quality of supply, improved grid stability and security and integration of additional RES. Nevertheless, also other regions, for example the east-west transmission network corridor between Moldova and Hungary, including the border area of Hungary, are expected to benefit from the project in the long-run.

The assessment shows that the project demonstrates a significant contribution to the six smart grid specific criteria outlined in Article 4(2) of the regulation and a positive outcome in the project's societal CBA.

2.3. **Danube InGrid** (Hungary and Slovakia)

2.3.1. General overview

The Danube InGrid project chiefly aims at enhancing cross-border coordination of electricity network management, with a specific focus on smartening data collection and exchange. The importance of the project for the Member States involved (Hungary and Slovakia) is highlighted by the fact that two DSOs participate on the Slovak side - the country's largest, Západoslovenská distribučná, a.s. (ZSD), and Východoslovenská distribučná, a.s. (VSD) -, no less than three DSOs participate on the Hungarian side - E.ON Észak-dunántúli Áramhálózati Zrt. (EED), ELMŰ Hálózati Kft. (ELMŰ) and ÉMÁSZ Hálózati Kft. (ÉMÁSZ) -, while the TSOs involved (SEPS for Slovakia and MAVIR for Hungary) are directly benefiting through improvements allowed by smart grids equipment to the optimisation of reactive power flow provision. Moreover, the Slovak TSO SEPS will also participate on the project as a project promoter.. Technically, the project will primarily consist of the enlargement and smartening of the networks' substation infrastructure and in the installation of remote control, data collection and exchange, and fault detection devices. In particular, this will involve the technical modernisation of 11 HV/MV and 1000 MV/LV transformer stations through installation of metering and communication devices and of automatic on-load tap changers (OLTCs). The project also includes installation of an optical fibre infrastructure for improved management of the MV network, construction of two new smart substations in Slovakia (with a transformation 400/110 kV and 110/22 kV, respectively) and of numerous micro substations ([16]) at HV/MV level in Hungary, including smart meters, a geographic information system (GIS) and a SCADA.

Main project goals:

- promote flexibility, resilience and security of the electricity system
- facilitate customer connectivity to the electricity system to reduce barriers to entry and increase competitiveness of the electricity market
- improve residential and business welfare through more dependable and secure electricity supply
- lessen environmental damage through better air and climate
- deepen European economic and electricity market integration.

Expected impacts:

- substantially enhanced data collection, exchange, and processing capabilities (especially forecasting) to enable stronger collaboration on efficient network management
- foster greater RES integration as well as deployment of electro-mobility
- introduce the capability of remote grid monitoring and management for faster detection and resolution of grid failures
- promote cross-border know-how (and more broadly technological) sharing and diffusion
- increase the network capacity (especially for connection of RES generation) through construction of smart substations
- diminish losses through improved grid (especially voltage) management.
- improve system reliability parameters (System Average Interruption Duration Index (SAIDI) and System Average Interruption Frequency Index (SAIFI)).

2.3.2. Compliance with the general and specific criteria of Article 4(1) of the regulation

Project's necessity for the priority thematic area of smart grids deployment (Compliance with the energy infrastructure category of Annex II(1)(e) to the regulation)

The Danube InGrid project aims at improving coordination of grid management between electricity distributors on both the Slovak and Hungarian side of the border, through enhanced ability for monitoring, controlling, and exchanging data over the power system in close to real time. This will take place through investments mainly at the distribution level, regarding the introduction of smart features and devices at the substation level as well as improved communication technology, easing demand response with the final goal of increasing the hosting capacity of esp. distributed RES.

([16]) Smaller substations installed more densely at MV network level.

The project is mainly motivated by the necessities of promoting decarbonisation esp. at the distribution system operation level, maintaining high levels of service quality and security of supply. However, the modernisation of a number of both primary and secondary substations will also enable greater ability to control voltage quality, as well as prevent and quickly solve problems related to grid faults. Generally, the larger availability of system state data will also ensure a positive impact for the project at the transmission level, with better opportunity to optimise system management, improve the planning of network maintenance and expansion, and decrease losses at all voltage levels.

The project enables two-way digital communication through the installation of several smart grid elements, including:

- construction of an optical fibre network for HV and MV grid management
- installation of smart metering devices
- metering and fault detection to remotely operated pole-mounted switches
- installation of a common cross-border cooperation data platform between Slovakia and Hungary, with a dedicated database server for HV and MV networks installed for the purpose of processing the data from the grid and its integration
- digitalisation of grid processes.

Better monitoring and control of the grid is a central objective of the project. This is made possible through a number of key pieces of infrastructure, including:

- modernisation of the technology of large numbers of existing transformer stations
- new SCADA systems and implementation of cybersecurity measures involving SCADA analytical algorithms
- voltage and current metering devices with communication
- installation of a new, modern GIS system with large capacity and smart functionalities.

The following newly constructed facilities allow the interactive management of electricity generation, transmission, distribution and consumption:

- smart 400/110 kV substation
- smart 110/22 kV substations
- micro substations
- automatic tap changer MV/LV transformers.

The project can therefore clearly be assessed as complying with the criteria for the energy infrastructure category of Annex II(1)(e) to the regulation and it also proves necessary for the priority thematic area of smart grids deployment (point 4(10) of Annex I to the regulation).

Project's demonstration of a cross-border impact (compliance with any of the criteria of Article 4. 1. (c))

The project takes place on the territory of two neighbouring Member States (Slovakia and Hungary), each featuring a key DSO as central participant and project promoter. An equivalent role is played by Slovakia's TSO SEPS and Hungary's TSO MAVIR.

The construction of monitoring, remote control and communication technology, including optical fibre-based cables for real-time information exchange, will enable cross-border data processing at the DSO level to allow much deeper interaction in the joint management of the network through the operation of a dedicated shared information technology (IT) platform to be used for various systems (e.g. network topology program based on a geographic information system and energy management system (EMS) SCADA). This will foster the intensified exploitation of the physical interconnection infrastructure currently existing at the TSO level, even though cross-border interconnection capacity is not directly addressed by the project. Furthermore, the greater availability and exchangeability of information on the status of the electricity system will lead to the construction of a joint data repository storing technical and non-technical data. This will permit deeper analysis of system state patterns and further promote efficient network management, with the final goal of (on the one hand) improving the system's RES accommodation capacity and (on the other) enhancing service continuity, quality, and resilience.

In this regard, the data exchange and joint network management character of the project clearly displays a cross-border dimension affecting two Member States, to comply with Article 4(1)(c)(i) of the regulation.

Project contribution to the smart grid specific criteria (Article 4(2)(c) of the Regulation) – energy system-wide cost-benefit analysis

This section illustrates the project contribution to the policy specific criteria as a way of assessing the benefits in the energy system-wide cost-benefit analysis (Article 4(1)(b)). Additionally, for projects falling into the priority thematic area of smart grids deployment, '*the cost-benefit analysis shall take into account the impacts on the indicators defined in Annex IV*' (Annex V (8) to the regulation).

The benefits of the Danube InGrid project are evaluated by the promoters according to each of the specific criteria in Article 4(2)(c) of the regulation and based on a selection from the 21 key performance indicators, derived from the criteria presented in Annex IV(4) to the regulation.

Tables 13-18 below depict the selected KPIs for capturing the project's impact against each specific criterion and the estimation approach used. Depending on the present uncertainties in the information provided by the promoters and the assumptions made, the JRC has used a colour-coded approach (Vasiljevska and Gras, 2017) to evaluate the project's contribution to each specific criterion. In addition, each project's impact has been assessed in view of the following two scenarios: a BaU scenario, i.e. without deployment of the project, and an SG scenario, i.e. with implementation of the project.

Policy criterion 1: integration and involvement of network users with new technical requirements with regard to their electricity supply and demand

The project is expected to accelerate integration of RES and demand response owing to the automatic control and metering system enabled by the project, which in turn would allow more efficient distribution network management.

The promoters demonstrate the project's contribution to the first policy criterion by making reference to a set of chosen KPIs as listed in Table 12.

Table 12. Danube InGrid: evaluation of project's impact against the first specific criterion

Selected KPIs	Calculation approach and impact evaluation	
KPI$_1$: reduction of greenhouse gas emissions	The promoters demonstrate a positive impact on this KPI due to the following aspects of the project: • increased automatic control and metering system, allowing more efficient distribution network management, thus leading to a decrease in network losses, relief of network congestion and a reduction in the need for redispatching and ultimately in the fossil generation (overall capacity and especially peak power). • more effective deployment of demand side, which will accelerate further integration of RES.	
KPI$_7$: operational flexibility provided for dynamic balancing of electricity in the network	The promoters report and demonstrate the project's positive impact on this KPI as a result of an increase in the remotely available capacity which can be utilised for balancing the distribution network. This is expected to take place owing to an increase in demand response, which will allow growing integration of RES while securing the grid stability (capability of automatic disconnection and reconnection of RES).	
KPI$_{14}$: ratio between minimum and maximum electricity demand within a defined time period	Flexibility resources and peak shaving are fostered by this project through advanced meter management (AMM), demand response and adjustments in consumption patterns due to the potential introduction of new dynamic tariffs. As a consequence, the project is expected to have a positive impact on this KPI, which is assessed through elaboration of data provided by the DSOs' dispatching centres.	

Source: Own elaboration, 2021.

Policy criterion 2: efficiency and interoperability of electricity transmission and distribution in day-to-day network operation

The project's main investments focus on enhancement of network management and control capabilities (e.g. innovative voltage regulation algorithms, availability of new flexibility resources, innovative grid protection/monitoring), which is expected to greatly improve network operational efficiency. The promoters demonstrate the project's contribution to the second policy criterion by referring to a set of chosen KPIs as listed in Table 13.

Table 13. Danube InGrid: evaluation of project's impact against the second specific criterion

Selected KPIs	Calculation approach and impact evaluation	
KPI_2: environmental impact of electricity grid infrastructure	Enhanced network management and control enabled by project deployment could reduce the need to build overhead lines and, in that respect, reduce the environmental impact of grid infrastructure. Furthermore, the Danube project proposes replacement of certain overhead power lines with underground cables, thus reducing the long-term environmental impact in terms of visual impact, soil occupation, threat to endangered animal species, etc. Reductions in GHG emissions are associated with reductions in other pollutants. The promoters make an effort to quantify this based on standard industry correlations.	
KPI_3: installed capacity of distributed energy resources in distribution networks	Enhanced network management and control capabilities (e.g. innovative voltage regulation algorithms, availability of new flexibility resources, innovative grid protection/monitoring) enabled by the Danube InGrid project would allow increased DER capacity to be safely integrated in the distribution grids. The project promoters report an increase in the network hosting capacity for DER through a positively-assessed KPI.	
KPI_{13}: level of losses in transmission and in distribution networks	The InGrid promoters acknowledge the challenges in estimating the future value of losses owing to the smart grid elements deployed in the project; nevertheless, the promoters expect a reduction in network losses due to improved network management introduced by the project. As the InGrid SG project is developed mainly at the DSO level, this KPI is evaluated with respect to distribution network losses. Based on consideration of the impact of new elements in the grid, the promoters calculate a net decrease in losses as a relative change in respect of the BaU scenario. This is based on both the positive expected effect of new cabling, grid optimisation and installation of new equipment (lowering the losses) as well as the increased number of elements and equipment, which in itself may lead to an increase in losses.	

Source: Own elaboration, 2021.

Policy criterion 3: network security, system control and quality of supply

The project aims to enhance the distribution network observability and controllability owing to the advanced meter management (AMM) elements brought in by the project, which in turn would also enable integration of higher levels of DER into the system. The promoters demonstrate the project's contribution to the third policy criterion by making a reference to a set of chosen KPIs as listed in Table 14.

Table 14. Danube InGrid: evaluation of project's impact against the third specific criterion

Selected KPIs	Calculation approach and impact evaluation	
KPI_4: allowable maximum injection of power without	The InGrid project mainly addresses the distribution network, and in this case the KPI indicates the increased distribution network hosting capacity in the project area, thus allowing an increase in DER in the region without compromising the operation of the transmission network.	

congestion risks in transmission networks	The InGrid promoters positively quantify this KPI as a result of an increase in the distribution network hosting capacity due to the installation of smart elements and smart distribution stations in the grid. The enhanced observability and controllability of the grid enabled by AMM elements in the project would allow improved network management and, ultimately, higher levels of DER in the system.	
KPI_5: energy not withdrawn from renewable sources due to congestion or security risks	The project promoters assess this KPI indirectly through the increase in flexible resources in the system. Smart grid elements should enable demand response participation, hence increase balancing possibilities and ultimately induce higher hosting capacity for intermittent RES. In this regard, the Danube InGrid project is expected to lower the amount of renewable energy not withdrawn as a result of network congestion or security risks owing to an increase in controllable load subject to demand-side management. At this stage of the project's development, promoters do not expect RES curtailment and therefore the KPI is quantified as potential increase in RES without congestion/security risks, as a result of growing controllable load, subject to demand-side participation.	
KPI_8: ratio of reliably available generation capacity and peak demand	Analogous to the ACON project, the InGrid project's promoters use an alternative approach for measuring this KPI as network capability to accommodate more renewable energy owing to better operational management, increased demand response and introduction of dynamic tariffs, consequently lowering the difference between the P_{min} and P_{max}. Therefore, this KPI is positively quantified.	
KPI_{10}: stability of the electricity system	This KPI is assessed indirectly as closely correlated with three other indicators: SAIDI/SAIFI reduction (**KPI_{11}**), voltage quality performance (**KPI_{12}**) and availability of network components and their impact on network performance (**KPI_{17}**). Nevertheless, no more accurate assessment can be provided at this stage of the project's development.	
KPI_{11}: duration and frequency of interruptions per customer, including climate-related disruptions	The KPI is expected to improve thanks to better monitoring and remote control capabilities enabled by the project. The project's promoters demonstrate its well-quantified impact on this KPI, based on previous feasibility studies and pilot projects.	
KPI_{12}: voltage quality performance	Voltage quality improvement is expected to improve thanks to better monitoring and management capabilities. The project's promoters demonstrate its positive impact on this KPI and quantify it based on a solid methodology and parameters provided by DSO statistics.	
KPI_{20}: exploitation of interconnection capacities	The project is not expected to physically increase the transfer capacity of any interconnection at transmission network level but rather reduce the load on the interconnectors via construction of a new 400/110 kV substation in the Slovak part of the project. This will result in an increase in capacity and security of supply at the distribution network level and ultimately allow increased load flow on the TSO interconnectors and available cross-border transfer capacity. The project's promoters positively quantify this KPI; nevertheless, uncertainties persist in the assumptions made.	

Source: Own elaboration, 2021.

Policy criterion 4: optimised planning of future cost-efficient network investments

The project is expected to increase the availability of the network components, mainly owing to the higher availability of data related to network maintenance and in particular to the increased capability for remote fault detection and resolution. It will also lead to greater grid utilisation and thereby bring new possibilities to future cost-efficient network planning. The promoters demonstrate the project's contribution to the fourth policy criterion by making reference to a set of chosen KPIs as listed in Table 15.

Table 15. Danube InGrid: evaluation of project's impact against the fourth specific criterion

Selected KPIs	Calculation approach and impact evaluation	
KPI_{16}: percentage utilisation (i.e. average loading) of electricity network components	The promoters expect a positive impact on this KPI due to increased distribution network capacity and improved network stability enabled by the InGrid project. This would ultimately lead to enhanced utilisation of the TSO-DSO interface in terms of power flows coming from the transmission network and increase the lifetime and reliability of network components and equipment at the TSO-DSO interface. Notwithstanding the expected positive impact, this KPI is not quantified at the current stage of the project's development.	
KPI_{17}: availability of network components (related to planned and unplanned maintenance) and its impact on network performances	The project is expected to have a positive impact on this KPI, first and foremost thanks to the increased capability for remote fault detection and resolution. The indicator is positively quantified based on assumptions and parameters imputed through pilot projects, feasibility studies and expert judgement.	
KPI_{18}: actual availability of network capacity with respect to its standard value	The actual availability of network capacity is assumed to increase thanks to the project owing to the smartening of substation infrastructure. In particular, new micro substations and MV/LV OLTC transformers on the Hungarian side will for instance secure an increase in network capacity by 251 MW. Similar to the ACON project, the InGrid project's promoters positively quantify this indicator by referring to the possible usage of each network element (as a percentage of its nominal capacity) in both BaU and SG scenarios.	

Source: Own elaboration, 2021.

Policy criterion 5: market functioning and customer services

The Danube InGrid project will provide more granular information on the energy consumption/generation, which would promote introduction of dynamic tariffs and engage end-users in more effective management of their energy consumption. This would in turn facilitate the provision of ancillary services to both DSOs and TSOs and move the market forward for new customer services. The promoters demonstrate the project's contribution to the fifth policy criterion by making reference to a set of chosen KPIs as listed in Table 16.

Table 16. Danube InGrid: evaluation of project's impact against the fifth specific criterion

Selected KPIs	Calculation approach and impact evaluation	
KPI_6: methods adopted to calculate charges and tariffs, as well as their structure, for generators, consumers and those that do both	The Danube InGrid project is expected to provide a more granular array of information to better allocate the electricity costs among different network users. Such information typically includes automatic and (close-to-) real-time energy consumption and/or generation data, detailed analysis of consumer/prosumer data in the form of clear tables and graphs used for customer energy bills, etc. Furthermore, this level of detail would further promote introduction of dynamic tariffs and potentially engage end-users in more effective management of their	

	energy consumption. Finally, more detailed information flows would allow regulators to assess RES contribution in provision of ancillary services to both DSOs and TSOs and move the market forward for new customer services.	
KPI_{19}: ratio between interconnection capacity of a Member State and its electricity demand	Cross-border interconnection capacity *per se* is not expected to rise owing to the project. However, better handling of consumption and generation at the distribution grid level will allow less utilisation of transmission-distribution transformation and hence of the transmission network infrastructure. As a consequence, the ratio between available interconnection capacity and electricity demand will probably rise.	
KPI_{21}: congestion rents across interconnections	The indicator cannot be computed owing to the absence of congestion rents in the area involved (no interconnection at the DSO level). However, the project will lead to better utilisation of the existing infrastructure and, specifically, less exploitation of the transmission network, fostering greater price alignment between neighbouring price zones. Nevertheless, this KPI cannot be quantified at this stage of the project's development.	

Source: Own elaboration, 2021.

Policy criterion 6: involvement of users in management of their energy usage

One of the project's main objectives is to increase the network hosting capacity for RES and, therefore, it also focuses on integration of flexibility resources (e.g. demand response) along with more effective grid management. The promoters demonstrate the project's contribution to the sixth policy criterion by referring to a set of chosen KPIs as listed in Table 17.

Table 17. Danube InGrid: evaluation of project's impact against the sixth specific criterion

Selected KPIs	Calculation approach and impact evaluation	
KPI_9: share of electricity generated from renewable sources	The promoters choose this KPI to address the project contribution to the sixth specific criterion, as the proportion of electricity generated from RES is expected to increase owing to more effective grid-balancing management and by tapping into enabled additional flexibility resources (including end-user involvement through demand response). The promoters positively quantify this KPI owing to increased RES connections in the project area enabled by the smart grid elements introduced in the project.	
KPI_{15}: demand-side participation in electricity markets and in energy efficiency measures	This KPI is closely linked to the involvement of users in effective management of their energy usage. In this respect, the Danube InGrid project is expected to increase the amount of load participating in demand-side management and energy efficiency measures in comparison with the BaU scenario. The KPI is therefore positively quantified using available data from the dispatch centres of both DSOs for the BaU scenario, plans for additional demand-side management resources and legislative requirements.	

Source: Own elaboration, 2021.

The following section presents the societal benefits of the Danube InGrid project in monetary terms along with the total cost (capital and operational expenditure) as communicated by the promoters. Furthermore, economic indicators such as the NPV, the IRR and the B/C ratio are used to verify whether the overall benefits outweigh the project's costs and therefore the project complies with the second general criteria of the regulation (Article 4(b)).

The promoters assumed the following values as variables used in the societal CBA:

- **demand growth:** an average annual demand growth of 1.38 %/year for HU and 1.35 %/year for SK has been assumed for the project area.
- **discount rate:** a value of 4 % has been used as societal discount rate (Vasiljevska and Gras, 2017).
- **time horizon:** 20 years has been chosen as the time horizon (as the project also considers traditional investments).
- **peak demand reduction:** owing to expected peak load shift, peak demand reduction was assumed to equal 200.3 MW in HU and 153.83 MW in SK.
- **electricity market price:** EUR 54 €/MWh ([17]).
- **value of electricity compensated by regulator (technical losses):** HU: 55.65 €/MWh, SK: 40.24 €/MWh.
- **cost of energy not supplied:** EUR 3 270/MWh and EUR 4 730/MWh for Hungary and Slovakia, respectively (Cambridge Economic Policy Associates Ltd "Study on the estimation of the value of lost load of electricity supply in Europe" (2018), p. 41).
- **carbon prices:** EUR 34.5€/t (European Commission, 2011).
- **fuel prices:** EUR 1.2 €/l (HU), EUR 1.1 €/l (SK).

The project reports a positive outcome for the societal CBA. The main monetary benefits and costs are listed below.

Main monetary benefits

The Danube InGrid project is expected to deliver a set of positive impacts and in that respect the following monetised benefits are communicated by the project promoters (starting from the largest to the smallest one):

- deferred distribution capacity investments
- electricity cost savings
- reduced operational and maintenance cost
- deferred distribution capacity investments
- electricity cost savings
- reduced CO_2 emissions and reduced fossil fuel usage
- reduced outage times
- reduced cost of equipment breakdowns
- reduced electricity technical losses
- prevention of blackout
- prevention of brownout
- total savings from nudging
- estimated reduction in electricity interruption costs
- reduced operational and maintenance cost.

Main costs

The project is in preparatory phase; therefore, cost estimations are mainly based on expert assessment of similar projects and on the current project plan under supervision by independent consultancies.

The main costs associated with the project deployment (starting from the highest to the lowest one) are:

- smart installations/devices on HV/MV level

([17]) http://www.eex.com/.

- optical Fibre Network on HV and MV network
- transmission/distribution transformers
- IT management for smart grids.

The overall project's benefits outlined above outweigh the project's costs and the project reports the following economic indicators: ENPV: 299.9 mil. €, IRR: 19.46%, B/C: 1.50.

Sensitivity analysis

The NPV of the project changes with variation of the following critical variables:

- **estimated percentage of consumption reduction with SG scenario:** lowering the percentage of consumption reduction by 40 % lowers the project NPV by EUR 129.3 million.
- **electricity price:** lowering the power price by 40 % lowers the project NPV by EUR 51.8 million.
- **decrease in outage time:** lowering the value of the assumed decrease in outage time by 40 % lowers the project NPV by EUR 17.2 million.
- **CO2 price:** decreasing carbon prices by 40 % lowers the NPV by EUR 17 million**.**
- **peak demand reduction:** lowering the value of the assumed peak demand reduction by both energy savings and peak load shifting by 40 % lowers the project NPV by EUR 13.4 million.

The promoters report that even in the constructed worst-case scenario, where all benefit reductions are slashed by 40 % at once, the expected NPV is positive, while the benefit/cost ratio is still above 1 (1.07).

Additional non-monetary benefits

The project proposal also includes a set of non-monetary impacts, such as:

- reduced air pollutant emissions (dust particles, SO_x, NO_x and CO) due to reduced line losses
- reduced air pollutant emissions (dust particles, SO_x, NO_x and CO) due to wider diffusion of low-carbon generation sources
- reduced soil occupation
- lower threat to animal species
- reduced visual impact.

2.3.3. Summary of the Danube InGrid project's evaluation

The Danube InGrid project aims to significantly improve the efficiency of (especially distribution system) operation services through increased availability of flexibility resources to allow better balancing, safer grid management, higher voltage quality, shorter and less frequent interruptions, lower RES curtailment and lower line congestion, all while increasing the network's hosting capacity with respect to intermittent RES and DG. This is obtained through the installation of new smart facilities, especially the construction of new smart substations (400/110 kV and 110/22 kV), multiple micro substations, automatic tap changer MV/LV transformers and remote fault detection devices. This allows radical improvement of the observability and remote controllability of the system.

This wealth of new and detailed system state information made available to each DSO is to be shared across borders in real time, or close to real time, through modern optical fibre communication technology also installed as part of the project, enabling much closer coordination in the operation of distribution systems. TSOs also stand to benefit from more efficient network management and clearly need to be well involved to fully tap into the project's potential. This will also build a shared data repository to be exploited for analysis of typical system conditions and their efficient management. Customers will also be incentivised towards more active participation through facilitated demand response and DG installation, potentially also through enabled dynamic pricing developments. Therefore, the Danube InGrid project both complies with Article 4(1)(c)(i) of the regulation and proves necessary for the priority thematic area of smart grids deployment (point 4(10) of Annex I to the regulation).

The Danube InGrid project demonstrates a significant contribution to the six smart grid specific criteria outlined in Article 4(2) of the regulation and a positive outcome in the project's societal CBA. Remarkably, this holds even in the worst-case scenario, with 40 % lower benefits constructed for sensitivity analysis purposes.

2.4. **Gabreta Smart Grids** (Czech Republic and Germany)

2.4.1. General overview

Named after the forest straddling the Bavarian-Czech border, the Gabreta Project bolsters coordination between the two Member States' electricity transmission and distribution systems. This is promoted by DSOs Bayernwerk Netz GmbH (BAG) and EG.D, a.s. (EDG), with active support from TSOs TenneT and ČEPS, respectively from Germany and the Czech Republic. The deeper integration of the neighbouring networks is pursued through a number of improvements in the ability to exchange energy and data, and of coordinating the management of frequency, voltage, and reactive power. The main technical upgrades include physical infrastructure strengthening the interaction of distribution grids, such as through additional interconnectors and new smart primary substations; infrastructure improving metering and monitoring, esp. through digitalisation of secondary substations, remote control appliances, and storage units to facilitate voltage management, universal monitors, locators on MV lines, reclosers, and controlling cabinets; installation of 5G, of optical network technologies, of Wavelength-Division Multiplexing, of a General Packet Radio Service (LTE), of BPL communication technologies, enabling bidirectional communication and data transfer; installation of voltage and reactive power management systems; and implementation of data hubs and cross-border data sharing platforms, SCADA, data storage systems for advanced metering, and intelligent algorithms for grid steering.

Main project goals:

- digitalisation and modernisation of the distribution grids of the cross-border neighbouring areas
- improved cross-border cooperation of between distribution and transmission system operators, through increased interconnection both at the physical and data sharing and management levels
- expansion of the hosting capacity especially with regards to distributed variable renewable energy sources
- improvement in the quality of service, in system flexibility, and in the security of supply.

Expected impacts:

- improved security of supply, resilience, flexibility of the distribution and transmission network
- increased ability to safely integrate deep distributed RES penetration
- deeper coordination between neighbouring system operation entities, through both physical and data exchange interconnection.

2.4.2. Compliance with the general and specific criteria of Article 4(1) of the regulation

Project's necessity for the priority thematic area of smart grids deployment (compliance with the energy infrastructure category of Annex II(1)(e) to the regulation)

On the way to a successful transition to a climate-neutral energy system, smart grids are a key enabler of the successful integration of high rates of variable RES while maintaining high levels of service quality and security of supply. This requires a discrete rise in the availability of system flexibility, to which end the improved network monitoring and controllability allowed by the project over a wide area including neighbouring networks astraddle the CZ-DE border provides one important tool.

The project features enhanced data collection and exchange but is also based on an increase in physical interconnection capacity, so that the impact of distribution as well as transmission network management can be expected to be very direct deepening system and market integration on the two sides of the border. The smartening of system control devices, first and foremost of substations, will also allow for better optimisation of system management, thus leading to lower losses, higher voltage quality, and improved system flexibility and resilience, enabling the provision of new forms of ancillary services through adoption of dynamic tariffs and other demand response services.

The project enables two-way digital communication through the installation of several smart grid elements, including:

- development of power line communication and optical fibre
- installation of Wavelength-Division Multiplexing (WDM), GPRS (LTE), BPL communication technology, 5G networks, etc.

Better monitoring and control of the grid is a central objective of the project. This is made possible through a number of key pieces of infrastructure, including:

- overhead line monitoring and grid control systems
- energy storage systems for balancing power supply and demand
- High Temperature Low Sag (HTLS) conductors or Thermal Resistant Aluminium Alloy (TAL) conductors replacing traditional ones;
- universal monitors, controlling cabinets, reclosers, remote-control devices, locators on MV power lines, overhead line monitoring and grid control systems
- construction of new digital secondary substations
- implementation of new Supervisory Control and Data Acquisition (SCADA) systems
- coils, capacitors or static VAR compensators SVC and other technologies for voltage and reactive power management
- Installation of Wavelength-Division Multiplexing (WDM), GPRS (LTE), BPL communication technology, 5G networks, etc.

Additionally, deployment of OT Analytics and SAM algorithms for grid steering automation would allow interactive management of electricity generation, transmission, distribution and consumption.

Integrated network management is facilitated through data communication infrastructure reinforcements, such as the following:

- data hubs and platforms for cross-border data sharing
- data storage systems for Advanced Metering Management.

The project can therefore clearly be assessed as complying with the criteria for the energy infrastructure category of Annex II(1)(e) to the regulation and it also proves necessary for the priority thematic area of smart grids deployment (point 4(10) of Annex I to the regulation).

Project's demonstration of a cross-border impact (compliance with any of the criteria of Article 4.(1)(c))

The project's remit includes the two Member States of the Czech Republic and Germany, with two DSOs playing the role of project promoter on either side of the border (these are EDG and BAG, respectively). Furthermore, TSOs Tennet and ČEPS are supporting the project at the transmission level, with active installation of smart appliances in primary substations.

Equipment devoted to monitoring, remote control, including broadband technology and optical fibres allowing real-time communication, will enable much stronger coordination of network management also achieved through specific facilities for data sharing. This is further reinforced through the deployment of SCADA technology. This will compound the direct cross-border energy exchange capacity improvement, brought about by elements of the project, to lead to deep regional integration in the operation of the power system. The steep increase in the volume of network state measurements, consented by the new monitoring devices, will also give rise to jointly accessible repositories of the newly collected data. This will promote advancements in power system analysis and forecasting, and further enhance the system's capability to absorb higher rates of variable RES generation while maintaining stability, flexibility, resilience and security of supply.

The project's cross-border impact is evident in consideration of the physical exchange capacity expansion, as well as of the dimension related to data sharing and regional management coordination. This leads to clearly assess its compliance with Article 4(1)(c)(i) of the regulation.

Project contribution to the smart grid specific criteria (Article 4(2)(c) of the Regulation) – energy system-wide cost-benefit analysis

This section illustrates the project contribution to the policy specific criteria as a way of assessing the benefits in the energy system-wide cost-benefit analysis (Article 4. 1 (b)). Additionally, for projects falling into the priority thematic area of smart grids deployment, '*the cost-benefit analysis shall take into account the impacts on the indicators defined in Annex IV*' (Annex V(8) to the regulation).

The benefits of the Gabreta project are evaluated by the promoters according to each of the specific criteria in Article 4(2)(c) of the regulation and based on a selection from the 21 key performance indicators, derived from the criteria presented in Annex IV(4) to the regulation.

Table 19-24 below depict the selected KPIs for capturing the project's impact against each specific criterion and the estimation approach used. For most of the KPIs, uncertainties persist either in the information provided or in the assumptions made, which is associated not only with the early stage of the project's development but also with the lack of similar pilot projects and studies in EU, which could have served as reference material to support the project's development. Depending on the present uncertainties in the information provided by the promoters and the assumptions made, the JRC has used a colour-coded approach (Vasiljevska and Gras, 2017) to evaluate the project's contribution to each specific criterion. In addition, each project's impact has been assessed in view of the following two scenarios: a BaU scenario, i.e. without deployment of the project, and an SG scenario, i.e. with implementation of the project.

Policy criterion 1: integration and involvement of network users with new technical requirements with regard to their electricity supply and demand

The promoters demonstrate the project's contribution to the first policy criterion by making reference to a set of chosen KPIs as listed in Table 18.

Table 18. Gabreta Smart Grids: evaluation of project's impact against the first specific criterion

Selected KPIs	Calculation approach and impact evaluation	
KPI_1: Reduction of greenhouse gas emissions	The promoters demonstrate a positive impact on this KPI due to the following aspects of the project: • increased automatic control and metering system, allowing more efficient distribution network management, thus leading to a decrease in network losses, relief of network congestion, and reduction in the need for redispatching and ultimately in fossil generation (overall capacity and especially peak power). • increased penetration of low-carbon modes of transportation. • more effective deployment of demand side, which will accelerate further integration of RES, esp. of DER capacity.	
KPI_3: Installed capacity of distributed energy resources in distribution networks	Enhanced network management and control capabilities (e.g. innovative voltage regulation algorithms, reactive power management, innovative grid protection/monitoring) enabled by the Gabreta project would allow increased DER capacity that can be safely integrated into the distribution grids. The Gabreta promoters report an increase in the network hosting capacity for DER and positively assessed this KPI.	
KPI_9: Share of electricity generated from renewable sources	The proportion of electricity generated from RES is expected to increase owing to more effective involvement of end-users in the management of their energy usage. The promoters positively quantify this KPI owing to increased RES connections in the project area enabled by the smart grid elements introduced by the project.	

Source: Own elaboration, 2021.

Policy criterion 2: efficiency and interoperability of electricity transmission and distribution in day-to-day network operation

The promoters demonstrate the project's contribution to the second policy criterion by referring to a set of chosen KPIs as listed in Table 19.

Table 19. Gabreta Smart Grids: evaluation of project's impact against the second specific criterion

Selected KPIs	Calculation approach and impact evaluation	
KPI_2: Environmental impact of electricity grid infrastructure	The Gabreta project involves the replacement of some overhead lines, which will lead to environmental benefits due to reduced disruption of green areas, so to decrease landscape impact, soil consumption, damage to the biosphere, etc. Furthermore, GHG emission cuts due to lower losses and to the fostering of electromobility are associated with lower levels of other pollutants. The project promoters quantify and monetise this through standard industry coefficients.	
KPI_{13}: Level of losses in transmission and in distribution networks	The Gabreta promoters acknowledge the challenges in estimating the future value of losses owing to the smart grid elements deployed in the project; nevertheless, they expect a reduction in network losses due to improvements in network management capability determined by the project. Although the Gabreta SG project possesses a TSO-level dimension, mainly pertaining to network management aspects and to the smartening of primary substations, this KPI is evaluated with respect to distribution network losses alone. Based on consideration of the impact of new elements in the grid, the promoters calculate a net decrease in losses as a relative change with respect to the BaU scenario. This is based on positive expectations on the effects of improved grid optimisation algorithms, and to the installation of new equipment enabling a higher capacity for system monitoring and management.	
KPI_{21}: Congestion rents across interconnections	In the current EU market setup, this benefit takes place at the transmission level, and given the project is mainly focussed on the distribution level this KPI is not quantified by the project promoters. However, based on increased energy exchange capacity brought about by the project, they argue that price convergence is likely to ensue. Also, better network management enabled by enhanced monitoring and control infrastructure – including larger storage capacity – will decrease the need for overexploitation of the power grid. This would ease the transmission system operator's burden to ensure energy flows take place without congestions. Nevertheless, this KPI cannot be quantified at this stage of the project's development.	

Source: Own elaboration, 2021.

Policy criterion 3: network security, system control and quality of supply

The promoters demonstrate the project's contribution to the third policy criterion by making reference to a set of chosen KPIs as listed in Table 20.

Table 20. Gabreta Smart Grids: evaluation of project's impact against the third specific criterion

Selected KPIs	Calculation approach and impact evaluation	
KPI_4: Allowable maximum injection of power without congestion risks in transmission networks	Since the Gabreta project mainly addresses the distribution network, the KPI indicates the increased MV/LV network hosting capacity in the project area, thus allowing an increase in DER in the region without compromising the operation of the transmission network. The Gabreta promoters positively quantify this KPI as a result of an increase in the distribution network hosting capacity due to the installation of smart elements such as distribution stations, storage and advanced monitoring functionalities in the grid. The enhanced observability and controllability of the grid	

	enabled by elements in the project would allow for improved network management and, ultimately, higher levels of DER in the system.	
KPI_5: Energy not withdrawn from renewable sources due to congestion or security risks	The promoters use this KPI to capture the project's impact on this specific criterion, as involvement of end-users (both consumers and prosumers) in effective management of the grid operation is critical for retail market functioning and the introduction of different customer services. In this regard, the Gabreta project is expected to reduce the amount of renewable energy not withdrawn owing to network congestion or security risks as a result of the increase in controllable load subject to demand-side management. RES curtailment registered on either side of the border is currently extremely low, so that using such values would lead to insignificant results. The KPI was instead quantified as potential increase in RES without congestion/security risks, as a result of growing controllable load, subject to demand-side participation.	
KPI_7: Operational flexibility provided for dynamic balancing of electricity in the network	The project is expected to significantly improve the operational flexibility of the electricity network for dynamic balancing as a result of effective integration and involvement of network users in managing their load. This will occur thanks to the spread of modern controllable electrical appliances such as heat pumps and electromobility, as well as to larger storage capacity. This could also lead to deeper integration of distributed RES. The Gabreta promoters report and demonstrate a significant increase in the operational flexibility of the network and therefore positively quantify this KPI.	
KPI_8: Ratio of reliably available generation capacity and peak demand	The Gabreta project is expected to increase the reliably available generation capacity owing to enhanced network management and control, and lower peak demand as a result of demand-side management and introduction of dynamic tariffs. The reliably available capacity is the part of net generating capacity actually available to cover the peak load (ENTSO-E, 2009) and as such is an indicator of the system's adequacy. As the Gabreta project mainly addresses the distribution network level, the promoters use an alternative approach and positively quantify this KPI as network capability to accommodate more renewable energy owing to better operational management and consequently lower the difference between the P_{min} and P_{max}.	
KPI_{10}: Stability of the electricity system	The project promoters assess this indicator as related to the three following KPIs: KPI_{11} (duration and frequency of interruptions per customer), KPI_{12} (voltage quality performance), and KPI_{17} (reduction of mean time between failures and mean time to repair), arguing that they are to result from the smartening of network equipment. Nevertheless, this KPI is not quantified at this stage of the project's development.	
KPI_{11}: Duration and frequency of interruptions per customer, including climate related disruptions	Better monitoring and control, improved network management, and easier fault detection and resolution enabled by the project's newly installed infrastructure are expected to lead to the reduction of the duration and frequency of interruptions, as captured by the standard industry indicators SAIDI and SAIFI. The project promoters are able to accurately quantify this benefit.	
KPI_{12}: Voltage quality performance	Improved network management is also expected to result in higher voltage quality, as captured by a diminished frequency of voltage violations. The project promoters are able to accurately quantify this benefit.	

KPI_{20}: Exploitation of interconnection capacities	The project promoters plausibly argue that the new line built at the distribution level will increase by 8 MW the network's exchange capacity, freeing up capacity on the existing transmission interconnectors and ultimately providing for higher security of supply. However, the indicator is not quantified.	

Source: Own elaboration, 2021.

Policy criterion 4: optimised planning of future cost-efficient network investments

The promoters demonstrate the project's contribution to the fourth policy criterion by making reference to a set of chosen KPIs as listed in Table 21.

Table 21. Gabreta Smart Grids: evaluation of project's impact against the fourth specific criterion

Selected KPIs	Calculation approach and impact evaluation	
KPI_{16}: Percentage utilisation (i.e. average loading) of electricity network components	As argued by the project promoters, the smart appliances of the project are expected to allow to consume more DER-generated energy within the distribution level, decreasing the need to employ the transmission and TSO-DSO transformation equipment. However, this benefit is not quantified in the CBA.	
KPI_{17}: Availability of network components (related to planned and unplanned maintenance) and its impact on network performances	The improved management algorithms and monitoring instruments involved in the project are expected to improve the values of both the mean time between failures and the mean time to repair, resp. due to employment of equipment closer to its optimal point, and to the easier detection and repair of faults. This is quantified by the project promoters with convincing accuracy.	
KPI_{18}: Actual availability of network capacity with respect to its standard value	The promoters select the actual availability of network capacity to address the project's impact on future cost-efficient investment. In this context, the Gabreta project is expected to increase the network capacity with respect to its nominal value mainly as a result of the reinforcement of substations. As the Gabreta SG project is developed mainly at the DSO level, the project's impact on this KPI is positively assessed owing to the installation of a new cross-border interconnection line at the distribution network level and of smart grid elements.	

Source: Own elaboration, 2021.

Policy criterion 5: market functioning and customer services

The promoters demonstrate the project's contribution to the fifth policy criterion by referring to a set of chosen KPIs as listed in Table 22.

Table 22. Gabreta Smart Grids: evaluation of project's impact against the fifth specific criterion

Selected KPIs	Calculation approach and impact evaluation	
KPI_6: Methods adopted to calculate charges and tariffs, as well as their structure, for generators, consumers and those that do both	Thanks to the distinct progress in system metering and monitoring, the Gabreta project is expected to make available a more granular array of information, which will allow better allocation of electricity costs between different network users. Such information typically includes automatic and (close-to-) real-time energy consumption and/or generation data and detailed analysis of consumer/prosumer data in the form of clear tables and graphs used for customer energy bills. Furthermore, this amount of information and detail would further promote the introduction of dynamic tariffs and potentially engage end-users in more effective management of their energy consumption. Finally, more detailed information flows	

	would allow regulators to assess RES contribution in provision of ancillary services to both DSOs and TSOs and move the market forward for new customer services.	
KPI_{19}: Ratio between interconnection capacity of a Member State and its electricity demand	For much the same reasons as KPI 16 and 20, the project promoters argue that the enhanced network management enabled by the project will allow for handling a larger extent of generation and demand at the local level. As a consequence, the utilisation of the TSO grid is expected to diminish, making in turn for a higher ratio between interconnection capacity and electricity demand. Analogously to the other related KPIs, however, this benefit is not quantified by the project promoters.	

Source: Own elaboration, 2021.

Policy criterion 6: involvement of users in management of their energy usage

The promoters demonstrate the project's contribution to the sixth policy criterion by referring to a set of chosen KPIs as listed in Table 23.

Table 23. Gabreta Smart Grids: evaluation of project's impact against the sixth specific criterion

Selected KPIs	Calculation approach and impact evaluation	
KPI_{14}: Ratio between minimum and maximum electricity demand within a defined time period	Due to the increased penetration of distributed generation and demand response, the demand profile is expected to flatten over the next years. The project promoters elaborate that this is likely to happen due to minimum demand increasing more than the rise in maximum demand, within growing overall demand levels. The KPI is therefore quantified accordingly.	
KPI_{15}: Demand side participation in electricity markets and in energy efficiency measures	This KPI is closely linked to the involvement of users in the effective management of their energy usage. In this respect, the Gabreta project is expected to increase the amount of load participating in demand-side management and energy efficiency measures in comparison with the BaU scenario. The KPI is therefore positively quantified using available data from the dispatch centres of both DSOs for the BaU scenario, plans for additional demand-side management resources and legislative requirements.	

Source: Own elaboration, 2021.

The following section presents the societal benefits of the GABRETA Smart Grids project in monetary terms along with the total cost (capital and operational expenditure), as communicated by the promoters. Furthermore, economic indicators such as the NPV, the IRR, and the B/C ratio are used to verify whether the project's overall benefits outweigh its costs and, therefore, whether or not the project complies with the second general criteria of the regulation (Article 4(b)).

The promoters assumed the following values for the variables used in the societal CBA.

- **Demand growth:** Electricity demand is assumed to grow in the future decades until 2050, in compliance with the document "EU Reference Scenario 2016-Energy, transport and GHG emissions Trends to 2050", mainly due to increased electrification of energy demand, especially for heating and cooling and for electromobility. Consequently, assumptions on demand growth rates are 0.8 %/year for EGD and 0.4 %/year for BAG.
- **Discount rate:** a value of 4 % has been assumed for the societal discount rate (Vasiljevska and Gras, 2017).
- **Time horizon:** Based on a 20-25 years predicted lifespan for most of the investments, the project promoters assume a time horizon of 25 years for this project.
- **Average electricity price in the project area:** 40.3 €/MWh
- **Value of electricity compensated by regulator (technical losses):** EGD: 32 €/MWh, BAG: 36.9 €/MWh.

- **Peak demand reduction**: despite expanding overall levels of electricity consumption (seen above), peak demand is assumed to decreased thanks to the peak shaving consented by the application of smart grids solutions. This is assumed to equal 100 MW for EGD, 297.9 MW for BAG.

- **CO_2 price:** the project promoters assume EUR 34.5 €/t, based on forecasts on CO2 prices in the upcoming ten years conducted by the EC.

- **Value of lost load:** EGD: 3 970 €/MWh, BAG: 12 410 €/MWh, quantified by the promoters based on the assumptions and methodology in Shivakumar, A.main, et al. "Valuing blackouts and lost leisure: Estimating electricity interruption costs for households across the European Union." Energy Research & Social Science 34 (2017): 39-48.

- **Fuel prices:** EGD: 1.043 €/litre, BAG: 1.245 €/litre.

The project reports positive outcomes of the societal CBA. The main monetary benefits and costs are listed below.

Main monetary benefits

The Gabreta project is expected to deliver a set of positive impacts and in that respect the following monetised benefits are communicated by the project promoters (starting from the highest to the lowest one):

- deferred distribution capacity investments
- electricity cost savings
- reduced CO2 emissions and reduced fossil fuel usage
- estimated reduction in electricity interruption costs for households
- reduced outage time
- reduced electricity technical losses
- reduced direct cost of equipment breakdowns.

Main costs

Given the preparatory phase of the Gabreta project, the currently forecast capital expenses – based on pilot projects and market research for particular technologies – will be made subject to regular supervision and updates as the works progress. The main costs currently foreseen for the project's deployment are as follows (starting from the highest to the lowest one):

- distribution grid communication
- modernisation of the distribution grid by smart elements
- interconnection and strengthening of distribution grids
- smart grids IT solutions.

The overall project's benefits outlined above outweigh the project's costs and the project reports the following economic indicators: ENPV: 325.5 mil. €, IRR: 10.32%, B/C: 1.35.

Sensitivity analysis

The NPV of the project changes with variation of the following critical variables:

- peak demand reduction due to energy savings and peak load shift: decrease ENPV by 16.9 mil €
- decrease in outage time: decrease ENPV by 19.9 mil €
- estimated % of consumption reduction with Smart Grid scenario: decrease ENPV by 163 mil €
- financial market energy rate: decrease ENPV by 25.5 mil €
- value of CO2: decrease ENPV by 29.7 mil €.

Even under the worst-case scenario, where key variables (s.a. estimated % of consumption reduction thanks to Smart Grids technology, decrease in outage time, percentage of reduced equipment breakdown, peak demand reduction due to energy savings and peak load shift, power prices, difference between peak and non-peak generation, and the social cost of CO2) are decreased by 40%, the Project manages to keep its NPV within the positive range, with a B/C ratio of 1.04.

Additional non-monetary benefits

The project proposal also includes a set of non-monetary impacts, such as:

- reduced air pollutants (dust particles, SOX, NOX and CO) emissions due to reduced line losses
- lower threat to animal species
- reduced visual impact.

2.4.3. Summary of the Gabreta Smart Grids project's evaluation

A variety of power system operation dimensions is impacted by the Gabreta project, ranging from improved metering and monitoring of the grid, higher flexibility and easier balancing, enhanced capabilities for frequency and voltage control, larger hosting capacity for integration of renewable generation (especially for distributed energy), smoothing of consumption profiles within an increase in overall demand levels, avoided line congestion and lower RES curtailment, easier fault detection and repair making for shorter and less frequent interruptions. These results are provided by an overall smartening of the equipment at the LV and MV level, with special regard to substations, meters, algorithms, and monitoring, control, and communication technology, as well as by a 8 MW expansion in energy exchange capacity at the distribution level. All this is expected to bring about a profound change in grid management patterns, bringing about truly regional coordination in the operation of the electricity network.

These enhancements in the ability to retrieve and exchange system state information in real time, also obtained through the adoption of fibre, BPL, and 5G communication technology, will create a substantial flow of data brought to the service of system optimisation, both in short-run management and in deeper long-run analysis of system patterns. It will be made available through the creation of data storage facilities shared by the region's network operators. Active end-customer participation, both as distributed energy generators and as potential providers of flexible demand, will be enabled through smart appliances, potentially through the adoption of dynamic pricing setups. The project can therefore clearly be assessed to comply with Article 4(1)(c)(i) of the regulation, as well as for the priority thematic area of smart grids deployment (point 4(10) of Annex I to the regulation).

The project promoters are able to clearly demonstrate the project's contribution to the six smart grid specific criteria outlined in Article 4(2) of the regulation, and its positive expected impact on social welfare within a societal cost-benefit analysis. This carries over to when stress tests are performed, such as through the computation of positive cost-benefit measures within a worst-case scenario where key benefits parameters are decreased by 40%. As a consequence, the project proves remarkably stable even through the application of sensitivity analysis methodologies.

2.5. Green Switch (Slovenia, Croatia and Austria)

2.5.1. General overview

Green Switch project develops on the need to effectively address growing requests for connection of renewable energy sources and increased peak load, also owing to integration of electric vehicles and heat pumps, which has recently resulted in increasing power flows in both distribution and transmission grids. To this end, the grid operators involved in the project face growing investment demands due to this increase in both load and variable generation, but also as result of the inability of the current grid to solve new patterns of power flows and increasing demands for quality of supply even in most remote areas. Challenges introduced at distribution network level cannot always be solved locally, particularly in rural areas where distributed generation often surpasses the total consumption. Increasing share of distributed sources and new loads require larger needs for flexibility, which has direct impact on the national and cross-national TSO networks. To tackle these issues in a more cost-efficient way, the distribution and transmission grid operators involved in the project have recognised the need for a more holistic and systemic approach by focusing on stronger cooperation and coordination between TSOs and DSOs and across border. In the absence of such approach the grid operators in the project would require larger flexibility needs in their grid areas or an increasing cross-border capacity by building new transmission lines – often characterised as lengthy and complex process. Joint approach to the common challenges in the project area would also result in more cost-effective solutions (e.g. 29%-37% of cost reduction for deployment of power control units for power flow management of the 220 kV network in comparison to the case of having each Member State to deal with the management of the 220 kV power flow separately).

The Green Switch project aims to optimise the utilization of existing infrastructure and efficiently integrate new technologies and advanced functionalities to enable higher hosting capacity, efficient integration of new loads and new type of loads (e.g. electric vehicles), thereby optimising future investments and improving security and the quality of operation and supply.

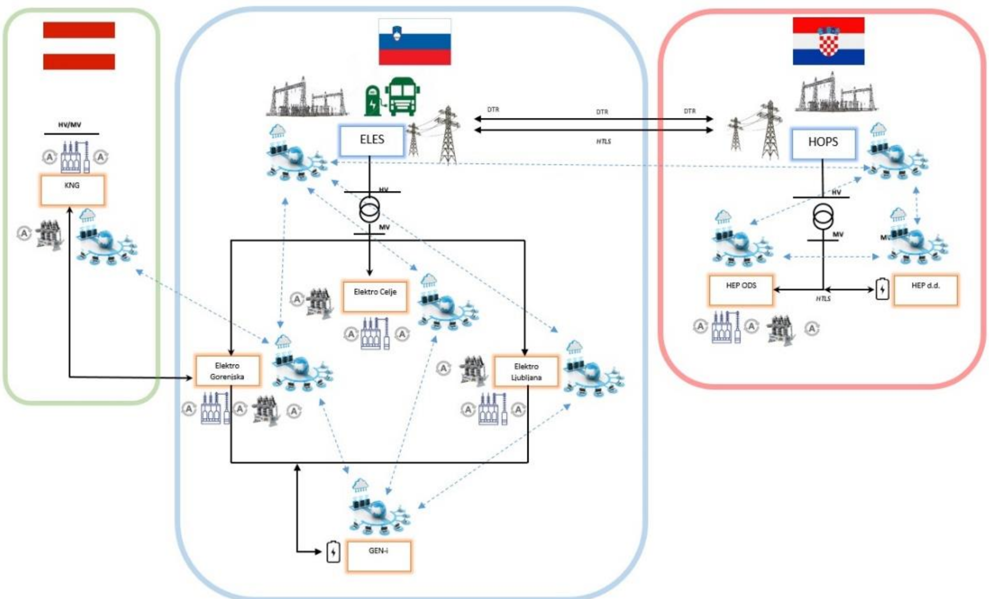
Finally, the Green Switch project brings the value of sector integration in the field of mobility and heating into the project to increase system flexibility and efficiency.

Smart grid technologies and functionalities to be deployed in this project include locational use of battery storage, power flow prediction and control systems, optimal supply of physical islands, and an advanced approach to providing distribution grid resilience by a cross-border connection while securing the supply to the customers in the bordering territories under emergency conditions.

The Green Switch project involves entities from three Member States (Figure 2), namely:

- Two TSOs: ELES (Slovenia) and the HOPS (Croatia)
- Five DSOs: Elektro Ljubljana (Slovenia), Elektro Gorenjska (Slovenia), Elektro Celje (Slovenia), KNG-Kärnten Netz GmbH (Austria), HEP-ODS (Croatia)
- One retailer: GEN-I (Slovenia)
- One retailer and producer: HEP (Croatia).

Figure 2. Green Switch project illustration



Source: Green Switch project, 2021

Main project goals:

- Increase hosting capacity for distributed renewable sources
- Allow efficient integration of new loads
- Optimise grid investments
- Improve quality of supply
- Improving observability of the distribution network
- Coordinated flexibility procurement and supply
- Increase cross-border capacity

- Optimal use of infrastructure.

Expected impacts:

- At least 20 % lower SAIDI index in selected MV feeders or secondary substations
- Better utilization of existing MV/LV transformers – at least 15 % higher limit in wintertime
- Increased hosting capacity of existing network – 550 MW of additional renewables can be installed in selected MV feeders and 1,350 MW at transmission level
- Deferred transmission and distribution investments
- 10 % lower peak demand using flexibility sources
- Increase of cross-border capacity at interconnectors between Slovenia and Croatia and increase of cross-border emergency capacity between Slovenia and Austria
- Production of 10 GWh of heat from at least 20 power transformers per year
- Provision of commercially available high-power infrastructure on frequent traffic locations for simultaneous fast charging of at least 50 busses or heavy-duty vehicles with the charging power of between 1-4 MW per vehicle.

2.5.2. Compliance with the general and specific criteria of Article 4(1) of the regulation

Project's necessity for the priority thematic area of smart grids deployment (compliance with the energy infrastructure category of Annex II(1)(e) to the regulation)

As previously mentioned, the Green Switch project is mainly driven by the need to increase hosting capacity both for new distributed generation as well as new loads, including new type of loads (electric vehicles). This requires installation of smart grid equipment, mainly at 10 kV level or higher, which will enable implementation of advanced functionalities to integrate new distributed generation and loads as well as increase reliability and quality of supply.

Main smart grid investments deployed in the project are the following, in line with the infrastructure category of Annex II(1)(e) to the regulation.

Distribution network level:

- Upgrade existing or install new Advanced Distribution Management System (ADMS) capable to support advanced functionalities.
- ICT network to connect all observability and controllability network elements (depending on terrain optical fibre, long-term evolution (LTE) radio, other).
- Upgrade existing secondary substations (MV/LV) or build new ones with automation and control equipment in selected areas (several possibilities, where applicable: phasor measurement unit (PMU), remote monitoring unit (RMU), remote control load break switches, short circuit indicators with remote reading capability).
- Additional measuring devices in selected areas
- Reclosers in selected areas.
- Additional cable to close MV loops in selected areas and interconnect the bordering network users for emergency backup supply
- Smart primary substations (HV/MV), where applicable
- Battery energy storage servicing the local network operation processes including the physical islanding use case.

Transmission network level:

- Power Control Systems
- HTLS technologies (high temperature line equipment)
- Expansion of DTR system
- New grid connections for the future heavy duty hyper charging stations in the vicinity of the highways

- ICT infrastructure between the existing and new nodes
- Equipment for heat extraction from transformers.

The project can therefore clearly be assessed as complying with the criteria for the energy infrastructure category of Annex II(1)(e) to the regulation and it also proves necessary for the priority thematic area of smart grids deployment (point 4(10) of Annex I to the regulation).

Project's demonstration of a cross-border impact (compliance with any of the criteria of Article 4(1)(c))

The Green Switch project involves three Member States by directly crossing the border of the Member States involved in the project. The project demonstrates cross-border dimension both at transmission and distribution network level. At transmission network level, TSOs from Slovenia and Croatia aim to increase the capacity of existing cross-border lines by installing high temperature wire technology (HTLS), Dynamic Thermal Rating (DTR) and install Power Control Systems to better control the cross-border flows, thereby increasing the safety and reliability of the electricity system in the project area as well as demonstrating positive impact on the neighbouring power systems.

Moreover, the project aims to increase the cross-border capacity at the DSO level in the project area by installing a MV cross-border emergency electrical connection between Austria (KAERNTEN NETZ) and Slovenia (Elektro Gorenjska) and upgrading another existent MV cross-border interconnection in the area of Seebergsattel (Jezersko), both with the aim to increase security of supply in the bordering area of both DSOs.

Based on the arguments above, the project complies with Article 4(1)(c)(ii) of the regulation.

Project contribution to the smart grid specific criteria (Article 4(2)(c) of the Regulation) – energy system-wide cost-benefit analysis

This section illustrates the project contribution to the policy specific criteria as a way of assessing the benefits in the energy system-wide cost-benefit analysis (Article 4(1)(b)). Additionally, for projects falling into the priority thematic area of smart grids deployment, '*the cost-benefit analysis shall take into account the impacts on the indicators defined in Annex IV*' (Annex V (8) to the regulation).

The Green Switch project promoters elaborate on the project's impact on each of the six specific criteria, selecting a set of indicators defined in Annex IV (hereafter referred as 'KPIs') to better capture this impact against a specific criterion.

The Table 24-30 below depict the selected KPIs for capturing the project's impact against each specific criterion and the estimation approach used. Depending on the present uncertainties in the information provided by the promoters and the assumptions made, the JRC has used a colour-coded approach (Vasiljevska and Gras, 2017) to evaluate the project's contribution to each specific criterion. In addition, each project's impact has been assessed in view of the following two scenarios: a BaU scenario, i.e. without deployment of the project, and an SG scenario, i.e. with implementation of the project.

Policy criterion 1: integration and involvement of network users with new technical requirements with regard to their electricity supply and demand

The Green Switch enables growing integration of distributed and renewable generation as well as demand side participation owing to increased degree of digitalisation and automation. Furthermore, it promotes development of flexibility platforms, which are essential for integration of flexibility resources and development of flexibility markets.

To this end, the project creates favourable conditions for integration and involvement of different network users with new technical requirements, such as flexible loads coming from EVs, heat pumps, buildings and industries through provision of user-friendly solutions and services (e.g. roaming, smart charging, etc.) and adoption of energy data management systems for industries, local municipalities, social housing, etc.

The promoters address the project's impact on the first specific criterion using the KPIs indicated in Table 24.

Table 24. Green Switch project: evaluation of project's impact against the first specific criterion

Selected KPIs	Calculation approach and impact evaluation

KPI_5: energy not withdrawn from renewable sources due to congestion or security risks	One of the main aims of the Green Switch project is to increase network hosting capacity for RES while ensuring security and reliability of supply. The promoters are not able to quantify this impact as there is no historical data on RES curtailment as according to national regulations, all RES connected to the grid can operate at maximum capacity. However, in some rural parts of the distribution grid in the project area, there has been cases of over-voltages triggering the DGs' disconnection from the network for a short period of time. Nevertheless, there is no record of the frequency of such cases and on the percentage of energy lost in that matter. Promoters report that situations of DG curtailment will be monitored during the project. The project is expected to contribute to better observability and voltage regulation of the network, thus resulting in more DGs being able to connect, and consequently more generation from DGs injected into the grid.	
KPI_6: methods adopted to calculate charges and tariffs, as well as their structure for generators, consumers and those that do both	The Green Switch project involves smart grid investments with a high degree of digitalisation and automation resulting in increased network observability. This would ultimately allow regulators to establish a tariff structure that would more accurately offset the costs incurred by the grid users. The implementation and integration of flexibility resources will strongly promote development and implementation of methods and mechanisms related to the provision of flexibility services. Data gathered will enable DSOs to determine which product is demanded on the flexibility market, define when the service needs are to be activated and measure its result. Users will be able to actively participate in flexibility markets and manage their demand. The network infrastructure installed within the project will enable to accurately monitor response from consumers which is not possible without upgrading the ICT system. The project would allow for more informed decision-making for the grid operators regarding grid developments, whereas the regulators would have more information about the potential of market-based solutions versus grid investments.	
KPI_{14}: ratio between minimum and maximum electricity demand within a defined time period	The Green Switch project is expected to reduce peak demand by deploying battery storage and demand response. The promoters define P_{min} and P_{max} as load in the selected secondary substations and industrial locations, as flexibility will be used only in areas where needed and estimate 100 secondary substations with rated power of 160 kVA to be included in provision of flexibility services. Additionally, deployment of battery storage in 30 industrial locations would also contribute to the peak load reduction. Based on the above, the promoters positively quantify the project's impact on this KPI.	
KPI_{15}: demand side participation in electricity markets and in energy efficiency measures	The promoters quantify the project's positive impact on this KPI owing to the deployment of 46 MW of energy storage in the project area and 2 MW of controllable load (in total 100 secondary substations are expected to be subject to demand-side participation).	

Source: Own elaboration, 2021.

Policy criterion 2: efficiency and interoperability of electricity transmission and distribution in day-to-day network operation

Advanced functionalities introduced in the project will increase network efficiency by increasing hosting capacity for RES, which will result in lower GHG emissions. Additionally, deployment of dynamic thermal rating (DTR) on lines and transformers enables better utilisation of the existing grid and deferral or possibly avoidance of transmission grid investments. It also increases the average loading of the grid and the actual availability of network capacity, including increase in NTC of the interconnectors included in the project. The project will have positive impact on reliability indicators, such as SAIDI and this way, increase network operational efficiency as an alternative to the installation of additional primary equipment, especially cabling.

The promoters address the project's impact on the second specific criterion using the KPIs indicated in Table 25.

Table 25. Green Switch project: evaluation of project's impact against the second specific criterion

Selected KPIs	Calculation approach and impact evaluation	
KPI$_1$: reduction of greenhouse emissions	The Green Switch project will implement advanced functionalities to increase network efficiency by increasing hosting capacity, which in turn will result in lower GHG emissions. The promoters demonstrate the project's positive impact on this KPI, and quantify this impact by referring to the following smart grid solutions deployed in the project, and the associated benefits: • increase in hosting capacity of the distribution network to integrate growing RES; • distribution level storage in Slovenia and Croatia will provide 46 MW of flexible units replacing same amount of gas-fired power plant capacity; • increased capacity by installing HTLS on 110 kV allows installation of at least 150 MW of wind farms which could not be connected due to grid limitations; • use of waste heat form the transformers for heating purposes; • installation of additional 1,200 MW of wind and solar power plants at transmission level in Croatia that currently cannot be connected due to network limitations; • increase of hosting capacity in 30 industrial locations by 26 MW, mainly for installation of solar power; • Inclusion of an additional 50 MW of new RES in the MV grid enabled by deployment of one storage system on the island of Cres in Croatia, upgrade of five existing lines with HTLS conductors, reconstruction of two exiting lines and installation of FACTS devices for voltage control at four locations.	
KPI$_2$: environmental impact of electricity grid infrastructure	The promoters demonstrate a positive environmental impact by referring to the smart grid investments deployed in the project, which allow for better utilisation of the existing grid and as a result increase grid efficiency, namely: • deployment of dynamic thermal rating on selected lines and transformers; • investment in hyper duty charging stations; • postponement of installation of one 110 kV and one 400 kV overhead line; • deployment of 20 MW of battery storage systems in Croatia, which will defer investments in transmission network lines and underground cables as well as avoid the investment in gas-fired power plants. It is worth mentioning here that the territory of	

	the islands Cres-Lošinj, included in the project, is part of the Natura 2000 ecological network land.	
KPI_3: installed capacity of distributed energy resources in distribution networks	The Green Switch project demonstrate positive impact on this KPI in the whole project area. More specifically, the promoters calculate the hosting capacity using model simulation on MV feeder or secondary substation level and referring to existing or future hosting capacity using different types of network elements or functionalities using Monte Carlo analysis. In Slovenia, the total possible hosting capacity is estimated on average at 200 kW per MV/LV transformer. Involved distribution companies have a total of 10,509 of those transformers, estimating the total hosting capacity at 2,101 MW. By implementing central voltage control in primary substations, the hosting capacity is estimated to increase by 10 %. Where secondary substations will be automated, loops constructed or additional voltage control implemented at a secondary substation, an average 50 % increase of hosting capacity can be expected. In total, the hosting capacity in involved distribution grid with SG scenario will be 2,346 MW – the difference of 245 MW. Additional 26 MW of solar will be able to be installed at industrial sites where storage will be constructed to allow for additional connections. In Austria, the hosting capacity will increase by 240 MW in the 20 MV feeders where substations will be automated and additional 65 MW in the rest of the network, mainly coming from new substations. In Croatia, additional 50 MW of renewable will be able to be installed because of the project, with some 90 % being solar and 10 % wind. The KPI is therefore, positively quantified for the whole project area.	
KPI_4: allowable maximum injection of electricity without congestion risks in transmission networks	The promoters quantify this KPI for Slovenian and Croatian part of the project by referring to the construction of HTLS on both 110 kV interconnections which would allow for connection of 150 MW of wind power in Slovenia. In Croatia, the promotors have calculated the KPI based on the worst-case power flow conditions, which resulted in connection of additional 1,200 MW.	
KPI_9: share of electricity generated from renewable sources	The promoters demonstrate positive project's impact on this KPI by calculating the sum of generation from additional hosting capacity at transmission and distribution level in all countries involved and by referring to KPI_3 and KPI_4.	
KPI_{10}: stability of the electricity system	The Green-Switch project demonstrate positive impact on the stability of the electricity system by referring to the installation of power control device in the project area. The Slovenian-Austrian 220 kV interconnection line (Podlog-Obersielach) is often overloaded (140 days in 2018), and these situations are mainly addressed by switching manoeuvres in the Podlog substation to remedy the situation. The deployment of power control device is expected to reduce this time to maximum 10 days. Detailed analysis on how this affects the possibility of large-scale interruptions will be conducted at a later stage of the project development.	
KPI_{11}: duration and frequency of interruptions per customer, including	The promoters demonstrate significant positive impact on this KPI owing to the smart grid solutions deployed in the project. More specifically, the promoters argue about the use of advanced FLISR and closed loop	

climate-related disruptions	functionalities on the SAIDI index, thus reducing the number of affected network users and duration of the outage. The KPI is quantified for the whole project area.	
KPI_{13}: level of losses in transmission and distribution networks	The Green Switch project enables better utilisation of the grid infrastructure. To this end, the promoters expect increase in transmission network losses by approximately 10% in Croatia and 3% in Slovenia. This results in a slight increase of the total network losses in the project area.	
KPI_{16}: percentage utilisation (i.e. average loading) of electricity network components	The Green Switch project is expected to increase the average loading of the grid owing to installation of DTR on interconnection lines between Slovenia and Croatia, which will allow for higher power exchange as NTC will increase by 15 % on average. Also, DTR system deployed in secondary substations is expected to increase the transformer maximum loading by 15% before replacing the transformers. Additionally, storage facilities in industrial sites will reduce peak load by distributing load to times with lower demand. Similarly, flexibility sources will also reduce peak load and shift consumption to times with lower load. The promoters report no analysis on how these measures will increase the average loading. They claim that additional analysis will be conducted at later stage of the project. For the Croatian part of the project, the upgrade of DTR and installation of power control devices will allow better utilisation of the transmission network and as a result lead to an expected increase in utilisation of electricity network components by approximately 5%. The number 5 % is related to the Croatian internal network and is a result of both DTR and power control devices. This value is a result of preliminary expert estimation, whereas detailed calculations will be conducted within the design phase of the project in 2021.	
KPI_{18}: actual availability of network capacity with respect to its standard value	The project demonstrates a positive impact on the actual availability of network capacity owing to the deployment of DTR and consequent better utilisation of the existing grid. The thermal rating is highly influenced by local weather conditions (outside temperature, wind, etc.) and the actual load of the line. DTR provides dynamic calculations of the thermal rating using local weather conditions (outside temperature, wind, etc.) and the actual load of the line. This way, the thermal rating can be changed according to specific conditions and still enable safe operation of the line. The promoters report an increase of 15 % in average grid capacity due to DTR. Similar results could be expected for all the lines in the SG scenario, resulting in increase of 15% of actual availability of network capacity with respect to its standard value.	
KPI_{19}: ratio between interconnection capacity of a Member State and its electricity demand	The smart grid investments deployed in the project contribute to increase in the cross-border capacity, thereby providing efficient alternative to building new network lines. The promoters calculate this KPI for all the interconnectors of the participating countries. In the BaU scenario the average NTC at the border between Austria and Slovenia is 950 MW for both directions, the average NTC on the border from Slovenia to Croatia is 1,200 MW and 800 MW from Croatia to Slovenia. While NTC on the border between Slovenia and Croatia is utilised 100 % of time, the NTC on the Austrian border is utilised less than 90 % of time. With the installation of power control devices, the NTC on the Slovenian-Austrian border can be expected to be utilised at	

	close to its nominal value. The NTC on the border between Croatia and Slovenia is expected to increase by 200 MW in each direction. Nevertheless, these figures are subject to discussions with the neighbouring TSOs, and it may occur that the actual NTC achieved will be lower than expected, as described in one of the project risks together with risk mitigation strategies. Based on the above, the promoters positively quantify this KPI.	
KPI_{20}: exploitation of interconnection capacities	Similarly to KPI_{19}, KPI_{20} also relates to an efficient upgrade of cross-border capacity. The exploitation of interconnection capacities can be calculated by comparing the yearly allocated NTC per border with the average yearly load flow on that same interconnection. In the Smart Grids scenario, the promoters assume that average load flow will increase by 50 MW on the direction from Austria to Slovenia due to power control devices and 70 MW on the direction from Croatia to Slovenia due to increased renewables generation and increased cross-border capacity. The exploitation rate for SG scenario for the project are: • SI-AT: NTC=950 MW, $\mu_i(load_{flow}) = 19$; ER=2% • AT-SI: NTC=950 MW, $\mu_i(load_{flow}) = 536$; ER=56% • SI-HR: NTC=1200 MW, $\mu_i(load_{flow}) = 413$; ER=34% • HR-SI: NTC=800 MW, $\mu_i(load_{flow}) = 60$; ER=7,5% The promoters calculated the KPI for the following interconnectors and directions: SI-IT: 34 %; SI-AT: 0%; AT-SI:-9%; SI-HR: 14%; HR-SI:-70%.	
KPI_{21}: congestion rents across interconnections	The Green Switch project is expected to increase NTC at the interconnectors of the Member States involved in the project. The promoters reports that this will most likely change the income for the neighbouring TSOs and based on their previous experience, such increase in capacity will be followed by a decrease in auction prices, and the net effect regarding income from auctions for cross-border capacity will be around 0. However, at this point promoters are not able to give an accurate estimation.	

Source: Own elaboration, 2021.

Policy criterion 3: network security, system control and quality of supply

The Green Switch project is expected to have positive impact on this criterion by implementing smart grid functionalities, and as a result increase network hosting capacity. Some of these functionalities include deployment of HTLS, power control devices, fault location, isolation, and service restoration (FLISR) and closed loop functionalities, battery storage, and demand response. This will improve voltage quality performance, reduce duration of outrages, and consequently increase the availability of network equipment.

The promoters address the project's impact on the third specific criterion using the KPIs indicated in Table 26.

Table 26. Green Switch project: evaluation of project's impact against the third specific criterion

Selected KPIs	Calculation approach and impact evaluation

KPI$_1$: reduction of greenhouse emissions	The Green Switch project will implement advanced functionalities to increase network efficiency by increasing hosting capacity, which in turn will result in lower GHG emissions. The promoters demonstrate positive project's impact on this KPI and quantify this impact by referring to the following smart grid solutions and deployed in the project and associated benefits: • increase in hosting capacity of the distribution network to integrate growing RES. • distribution level storage in Slovenia and Croatia will provide 46 MW of flexible units replacing same amount of gas-fired power plant capacity. • increased capacity by installing HTLS on 110 kV allows installation of at least 150 MW of wind farms which could not be connected due to grid limitations. • use of waste heat form the transformers for heating purposes. • installation of additional 1,200 MW of wind and solar power plants at transmission level in Croatia that currently cannot be connected due to network limitations. • increase of hosting capacity in 30 industrial locations by 26 MW, mainly for installation of solar power. Inclusion of an additional 50 MW of new RES in the MV grid enabled by deployment of one storage system on the island of Cres in Croatia, upgrade of five existing lines with HTLS conductors, reconstruction of two exiting lines, and installation of FACTS devices for voltage control at four locations.	
KPI$_3$: installed capacity of distributed energy resources in distribution networks	The Green Switch project demonstrate positive impact on this KPI in the whole project area. More specifically, the promoters calculate the hosting capacity using model simulation on MV feeder or secondary substation level and referring to existing or future hosting capacity using different types of network elements or functionalities using Monte Carlo analysis. In Slovenia, the total possible hosting capacity is estimated on average at 200 kW per MV/LV transformer. Involved distribution companies have total 10,509 of those transformers, estimating the total hosting capacity at 2,101. MW. By implementing central voltage control in primary substations, the hosting capacity is estimated to increase by 10 %. Where secondary substations will be automated, loops constructed or additional voltage control implemented at a secondary substation, an average 50 % increase of hosting capacity can be expected. In total the hosting capacity in involved distribution grid with SG scenario will be 2,346 MW – the difference of 245 MW. Additional 26 MW of solar will be able to be installed at industrial sites where storage will be constructed to allow additional connections. In Austria, the hosting capacity will increase by 240 MW in the 20 MV feeders where substations will be automated and additional 65 MW in the rest of the network, mainly coming from new substations. In Croatia additional 50 MW of renewable will be able to be installed because of the project, with some 90 % being solar and 10 % wind. Therefore, the KPI is positively quantified for the whole project area.	
KPI$_4$: allowable maximum injection of electricity without	The promoters quantify this KPI for Slovenian and Croatian part of the project by referring to the construction of HTLS on both 110 kV interconnections which would allow for connection of 150 MW of wind power in Slovenia.	

congestion risks in transmission networks	In Croatia, the promotors have calculated the KPI based on the worst-case power flow conditions, which resulted in connection of additional 1.200 MW.	
KPI$_7$: operational flexibility provided for dynamic balancing of electricity in the network	The promoters demonstrate the project's positive impact on this KPI by referring to the deployment of 46 MW of energy battery storage, which will prove operational flexibility for balancing at distribution network level as well as for providing ancillary services at transmission network level.	
KPI$_8$: ratio of reliably available generation capacity and peak demand	The Green Switch project enables increase in the reliably available generation capacity by referring to the installation of 46 MW of energy storage in the project area as well as controllable loads. The promoters quantify positive project's impact on this KPI.	
KPI$_9$: share of electricity generated from renewable sources	The promoters demonstrate positive project's impact on this KPI by calculating the sum of generation from additional hosting capacity at transmission and distribution level in all countries involved and by referring to KPI$_3$ and KPI$_4$.	
KPI$_{10}$: stability of the electricity system	The Green-Switch project demonstrate positive impact on the stability of the electricity system by referring to the installation of power control device in the project area. Slovenian-Austrian 220 kV interconnection line (Podlog-Obersielach) is often overloaded (140 days in 2018), and these situations are mainly addressed by way of switching manoeuvres in the Podlog substation to remedy the situation. The deployment of the power control device is expected to reduce this time to a maximum of 10 days. Detailed analysis on how this affects the possibility of large-scale interruptions will be conducted at a later stage of the project development.	
KPI$_{11}$: duration and frequency of interruptions per customer, including climate-related disruptions	The promoters demonstrate significant positive impact on this KPI owing to the smart grid solutions deployed in the project. More specifically, the promoters argue about the use of advanced FLISR and closed loop functionalities on the SAIDI index, thus reducing the number of affected network users and duration of the outage. The KPI is quantified for the whole project area.	
KPI$_{12}$: voltage quality performance	The promoters demonstrate the project's positive impact on this KPI owing to the smart grid investments and functionalities in the project area, such as state estimation, ADMS, and voltage control functionality. The smart grid solutions deployed in the project is expected to solve the problem of over-voltages in the project area – e.g. in Croatia in 2019 the period when the voltage exceeded its maximum limit corresponded to 0.25 % of the time (22 hours in the year), whereas the project deployment is expected to decrease that time to one hour per year.	
KPI$_{17}$: availability of network components (related to planned and unplanned maintenance) and its	The project is expected to have positive impact on this KPI owing to deployment of FLISR and closed loop operation, which will result in reduction of outages and consequently increase in the availability of the equipment. The promoters report reductions of 10 %, 20 %, and 30 % for Austria, Slovenia, and Croatia respectively.	

impact on network performances		

Source: Own elaboration, 2021.

Policy criterion 4: optimised planning of future cost-efficient network investments

The Green Switch project demonstrates positive impact on this criterion by referring to the following activities of the project: coordination of the planning and operation procedures of the distribution networks with the planning and operation of electric mobility, energy management and power-to-heat solutions; integration of co-generation facilities, heat pumps and thermal storage to efficiently manage variable non-dispatchable RES; efficient planning of the design and location of future EV and hydrogen charging infrastructure, etc. Some transmission network investments (one 110 kV OHL and one 400 kV OHL) are expected to be postponed and the need for new power plants will be reduced owing to the project deployment. Finally, the smart grid investments included in the project will increase cross-border capacity and provide efficient alternative to building new lines.

The promoters select the following KPIs (Table 27) to demonstrate the project's impact this specific criterion.

Table 27. Green Switch project: evaluation of project's impact against the fourth specific criterion

Selected KPIs	Calculation approach and impact evaluation	
KPI_2: environmental impact of electricity grid infrastructure	The promoters demonstrate positive environmental impact by referring to the smart grid investments deployed in the project, which allow for better utilisation of the existing grid and as a result increase grid efficiency, namely: • deployment of dynamic thermal rating on selected lines and transformers. • investment in hyper duty charging stations. • postponement of installation of one 110 kV and one 400 kV overhead line. • deployment of 20 MW of battery storage systems in Croatia defer investments in transmission network lines and underground cables as well as avoid the investment in gas-fired power plant. Worthy to note here is that the territory of the islands Cres-Lošinj included in the project is part of the Natura 2000 ecological network land.	
KPI_3: installed capacity of distributed energy resources in distribution networks	The Green Switch project demonstrate positive impact on this KPI in the whole project area. More specifically, the promoters calculate the hosting capacity using model simulation on MV feeder or secondary substation level and referring to existing or future hosting capacity using different types of network elements or functionalities using Monte Carlo analysis. In Slovenia total possible hosting capacity is estimated on average at 200 kW per MV/LV transformer. Involved distribution companies have total 10.509 of those transformers, estimating the total hosting capacity at 2.101. MW. By implementing central voltage control in primary substations, the hosting capacity is estimated to increase by 10 %. Where secondary substations will be automated, loops constructed or additional voltage control implemented at a secondary substation, an average 50 % increase of hosting capacity can be expected. In total the hosting capacity in involved distribution grid with SG scenario will be 2.346 MW – the difference of 245 MW. Additional 26 MW of solar will be able to be installed at industrial sites where storage will be constructed to allow additional connections. In Austria, the hosting capacity will increase by 240 MW in the 20 MV feeders where substations will be automated and additional 65 MW in the rest of the network, mainly coming from new substations.	

	In Croatia additional 50 MW of renewable will be able to be installed because of the project, with some 90 % being solar and 10 % wind. The KPI is therefore, positively quantified for the whole project area.	
KPI_4: allowable maximum injection of electricity without congestion risks in transmission networks	The promoters quantify this KPI for Slovenian and Croatian part of the project by referring to the construction of HTLS on both 110 kV interconnections which would allow for connection of 150 MW of wind power in Slovenia. In Croatia, the promotors have calculated the KPI based on the worst-case power flow conditions, which resulted in connection of additional 1.200 MW.	
KPI_7: operational flexibility provided for dynamic balancing of electricity in the network	The promoters demonstrate the project's positive impact on this KPI by referring to the deployment of 46 MW of energy battery storage, which will prove operational flexibility for balancing at distribution network level as well as for providing ancillary services at transmission network level.	
KPI_9: share of electricity generated from renewable sources	The promoters demonstrate the project's positive impact on this KPI by calculating the sum of generation from additional hosting capacity at transmission and distribution level in all countries involved and by referring to KPI_3 and KPI_4.	
KPI_{11}: duration and frequency of interruptions per customer, including climate-related disruptions	The promoters demonstrate significant positive impact on this KPI owing to the smart grid solutions deployed in the project. More specifically, the promoters argue about the use of advanced FLISR and closed loop functionalities on the SAIDI index, thus reducing the number of affected network users and duration of the outage. The KPI is quantified for the whole project area.	
KPI_{16}: percentage utilisation (i.e. average loading) of electricity network components	The Green Switch project is expected to increase the average loading of the grid owing to installation of DTR on interconnection lines between Slovenia and Croatia, which will allow for higher power exchange as NTC will increase by 15 % on average. Also, DTR system deployed in secondary substations is expected to increase the transformer maximum loading by 15% before replacing the transformers. Additionally, storage facilities in industrial sites will reduce peak load by distributing load to times with lower demand. Similarly, flexibility sources will also reduce peak load and shift consumption to times with lower load. The promoters report no analysis on how these measures will increase the average loading and they claim that additional analysis will be conducted at later stage of the project. For the Croatian part of the project, the upgrade of DTR and installation of power control devices will allow better utilisation of the transmission network and as a result lead to an expected increase in utilisation of electricity network components by approximately 5%. The number 5 % is related to the Croatian internal network and is a result of both DTR and power control devices. This value is a result of preliminary expert estimation, whereas detailed calculations will be conducted within the design phase of the project in 2021.	

KPI_{19}: ratio between interconnection capacity of a Member State and its electricity demand	The smart grid investments deployed in the project contribute to increase in the cross-border capacity, thereby providing efficient alternative to building new network lines. The promoters calculate this KPI for all the interconnectors of the participating countries. In the BaU scenario the average NTC at the border between Austria and Slovenia is 950 MW for both directions, the average NTC on border from Slovenia to Croatia is 1200 MW and 800 MW from Croatia to Slovenia. While NTC on border between Slovenia and Croatia is utilized 100 % of time, the NTC on Austrian border is utilised less than 90 % of time. With the installation of power control devices, the NTC on the Slovenian-Austrian border can be expected to be utilised at close to its nominal value. The NTC on the border between Croatia and Slovenia is expected to increase by 200 MW in each direction. Nevertheless, these figures are subject to discussions with the neighbouring TSOs, and it may occur that the actual NTC achieved will be lower than expected, as described in one of the project risks together with risk mitigation strategies. Based on the above, the promoters positively quantify this KPI.	
KPI_{20}: exploitation of interconnection capacities	Similarly to KPI_{19}, KPI_{20} also relates to an efficient upgrade of cross-border capacity. The exploitation of interconnection capacities can be calculated by comparing the yearly allocated NTC per border with the average yearly load flow on that same interconnection. In the Smart Grids scenario, the promoters assume that average load flow will increase by 50 MW on the direction from Austria to Slovenia due to power control devices and 70 MW on the direction from Croatia to Slovenia due to increased renewables generation and increased cross border capacity. The exploitation rate for SG scenario for the project are: • SI-AT: NTC=950 MW, $\mu_i(load_{flow}) = 19$; ER=2% • AT-SI: NTC=950 MW, $\mu_i(load_{flow}) = 536$; ER=56% • SI-HR: NTC=1200 MW, $\mu_i(load_{flow}) = 413$; ER=34% • HR-SI: NTC=800 MW, $\mu_i(load_{flow}) = 60$; ER=7,5% The promoters calculated the KPI for the following interconnectors and directions: SI-IT: 34 %; SI-AT: 0%; AT-SI:-9%; SI-HR: 14%; HR-SI:-70%.	
KPI_{21}: congestion rents across interconnections	The Green Switch project is expected to increase NTC at the interconnectors of the Member States involved in the project. The promoters reports that this will most likely change the income from auctions for the neighbouring TSOs and based on their previous experience, such increase in capacity will be followed by decrease in auction prices, and the net effect regarding income from auctions for cross-border capacity will be around 0. However, at this point promoters are not able to give an accurate estimation.	

Source: Own elaboration, 2021.

Policy criterion 5: market functioning and customer services

The Green Switch project demonstrates positive impact on this policy criterion owing to increased digitalisation and automation included in the project, which will allow the regulators to develop tariff structure that would more accurately offset the costs incurred by grid users. Furthermore, the project promotes development of flexibility platforms, and facilitates demand side participation, which are both vital to the development of a well-functioning flexibility market. Finally, the project increases NTC and the average load flow at the interconnectors included in the project and this way, it contributes to better utilisation of the interconnection lines and better functioning of the EU internal energy market.

The promoters demonstrate the project's impact on the fifth specific criterion using the KPIs indicated in Table 28.

Table 28. Green Switch project: evaluation of project's impact against the fifth specific criterion

Selected KPIs	Calculation approach and impact evaluation	
KPI_6: methods adopted to calculate charges and tariffs, as well as their structure for generators, consumers and those that do both	The Green Switch project involves smart grid investments with high degree of digitalisation and automation, which results in increased network observability. This would ultimately allow regulators to establish tariff structure that would more accurately offset the costs incurred by the grid users. The implementation and integration of flexibility resources will strongly promote development and implementation of methods and mechanisms related to the provision of flexibility services. Data gathered will enable DSOs to determine the product on the flexibility market, define when the service needs to be activated and measure its result. Users will be able to actively participate in flexibility markets and manage their demand. The network infrastructure installed within the project will enable to accurately monitor response from consumers which is not possible without upgrading the ICT system. The project would allow more informed decision-making for the grid operators regarding grid developments, whereas the regulators would have more information about the potential of market-based solutions versus grid investments.	
KPI_{14}: ratio between minimum and maximum electricity demand within a defined time period	The Green Switch project is expected to reduce peak demand by deploying battery storage and demand response. The promoters define P_{min} and P_{max} as load in the selected secondary substations and industrial locations, as flexibility will be used only in areas where needed and estimate 100 secondary substations with rated power of 160 kVA to be included in provision of flexibility services. Additionally, deployment of battery storage in 30 industrial locations would also contribute to the peak load reduction. Based on the above, the promoters positively quantify the project's impact on this KPI.	
KPI_{15}: demand side participation in electricity markets and in energy efficiency measures	The project is expected to increase demand side participation as a valuable source for the provision of ancillary services owing to deployment of 46 MW of energy storage and 2 MW of controllable loads. The promoters provide positive quantification of this KPI.	
KPI_7: operational flexibility provided for dynamic balancing of electricity in the network	The promoters demonstrate positive project's impact on this KPI by referring to the deployment of 46 MW of energy battery storage, which will prove operational flexibility for balancing at distribution network level as well as for providing ancillary services at transmission network level.	
KPI_{19}: ratio between interconnection capacity of a Member State and its electricity demand	The smart grid investments deployed in the project contribute to increase in the cross-border capacity, thereby providing efficient alternative to building new network lines. The promoters calculate this KPI for all the interconnectors of the participating countries. In the BaU scenario the average NTC at the border between Austria and Slovenia is 950 MW for both directions, the average	

	NTC on border from Slovenia to Croatia is 1,200 MW and 800 MW from Croatia to Slovenia. While NTC on border between Slovenia and Croatia is utilised 100 % of time, the NTC on Austrian border is utilised less than 90 % of time. With the installation of power control devices, the NTC on the Slovenian-Austrian border can be expected to be utilised at close to its nominal value. The NTC on the border between Croatia and Slovenia is expected to increase by 200 MW in each direction. Nevertheless, these figures are subject to discussions with the neighbouring TSOs, and it may occur that the actual NTC achieved will be lower than expected, as described in one of the project risks together with risk mitigation strategies. Based on the above, the promoters positively quantify this KPI.	
KPI_{20}: exploitation of interconnection capacities	Similarly to KPI_{19}, KPI_{20} also relates to an efficient upgrade of cross-border capacity. The exploitation of interconnection capacities can be calculated by comparing the yearly allocated NTC per border with the average yearly load flow on that same interconnection. In the Smart Grids scenario, the promoters assume that average load flow will increase by 50 MW on the direction from Austria to Slovenia due to power control devices and 70 MW on the direction from Croatia to Slovenia due to increased renewables generation and increased cross border capacity. The exploitation rate for SG scenario for the project are: • SI-AT: NTC=950 MW, $\mu_i(load_{flow}) = 19$; ER=2% • AT-SI: NTC=950 MW, $\mu_i(load_{flow}) = 536$; ER=56% • SI-HR: NTC=1200 MW, $\mu_i(load_{flow}) = 413$; ER=34% • HR-SI: NTC=800 MW, $\mu_i(load_{flow}) = 60$; ER=7,5% The promoters calculated the KPI for the following interconnectors and directions: SI-IT: 34 %; SI-AT: 0%; AT-SI:-9%; SI-HR: 14%; HR-SI:-70%.	
KPI_{21}: congestion rents across interconnections	The Green Switch project is expected to increase the NTC at the interconnectors of the Member States involved in the project. The promoters report that this will most likely change the income from auctions for the neighbouring TSOs and based on their previous experience, such increase in capacity will be followed by decrease in auction prices, and the net effect regarding income from auctions for cross-border capacity will be around 0. However, at this point promoters are not able to give an accurate estimation.	

Source: Own elaboration, 2021.

Policy criterion 6: involvement of users in the management of their energy usage

The Green Switch project demonstrates positive impact on this policy criterion owing to increased digitalisation and automation included in the project, which will allow the regulators to develop tariff structure that would more accurately offset the costs incurred by grid users. This would encourage network users to be better involved in management of their energy usage. The project also includes battery storage and facilitate demand side participation.

The promoters demonstrate the project's impact on this specific criterion using the KPIs indicated in Table 29.

Table 29. Green Switch project: evaluation of project's impact against the sixth specific criterion

Selected KPIs	Calculation approach and impact evaluation

KPI_6: methods adopted to calculate charges and tariffs, as well as their structure for generators, consumers and those that do both	The Green Switch project involves smart grid investments with high degree of digitalisation and automation, which results in increased network observability. This would ultimately allow regulators to establish tariff structure that would more accurately offset the costs incurred by the grid users. The implementation and integration of flexibility resources will strongly promote development and implementation of methods and mechanisms related to the provision of flexibility services. Data gathered will enable DSOs to determine the product on the flexibility market, define when the service needs to be activated and measure its result. Users will be able to actively participate in flexibility markets and manage their demand. The network infrastructure installed within the project will enable to accurately monitor response from consumers which is not possible without upgrading the ICT system. The project would allow more informed decision-making for the grid operators regarding grid developments, whereas the regulators would have more information about the potential of market-based solutions versus grid investments.	
KPI_{14}: ratio between minimum and maximum electricity demand within a defined time period	The Green Switch project is expected to reduce peak demand by deploying battery storage and demand response. The promoters define P_{min} and P_{max} as load in the selected secondary substations and industrial locations, as flexibility will be used only in areas where needed and estimate 100 secondary substations with rated power of 160 kVA to be included in provision of flexibility services. Additionally, deployment of battery storage in 30 industrial locations would also contribute to the peak load reduction. Based on the above, the promoters positively quantify the project's impact on this KPI.	
KPI_{15}: demand side participation in electricity markets and in energy efficiency measures	The project is expected to increase demand side participation as a valuable resource for the provision of ancillary services owing to deployment of 46 MW of energy storage and 2 MW of controllable loads. The promoters provide positive quantification of this KPI.	

Source: Own elaboration, 2021.

The following section presents the societal benefits of the Green Switch project in monetary terms along with the total cost (capital and operational expenditure), as communicated by the promoters. Furthermore, economic indicators such as the NPV, the IRR and the B/C ratio are used to verify whether the overall project' benefits outweigh the project's costs and, therefore, whether or not the project complies with the second general criteria of the regulation (Article 4(b)).

The promoters assumed the following values for the variables used in the societal CBA.

- **Demand growth:** average demand growth of 2.1 % in the period from 2020 – 2025
- **Discount rate:** a value of 4 % has been assumed for the societal discount rate (Vasiljevska and Gras, 2017)
- **Time horizon:** 15 years
- **Peak load growth**: 1.5%
- **Price of energy losses**: 53 €/MWh [18]
- **CO_2 price:** Commission reference scenario up to 2030 [19]

[18] www.eex.com

[19] IHS Markit: European Power Planning Case: Comparing the August 2020 and February 2021 Outlooks, 1st of February 2021

- **Value of lost load:** 11 €/kWh [20]

The project reports positive outcomes of the societal CBA. The main monetary benefits and costs are listed below (in descending order).

Main monetary benefits

- Deferred transmission investment
- Avoided transmission investment
- Reduction of GHG emissions
- Avoided generation capacity investment for spinning reserves
- Value of service
- Societal welfare due to increased cross-border capacity
- Deferred distribution investment
- Reduced cost of maintenance.

Main costs (per project participant) - CAPEX

ELES:

- Power control devices
- HTLS on two 110 kV lines
- Grid connection for heavy duty charging stations
- Extraction of heat from transformers
- Extension of DTR system
- ICT network.

Elektro Celje:

- Automation of new secondary substation
- Cabing (for creating loops)
- ICT network
- Advanced Demand Management System (ADMS)
- Automation of old secondary substation
- Recloser.

Elektro Gorenjska:

- Advanced Demand Management System (ADMS)
- Automation of primary substation
- Automation of new secondary substation
- Automation of old secondary substation
- Cabling (for creating loops)
- ICT network

KNG:

- Cabling (for creating loops)

[20] Value used by comparable projects/states in previous PCI applications

- Automation of primary substation
- ICT network
- Automation of new secondary substation
- Automation of old secondary substation
- Cross-border connection
- Advanced Demand Management System (ADMS).

HEP ODS:

- HTLS
- Automated primary substation
- Automation of old secondary substation
- ICT network
- FACTS.

HOPS:

- Power control devices
- HTLS on two 110 kV
- ICT network
- Extension of DTR system.

GEN-I:

- Battery storage
- VPP.

HEP:

- Battery storage.

Main costs – OPEX

- Maintenance
- Insurance costs
- Operation (cost of full time equivalent for persons working on the assets and functionalities during the project lifespan).

The overall project's benefits outlined above outweigh the project's costs and the project reports the following economic indicators: ENPV: €538.5 mil., IRR: 64 %, B/C: 4.05.

Sensitivity analysis

Critical variables in the project, which have been also subject to sensitivity analyses are the following:

- Reducing avoided GHG emissions by 50 % (decrease in NPV by 261.9 mil. €)
- Increasing investment costs by 30 % (decrease in NPV by 60.3 mil. €)
- Reducing benefits of higher value of service by 50 % (decrease in NPV by 35.7 mil. €).

Additional non-monetary benefits

The project proposal also includes a set of non-monetary impacts, such as:

- Societal welfare due to increased cross-border capacity

- Flexibility market in Austria
- Increased security of supply.

2.5.3. Summary of the Green Switch project's evaluation

The Green Switch project includes an area with increasing power flows on both distribution and transmission grid coming from growing penetration of renewable energy sources, as well as increasing peak consumption from electric vehicles and heat pumps. To this end, the grid operators involved in the project face increasing investment demands to tackle these challenges while at the same time ensuring security and quality of supply.

The basic idea behind the Green Switch project is to optimise the utilisation of existing infrastructure and efficiently integrate new technologies and advanced functionalities to allow for higher hosting capacity, efficient integration of new loads and new type of loads (e.g. electric vehicles), optimise future investments and improve the security and the quality of operation and supply.

The project involves partners from Slovenia, Croatia and Austria, and more specifically, TSOs, DSOs, retailer and a generation company. The project promoters have recognised the value of cooperation among partners facing similar challenges in their grid areas and proposes cost-effective solutions by responding to common needs for complex management of power flows at transmission and distribution network levels. For example, the project is expected to lead to 29% - 37% of cost reduction for deployment of power control units for power flow management of the 220 kV network as opposed to each Member having to deal with this challenge separately.

Similarly, DSOs in all three countries need to integrate growing requests for connection of distributed generation and new loads. Smart grid functionalities included in the project are seen as the only alternative for a timely and sufficient increase of the hosting capacity of existing grid and improving the security and quality of supply while reducing the need for costly and lengthy investments in primary network equipment. Nevertheless, these large amounts of new loads and generation connected to the distribution grid will have an impact on the high voltage level and ultimately contribute to increased volatility of cross-border flows that need to be managed by the TSOs, which again confirms the added value of joint approach to these common challenges. This requires installation of smart grid equipment, mainly at 10 kV level or higher which will enable implementation of advanced functionalities to integrate new distributed generation and loads as well as increase reliability and quality of supply (compliance with the criteria of Article 4(1)(c)).

The project demonstrates cross-border dimension both at transmission and distribution network level. At transmission network level, TSOs from Slovenia and Croatia aim to increase the capacity of existing cross border lines by installing high temperature wire technology (HTLS), Dynamic Thermal Rating (DTR) and install Power Control Systems to better control the cross-border flows, thereby increasing the safety and reliability of the electricity system in the project area as well as demonstrating positive impact on the neighbouring power systems. Moreover, the project aims to increase the cross-border capacity at the DSO level in the project area by installing a MV cross-border emergency electrical connection between Austria (KAERNTEN NETZ) and Slovenia (Elektro Gorenjska) and upgrading another existent MV cross-border interconnection in the area of Seebergsattel (Jezersko), both with the aim to increase security of supply in the bordering area of both DSOs.

In addition, the project demonstrates a significant contribution to the six smart grid specific criteria outlined in Article 4(2) of the regulation and a positive outcome in the project's societal CBA.

3. Summary of the projects' evaluation

The outcome of the projects' overall evaluation is summarised in the tables below and in line with the analysis presented in the previous sections. Table 30 illustrates an overview of the projects' compliance with the eligibility requirements of Article 4 of the regulation, namely (1) the project's necessity for the thematic area of smart grids deployment, (2) the project's compliance with the general criteria under Article 4(1)(c) and (3) a positive outcome of the societal CBA. Positive CBA outcome demonstrates that the project's overall benefits outweigh the project's costs by significantly contributing to the six policy criteria of Article 4(2)(c) to the regulation.

Table 30. Overview of projects' compliance with the general criteria of the regulation (Article 4)

Project name	Necessity for the priority thematic area of smart grids	Compliance with the general criteria (Article 4(1)(c))	Positive outcome in the societal CBA
ACON	✓	✓	✓
CARMEN	✓	✓	✓
Danube InGrid	✓	✓	✓
Gabreta Smart	✓	✓	✓
Green Switch	✓	✓	✓

Source: Own elaboration, 2021.

Table 31 illustrates the projects' assessment related to the contribution of each project proposal to the six smart grid specific criteria outlined in Article 4(2)(c) to the regulation, using the key performance indicators indicated in Annex IV (4) to the regulation and based on the information provided by the promoters. Some of these impacts were further monetised by the promoters and used in the societal CBA. This way, the assessment presented in Table 33 should be seen as complementary to the outcome of the societal CBA.

Table 31. Overall project contribution to the smart grid specific criteria

Policy criteria	ACON	CARMEN	Danube InGrid	Gabreta	Green Switch
Integration and involvement of network users with new technical requirements with regard to their electricity supply and demand					
Efficiency and interoperability of electricity transmission and distribution in day-to-day network operation					
Network security, system control and quality of supply					
Optimised planning of future cost-efficient network investments					
Market functioning and customer services					

Involvement of users in management of their energy usage					

Source: Own elaboration, 2021.

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List of abbreviations

ACER	Agency for Cooperation of Energy Regulators
ACON	Again COnnected Networks
ADMS	Advanced Distribution Management System
AMM	advanced meter management
BAU	business as usual
B/C	benefit/cost
BPL	Broadband over power lines
CBA	cost-benefit analysis
DER	distributed energy sources
DG	distributed generation
DSM	demand-side management
DSO	distribution system operator
DTR	dynamic thermal rating
ENTSO-E	European Network of Transmission System Operators for Electricity
FACTS	Flexible Alternating Current Transmission System
FLISR	Fault Location, Isolation, and Service Restoration
GHG	greenhouse gas
GIS	geographic information system
HV	high voltage
HVDC	high-voltage direct current
HTLS	high temperature low sag conductor
ICT	information and communication technology
IRR	internal rate of return
IT	information technology
KPI	key performance indicator
LV	low voltage
MV	medium voltage
NPV	net present value
NTC	net transfer capacity
OLTC	on-load tap changer
PCI	project of common interest
PLC	power line carrier
PMU	phasor measurement unit
R&D	research and development
RES	renewable energy sources

RMU	remote monitoring unit
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SCADA	supervisory control and data acquisition
SEPS	Slovenská elektrizačná prenosová sústava
SG	smart grid
TEN-E	Trans-European Networks for Energy
TSO	transmission system operator

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