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Solutions for the monitoring and digitalisation of high-voltage underground networks

September 2020

Translation of a document originally issued in Spanish. In the event of a discrepancy, the Spanish-language version prevails.

Objective of the document

The objective of this document is to **provide relevant information for the consideration, for remuneration purposes, of the investments in solutions based on the use of optical current transformers for the advanced monitoring of high-voltage underground networks.**

In this connection, the objective of this document is to inform about the nature of **these investments with reference to the regulatory requirements relating to electricity transmission and distribution:**

- **As regards electricity transmission,** relevant information is presented concerning the possibility of considering these investments as **"singular projects"** by their categorisation as **investments in switching stations and telecontrol or as pilot projects.**

- **As regards electricity distribution,** relevant information is presented concerning the consideration of these investments within the field of **digitalisation.** In this connection, **this document presents information about the potential classification of these investments as as investments in digitalisation,** which are related to **(i) the contribution of the solution to the main objectives of Circular 6/2019, (ii) their contribution to the guiding principles of the Integrated Spanish Energy and Climate Plan (NECP) in relation to digitalisation and decarbonisation** and **(iii) another series of ancillary benefits that are expected as a result of their implementation.**

Executive summary

Solutions for the maintenance and localisation of faults on underground cables

1 High-voltage underground electricity networks are assets that **require a high level of investment** by the companies engaged in the transmission and distribution of electricity. Such **networks have multiple benefits,** although they **also entail greater complexity in terms of their installation and assembly**, and in relation to their **operation and maintenance over their useful lives. The maintenance of underground cables and, particularly, the solutions that enable comprehensive maintenance (predictive, preventive and corrective) are critical in order to avoid future faults and increased system costs.**

2 **Traditional preventive maintenance** of **high-voltage underground networks is characterised by the performance of regular field tests, involving, among other things, live-line work, scheduled supply outages and team field trips.** In addition, **the difficulty of performing predictive maintenance and the lack, in many cases, of ongoing monitoring of the conditions of the cable, increases the need to carry out corrective maintenance, which often gives rise to prolonged outages resulting from the difficulty associated with the general pre-localisation and specific localisation of faults.**

3 In this connection, the **development of innovative solutions relating to the digitalisation, and, in particular, to the advanced monitoring of underground high-voltage cables** provides **global tools for the maintenance of these assets. The solutions based on the use of optical current transformers enable the unification of predictive maintenance,** through **ongoing monitoring of the status of the facility,** with **specific functions for corrective maintenance** such as the **pre-localisation and localisation of the fault** and the **discrimination of the origin of the fault in mixed sections (aerial-underground).**

4 **These maintenance improvements enable outage times and live-line work to be minimised.** As a result, **tangible benefits are obtained for the whole system,** through the **reduction in outages and the identification of points of the network with greater degradation,** which makes it possible to **enhance equipment before faults occur, thus avoiding reductions in their useful life,** and to take **actions in areas of the network with a high level of losses.**

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Solutions for the maintenance and localisation of faults on underground cables

5 Moreover, **the regulatory methodologies introduced in recent regulatory Circulars set by the Spanish National Markets and Competition Commission (CNMC) make it possible for the contribution of these solutions to a more optimum management of the electricity networks, both in terms of transmission and distribution, to give rise to the generation of efficiencies that consumers may benefit from over successive regulatory periods. In addition, the implementation of this solution could provide a complementary tool for the remuneration mechanisms, based on incentives, to enhance the quality of supply and reduce losses.**

6 **The implementation of this type of solutions is aligned with the digitalisation, electrification and decarbonisation objectives of the Spanish energy policy for 2030, as well as with the European Commission's objectives in the context of the post-COVID-19 "reconstruction", centred on a recovery "towards a greener, digital and more resilient Europe". It is also necessary to consider the contribution in terms of employment and the innovation of the Spanish companies that develop this type of technological solutions.**

7 As indicated in the previous points, **these solutions can provide the system with a series of quantitative and qualitative benefits.** In this connection, **in order to ensure the investments enabling these solutions are made, the managers of electricity transmission and distribution networks must be able to process them using the existing regulatory mechanisms.**

8 **In order to evaluate the solution, a generally accepted methodology has been applied, which was originally proposed by the Electric Power Research Institute (EPRI) and subsequently used by the European Commission for the preparation of guidelines for cost-benefit analysis in certain industry solutions,** such as the deployment of smart meters or the development of smart grids.

Executive summary

Solutions for the maintenance and localisation of faults on underground cables

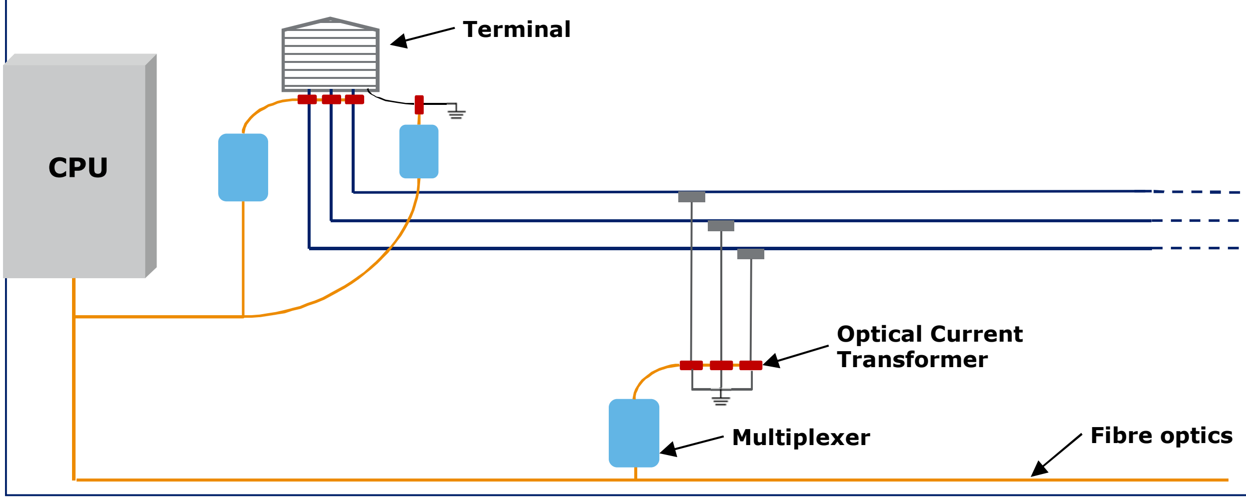
Main elements and functionalities of the solution based on optical current transformers for the monitoring of high-voltage underground cables

Solution functionalities

Predictive maintenance + **Fault discrimination on mixed lines** + **Localisation of the fault**

Non-exhaustive analysis

Basic outline of the implementation of the solution in a high-voltage underground cable



Basic elements for the implementation of the solution

Processing unit

This is the **component in charge of processing the information from the optical current transformers**, in order to show the results to the network manager so that continuous knowledge of its status is provided.

Optical Current Transformers

These elements **make it possible to capture the information on the state of the cable by measuring the nominal current of the cable or the current of the screens.** These are passive elements that send the information to the processing unit through the optical fibre.

Multiplexer

Passive elements that allow for different optical current transformers **to be shared on the same fibre, minimising the use of optical fibre.**

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The Spanish electricity transmission network has 1,076 km of underground cables[1], with the following voltage levels:

- **88 km of 400 kV**
- **988 km at voltages of up to 220 kV**

The electricity distribution network has more than 2,000 km of underground cables of more than 36 kV, approximately **75% of cables with a voltage of up to 110 kV and 25% of cables with a voltage between 110 kV and 220 kV.**

Underground electricity cables have a series of common features

- **Expensive repairs and complex logistics**
- **Monitoring complexity**
- **Difficulty of visual inspection**
- **There is a risk of failure caused by external agents**
- **Typically, these are critical facilities**

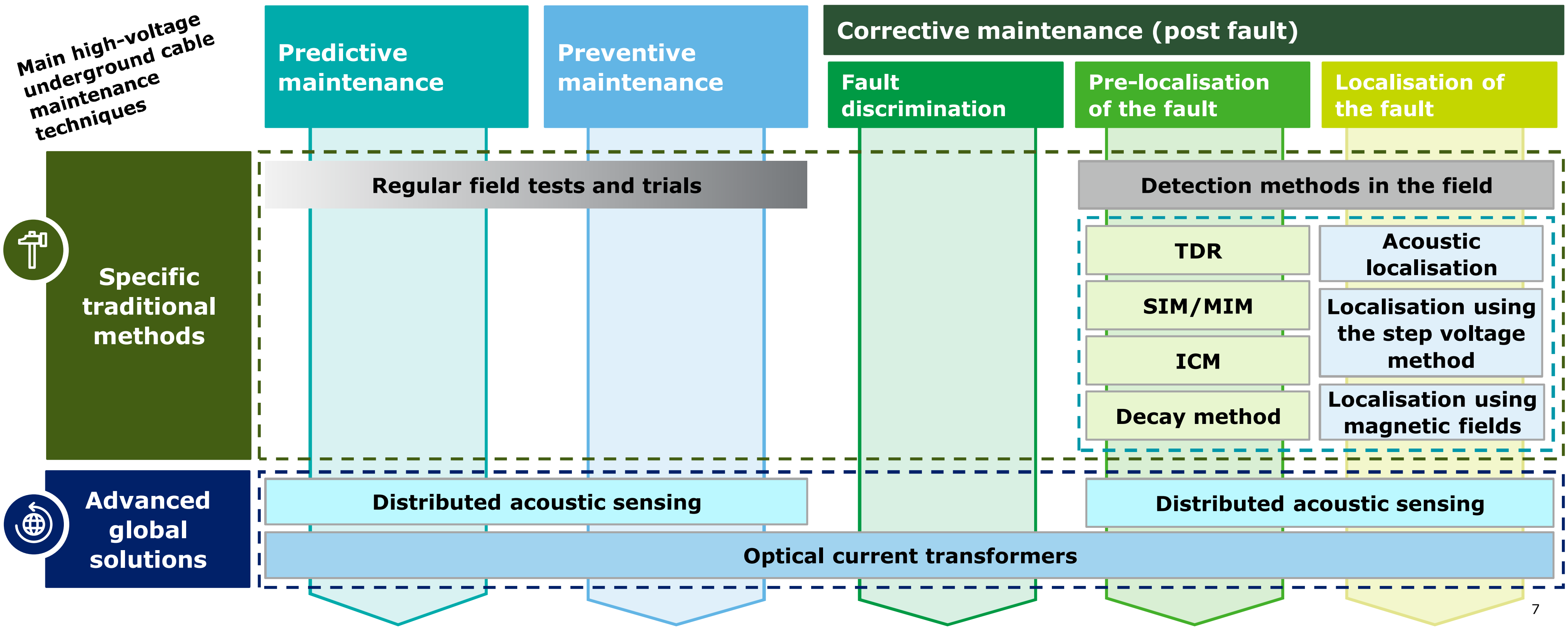
There are **especially sensitive points relating to the operation and maintenance of high-voltage underground networks: (i) cable joints and connections, (ii) switchgear and (iii) network terminal points.**

(1) Source: *Preliminary report of the Spanish Electricity System 2019* – Red Eléctrica de España (REE)

Executive summary

Solutions for the maintenance and localisation of faults on underground cables

2 **Traditional preventive maintenance** of **high-voltage underground networks is characterised by the performance of regular field tests, involving, among other things, live-line work, scheduled supply outages and team field trips.** In addition, **the difficulty of performing predictive maintenance and the lack, in many cases, of ongoing monitoring of the conditions of the cable, increases the need to carry out corrective maintenance, which often gives rise to prolonged outages resulting from the difficulty associated with the general pre-localisation and specific localisation of faults.**



Executive summary

Solutions for the maintenance and localisation of faults on underground cables

3

In this connection, the **development of innovative solutions relating to the digitalisation, and, in particular, to the advanced monitoring of underground high-voltage cables** provides **global tools for the maintenance of these assets. The solutions based on the use of optical current transformers enable the unification of predictive maintenance,** through **ongoing monitoring of the status of the facility,** with **specific functions for corrective maintenance** such as the **pre-localisation and localisation of the fault** and the **discrimination of the origin of the fault in mixed sections (aerial-underground).**

Main functionalities of the advanced monitoring of high-voltage underground cables using optical current transformers

Predictive maintenance

It uses **the currents flowing through the cable screens** as a reference.

The **screen circuits run right along the cable**, so they can provide information about its state, thereby making it possible to:

- **Monitor the integrity of the grounding circuit.**
- Obtain real-time **information on the state of operation of the cable** and assess any **possible degradation of its insulation.**

Fault discrimination on mixed lines

It facilitates **discrimination, in mixed lines, of whether the fault originates from the aerial or underground section.**

This solution **enables the reclosers to act as long as the fault occurs in overhead sections, avoiding reclosing in the event of a fault in the underground section.** In this way, **any line downtime due to ignorance of the real origin of the fault is reduced.**

Localisation of the fault

It **makes it possible to pre-localise the area where the fault is located and to localise it exactly** if an impedance model of the facility is available.

The operation of the solution determines, sequentially, (i) **the fault phase**, (ii) the **main faulty part**, (iii) the **lesser faulty part** and (iv) the **fault point**.

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Solutions for the maintenance and localisation of faults on underground cables

4 **These maintenance improvements enable outage times and live-line work to be minimised.** As a result, **tangible benefits are obtained for the whole system,** through the **reduction in outages and the identification of points of the network with greater degradation,** which makes it possible to **enhance equipment before faults occur, thus avoiding reductions in their useful life,** and to take **actions in areas of the network with a high level of losses.**

An analysis has been performed of the costs and benefits associated with a global implementation of the solution in the Spanish high-voltage underground network, both in transmission and distribution.

Estimated costs	Initial capital expenditure (CapEx)	**EUR 53.2 – EUR 58.2 M**	Estimated annual OPEX	**EUR 0.5 – EUR 0.6 M/year**
Estimated benefits	Annual benefits associated with the reduction in interruption times	**EUR 4.7 – EUR 5.8 M/year**	Annual benefits associated with the reduction in losses	**EUR 0.13 – EUR 0.18 M/year**

2 scenarios have been considered: scenario 1 does not envisage network developments or increases in demand, whereas scenario 2 does envisage both network developments and increases in demand in parallel with the electrification process of the economy. In both cases, it is observed that the implementation of the solution would give rise to net benefits for the system.

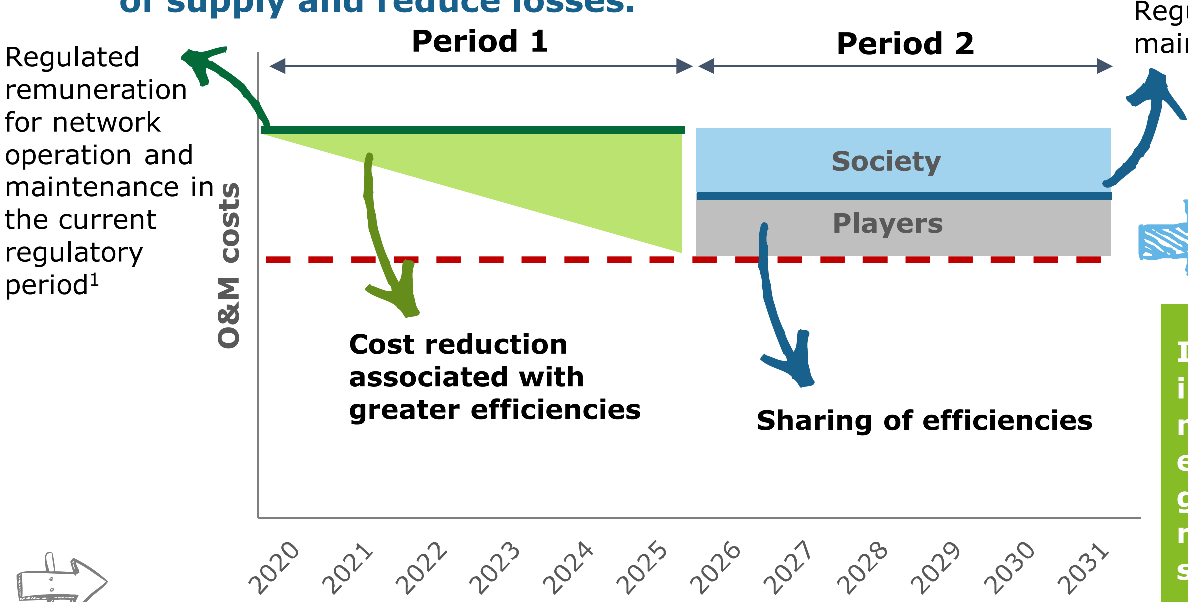
Estimated global outcome	Current net benefit of the investment (NPV)[1]	**Scenario 1:** EUR 6.2 – EUR 25.7 M	**Scenario 2:** EUR 10.5 – EUR 33.1 M

(1) Discount rate used: 5.58%.

Executive summary

Solutions for the maintenance and localisation of faults on underground cables

5 Moreover, **the regulatory methodologies introduced in recent regulatory Circulars set by the Spanish National Markets and Competition Commission (CNMC) make it possible for the contribution of these solutions to a more optimum management of the electricity networks, both in terms of transmission and distribution, to give rise to the generation of efficiencies that consumers may benefit from over successive regulatory periods. In addition, the implementation of this solution could provide a complementary tool for the remuneration mechanisms, based on incentives, to enhance the quality of supply and reduce losses.**



Benefit for society

The benefits arising from the efficiencies achieved in the current regulatory period will be shared out among companies and society in the next regulatory period

Investment in tools that provide more information on the condition of the high- and middle-voltage underground network enables efficiency to be increased and, at the same time, gives rise to a series of ancillary benefits that reduce industry costs and increase physical safety and security of supply.

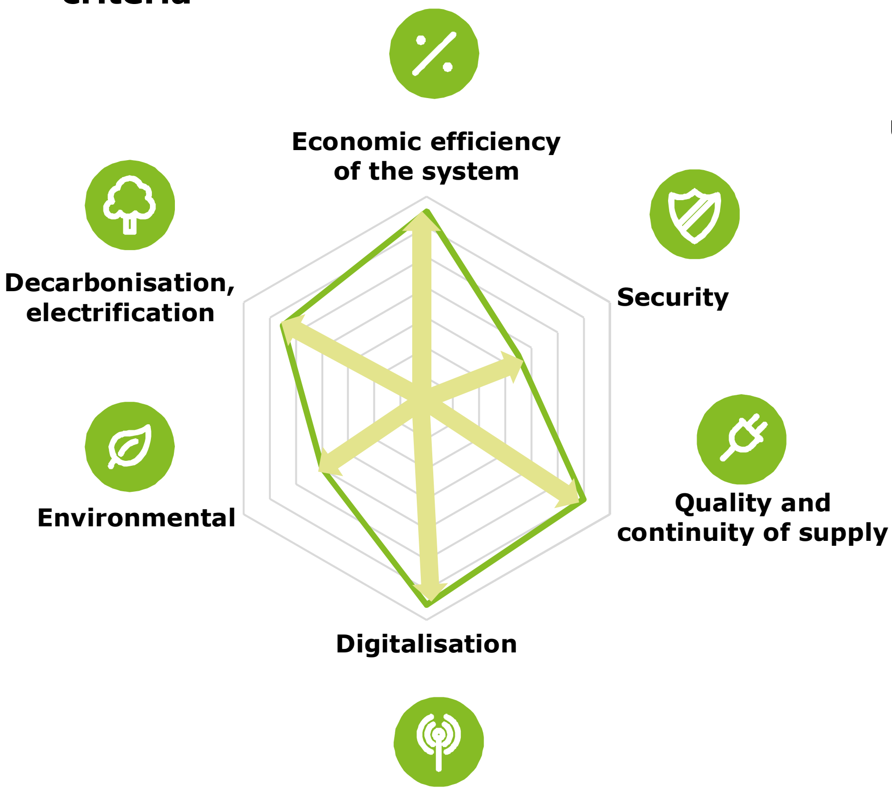
The current incentives to improve the quality of supply and reduce electricity distribution losses are zero-sum remuneration mechanisms, which foster competition between companies. However, in order to enhance levels of quality and losses above a particular threshold, the development of solutions such as the one analysed in this document would enable companies to be provided with the tools required for a global improvement in indicators, which would complement the improvements achieved by means of incentives.

(1) With respect to the methodology for determining the remuneration for electricity distribution, the cost reduction is performed each year of the 2020-2025 regulatory period with an annual reduction of approximately 3%. However, in adjustments prior to future regulatory periods, the greater efficiencies can be shared among companies and users, giving rise to an economic benefit for society.

Solutions for the maintenance and localisation of faults on underground cables

6 **The implementation of this type of solutions is aligned with the digitalisation, electrification and decarbonisation objectives of the Spanish energy policy for 2030, as well as with the European Commission's objectives in the context of the post-COVID-19 "reconstruction", centred on a recovery "towards a greener, digital and more resilient Europe". It is also necessary to consider the contribution in terms of employment and the innovation of the Spanish companies that develop this type of technological solutions.**

Evaluation of the impact of the solution in relation to the applicable regulatory criteria



Significance of the ancillary benefits

The solution provides **benefits in terms of security**, by contributing towards a reduction in live-line working, and **aspects relating to the environment and the energy policy of decarbonisation and electrification**, by permitting enhanced monitoring of the underground networks, which are more resilient to climate change, and by optimising the functioning of these networks in the face of changing charge scenarios associated with the integration of renewable energy technologies, **which makes it possible to provide enhanced information on key matters such as wave quality.**

Contribution to economic recovery

The promotion of the **digitalisation of the electricity transmission and distribution networks** constitutes a vector boosting economic activity, given the importance of the Spanish companies working in this field.

In addition, **the development of this type of tools may be favoured by the investment programmes being designed by the European Commission, the bases of which consider the ecological and digital transition to be a key lever for boosting activity and fostering economic recovery in the aftermath of the COVID-19 pandemic.**

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Solutions for the maintenance and localisation of faults on underground cables

7 As indicated in the previous points, **these solutions can provide the system with a series of quantitative and qualitative benefits.** In this connection, **in order to ensure the investments enabling these solutions are made, the managers of electricity transmission and distribution networks must be able to process them using the existing regulatory mechanisms.**

Scope of application	Reference legislation	Possible regulatory mechanisms that would be a good fit for the proposed solution	
Electricity transmission	**Circular 5/2019** and **Circular 7/2019**	**Singular facilities**	*Those transmission facilities that have **design, configuration, operational or technical conditions that differentiate them from the standard facilities considered in the reference unit values included in the corresponding Circular.*** *[…] **switching stations and telecontrol of the transmission network, since they lack a unit reference value.*** *Those **investments made by the transmission companies in pilot projects**. These investments must represent a **quantifiable benefit** for the system in terms of security, quality, efficiency, objectivity and transparency, for which the request for recognition of this type of investment must be accompanied by a **cost-benefit analysis and a technical report**.*
Electricity distribution	**Circular 6/2019**	**Investments in network digitalisation and automation necessary for the energy transition** **Advanced High-Voltage Monitoring Systems (from 36 kV).** **Network sensorisation and monitoring equipment.**	**Investments in pilot projects** In a manner similar to the Transmission Circular, **Circular 6/2019** includes the possibility of making **investments in pilot projects,** which must represent a **quantifiable benefit** for the system **in terms of security, quality, efficiency, objectivity and transparency**.

Executive summary

Solutions for the maintenance and localisation of faults on underground cables

8 **In order to evaluate the solution, a generally accepted methodology has been applied, which was originally proposed by the Electric Power Research Institute (EPRI) and subsequently used by the European Commission for the preparation of guidelines for cost-benefit analysis in certain industry solutions,** such as the deployment of smart meters or the development of smart grids.

Characterise the Project

1. Review and describe **technologies, elements** and **goals of the project.**
2. **Map assets onto functionalities.**

Estimate Benefits

3. **Map functionalities onto benefits.**
4. **Establish the baseline**
5. **Monetise benefits and identify beneficiaries.**

Compare Cost and Benefits

6. **Identification and quantification of the main costs of the solution.**
7. **Quantitative comparison of the costs and benefits** derived from the implementation of the solution.

Qualitative Analysis

8. Evaluation of the **contribution of the solution to the main specific criteria established by the regulation setting up the framework for the solution**.
9. **Identification and estimation of other aspects and qualitative social impacts that are difficult to assess quantitatively.**

Evaluation of the solution

1 2 3 4 5 6 7 8 9

Analysis methodology

General description

A generally accepted **methodology** has been applied (prepared by the Electric Power Research Institute (EPRI)), which in turn is used by the **European Commission in the preparation of guidelines for cost-benefit analysis in certain solutions in the electricity industry**, such as the deployment of smart meters or the development of smart grids. This analysis is proposed **considering both quantitative and qualitative impacts**.

Characterise the Project

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Analysis methodology

Step 1: Review and describe technologies, elements and goals of the project.

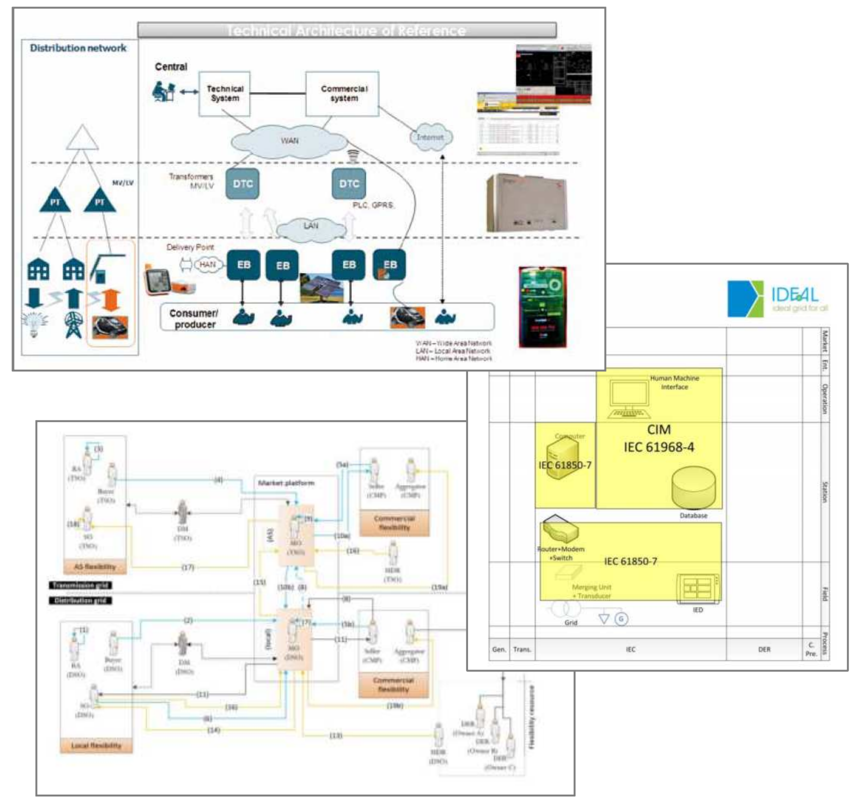
The first stage for carrying out the cost-benefit analysis is the **definition of the elements that make up the solution, as well as the main objectives sought with its implementation**.

The proposed solution must be clearly defined as a self-sufficient unit of analysis. To this end, as a minimum the following information should be provided:

-Non-exhaustive analysis-

- Characteristics of the electrical network where the solution would be implemented.
- Regulatory context and its impact as a framework in which the solution would be implemented.
- Clear definition of the objectives of the solution, as well as the expected impacts at socioeconomic level.
- Description of main solutions applied in the current scenario.
- Main technical features of the new proposed solution.
- Any other feature that helps define the solution, adding value and setting it apart from other more classical or traditional solutions.
- Relevant players in the implementation of the solution, involved both directly and indirectly.

Illustrative examples



Step 1: Review and describe the project

Characteristics of the electrical network where the solution would be implemented.

Difficulty of visual inspection

High-voltage underground power cables, together with the accompanying communication elements, **are designed to operate over a useful life of several decades without the possibility of periodic visual inspections.**

Monitoring complexity

Monitoring for the pre-detection of effects such as corrosion, damage or wear on the cable is critical, and, in turn, **difficult to perform.** Usually, **a power outage is the first indicator of a facility failure.**

Expensive repairs and complex logistics

Repair on an underground high-voltage cable is a logistically complex and expensive process, due to the difficulty of accessing the area where it is identified that the fault may have occurred.

There is a risk of failure caused by external agents

In addition to the risk of a failure in the facility due to a fault in the cable, **there is also a high risk that it will occur due to external factors, caused by third parties or weather events. In these cases it is essential to optimise the fault localisation process.**

These are critical facilities

Since underground high-voltage power cables are typically **critical facilities due to the type of facilities they supply**, it is **important to have rapid detection methods that are able to accurately identify the point on the cable where the fault has occurred.**

Monitoring of new and existing cables

It is recommendable **to have monitoring systems in underground high-voltage cables** that can be housed on new cables at the time of their construction, as well as systems that can be easily fitted to existing cables.

Step 1: Review and describe the project

Characteristics of the electrical network where the solution would be implemented.

Predictive maintenance

The **most advanced predictive maintenance methods consist of sensorisation and monitoring** that allow **continuous data collection** which **gives an insight into the status of the facility.**

Traditional predictive maintenance methodologies consist of carrying out **tests based on diagnostic evaluations** based on the age or criticality of the equipment, the forces they are subjected to, the degree of use, etc.

Preventive maintenance

It is **routine maintenance that is carried out regardless of the state of the facility**, in order to mitigate the risk of failure.

Additionally, preventive maintenance **may originate as a consequence of aspects identified in predictive maintenance.** In this case, the objective is **to correct the detected anomalies and recover the regulatory conditions** of the facility and improve its functionality after the deterioration suffered as a result of, inter alia, aging and external conditions.

Corrective maintenance (post failure)

Fault discrimination

It makes it possible **to ascertain whether the fault has occurred in the aerial or underground section of the cable.**

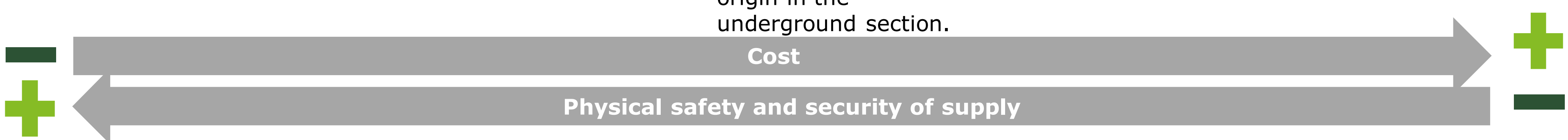
This aspect is **key to enabling the possible reclosing of the aerial section of the cable.** Awareness of the origin of the fault reduces downtime in cases where the fault is found in the aerial section and mitigates possible additional risks associated with reclosing in those cases where the fault has its origin in the underground section.

Pre-localisation of the fault

Tests or trials that **facilitate the approximate location of the fault to be determined**, in order to reduce uncertainty about the area in which it is located, **optimising the concomitant process of locating the exact spot.**

Localisation of the fault

Confirmation of the exact location of the fault, in order to **minimise the time and cost of repair.** In this regard, it must be taken into consideration that in underground networks **repairs usually require excavations and are logistically complex operations**, so it is necessary to obtain an exhaustive detail of the origin of the fault.



Step 1: Review and describe the project

Characteristics of the electrical network where the solution would be implemented.

In-depth knowledge of the underground electrical network is necessary to be able to identify its critical points and classify them to carry out the most complete and accurate predictive maintenance possible.

The critical points of an underground electrical network are those that **degrade most rapidly, so that a loss of insulation can occur, or those points that are critical to the security of the network.**

1 **Cable joints and connections**

2 **Switchgear**

3 **Network terminal points**

In order to correctly identify the critical points of the underground electrical facility, the way in which it degrades must be known.

Cable degradation

The origin can be:
- Thermal
- Electrical
- Mechanical
- Environmental
- A combination of various factors

Treeing

Insulation failure causing electrical current to flow through the insulation to the exterior

Insulation loss

The cable no longer has the same safety conditions as those for which it was designed

Partial discharges

Insulation failure produces localised discharges that partially breach the insulation

Deflagration of cable or insulation

Ultimate consequence of partial discharges occurring in relation to the conductor

Well-designed predictive maintenance should anticipate where and when degradation can occur in the facility, and ultimately prevent cable degradation from leading to more serious consequences.

Step 1: Review and describe the project

Characteristics of the electrical network where the solution would be implemented.

Preventive maintenance, unlike predictive maintenance, is routine and does not include complete supervision of the facility. In certain cases, predictive maintenance makes it possible to raise the alarm regarding the state of the facility and the preventive maintenance consists, in such cases, of **replacing cables or other elements that have deteriorated. Corrective maintenance is performed once the fault has occurred, and the main difficulty lies in locating the fault.**

Before the failure — *After the failure*

Types of maintenance

Preventive maintenance

Involving **maintenance prior to the appearance of cable faults.** Unlike predictive maintenance, **preventive maintenance is routine, less sophisticated and often involves replacing certain components of the facility.**

Preventive maintenance tasks include:

- ✓ Visual inspection of the structure.
- ✓ Visual inspection of the cable joints.
- ✓ Surface resistance test.
- ✓ Insulation test between conductors.
- ✓ Thermal cable joint scanner.
- ✓ Replacement of deteriorated cables.

Corrective maintenance

It is carried out **once the fault has occurred** and its objective is, firstly, **to pre-localise the fault position,** then to **localise the exact point and ultimately restore the current flow through the cable.** In the case of **mixed lines, it includes verifying the origin of the fault,** determining whether it is in the aerial or underground section.

Corrective maintenance tasks include:

- ✓ Visual inspection of the cable routing.
- ✓ Insulation tests between conductor and earth.
- ✓ Precise determination of the fault.
- ✓ Analysis of the causes of the fault and implementation of preventive measures.

Step 1: Review and describe the project

Characteristics of the electrical network where the solution would be implemented.

The main players mentioned above, both external to the underground electrical facility and those linked to it, can cause different types of damage to it, causing faults of varying levels of magnitude. Traditional predictive and preventive maintenance, based on conducting field trials, **does not allow for continuous and complete supervision that minimises the need for corrective maintenance.**

01

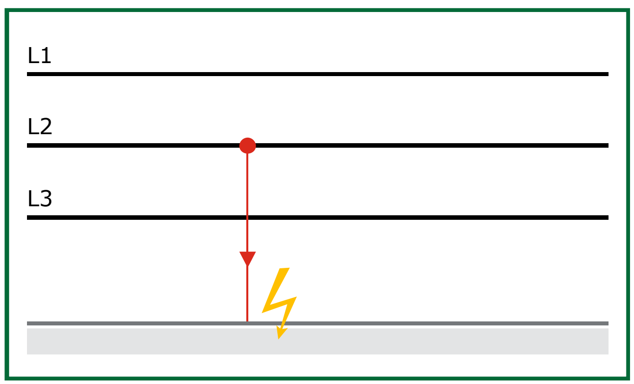
Short circuit

This occurs when, at the point of fault, **damage to the conductor insulation causes a connection to occur between the conductor and the screen that allows current to pass.** In general, the short circuit occurs between the conductor and the shield as a consequence of the degradation of the insulation. Residually, this fault can occur between two of the phases, or among the three phases (three-phase short circuit).

02

Earth leakage

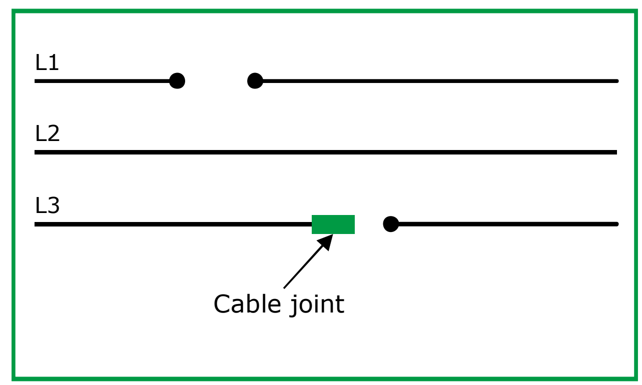
In this case, the fault is caused by the **earthing of an isolated network**, or by **earth leakage of an earthed network**.



03

Open circuit faults

These occur when **one or more conductors break** and a discontinuity occurs in the supply. They can also occur when, **due to mechanical stress, a conductor loses connection at the cable joint.**



Step 1: Review and describe the project

Characteristics of the electrical network where the solution would be implemented.

The main players mentioned above, both external to the underground electrical facility and those linked to it, can cause different types of damage to it, causing faults of varying levels of magnitude. Traditional predictive and preventive maintenance, based on conducting field trials, **does not allow for continuous and complete supervision that minimises the need for corrective maintenance.**

04

Intermittent faults

Sometimes **the failures are not constant, but arise only in the cable under certain conditions of intensity of electric current flowing through it.**

05

Faults in cable jackets

Damage to the cable sheaths **does not always directly cause a fault, but may be the cause of a long-term fault,** due to moisture penetration or conductor corrosion.

06

Fires

As a consequence of any of the above faults, a spark can start a **fire, spreading through the underground gallery, damaging other parts of the facility.**

Image source: Thorne & Derrick, CBC Radio Canada

1 2 3 4 5 6 7 8 9

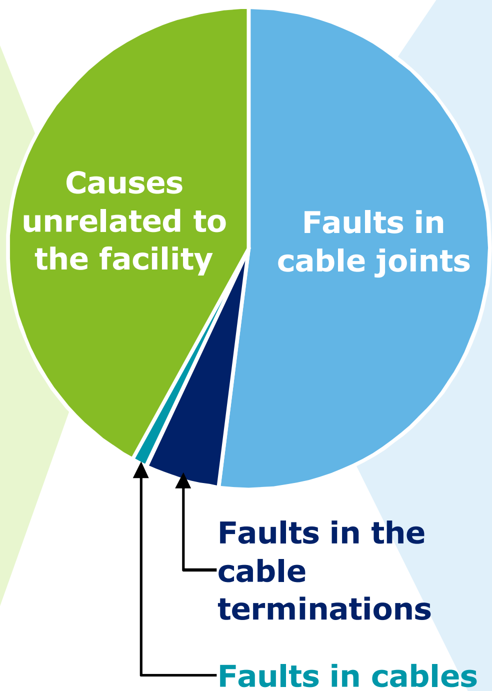
Step 1: Review and describe the project

Characteristics of the electrical network where the solution would be implemented.

Corrective maintenance is carried out once the fault or failure has affected the underground cable. In this sense, the **main causes of faults** in a high-voltage underground cable are, for the most part, due to **faults not produced strictly on the facility and to faults that occur in the joints between different cables.**

- **Maintenance** work and tasks **carried out without the proper protections in the vicinity of the facility.**
- **Damage caused during the transfer or assembly of the elements of the facility and not detected at start-up.**
- **Insulation defects not detected at start-up,** such as contamination, vacuoles, profusions or fouling between materials in the different layers of the cable.
- **Ambient humidity or water ingress.**
- **Loads on the facility due to the passage of vehicles.**
- **Unstable terrain,** which can lead to unwanted movement of earth.

Illustrative data



Of electrical origin:

- Voltage surges after opening and closing switches.
- Partial discharges.
- Lightning.

Of thermal origin:

- Increase in the admissible capacity on the conductor over long periods of time.
- High environmental temperature conditions.

Of mechanical origin:

- Excessive stress on the conductor in its placement or its arrangement with a radius of curvature below the minimum limit.
- Conditions of pressure or vibrations to which the materials are subjected due to, for example, works that take place in the vicinity.

Of environmental origin:

- Environmental agents, despite being a buried facility, can affect and accelerate the degradation of materials.

Joints: manual physical and electrical connection made between two different cable fragments.
Terminal: each of the two ends of the underground power cable.

Step 1: Review and describe the project

Regulatory context and its impact as a framework in which the solution would be implemented.

The Spanish central government, in collaboration with the autonomous community governments, **draws up an energy plan every four years, defining what the electricity system will be like in the medium and long term. For the period 2021-2026 this process began with the publication of Ministerial Order TEC/212/2019, of February 25,** which initiated the procedure to make proposals for the development of the electric power transmission network with a time horizon of 2026.

Main guiding principles of electricity transmission network planning

- ✓ **Compliance with energy and climate commitments** will be made at national level in the Spanish **NECP 2021-2030.**
- ✓ The **contribution** to **guarantee the security of supply of the electricity system.**
- ✓ The **removal of existing technical restrictions on the electricity transmission network.**
- ✓ **Compliance** with the principles of **economic efficiency** and the principle of **economic and financial sustainability of the electricity system.**
- ✓ **Maximising the use of the existing network**, renovating, expanding capacity, using new technologies and reusing existing facilities.

Main aspects included in the **draft National Integrated Energy and Climate Plan (NECP) regarding the digitisation and management of electricity transmission and distribution networks:**

- ***Networks will have to undergo an important digitalisation process that will allow them to improve their monitoring, control and automation systems.*** *Additionally, the digitalisation of networks will allow for effective demand management and integrate new services for consumers.*
- ***One mechanism to promote them is the remuneration schemes for regulated electricity distribution and transmission activities that make possible the necessary advance in digitalisation, encourage innovation and the application of alternative solutions to traditional investments that can bring savings to the system*** *and recognise the higher level of interaction of network managers with users.*

Main aspects included in the **draft of Spain's National Plan for Adaptation to Climate Change:**

- ***Improve knowledge of the potential impacts of climate change on the functionality and resilience of energy generation, transmission, storage and distribution systems*** *and specify adaptation measures to avoid or reduce the identified risks.*
- ***Identify risks arising from extreme events in critical energy infrastructure*** *and apply measures to prevent them losing functionality.*

Step 1: Review and describe the project

Regulatory context and its impact as a framework in which the solution would be implemented.

Spanish National Markets and Competition Commission (CNMC) **Circular 5/2019**, of 5 December, **which establishes the methodology for calculating the remuneration for the activity of electricity transmission**, establishes the type of regulated remuneration from which the **solution in the area of electricity transmission could benefit**:

Considerations on the methodology for **calculating the remuneration for the activity of electricity transmission.**

Inclusion in existing types of facility

Circular 7/2019 establishes a series of **new standard facilities associated with network modernisation and digitalisation and which may be classified as singular facilities.**

Static Synchronous Compensator	Static VAR Compensator	Thyristor Controlled Reactor	Thyristor Switched Reactance	Static Synchronous Series Compensator
Overload Line Controller	Unified Power Flow Controller	Interline Power Flow Controller	Thyristor Controlled Series Capacitor	…

Singular facilities

- Those **transmission facilities that have design, configuration, operational or technical conditions that differentiate them from the standard facilities considered in the reference unit values**included in the corresponding Circular.
- Submarine cables, lines developed in direct current and converting stations from alternating current to direct current, as well as **switching stations and telecontrol of the transmission network, since they lack a unit reference value.**
- Those **investments made by the transmission companies in pilot projects.** These **investments must represent a quantifiable benefit for the system in terms of security, quality, efficiency, objectivity and transparency,** for which the request for recognition of this type of investment must be accompanied by a **cost-benefit analysis** and a **technical report.**

In general, **the regulatory useful life of the singular facilities will be 40 years.**

Step 1: Review and describe the project

Regulatory context and its impact as a framework in which the solution would be implemented.

Spanish National Markets and Competition Commission (CNMC) **Circular 6/2019**, of 5 December, **which establishes the methodology for calculating the remuneration for the activity of electricity distribution**, establishes the type of regulated remuneration from which the **solution in the area of electricity distribution could benefit**:

Considerations on the methodology for **calculating the remuneration for the activity of electricity distribution.**

Investments in network digitalisation and automation necessary for the energy transition

The Circular establishes as **remunerable investment the investments in network digitalisation and automation necessary for the energy transition,** namely those associated with smart grids, remote management and the technical management systems associated with both.

The following, among others, are within these categories:

1. **Advanced High-Voltage Supervision Systems (from 36 kV).**
2. **Network sensorisation and monitoring equipment.**
   - ✓ Partial discharge monitoring
   - ✓ Sensorisation of earths
   - ✓ Other equipment

These technical facilities will generally have a **regulatory useful life of 12 years.**

Investments in pilot projects

The Circular establishes the **recognition of investments**, against distribution costs, **as those made by distribution companies in pilot projects.**

It must be guaranteed that the aforementioned **investments represent a quantifiable benefit for the system in terms of:**

- ✓ **Security**
- ✓ **Quality**
- ✓ **Efficiency**
- ✓ **Objectivity**
- ✓ **Transparency**

Applications for recognition of this type of investment must be accompanied by a **cost-benefit analysis and a technical report.**

The **remuneration** for these investments **will be set by resolution of the CNMC, which will also determine the expected regulatory useful life of the asset.**

Step 1: Review and describe the project

Definition of the objectives of the solution and the main expected impacts at socioeconomic level.

Increase in the resilience of the electrical network

Reactivation and recovery of the economy after the emergency associated with COVID-19

Boost to energy transition and decarbonisation of the economy

Growth and increase in the billings of companies providing innovative solutions

Add value to existing equipment or facilities through digitalisation

Improve the competitiveness of Spanish products

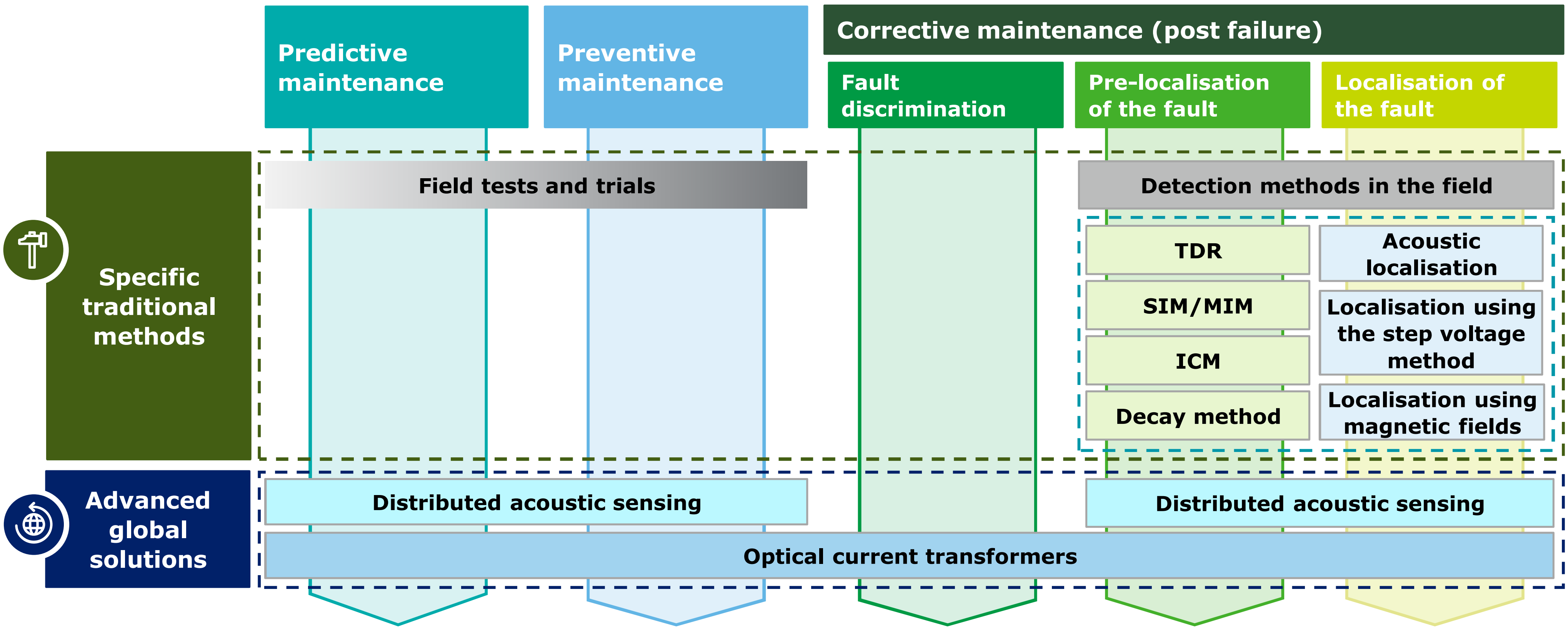
New R&D projects that promote the development of present-day technologies

Creation of employment with higher added value for the Spanish economy as a whole

Opportunities for growth and development at national and international level (exports), both in the electricity industry and in other sectors

Step 1: Review and describe the project

Description of main solutions applied in the current scenario



Traditional maintenance solutions are typically preventive and are based on carrying out **routine on-site checks** on the section of the underground cable, which enables preventive detection of certain insufficiencies in the state of the facility. In the **post-failure area of action, traditional corrective maintenance is based on a field visit and a pre-localisation and long-term localisation process.**

Certain more advanced solutions allow for continuous monitoring of the condition of the underground cable, as well as differentiation, pre-localisation and localisation of the fault, without the need to deploy maintenance teams, thereby reducing cost and increasing security.

Step 1: Review and describe the project

Description of main solutions applied in the current scenario

The **traditional predictive and preventive maintenance methodology in underground cables** consists of periodically carrying out **a series of tests and trials**. These data captures can be carried out on the cable in service or out of service. **This traditional methodology has various drawbacks in terms of accuracy, security, time and costs.**

Visual inspection

This is the **most basic test**, and consists of visually analysing the cable and other associated components in order to identify possible incidents.

Temperature measurement

The **temperature is measured in different parts of the facility** under normal operating conditions.

Verification of grounding connections

It is verified that **the resistance of the ground connection is the appropriate considering the value set for the project.**

Cable jacket stress test

DC voltage is applied between the cable jacket and a reference electrode, and it is verified that the voltage remains stable over time.

Continuity and resistance testing of the screens

The **continuity of the screen is checked along the cable and its joints**, and the resistance values set by the manufacturer must be maintained.

Insulation stress test

This test is performed **to assess the existence of imperfections or anomalies** that can lead to **perforation or premature aging**.

Partial discharge measurement

Small imperfections in the cable can cause **discharges and cause perforations, shortening the life of the cable.**

Tan delta testing δ

This test **provides essential information about the condition of the cable insulation.**

Ability to offer a comprehensive solution	✗
Efficiency in terms of time and costs	↓
Risk to physical safety	↑
Accuracy in locating the fault	N/A

Step 1: Review and describe the project

Description of main solutions applied in the current scenario

Because it is generally not possible to visually detect the **location of an underground fault**, the fault detection methodology is based on **two phases**. First, a **rough location detection** is performed using technical methods where the cables start. Some of the most widely used methods are as follows:

Phase I

1 **TDR**	**Time-domain reflectometry** (TDR) is used to detect low resistive cable faults, interruptions and the location of cable joints or splices. A **low-voltage impulse** is sent along a conductor and reflections are observed at the points in the cable where a **discontinuity of the impedance** appears.
2 **SIM/MIM**	The **secondary or multiple impulse method** is used to detect high resistivity faults. It consists of sending a **high-voltage impulse** through the cable which makes it possible to **change the fault** into a low resistive fault. It is then possible to use the TDR to detect the fault.
3 **ICM**	The **impulse current method** (ICM) is used to detect high resistive faults in **very long conductors**. It is used in conjunction with the TDR and consists of **generating a voltage surge** that causes flashing at the faulty location. These impulses can be detected using TDR.
4 **Decay method**	This pre-localisation method is useful for certain types of cables where **the breakdown voltage is higher than the rated voltage of a surge generator.** The TDR is used in conjunction with a surge generator, a transient wave is sent whose oscillation period makes it possible to calculate the distance to the fault.

Ability to offer a comprehensive solution ✗ | **Efficiency in terms of time and costs** ↓ | **Risk to physical safety** ↑ | **Accuracy in locating the fault** ↓

Step 1: Review and describe the project

Description of main solutions applied in the current scenario

Once the approximate location of the fault has been obtained, a **technical team is sent to this approximate location** to be able to **detect the exact location of the fault** and in this way, be able to **begin corrective maintenance work** on the cable.

Phase II

Acoustic localisation

High-voltage impulses are sent into the ground through which the cable runs and an acoustic signal is produced that can be detected by the operator with a field microphone and headphones. The closer the impulse is emitted to the fault, **the greater the amplitude of the sound.**

Localisation using the step voltage method

In the event of **a fault in the cable jacket or short circuits to ground**, the acoustic detection method cannot be used. A series of **voltage impulses are sent into the ground** that will create a **voltage drop** and by placing **two probes** in the ground it is possible to measure voltage gradients and thus identify the fault location.

Localisation using magnetic fields

It is useful for detecting **low resistive faults in multi-pole cables.** A **high frequency acoustic signal** is sent to the cable with the fault together with a current signal that is detected with a detection coil. Since the acoustic signal returns to the fault position, the place where the coil does not read any signal is considered to be the fault location.

Identification of the cable

Once the trench has been opened at the location of the fault, **if there are several cables** it is necessary **to identify the cable with the fault**. To do so, a transmitter is connected with a capacitor that is charged and discharged on the cable. After this, a **clamp meter** is used to discard "healthy" cables and identify the cable with the fault.

Ability to offer a comprehensive solution	✗
Efficiency in terms of time and costs	↓
Risk to physical safety	↑
Accuracy in locating the fault	↑

Step 1: Review and describe the project

Description of main solutions applied in the current scenario

Traditional methods of predictive and preventive maintenance, as well as pre-localisation and localisation of faults, **depend mainly on the ability of human capital to use techniques and tools.** The manipulation of high-voltage cables poses a **danger for the workers**. Additionally, **the transfer of personnel to the area in which the fault has occurred may be hindered by health emergencies (COVID-19),** in addition to representing an **increase in costs.**

Identification of the risks associated with carrying out work in the field

Current leakage

Due to the insulation to which underground cables are subjected, the risk of a current leakage is less than that of an aerial line. However, **the fault could have damaged the cable insulation and energised the ground.** Therefore, the surrounding terrain could be affected by the existence of current leakage that can cause **damage and injury without the operators having approached or handled electrical equipment.**

Direct cable handling

Once the point where the fault has occurred has been localised, there may be several cables running through that point. **The process of identifying the affected cable is critical** since acting on an incorrect cable can have serious consequences for the personnel in question.

Need to use a wide variety of equipment

To carry out the predictive and preventive maintenance, and the pre-localisation of the fault and its subsequent accurate localisation, **it is necessary to use multiple techniques and tools, which entails the need for a large number of switchgears and technical equipment, as well as specific training of the personnel who carry out these tasks.**

Other consequences of moving staff

The movement of personnel in the process of pre-localisation and localisation of the fault presents another series of disadvantages with respect to remote localisation:

Increase in time and costs

Possible difficulties as a consequence of health emergencies

The recent emergency associated with COVID-19 has highlighted the need for facility analysis tools that can be remotely monitored, thereby allowing the impact of this type of unforeseen event to be minimised.

Step 1: Review and describe the project

Description of main solutions applied in the current scenario

Distributed Acoustic Sensing (DAS) is a **real-time monitoring and fault detection solution that uses the optical fibre that accompanies the underground cable as a sensing medium.**

What does it consist of?

- Distributed Acoustic Sensing is an **advanced variant of time domain reflectometry (TDR).** This system uses the fibre optic cable as a sensor medium to detect and locate small vibrations along the length of the cable.
- Through the DAS monitoring system, **the fibre optic cable is capable of detecting vibroacoustic events that occur along the length of the cable,** allowing the location of the disturbance to be detected. Thus, the optical fibre becomes a distributed sensor.
- Unlike the traditional solutions described above, **Distributed Acoustic Sensing provides**, in addition to a more accurate localisation of the point where the fault has occurred, **continuous cable monitoring, thus furnishing real-time information on its condition**, allowing for the possibility of applying preventive maintenance or acting on the cable before the fault occurs.
- Therefore, **it is not necessary to transport work teams to where the cable is located to carry out predictive or preventive maintenance tasks, or to pre-localise the fault,** with the consequent cost and time savings that this entails.
- However, as it is based on the detection of vibroacoustic events that occur on the underground cable, sometimes the **system can give a warning indicating that an incident has occurred on the cable, which would be a false positive reading.**

Ability to offer a comprehensive solution ✗

Efficiency in terms of time and costs ➔

Risk to physical safety ➔

Accuracy in locating the fault ➔

Step 1: Review and describe the project

Main technical features of the new proposed solution based on Optical Current Transformers

Technology based on optical current transformers **can be applied in three areas (predictive maintenance, fault discrimination and fault localisation and pre-localisation).** In any of the applications, **the technology uses the same type of components: a processing unit (CPU), a series of optical current transformers and a series of multiplexers.** Additionally, in all cases, **the partial and optimised use of fibre optics as a system element is required,** through which **the interrogator located in the processing unit sends pulses of light, which are modified by the transformer and returned to the processing unit.**

Processing unit

This is the **component in charge of processing the information from the optical current transformers**, in order to show the results to the network manager so that continuous knowledge of its status is provided.

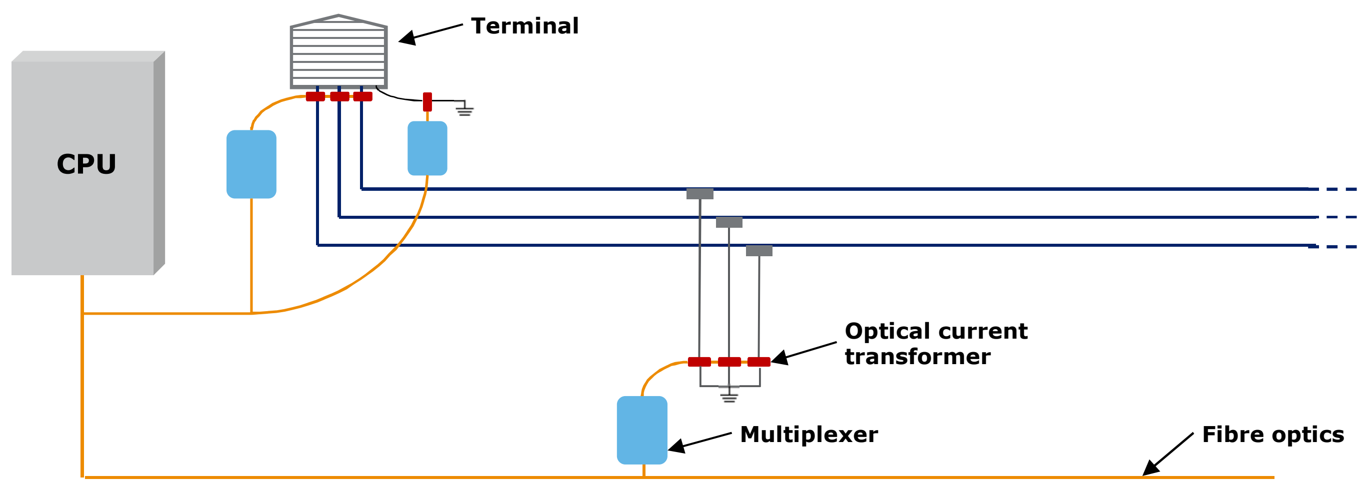
Optical Current Transformers

These elements **make it possible to capture the information on the state of the cable by measuring the nominal current of the cable or the current of the screens.** These are passive elements that send the information to the processing unit through the optical fibre.

Multiplexer

Passive elements that allow for different optical current transformers to be shared on the same fibre, minimising the use of optical fibre.

- **Ability to offer a comprehensive solution** ✓
- **Efficiency in terms of time and costs** ↑
- **Risk to physical safety** ↓
- **Accuracy in locating the fault** ↑



Step 1: Review and describe the project

Main technical features of the new proposed solution based on Optical Current Transformers

The use of **optical sensors allows continuous supervision and monitoring of the state of underground power cables without the need for external power** (they are passive elements) and they are **easily installed**. The main applications of this technology are **predictive cable maintenance, fault discrimination on mixed lines, and fault localisation on the cable.**

This technology can jointly offer three functionalities that provide a **detailed insight into the state of the cable**, through both **maintenance** (predictive) and **protection** (discrimination and fault localisation):

Predictive maintenance

- It uses **the currents flowing through the cable screens** as a reference.
- The **screen circuits run right along the cable**, so they can provide information about its state, thereby making it possible to:
  - **Monitor the integrity of the grounding circuit.**
  - Obtain real-time **information on the state of operation of the cable** and assess any **possible degradation of its insulation.**

Fault discrimination on mixed lines

- It facilitates **discrimination, in mixed lines, of whether the fault originates from the aerial or underground section.**
- This solution **enables the reclosers to act as long as the fault occurs in aerial sections, avoiding reclosing in the event of a fault in the underground section.** In this way, **any line downtime due to ignorance of the real origin of the fault is reduced.**

Localisation of the fault

- It **makes it possible to pre-localise the area where the fault is located and to localise it exactly** if an impedance model of the facility is available.
- The operation of the solution determines, sequentially, (i) the fault phase, (ii) the main faulty part, (iii) the lesser faulty part and (iv) the fault point.

MAINTENANCE

- ↑ **Greater requirements for data processing**
- ↓ **Lower data capture frequency**

PROTECTION

- ↓ **Fewer requirements for data processing**
  he short-circuit currents are higher and the required sensitivity is lower.
- ↑ **Greater data capture frequency**

Step 1: Review and describe the project

Other characteristics that help define the solution, setting it apart from the traditional ones

The use of **optical sensors allows continuous supervision and monitoring of the state of underground power cables without the need for external power** (they are passive elements) and they are **easily installed**. The main applications of this technology are **predictive cable maintenance, fault discrimination on mixed lines, and fault localisation on the cable.**

Main advantages of this technology

Ease of installation

These systems can be installed and commissioned in short periods of time (2-3 days). Installation in the field is performed through **simple fibre optic mergers that can be carried out by companies dedicated to the installation of conventional fibre optics. Elements can be fitted during the construction of the facility or afterwards.**

Does not require external power

The **elements within the actual underground cable facility** (optical current transformers and multiplexers) **are passive elements that do not require external power.**

Optimises the use of fibre optics

The technology used **makes it possible to optimise the use of the existing fibre optics,** without the need to lay new fibre and minimising the number of fibres used, through the use of **multiplexers that increase the number of optical current transformers connected to the same fibre.**

Minimises the need for field maintenance

In the case of predictive maintenance, **this solution makes it possible to know the status of the cable on a continuous basis without the need for periodic field tests.** Additionally, in relation to corrective maintenance, **it makes remote pre-localisation of the origin of the fault possible, as well as its localisation. By avoiding the movement of personnel to the facility, greater efficiency is achieved in terms of costs and time, and the risks associated with physical safety are reduced.**

These are standardised and modular solutions

The solution **consists of 3 elements (processing unit, optical current transformers and multiplexers), the number and placement of which can be adapted depending on the specific needs and characteristics** of the site.

Step 1: Review and describe the project

Relevant players in the implementation of the solution

The implementation of the solution is not limited only to this scenario, but rather favourable legislative and regulatory conditions must be defined that encourage both prior research and development by suppliers and subsequent implementation by distributors and transmitters.

Central government

The Government is **responsible for establishing the energy policy guidelines to be followed at national level.** The Spanish **NECP** has evidenced that the **digitalisation and modernisation of the networks will be key elements for energy transition.**

Distributors and transmitters

The existence of innovative solutions, in a context of **fostering digitalisation at regulatory level, allows transmitters and distributors to acquire a greater continuous knowledge of the state of their networks, as well as other complementary benefits,** such as increased worker safety, cost reduction, resilience to adverse events, etc.

CNMC

The CNMC, as regulator, and following energy policy guidelines, is in charge of developing the remuneration methodology related to the transmission and distribution of electrical energy. In recent regulatory developments, i**t has placed special emphasis on the treatment of investments made in digitalisation assets and increased efficiency in network operation and maintenance.**

Providers

It is the providers, firstly, **in a context of fostering the development of innovative solutions,** that are dedicating technical and human resources to develop such solutions, thereby promoting the development of the economy and talent at national level.

Analysis methodology

General description

A generally accepted **methodology** has been applied (prepared by the Electric Power Research Institute (EPRI)), which in turn is used by the **European Commission in the preparation of guidelines for cost-benefit analysis in certain solutions in the electricity industry**, such as the deployment of smart meters or the development of smart grids. This analysis is proposed **considering both quantitative and qualitative impacts**.

Characterise the Project

1 Review and describe **technologies, elements** and **goals of the project.**

2 **Map assets onto functionalities.**

Estimate Benefits

3 **Map functionalities onto benefits.**

4 **Establish the baseline**

5 **Monetise benefits and identify beneficiaries.**

Compare Cost and Benefits

6 **Identification and quantification of the main costs of the solution.**

7 **Quantitative comparison of the costs and benefits** derived from the implementation of the solution.

Qualitative Analysis

8 Evaluation of the **contribution of the solution to the main specific criteria established by the regulation setting up the framework for the solution.**

9 **Identification and estimation of other aspects and qualitative social impacts that are difficult to assess quantitatively.**

Analysis methodology

Step 2: Map assets onto functionalities

The second step consists of mapping which components of the solution to be analysed activate each of the functionalities defined for an asset that is necessary for the activity. Each functionality is associated with one or more benefits, and, accordingly, it is essential to clearly establish the relationship between the components developed and the functionalities they provide.

Illustrative example

Hardware	*Component 1*
	Component 2
	Component 3
	…
	Component n
Software	*Component a*
	Component b
	Component c
	…
	Component z

1 Definition of all the components of the solution that must be taken into account in carrying out the cost-benefit analysis.

2 The specific criteria established by the regulation establishing the framework for the solution are broken down into a series of functionalities required by each criteria.

Illustrative example

	Criterion 1		**Criterion 2**		**Criterion n**	
Assets	**F_1**	**F_2**	**F_3**	**F_4**	**…**	**F_n**
Solution 1	●	●	●			●
Solution 2	●	●		●		
Solution 3		●	●		●	
…		●				
Solution n		●		●	●	●
Combination of solutions	●	●	●	●	●	●

3 A relationship is established between the previously defined components of the solution and the functionalities. The points on which the matrix's cells show the functionalities provided by the solution and which components activate each one of them.

Illustrative examples

Examples of criteria:

- Economic efficiency of the system
- Benefits in security of supply
- Benefits in quality and continuity of supply
- Technical efficiency of the system
- Other aims of energy policy: decarbonisation, digitalisation, etc.

Step 2: Map assets onto functionalities

Description of the functionalities provided by the solution

Criteria	ID	Functionalities
Economic efficiency of the system	1	Optimisation of the maintenance strategy and renewal of assets
	2	Modularity in the solution that enables it to be adapted to different types of underground networks, voltages and/or players' requirements
	3	Additional harnessing of assets existing in the network for maintenance (e.g. optical fibre)
	4	Continuous measurement of the losses arising in the cable screens
Security	5	Continuous monitoring of underground networks that facilitate the connection with critical assets (both generation and consumption)
	6	Blocking of reclosing in aerial-underground connections if the fault is underground, through fault discrimination
	7	Storage of the information obtained by the sensors in the network manager's own servers
Quality and continuity of supply	8	Specific supervision of critical points of the network (joints, terminations)
	9	Unblocking of reclosing in aerial-underground connections if the fault is aerial, through fault discrimination
	10	Digital communication between teams and interconnection to facilitate certain protections
	11	Continuous supervision of wave quality through the measurement of harmonics
Digitalisation	12	Real time gathering of data on the working condition of underground cables
	13	Direct cloud storage of information relating to the upkeep of the facility
	14	Possibility of fully integrating the solution in the SCADA system of the transmission/distribution company's network
	15	Measurement of electricity aggregates (intensity, voltage) in order to obtain the key parameters for the upkeep of the cable
	16	Continuous measurement of screen currents
	17	Minimisation of the risk associated with "false positives" as a result of the measurement of a non-electricity aggregate
	18	Sensorisation through passive elements that do not require electrical connection to carry out maintenance
	19	Capacity to integrate sensors for continuous measurement of non-electric parameters (temperature, vibration)
	20	Optimisation of the integration of protection and control elements
	21	Pre-localisation of the fault point
	22	Localisation of the fault point
Environmental, decarbonisation, electrification	23	Minimisation of the possibility of fires associated with live-line work
	24	Minimisation of the contamination associated with trips in conventional vehicles to carry out maintenance tasks
	25	Increase in the reliability of underground networks, which are less affected by extreme weather events
	26	Reduction in dumping of the generation of renewable energy that cannot be managed through the early detection of faults in the underground network

Step 2: Map assets onto functionalities

Map of the functionalities for each solution

Once all the functionalities have been defined, on the basis of the criteria to be met by a project considered to be innovative, the matrix shows which solutions are capable of responding to each functionality.

Criteria	Economic efficiency of the system				Security			Quality and continuity of supply				Digitalisation											Environmental, decarbonisation, electrification			
Functionalities	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**
Possible solutions																										
Field tests and trials	✓	✓						✓							✓											✓
Traditional pre-localisation methods		✓													✓						✓					
Traditional localisation methods		✓													✓							✓				
Distributed acoustic sensing	✓	✓	✓		✓		✓			✓		✓	✓	✓				✓	✓		✓	✓	✓	✓	✓	✓
Optical current transformers	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Analysis methodology

General description

A generally accepted **methodology** has been applied (prepared by the Electric Power Research Institute (EPRI)), which in turn is used by the **European Commission in the preparation of guidelines for cost-benefit analysis in certain solutions in the electricity industry**, such as the deployment of smart meters or the development of smart grids. This analysis is proposed **considering both quantitative and qualitative impacts**.

Characterise the Project

1. Review and describe **technologies, elements** and **goals of the project.**
2. **Map assets onto functionalities.**

Estimate Benefits

3. **Map functionalities onto benefits.**
4. **Establish the baseline**
5. **Monetise benefits and identify beneficiaries.**

Compare Cost and Benefits

6. **Identification and quantification of the main costs of the solution.**
7. **Quantitative comparison of the costs and benefits** derived from the implementation of the solution.

Qualitative Analysis

8. Evaluation of the **contribution of the solution to the main specific criteria established by the regulation setting up the framework for the solution.**
9. **Identification and estimation of other aspects and qualitative social impacts that are difficult to assess quantitatively.**

Analysis methodology

Step 3: Map functionalities onto benefits

The aim of the second mapping is to relate the functionalities identified in step 2 with the potential benefits that each one can give rise to. Each functionality must be considered individually and analysed as it could contribute to each of the benefits in the left-hand column of the table.

The methodology developed establishes a detailed series of benefits, which, in turn, can be grouped into the following main categories (non-exhaustive list):

Illustrative examples

Reduction in maintenance costs	Reduction in operating costs	Reduction in electricity losses and losses due to fraud	Increase in personal safety
Reduction in CO_2 emissions	Reduction in post-outage reconnection times	Reduction in trips	Others

Illustrative example

	Criterion 1		Criterion 2		Criterion n	
Benefits	**F_1**	**F_2**	**F_3**	**F_4**	**…**	**F_n**
Benefit 1	●		●			
Benefit 2						
Benefit 3		●			●	
Benefit 4				●		
…	●		●		●	●
Benefit n		●	●			

In this mapping, the functionalities defined and used in step 2 are related to the benefits. Following the analysis, the points indicate the benefits that are activated on the basis of each functionality.

It is probable that certain functionalities identified in step 2 may not be mapped on to any of the benefits in step 3. Although each component must be related to at least one functionality, not all of them necessarily activate a benefit.

The main reasons for this circumstance in the mapping are:

- Nature, size or scope of the solution.
- Applicability of the benefits.
- Monetisation of the benefits.
- Applicable legislation.

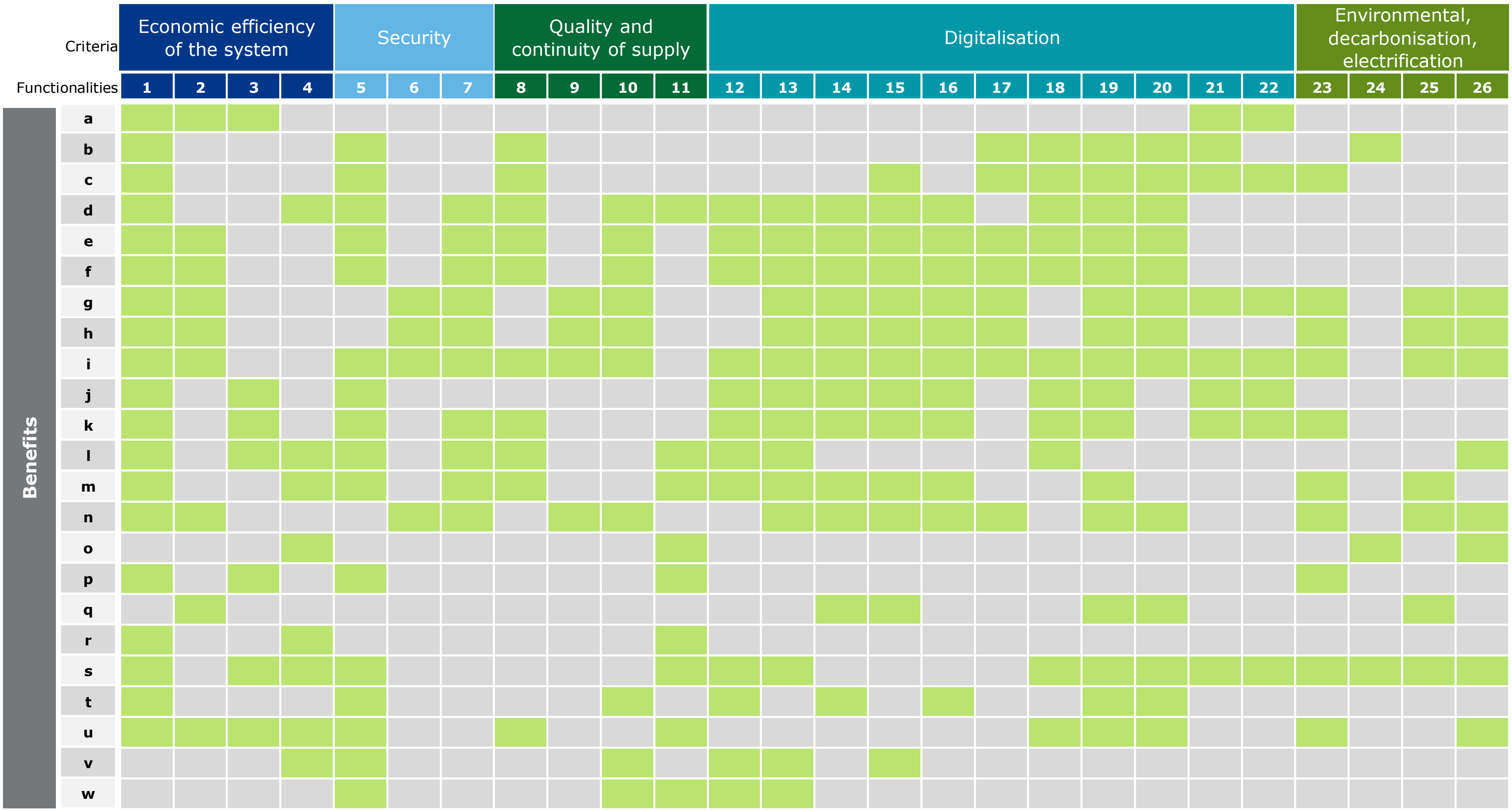
Step 3: Map functionalities onto benefits

Description of the benefits identified

ID	Benefits
a	Increase in efficiencies for the system as a whole as a result of optimising the maintenance of the underground cables
b	Reduction in the number of field trips carried out by the network management companies' teams
c	Reduction in manual live-line work
d	Increase in real-time knowledge of the status of the facility
e	Reduction in the TIEPI (interruption time equivalent to installed capacity) associated with scheduled interruptions (preventive maintenance)
f	Reduction in the NIEPI (number of interruptions equivalent to installed capacity) associated with scheduled outages (preventive maintenance)
g	Reduction in the TIEPI (interruption time equivalent to installed capacity) associated with unscheduled outages (corrective maintenance)
h	Reduction in the NIEPI (number of interruptions equivalent to installed capacity) associated with unscheduled outages (corrective maintenance)
i	Reduction in non-availability in underground stretches of the transmission network
j	Reduction in the time required to localise faults
k	Reduction in errors associated with the use of multiple pieces of equipment in maintenance tasks
l	Encouragement of innovation and development of new technologies with a view to obtaining a 100% renewable energy system using digitalisation and network integration solutions
m	Reduction in the need to replace facilities as a result of lack of predictive/preventive maintenance
n	Reduction in excavation tasks on land close to the underground facility
o	Reduction in greenhouse gas emissions
p	Reduction in waste associated with electrical and electronic equipment
q	Greater resilience of underground networks to extreme weather events
r	Facilitate the harnessing of opportunities for employment and improving competitiveness generated by the energy transition
s	Generation of innovative technical knowledge in order to modernise and transform production processes
t	Remote supervision that minimises the number of trips to the facility
u	Contribution to the development and control of underground networks in order to reduce isolated systems' dependence on fossil fuels
v	Reduction in system technical losses
w	Increase in the information relating to wave quality

Step 3: Map functionalities onto benefits

Map of functionalities to the associated benefits



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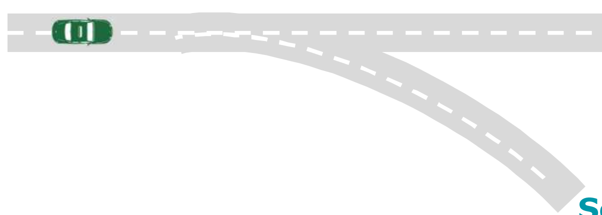
Analysis methodology

Step 4: Establish the baseline.

The objective of establishing the project baseline is to formally define the "control state" that reflects the system condition which would have occurred had the project not taken place.

In order to appropriately assess a possible solution, several scenarios are defined: (i) the Business as Usual (BAU) scenario and (ii) the "with solution" scenario.



Scenario A shows the baseline conditions that reflect what the system would have been ***without*** the defined solution.

Scenario B shows the conditions, defined using metrics, that reflect the system ***with*** the implementation of the defined solution.

In order to define any particular benefit, it is necessary to define scenarios A and B and the assumptions used to define it, and measure the difference in that benefit metric between scenarios A and B.

Type of Benefit	Assumptions - Scenario A (baseline scenario)	Expected results	Assumptions - Scenario B (estimated scenario)	Expected results

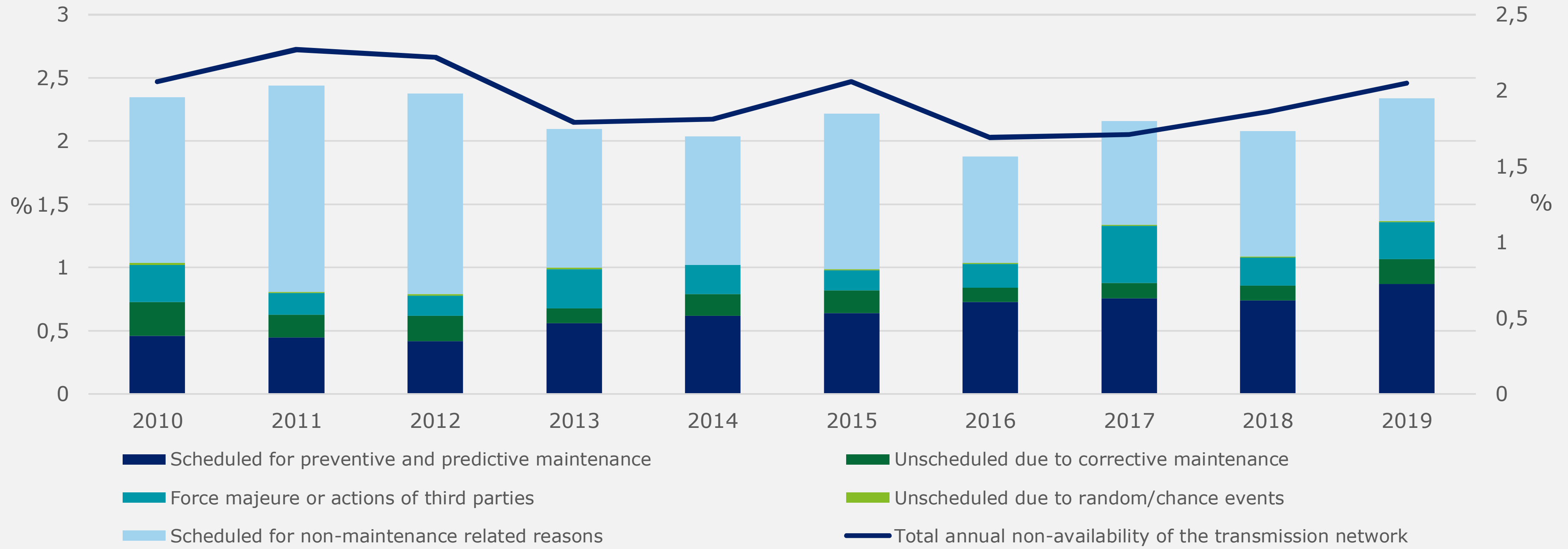
The assumptions and values used to define the two scenarios may refer to both historical values and predictions made.

1 2 3 4 5 6 7 8 9

Step 4: Establish the baseline

Evolution of the non-availability rate of Red Eléctrica's (REE) transmission network in mainland Spain

Annual evolution - 2010-2019:



Since 2010, **the network non-availability rate due to scheduled preventive and predictive work has increased almost two-fold.**

The unscheduled non-availability rate due to corrective work fell by ~25% in the period from 2010-2019.

The total annual non-availability rate of the transmission network has not changed significantly since 2010, remaining at around 2%.

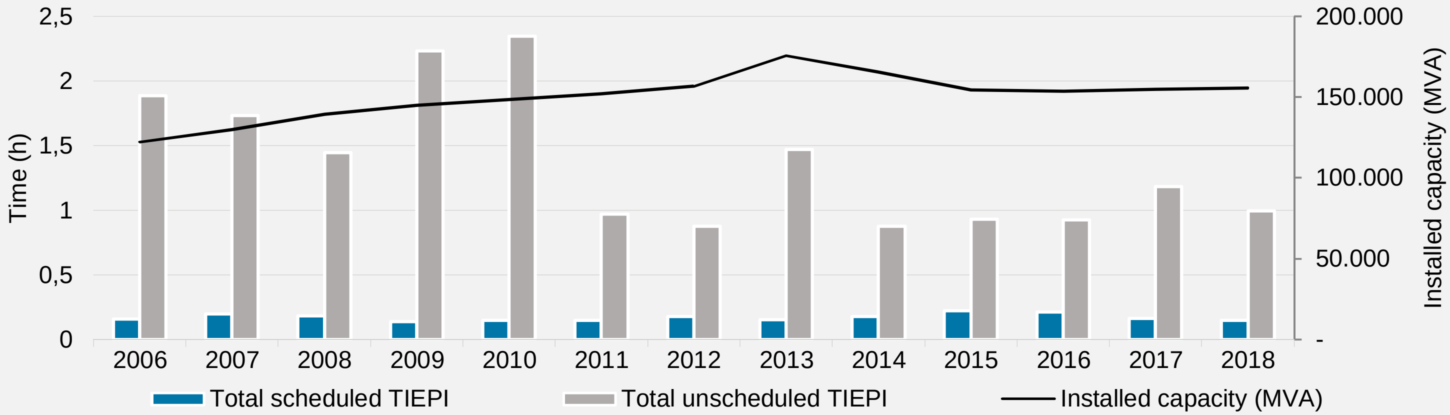
Source: REData - Red Eléctrica (REE)

Step 4: Establish the baseline

Historical evolution of TIEPI[1] and NIEPI[2] at the distribution companies

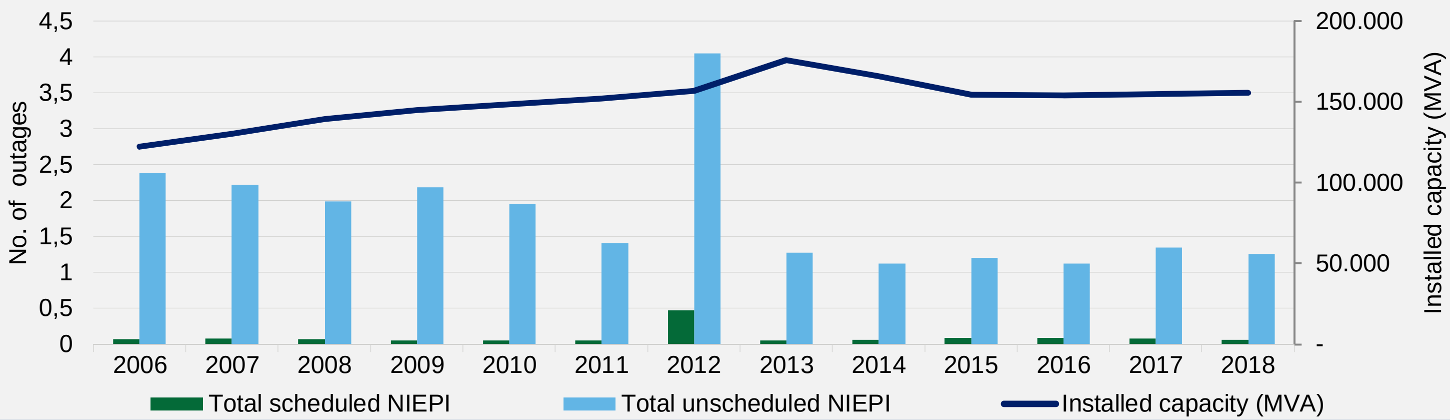
Historical TIEPI data included in the Spanish electric power quality system ("CEL system") (Sector, 2006-2018)

Annual evolution of TIEPI - 2006-2018:



Historical NIEPI included in the CEL system (Sector, 2006-2018)

Annual evolution of NIEPI - 2006-2018:



(1) TIEPI refers to Spanish quality of supply index, equivalent to ASIFI (Average System Interruption Frequency Index).
(2) NIEPI refers to Spanish quality of supply index, equivalent to ASIDI (Average System Interruption Duration Index).

In the last 12 years, while the **TIEPI and NIEPI relating to own unscheduled outages has fallen considerably**, the indicator of **scheduled distribution outages has remained substantially unchanged**

These scheduled distribution interruption values **might be reduced if there are systems or equipment available that are capable of monitoring the network in real time, avoiding triggering power cuts to enable predictive and preventive maintenance work to be performed on site. Also, constant monitoring would also contribute to a reduction in unscheduled interruptions caused by faults not detected in time.**

Step 4: Establish the baseline

Historical evolution of TIEPI and NIEPI at the distribution companies

The existence of supply outages, for scheduled or unscheduled reasons, is a significant cost for consumers of all kinds (domestic, commercial and industrial). **Any kind of improvement in the network that enables the interruption times to be reduced would be a benefit in terms of reducing costs for end energy consumers.**

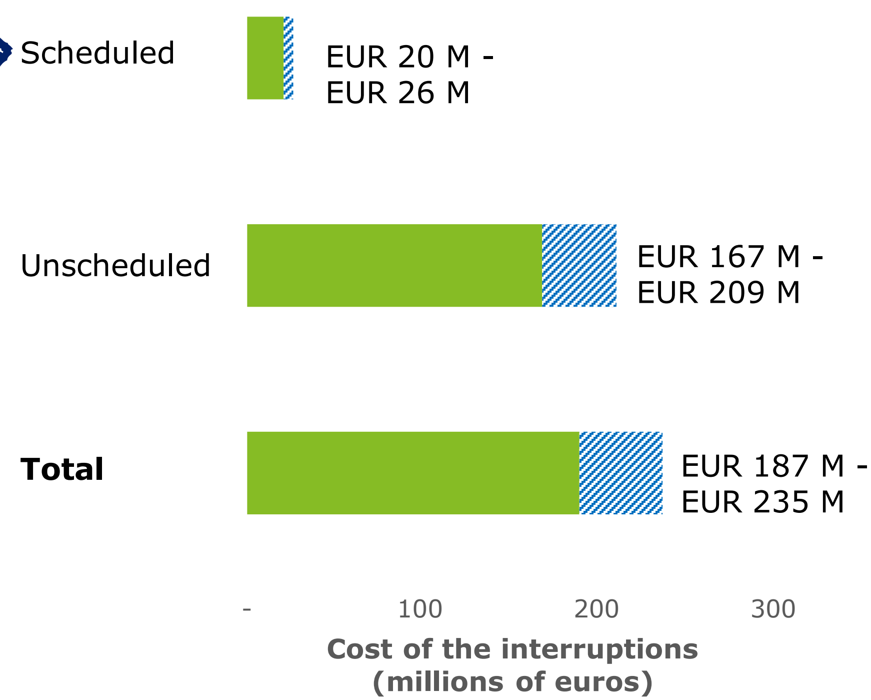
Average TIEPI values, 2006-2018

Total TIEPI	**1.546 hours**
Scheduled TIEPI	**0.171 hours**
Unscheduled TIEPI	**1.375 hours**

Cost of energy not supplied (EUR/kWh)

Domestic customers	**7.9 – 8.8**
Services Sector, low/middle voltage	**6.6 – 9.2**
Industrial sector, middle voltage	**1.5 – 2.5**

Estimated annual cost of supply interruptions[1]



The estimated annual costs of supply outages amount to between approximately EUR 187 million and EUR 235 million, of which between EUR 167 million and EUR 209 million relate to unscheduled interruptions and between EUR 20 million and EUR 26 million to planned interruptions.

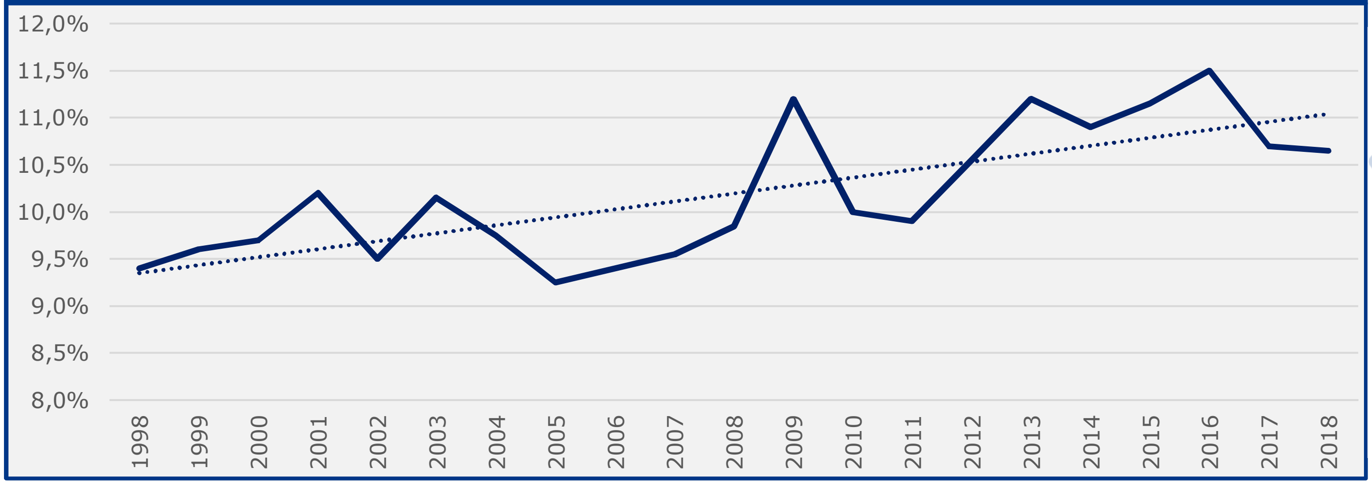
Source: CEL system (Ministry for Ecological Transition and Demographic Challenge, Agency for the Cooperation of Energy Regulators (ACER, 2018), in-house analysis.

(1) The cost of supply interruptions was estimated for interruptions at voltages of equal to or less than 36 kV.

Step 4: Establish the baseline

Historical evolution of losses in the Spanish electricity system

Evolution of losses by comparing demand at power plant busbars and consumption



Average losses in mainland Spain resulting from comparing demand at power plant busbars and consumption **have been** gradually **increasing** from an average level of losses of **9.5% between 1998 and 2008** to average losses of **10.7% between 2009 and 2018.**

Standard loss coefficients set in Circular 3/2020

	Time periods					
Voltage	**Period 1**	**Period 2**	**Period 3**	**Period 4**	**Period 5**	**Period 6**
2.0 TD	16.70%	16.30%	18.00%	-	-	-
3.0 TD	16.60%	17.50%	16.50%	16.50%	13.80%	18.00%
6.1 TD	6.70%	6.80%	6.50%	6.50%	4.30%	7.70%
6.2 TD	5.20%	5.40%	4.90%	5.00%	3.50%	5.40%
6.3 TD	4.20%	4.30%	4.00%	4.00%	3.00%	4.40%
6.4 TD	1.60%	1.60%	1.60%	1.60%	1.50%	1.70%

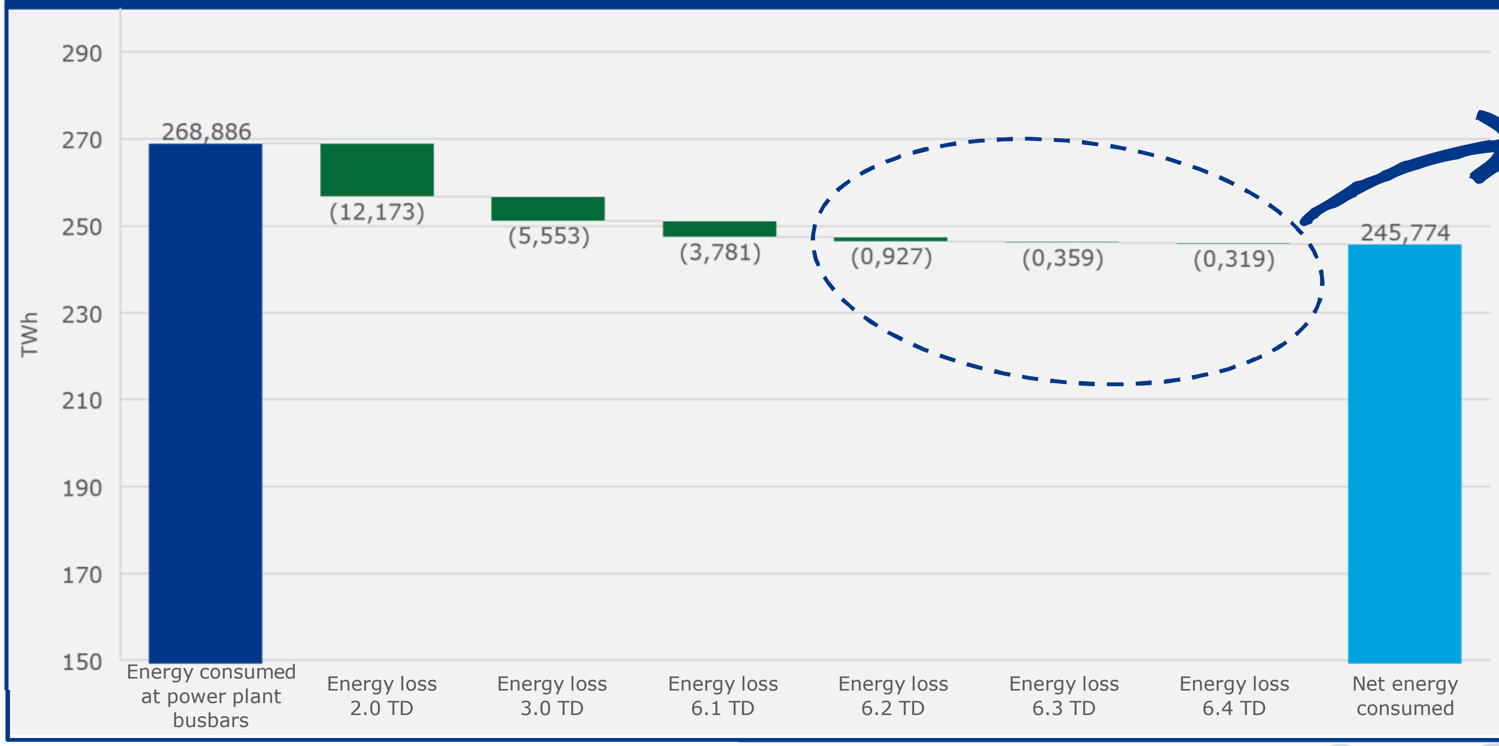
These losses represent a **cost for the electricity system as a whole,** which is distributed among all consumers. The existence of **equipment or systems capable of monitoring through cable screens on an ongoing basis the losses of current in underground cables would contribute to reducing the level of technical losses** and, accordingly, would give rise to a saving for the system.

Source: CNMC

Step 4: Establish the baseline

Historical evolution of losses in the Spanish electricity system

Breakdown of losses by voltage level between busbars and consumption in 2018



The losses arising at voltages of equal to or greater than 30 kV between power plant busbars and consumption represent annual energy losses of approximately 1.605 TWh. This represents approximately 7% of total energy lost between power plant busbars and consumption.

Estimated cost to the system of losses in high-voltage lines

Total high-voltage power lines *(transmission + distribution)*	**EUR 63.7 M – EUR 91.9 M**
Underground high-voltage power cables *(transmission + distribution)*	**EUR 1.3 M – EUR 1.8 M**

Although losses in electricity lines occur mainly in low-voltage lines, **losses in high-voltage lines also give rise to a significant cost for the system as a whole, which is estimated at between EUR 63.7 million and EUR 91.9 million per year. In this connection, the estimated cost associated with the underground high-voltage network is between approximately EUR 1.2 million and EUR 1.8 million,** since at these voltage levels the underground network is quantitatively smaller and, additionally, suffers lower levels of losses than the aerial network.

Source: CNMC, REE, in-house analysis.

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Step 5: Monetise benefits and identify beneficiaries

Once the baseline and solution scenarios have been defined, **it is necessary to identify, collect and report the data required for the quantification and monetisation of the benefits.** This step, in turn, consists of five sub-steps.

Identify and compile the data

The benefits identified (in Step 3) and the various scenarios (identified in Step 4) determine the type of data needed for the evaluation.

Quantify the benefits

The benefits of a solution will represent the change between the baseline conditions and the hypothetical conditions following implementation of the solution. Depending on the solution to be implemented, changes can occur at different levels.

Monetise the benefits

This sub-step involves monetising (i.e. expressing in equivalent economic terms) the benefits quantified in the previous sub-step so that the quantifiable benefits can be compared using a common unit of measurement.

Identify the beneficiaries

The analysis will attempt to identify the various beneficiaries in the electricity system for each of the benefits (users, system operators and, ultimately, society).

Assess uncertainty

Additionally, the level of precision in the quantification and monetisation of the benefits will be identified, since it is more difficult to assess certain benefits based on environmental or social factors, for instance, than it is to assess technical benefits.

Step 5: Monetise benefits and identify beneficiaries

Benefits associated with the reduction in interruptions and improved quality of supply

With respect to quality of supply, the use of optical current transformers would enable ongoing monitoring and the swifter location of faults in the underground network, which would result in **fewer grid interruptions, thereby allowing costs to be reduced for both domestic users and users in the services sector and industry.**

Beneficiaries	Domestic users	Services sector users	Industrial users
Estimated consumption	79 GWh	53 GWh	71 GWh
Estimated total cost of interruptions	EUR 109 – 123 M/year	EUR 62 – 85 M/year	EUR 16 - 27 M/year
Estimated cost associated with interruptions in underground cables and aerial-underground connections (>36kV)	EUR 4.6 – 5.1 M/year	EUR 2.6 – 3.5 M/year	EUR 0.7 – 1.1 M/year
Estimated benefit associated with a 60% reduction in the duration of the interruptions	EUR 2.7 – 3.0 M/year	EUR 1.5 – 2.1 M/year	EUR 0.5 – 0.7 M/year

The consumption estimated by the Spanish National Markets and Competition Commission (CNMC) for 2019 was considered, solely taking into account consumption at a voltage level of 36 kV or lower.

Estimated annual benefit: EUR 4.7 – 5.8 M/year

Source: CNMC (*Resolution referring data to the Directorate General of Energy Policy and Mines for the preparation of the scenario regarding revenue and costs of the electrical system for 2019), equipment manufacturers, Cigré, own analysis.*

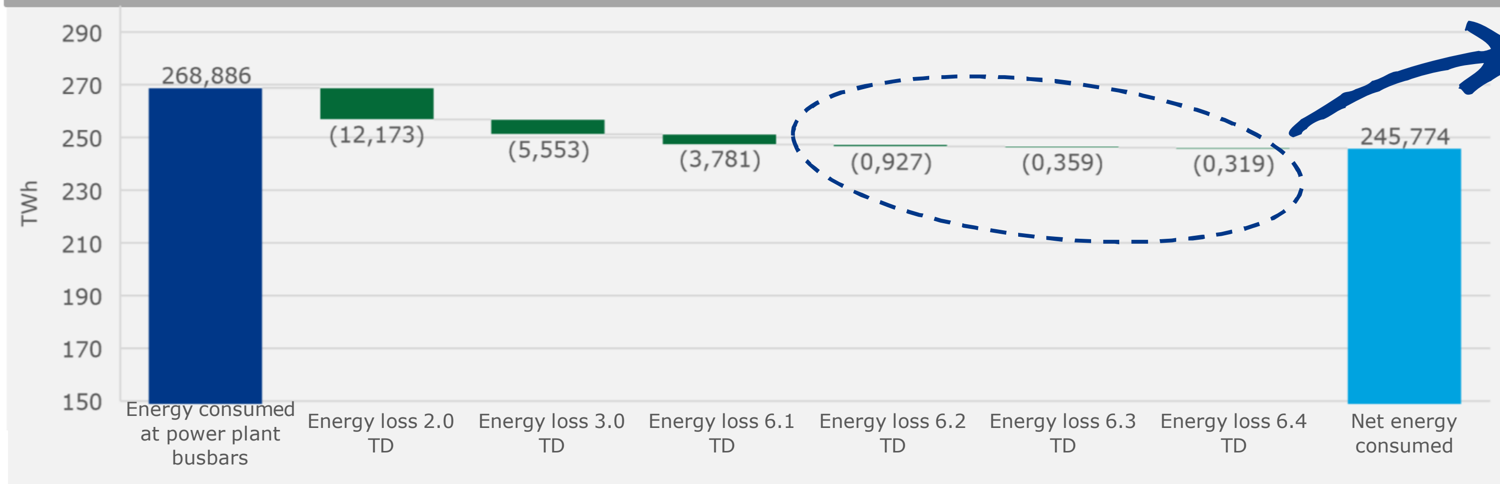
Step 5: Monetise benefits and identify beneficiaries

Benefits associated with reduced electricity losses

Despite the fact that most electricity losses occur in the low-voltage network and in areas of the middle-voltage network up to 36 kV, **ongoing monitoring of underground cables with a voltage higher than 36 kV** using **advanced solutions such as optical current transformers** provides an additional benefit by offering the possibility of **identifying points of the network with high levels of loss, mainly associated with screen current.**

Beneficiaries → **All types of electricity system user** → The cost of the losses is borne by all users, particularly low-voltage users.

Breakdown of losses by voltage level between busbars and consumption in 2018



~1.6 TWh

Estimated losses at voltage levels >30kV

Total high-voltage power lines *(transmission + distribution)*

EUR 63.7 M - EUR 91.9 M

Underground high-voltage power cables *(transmission + distribution)*

EUR 1.3 M - EUR 1.8 M

Estimated annual benefit **EUR 0.13 – 0.18 M/year**

It was considered that the enhanced information and ongoing monitoring of the condition of the underground high-voltage cables would enable points of the network with high levels of loss to be identified and would lead to an ***overall reduction of 10%.***

Source: loss coefficients (included in *CNMC Circular 3/2020, of 15 January, establishing the calculation methodology for electricity transmission and distribution tolls),* UK Planning Inspectorate, Sustainable Energy Handbook (EU), equipment manufacturers, own analysis.

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Analysis methodology

Step 6: Quantification of costs

The costs of the solution are those incurred throughout the implementation thereof with respect to the baseline scenario. This step requires each cost component to be meticulously broken down to provide a faithful reflection of the actual investment made.

Identification of costs

To identify the main costs that will be incurred in the solution, they will be evaluated:

- Internally by the company.
- On the basis of the information provided by the suppliers.
- Using estimates for similar solutions that may already exist in the market.
- By means of any other mechanism that enables the costs associated with the solution to be identified.

The cost types that will be identified for subsequent quantification can be classified under either of the following two categories:

Capital expenditure (CapEx)	Operating expenditure (OPEX)

Quantification of costs

The quantification of the costs of the solution is a key process for ascertaining the return on investment, which shows whether it is positive.

Step 6: Quantification of costs

Identification and quantification of costs associated with a general system installation

For the installation of grid monitoring devices in the underground network based on the use of **optical current transformers, account must be taken of both initial installation costs (CapEx) and recurring operating expenses.**

The effect of the general installation of equipment in the high-voltage underground network is estimated in terms of both electricity transmission and distribution.

Capital expenditure (CapEx)

- **Processing unit (CPU)**
- **Optical current transformers**
- **Multiplexers**

Estimated initial CapEx — **EUR 53.2 – 58.2 M**

Operating expenditure (OPEX)

- **Cost associated with the partial re-leasing of the optical fibre network leased to other agents**
- **Cost of interpreting the information and of the remote operation of the equipment by company personnel**

Estimated annual OPEX — **EUR 0.5 – 0.6 M**

- **The system does not require the installation of any additional optical fibre;** it is based on optimising use of the fibre already installed.
- The system can be developed **in both newly-built sections of the underground network and in other existing sections.**
- Optical current transformers and multiplexers are **passive elements with a useful life similar to that of the sections of network** (40 years). The partial replacement of the processing units once every 12 years has been considered.

Use of the fibre by the system is optimised through multiplexing, which enables the same fibre to be used in parallel for company or third-party communications.

Source: equipment manufacturers, own analysis.

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Analysis methodology

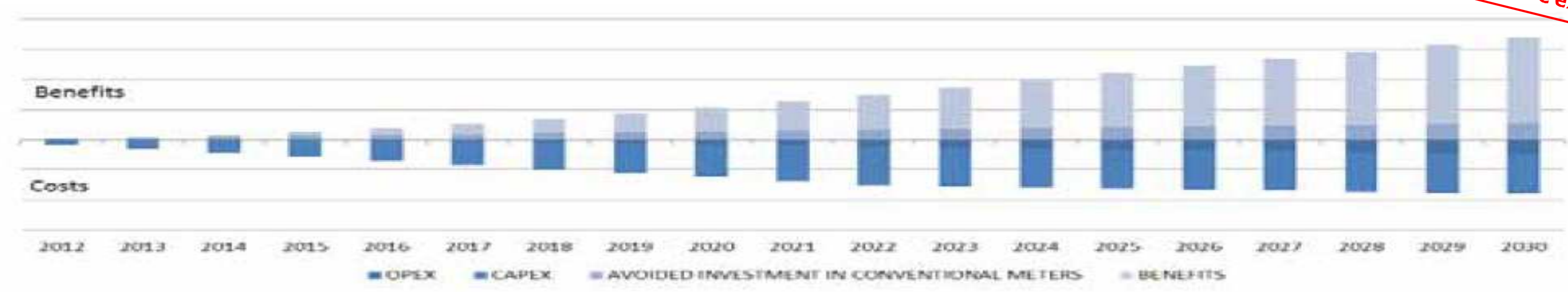
Step 7: Comparison of cost and benefits

Once the costs and benefits of the solution have been estimated, they must be compared and evaluated to determine the cost-effectiveness of the implementation of the solution.

Cumulative comparison

This method presents costs and benefits cumulatively. This approach is useful in identifying the point in time when the break-even point is passed, i.e. when benefits exceed costs.

Illustrative example



Benefit-cost ratio

This method consists of representing the value of the solution as a ratio of benefits to costs, either on an annual basis or on a present value basis.

This is a simple way of representing the size of the benefits relative to that of the costs. If the ratio is greater than one, the solution is cost-effective.

Step 7: Comparison of cost and benefits

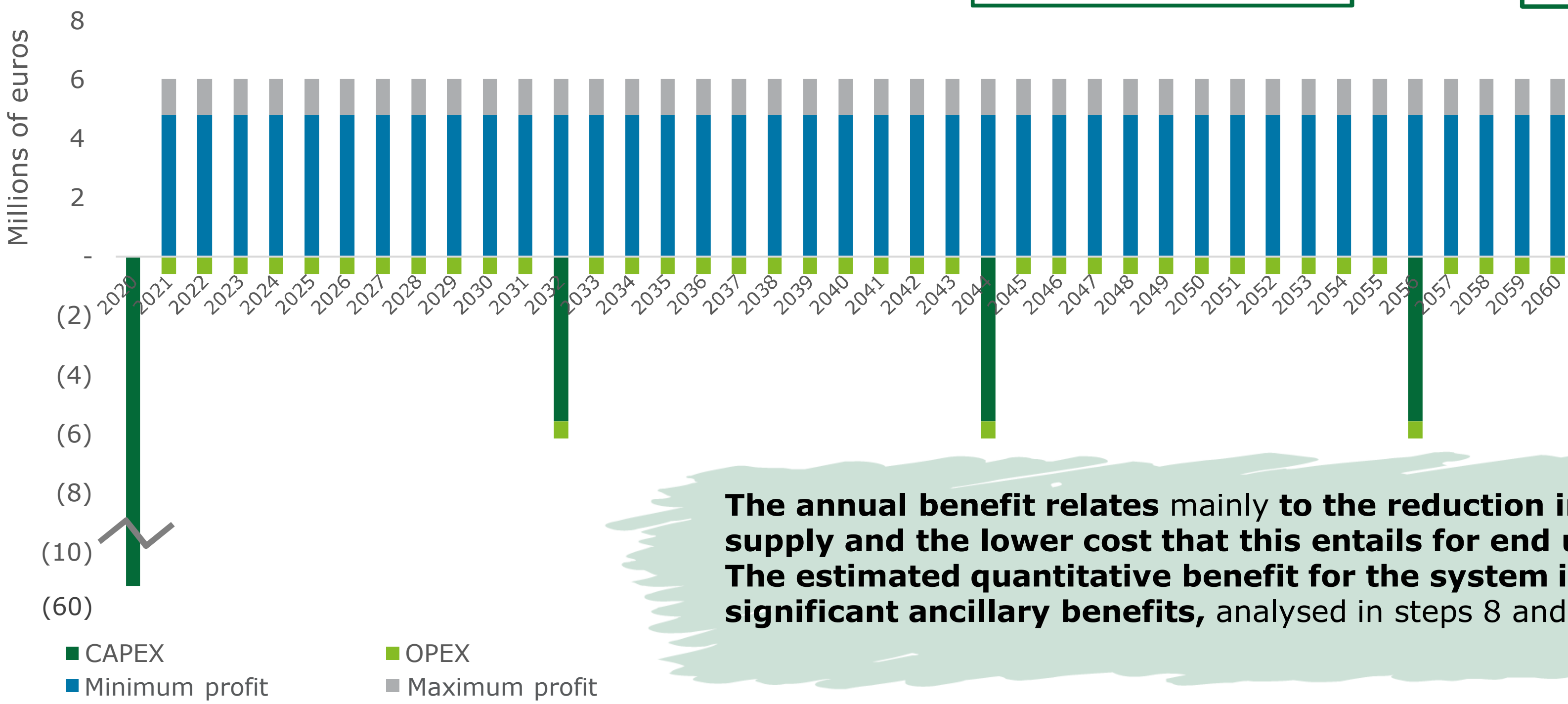
Main results of the cost-benefit evaluation (scenario 1)

Consideration over a 40-year period of the costs and benefits associated with the general installation of monitoring and fault location systems, based on optical current transformers, in the high-voltage underground network would result in a global benefit of between **EUR 6.2 million and EUR 25.7 million.** This benefit would imply **a return of up to 9% on the system,** considering the applied hypothesis and criteria.

Scenario 1 (based on constant demand and network size)

- **Stable energy demand**
- **Absence of significant new network developments.**

Current net benefit of the investment (NPV)[1]	Return on systems installation (IRR)
EUR 6.2 M - EUR 25.7 M	6.4% - 9.0%



The annual benefit relates mainly **to the reduction in interruptions in supply and the lower cost that this entails for end users.**
The estimated quantitative benefit for the system is accompanied by significant ancillary benefits, analysed in steps 8 and 9.

Discount rate used: 5.58%.
Source: own analysis.

Step 7: Comparison of cost and benefits

Main results of the cost-benefit evaluation (scenario 2)

Consideration, in a scenario in which electrification of the economy is increased, over a 40-year period of the costs and benefits associated with the general installation of monitoring and fault location systems, based on optical current transformers, in the high-voltage underground network would result in a global benefit of between **EUR 10.5 million and EUR 33.1 million.** This benefit would imply **a return of up to 9.3% on the system,** considering the applied hypothesis and criteria.

Scenario 2 (based on an accelerated process of electrification of the economy)

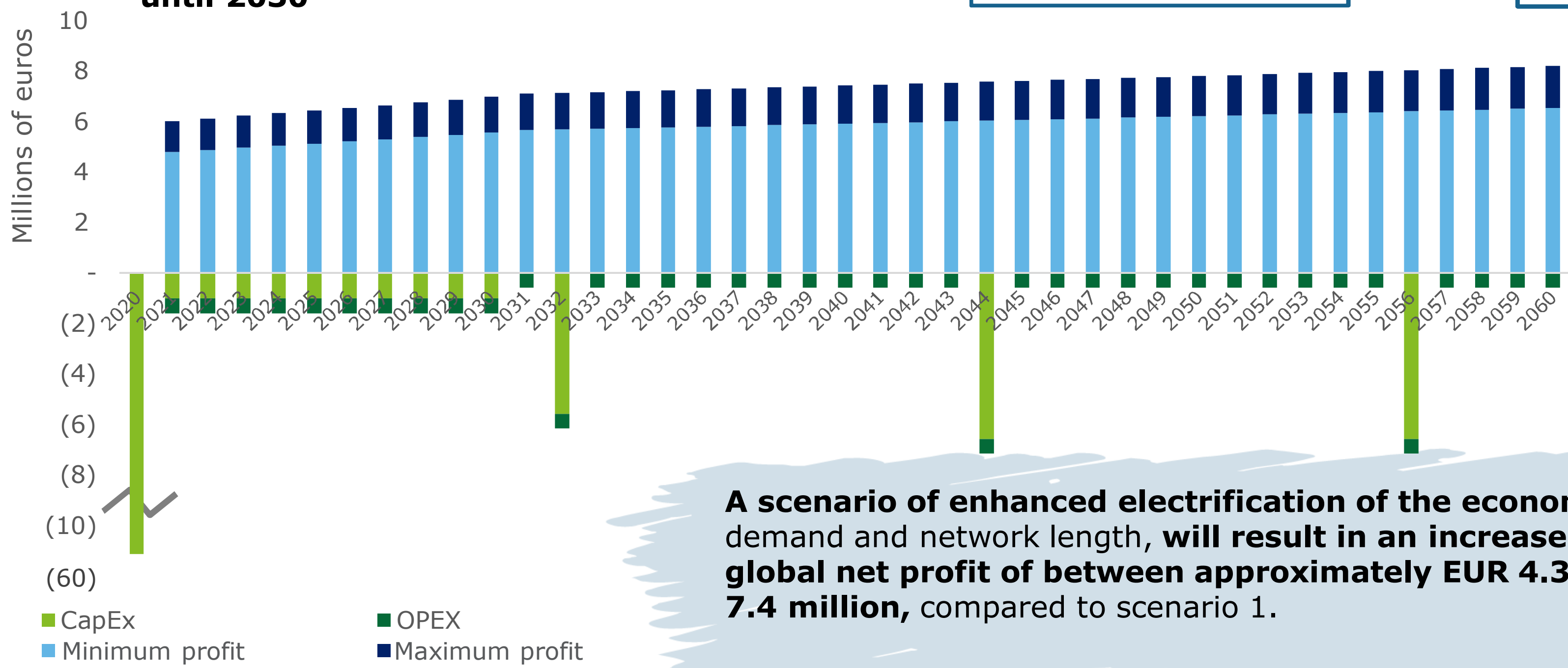
- **Increased energy demand** (+1.7% per year until 2030, +0.5% per year from 2030 onwards)
- **Network increase of +1.8% per year until 2030**

Current net benefit of the investment (NPV)[1]

EUR 10.5 M - EUR 33.1 M

Return on systems installation (IRR)

6.8% - 9.3%



A scenario of enhanced electrification of the economy, with increased demand and network length, **will result in an increase in the expected global net profit of between approximately EUR 4.3 million and EUR 7.4 million,** compared to scenario 1.

Discount rate used: 5.58%.
Source: own analysis.

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Analysis methodology

Step 8: Qualitative evaluation of the contribution of the solution to the regulatory criteria

Certain benefits are difficult to assess in economic terms, and they cannot therefore form part of the cost-benefit analysis. The qualitative evaluation performed in this step **enables, through the definition and assessment of a series of KPIs, various solutions to be differentiated in qualitative terms on the basis of their merits**, which **serves to supplement the economic analysis conducted in previous steps.**

The **benefits of the solution defined in step 3** are considered, **and KPIs associated with each benefit are established.**

The **specific criteria established by the regulation** setting out the framework of the solution and defined in step 2 are considered.

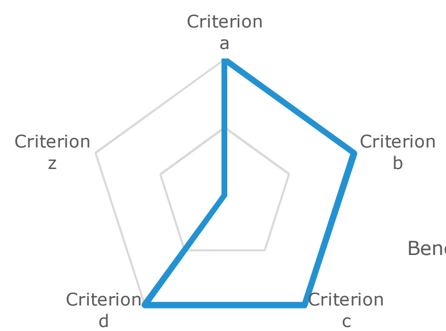
Relationships between the specific criteria established by the regulation and the KPIs associated with the benefits are identified, and discrete weights (0-1) enabling the significance of the criterion-KPI relationship to be quantified are allocated. The analysis must include the allocation of an element that constitutes a "link" between a given criterion or regulatory objective and a specific benefit.

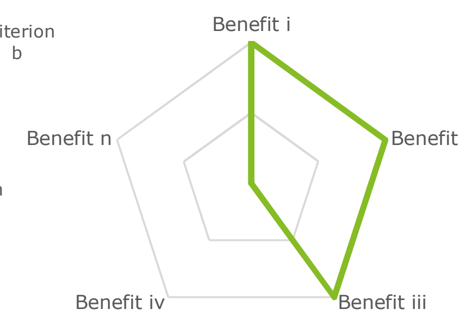
Illustrative example

		Criterion a	Criterion b	Criterion z	
Benefit i	KPI_1^i	Weight 1	-	Weight 13	Σ Weights
	KPI_2^i	-	Weight 7	Weight 14	
Benefit ii	KPI_1^{ii}	Weight 2	Weight 8	-	Σ Weights
	KPI_2^{ii}	Weight 3	-	-	
	KPI_3^{ii}	-	Weight 9	Weight 15	
	KPI_4^{ii}	-	Weight 10	Weight 16	
Benefit n	KPI_1^n	Weight 4	Weight 11	-	Σ Weights
	KPI_2^n	Weight 5	Weight 12	Weight 17	
	KPI_3^n	Weight 6	-	Weight 18	
		Σ Weights	Σ Weights	Σ Weights	

Each solution can be analysed on two planes (criteria and benefits), so that **the impact of the solution will be greater the larger the area in the diagram.**

Illustrative examples



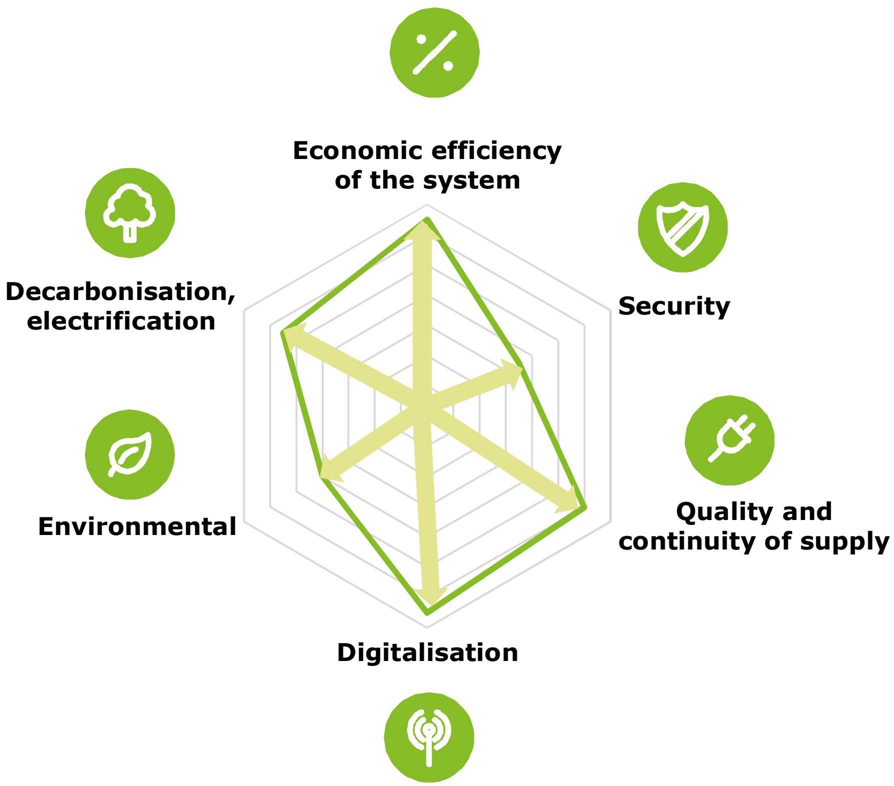


Step 8: Qualitative evaluation of the solution in respect of the regulatory criteria

Impact of the solution on the criteria established in the regulations

In order to **evaluate the significance of the benefits defined in step 3** that have not been quantified in the cost-benefit analysis, **a series of indicators (KPIs) have been defined to serve as parameters for evaluating the achievement by the solution of the aforementioned benefits.** Each KPI is allocated a weight in relation to the applicable regulatory criteria, which enables the **global impact of the solution on each of the criteria** to be ascertained.

Evaluation of the impact of the solution in relation to the applicable regulatory criteria



Solution with comprehensive benefits

The **use of global solutions that allow predictive and corrective maintenance of underground cables**, by means of optical current transformers, presents benefits relating mainly to three regulatory criteria: **(i) greater economic efficiency of the system; (ii) promotion of the digitalisation of networks; and (iii) improved quality and continuity of supply.** The benefits associated with the solution are **positive, both on a social level** (greater efficiency, better supply quality) **and from the standpoint of the network management companies** (a higher degree of digitalisation).

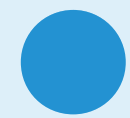
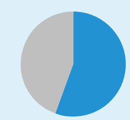
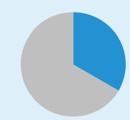
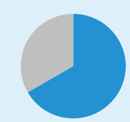
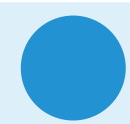
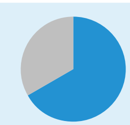
Significance of other ancillary benefits

The solution also provides **benefits in terms of security**, by contributing towards a reduction in live-line working, and **aspects relating to the environment and the energy policy of decarbonisation and electrification**, by permitting enhanced monitoring of the underground networks, which are more resilient to climate change, and by optimising the functioning of these networks in the face of changing charge scenarios associated with the integration of renewable energy technologies.

Step 8: Qualitative evaluation of the solution in respect of the regulatory criteria

Weights associated with each of the identified KPIs of the qualitative benefits

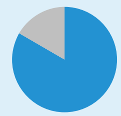
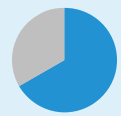
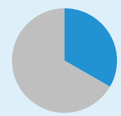
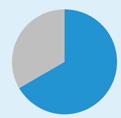
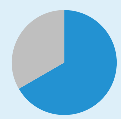
In order to **evaluate the significance of the benefits defined in step 3** that have not been quantified in the cost-benefit analysis, **a series of indicators (KPIs) have been defined to serve as parameters for evaluating the achievement by the solution of the aforementioned benefits.** Each KPI is allocated a weight in relation to the applicable regulatory criteria, which enables an impact associated with the benefits to be ascertained.

Qualitative benefits	KPIs	Impact
Increase in efficiencies for the system as a whole as a result of optimising the maintenance of the underground cables	Cost associated with the system charges for end users Corrective maintenance budget	
Reduction in the number of field trips carried out by the network management companies' teams	Number of traffic accidents Level of use of fossil fuels in vehicles Optimisation of human resources	
Reduction in manual live-line work	Occupational accident rate Number of occupational accidents associated with live-line work	
Increase in real-time information on the status of the facility	Sensitivity of measurement Volume of data collected per unit of time	
Reduction in the time required to localise faults	Cable degradation associated with the fault Accuracy in pre-localising and localising the fault	
Reduction in errors associated with the use of multiple pieces of equipment in maintenance tasks	Number of pieces of equipment used	

Step 8: Qualitative evaluation of the solution in respect of the regulatory criteria

Weights associated with each of the identified KPIs of the qualitative benefits

In order to **evaluate the significance of the benefits defined in step 3** that have not been quantified in the cost-benefit analysis, **a series of indicators (KPIs) have been defined to serve as parameters for evaluating the achievement by the solution of the aforementioned benefits.** Each KPI is allocated a weight in relation to the applicable regulatory criteria, which enables an impact associated with the benefits to be ascertained.

Qualitative benefits	KPIs	Impact
Encouragement of innovation and development of new technologies with a view to obtaining a 100% renewable energy system using digitalisation and network integration solutions	Percentage of the budget of the electrical companies earmarked for R&D+i Optimisation of the load level of underground networks in the face of changing energy technologies	
Reduction in the need to replace facilities as a result of lack of predictive/preventive maintenance	Increase in the useful life of facilities Reduction in the level of replacement of assets that have not come to the end of their useful lives.	
Reduction in excavation tasks on land close to the underground facility	Extent to which existing vegetation is affected Cost of replacing surfaces	
Reduction in greenhouse gas emissions	CO_2 emissions NOx emissions Emission of other hazardous particles	
Reduction in waste associated with electrical and electronic equipment	Volume of electrical and electronic waste	

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Weights associated with each of the identified KPIs of the qualitative benefits

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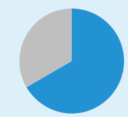
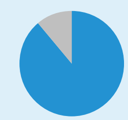
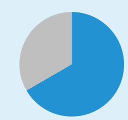
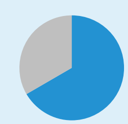
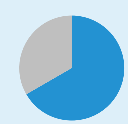
Qualitative benefits	KPIs	Impact
Greater resilience of underground networks to extreme weather events	Volume of facilities put out of operation due to force majeure	
Facilitating the harnessing of opportunities for employment and improving competitiveness generated by the energy transition	Increased billings of Spanish electrical equipment companies Increased exports by Spanish electrical equipment companies Employment growth in high value-added industries	
Generation of innovative technical knowledge in order to modernise and transform production processes	Increase in the number of registered patents	
Contribution to the development and control of underground networks in order to reduce isolated systems' dependence on fossil fuels	Level of interconnection between isolated systems and the Spanish mainland system Level of fossil fuel-based energy generation in isolated systems	
Increase in the information relating to wave quality	Degradation of electrical devices in end uses associated with deficient product quality Degradation of network equipment associated with deficient product quality	

Analysis methodology

General description

A generally accepted **methodology** has been applied (prepared by the Electric Power Research Institute (EPRI)), which in turn is used by the **European Commission in the preparation of guidelines for cost-benefit analysis in certain solutions in the electricity industry**, such as the deployment of smart meters or the development of smart grids. This analysis is proposed **considering both quantitative and qualitative impacts**.

Characterise the Project

1. Review and describe **technologies, elements** and **goals of the project.**
2. **Map assets onto functionalities.**

Estimate Benefits

3. **Map functionalities onto benefits.**
4. **Establish the baseline.**
5. **Monetise benefits and identify beneficiaries.**

Compare Cost and Benefits

6. **Identification and quantification of the main costs of the solution.**
7. **Quantitative comparison of the costs and benefits** derived from the implementation of the solution.

Qualitative Analysis

8. Evaluation of the **contribution of the solution to the main specific criteria established by the regulation setting up the framework for the solution**.
9. **Identification and estimation of other aspects and qualitative social impacts that are difficult to assess quantitatively.**

Analysis methodology

Step 9: Identification and estimation of other aspects and qualitative impacts

In addition to the qualitative evaluation of the solutions performed in step 8, **the qualitative analysis must identify and evaluate all the costs and benefits of a given solution for society, which cannot be monetised or therefore included in the economic analysis conducted in previous steps (the externalities of the solution).**

1. The **externalities must be listed** and **preferentially expressed in physical units, so that the analysis can be as rigorous and objective as possible.**

2. **The establishment of indicators for each externality is recommended**, and the **choice and calculation of each indicator should be appropriately motivated.**

3. **Where the calculation of an indicator is not possible, a detailed description of the estimated impacts of the solution** should be provided.

Possible externalities of a solution (illustrative examples)

…in terms of employment

…in relation to safety

…through possible environmental impacts

…in terms of social acceptance

…in relation to the possible time savings for consumers

…creating an innovative market ecosystem

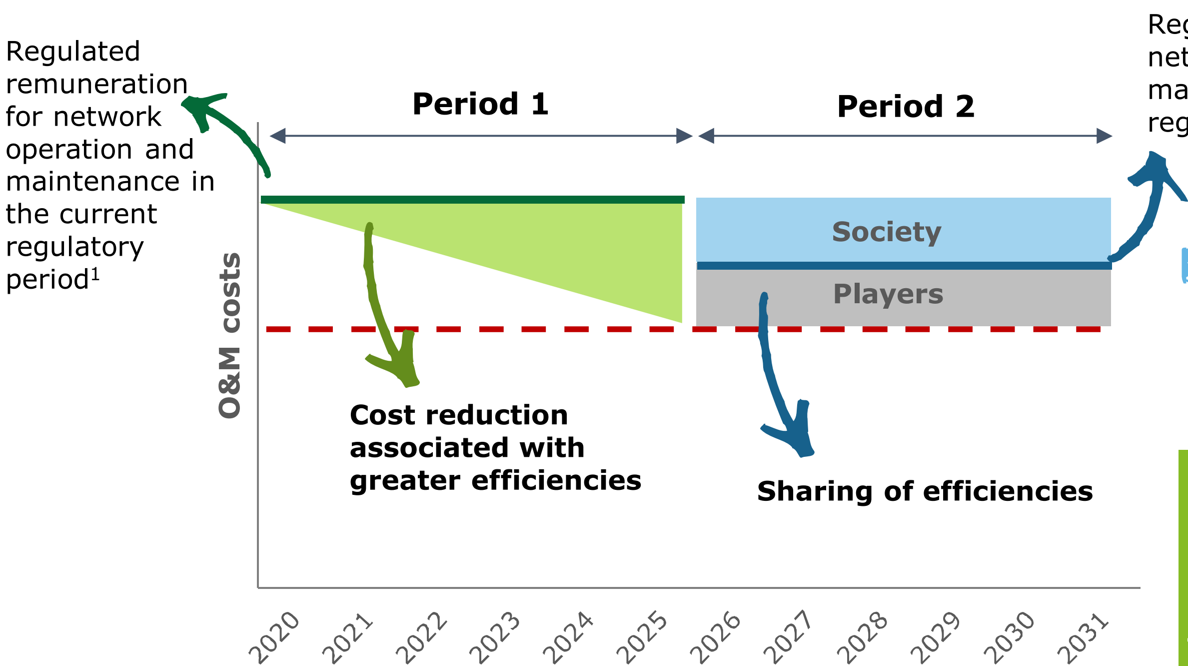
…in relation to privacy

Step 9: Identification and estimation of other aspects and qualitative impacts

The digitalisation of the networks contributes towards increased efficiency

The introduction of **efficiency requirements into the methodologies for determining the remuneration of electricity transmission and distribution activities creates efficiencies in relation to operating and maintenance costs. These efficiencies will benefit society in future regulatory periods,** through regulatory mechanisms for sharing the efficiencies generated.

Regulatory developments concerning electricity networks, by means of the regulatory Circulars approved by the CNMC for the 2020-2025 regulatory period, include **efficiency criteria relating to the operating and maintenance costs of electricity transmission and distribution companies.**



Benefit for society

The benefits arising from the efficiencies achieved in the current regulatory period will be shared out among companies and society in the next regulatory period

Investment in tools that provide more information on the condition of the high- and middle-voltage underground network enables efficiency to be increased and, at the same time, gives rise to a series of ancillary benefits that reduce industry costs and increase physical safety and security of supply.

(1) With respect to the methodology for determining the remuneration for electricity distribution, the cost reduction is performed each year of the 2020-2025 regulatory period with an annual reduction of approximately 3%. However, in adjustments prior to future regulatory periods, the greater efficiencies can be shared among companies and users, giving rise to an economic benefit for society.

Step 9: Identification and estimation of other aspects and qualitative impacts

Functions established for electricity transmission and distribution companies

Spanish Electricity System Law 24/2013 establishes the functions and obligations to be fulfilled by electricity transmission companies. Solutions such as the one considered would be adapted to the regulatory mechanisms in force and would contribute to the fulfilment by the electricity transmission companies of the functions attributed to them by the regulations.

Functions associated with electricity transmission under Spanish Electricity System Law 24/2013

-Non-exhaustive analysis-

- **Execute the transmission facility maintenance plans.**
- **Execute the system operator's instructions to restore the service** in the event of general power outages.
- **Comply** at all times **with the instructions of the system operator for the operation of the transmission network.**
- **Guarantee the development and extension of the transmission network by executing the planning of the approved transmission network**, to ensure the maintenance and improvement of a network configured on the basis of minimum cost and consistent and uniform criteria.
- Perform its activities as authorised and pursuant to the applicable provisions, **providing a regular and continuous transmission service in observance of the quality levels determined by government regulation and maintaining the facilities in an adequate state of repair and technical correctness.**
- **Allow its facilities to be used for energy transfers and its transmission networks to be used** by all authorised parties, on a non-discriminatory basis, in accordance with the technical transmission standards.
- **Direct and maintain its facilities.**

To comply with certain functions established by the Spanish Electricity System Law, electricity transmission companies do not have a mechanism whereby they are directly remunerated for the aforementioned activities. In this regard, solutions that enable a greater degree of monitoring and better network information would contribute, through the remuneration regulated in respect of assets, to fulfilment of the regulatory functions associated with electricity transmission.

Step 9: Identification and estimation of other aspects and qualitative impacts

Functions established for electricity transmission and distribution companies

Spanish Electricity System Law 24/2013 establishes the functions and obligations to be fulfilled by electricity transmission companies. Solutions such as the one considered would be adapted to the regulatory mechanisms in force and would contribute to the fulfilment by the electricity distribution companies of the functions attributed to them by the regulations.

Functions associated with electricity distribution

-Non-exhaustive analysis-

- **Perform its activities** as authorised and pursuant to the applicable provisions, **providing a regular and continuous distribution service in observance of the quality levels determined** by government regulation.
- Be responsible for the **construction, operation, maintenance** and, where necessary, development of its distribution network.
- **Analyse requests to connect to the distribution networks that they manage** and reject or, where appropriate, condition connection to the networks in accordance with the regulatory criteria.
- Submit the **information required by the Spanish central government to establish remuneration.**
- **Expand the distribution facilities as necessary to cater for new electricity supply demands** in the terms established by regulation.
- **Establish and implement the maintenance plans** for its distribution network facilities.

In electricity distribution, in addition to asset-based remuneration (investment and operation and maintenance), companies are also remunerated under the remuneration for other regulated tasks ("ROTD") model. With respect to operation and maintenance and the ROTD, **the current regulation proposes mechanisms which pursue increased efficiency through cost reduction.**

This increase in efficiency will result in a greater share of the benefits for the system in successive regulatory periods. To achieve these efficiency targets and, at the same time, properly comply with the functions stipulated for electricity distribution, the distribution companies need to be able to develop tools that provide extensive information on, and contribute to the digitalisation of, their network.

Step 9: Identification and estimation of other aspects and qualitative impacts

The digitalisation of the networks will enable product quality to be measured in a more effective manner

The **challenges associated with the modernisation of the networks and the integration of renewable energies** make **network operation more complex**, in which respect **security, quality and efficiency criteria** must be followed. **More complex power flows and the heavy presence of renewable energies pose a challenge from the standpoint of electricity product quality.**

Network stability

- **Short-circuit currents** are characterised by a **virtually instantaneous increase, several times higher than the nominal current** of a facility.
- The integration of the distributed power may cause **power inputs downstream** from traditional protection, which could give rise to **distortion that conceals the existence of a fault**, impeding the protection mechanisms.

Network load level

- **Renewable energy** is characterised by **intermittent generation concentrated in specific periods.** This situation can cause **peak loads to surpass the operational limits of the network design.**
- **The use of reactive power** to regulate the voltage of the system may cause a **further increase in the network load.**
- **Facility overload reduces the useful life of the equipment and increases maintenance costs.**

Wave quality

- **Harmonics:** these have increased due to the more widespread use of power electronics. This increase has a negative impact on the network.
- **Transients:** the connection and disconnection of the power distributed to the system may cause the appearance of transients in the wave.
- **Balance between phases:** any variances with respect to the optimum operating conditions, in which the voltage curves of the three phases differ by a 120º angle and have the same amplitude implies an imbalance.

In view of the challenges posed in the future for distribution networks, it is necessary to adapt them and incorporate new technologies, at all times maintaining the wave quality required by the standards. To this end, it is increasingly important to monitor the wave quality parameters on an ongoing basis and in real time, in order to identify potential threats and design corrective action plans.

Step 9: Identification and estimation of other aspects and qualitative impacts

Digitalisation may contribute towards improving the loss rates and supply quality

Circular 6/2019, of 5 December, of the CNMC, which establishes the methodology for calculating the remuneration for the activity of electricity distribution, **establishes new mechanisms for regulating incentives to reduce loss and distribution company quality incentives**, so that the latter can see a significant improvement in their values in the next regulatory period.

Main developments included in Circular 6/2019

Both incentives have been reformulated, since, according the Regulator, in recent **years losses had risen significantly across the whole of the industry, and an improvement in the quality level of the distribution networks was not** generally **observed**. Therefore, the incentives defined in the previous Royal Decree 1048/2013 were failing to properly perform their function.

The companies **are compared solely with the industry average for the incentive**, and **they will be rewarded or penalised on the basis of their performance** with respect to the industry average.

These incentives are economically neutral for the system, since the penalties of some players finance the rewards of others.

These new mechanisms may **discourage the development of assets** or tools **at companies whose rates fall below the industry average**, since **receiving a reward might make them consider that their performance is adequate** with respect to their supply quality level and losses.

The outcome of this reformulation would not, therefore, be what had been sought by the methodology described in the Circular; rather, **the indicator values would stagnate and not be reduced.**

In this regard, the consideration, for remuneration purposes, of **innovative tools** such as **real-time underground network monitoring systems using optical current transformers would reduce the loss rates and improve supply quality at industry level.**

Step 9: Identification and estimation of other aspects and qualitative impacts

Expected evolution of the electrical equipment manufacturing industry

The implementation of innovative solutions associated with the digitalisation of the electricity transmission and distribution networks contributes towards **the development of the Spanish electrical equipment industry, consolidating this part of the production system, boosting quality employment, R&D investment, a reduction in imports of foreign equipment and the promotion of Spanish exports.**

An investment of between ~EUR 5,000 million and EUR 6,000 million in digitalisation and automation of electricity networks in Spain is expected between 2017 and 2030.

This represents around **~10.9% of total investment in electricity networks in the 2017-2030 period.**

Additionally, automation and digitalisation constitute a key driver of the energy transition. This constitutes an opportunity for electrical equipment manufacturers, since...

1. **Their growth potential in Spain could become up to ~1.4 times greater** thanks to the currently untapped market and the development of new equipment
2. **Their export growth potential could become up to ~0.9 times greater** due to the rise in exports as a result of transition growth drivers
3. This increase in activity could entail **direct employment growth of ~25% at equipment manufacturing companies**

Electrical equipment manufacturers earmark up to 3-5% of their total revenue for R&D projects. This value is above the manufacturing industry average of ~0.6% of total revenue earmarked for R&D. In addition, this is one of the industrial sectors that generates the highest quality of employment in terms of salary.

Source: The electrical equipment manufacturing industry in the face of the energy transition: an opportunity for industry (Monitor Deloitte).

Step 9: Identification and estimation of other aspects and qualitative impacts

Recovery of the economy following the crisis caused by COVID-19

The development of solutions associated with the digitalisation of the network and the electrification of the economy could constitute a driving force for economic recovery following the COVID-19 pandemic. In this regard, **the initial "rebuilding" proposals that the European Commission is designing indicate that this process will be heavily linked to the development of a "more resilient, greener and digital Europe".**

Recovery towards a more resilient, greener and digital Europe

Support the Member States so that they can recover, repair their damage and emerge from the crisis in a stronger position

- **European Recovery and Resilience Facility**, embedded in the European Semester
- **Support the green transition to a climate-neutral economy**

Relaunch the economy and support private investment

- Strengthened InvestEU programme, including a **Strategic Investment Facility**
- New Solvency Support Instrument to support the solvency of viable companies

Learn from the crisis and address strategic European challenges

- New Health Programme to help Europe prepare for future health threats
- Reinforced EU Civil Protection Mechanism to respond to large-scale emergencies

This plan is built around two investment channels:

A new **recovery instrument of EUR 750 billion**, called ***"Next Generation EU"***, for 2021-2024

A reinforced long-term budget of the European Union for 2021-2027

The European Commission remains committed to the green and digital transition, which it deems essential for relaunching the European economy.

Appendix I: Analysis methodology

Analysis methodology

General description

A generally accepted **methodology** has been applied (prepared by the Electric Power Research Institute (EPRI)), which in turn is used by the **European Commission in the preparation of guidelines for cost-benefit analysis in certain solutions in the electricity industry**, such as the deployment of smart meters or the development of smart grids. This analysis is proposed **considering both quantitative and qualitative impacts**.

Characterise the Project

1. Review and describe **technologies, elements** and **goals of the project.**
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Qualitative Analysis

8. Evaluation of the **contribution of the solution to the main specific criteria established by the regulation setting up the framework for the solution**.
9. **Identification and estimation of other aspects and qualitative social impacts that are difficult to assess quantitatively.**

Analysis methodologies

Step 1: Review and describe technologies, elements and goals of the project.

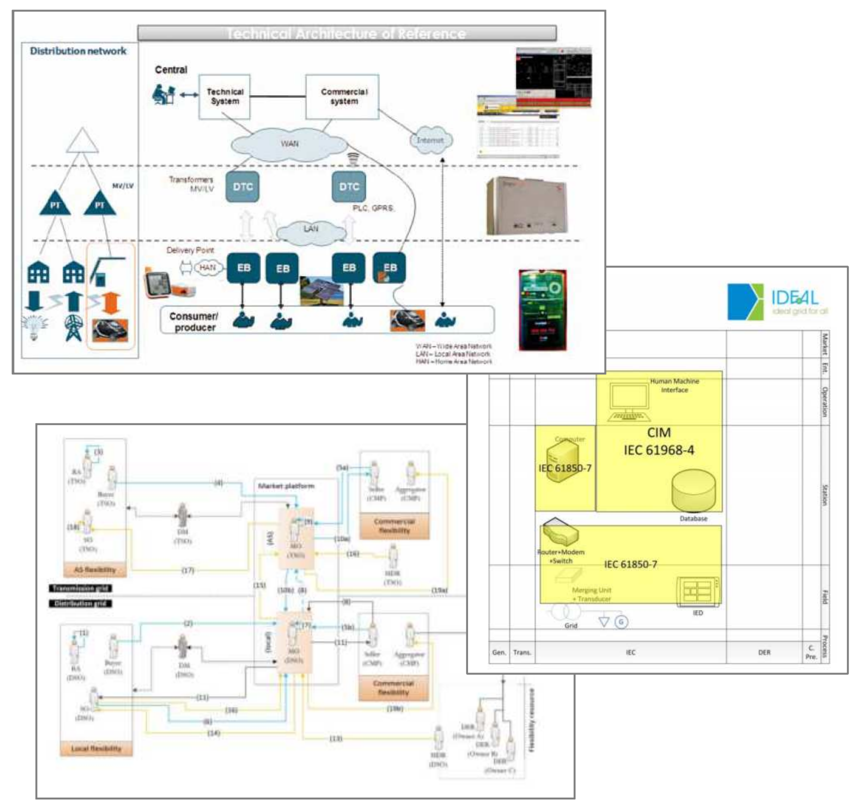
The first stage for carrying out the cost-benefit analysis is the **definition of the elements that make up the solution, as well as the main objectives sought with its implementation**.

The proposed solution must be clearly defined as a self-sufficient unit of analysis. To this end, as a minimum the following information should be provided:

-Non-exhaustive analysis-

- Characteristics of the electrical network where the solution would be implemented.
- Regulatory context and its impact as a framework in which the solution would be implemented.
- Clear definition of the objectives of the solution, as well as the expected impacts at socioeconomic level.
- Description of main solutions applied in the current scenario.
- Main technical features of the new proposed solution.
- Any other feature that helps define the solution, adding value and setting it apart from other more classical or traditional solutions.
- Relevant players in the implementation of the solution, involved both directly and indirectly.

Illustrative examples



Analysis methodology

Step 2: Map assets onto functionalities

The second step consists of mapping which components of the solution to be analysed activate each of the functionalities defined for an asset that is necessary for the activity. Each functionality is associated with one or more benefits, and, accordingly, it is essential to clearly establish the relationship between the components developed and the functionalities they allow.

Illustrative example

Hardware
- *Component 1*
- *Component 2*
- *Component 3*
- …
- *Component n*

Software
- *Component a*
- *Component b*
- *Component c*
- …
- *Component z*

1 Definition of all the components of the solution that must be taken into account in carrying out the cost-benefit analysis.

2 The specific criteria established by the regulation establishing the framework for the solution are broken down into a series of functionalities required by each criteria.

Illustrative example

	Criterion 1		Criterion 2		Criterion n	
Assets	**F_1**	**F_2**	**F_3**	**F_4**	**…**	**F_n**
Solution 1	●	●	●			●
Solution 2	●	●		●		
Solution 3		●	●		●	
…		●				
Solution n		●		●	●	●
Combination of solutions	●	●	●	●	●	●

3 A relationship is established between the previously defined components of the solution and the functionalities. The points on which the matrix's cells show the functionalities provided by the solution and which components activate each one of them.

Illustrative examples

Examples of criteria:
- Economic efficiency of the system
- Benefits in security of supply
- Benefits in quality and continuity of supply
- Technical efficiency of the system
- Other aims of energy policy: decarbonisation, digitalisation, etc.

Analysis methodology

Step 3: Map functionalities onto benefits

The aim of the second mapping is to relate the functionalities identified in step 2 with the potential benefits that each one can give rise to. Each functionality must be considered individually and analysed as it could contribute to each of the benefits in the left-hand column of the table.

The methodology developed establishes a detailed series of benefits, which, in turn, can be grouped into the following main categories (non-exhaustive list):

Illustrative examples

- Reduction in maintenance costs
- Reduction in operating costs
- Reduction in electricity losses and losses due to fraud
- Increase in personal safety
- Reduction in CO_2 emissions
- Reduction in post-outage reconnection times
- Reduction in trips
- Others

Illustrative example

	Criterion 1		Criterion 2		Criterion n	
Benefits	**F_1**	**F_2**	**F_3**	**F_4**	**…**	**F_n**
Benefit 1	●		●			
Benefit 2						
Benefit 3		●			●	
Benefit 4				●		
…	●		●		●	●
Benefit n		●	●			

In this mapping, the functionalities defined and used in step 2 are related to the benefits. Following the analysis, the points indicate the benefits that are activated on the basis of each functionality.

It is probable that certain functionalities identified in step 2 may not be mapped on to any of the benefits in step 3. Although each component must be related to at least one functionality, not all of them necessarily activate a benefit.

The main reasons for this circumstance in the mapping are:

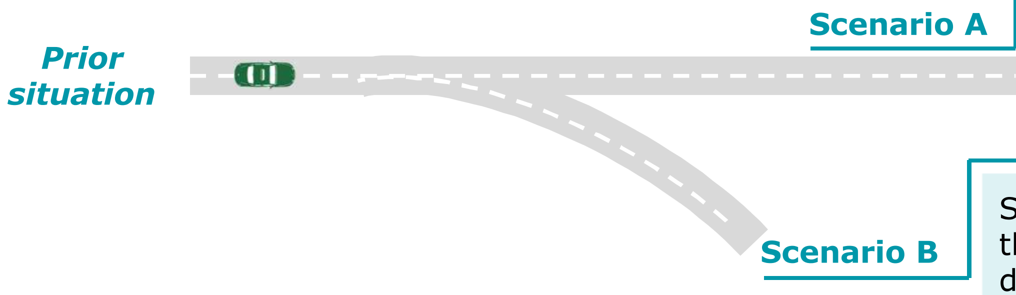
- Nature, size or scope of the solution.
- Applicability of the benefits.
- Monetisation of the benefits.
- Applicable legislation.

Analysis methodology

Step 4: Establish the baseline.

The objective of establishing the project baseline is to formally define the "control state" that reflects the system condition which would have occurred had the project not taken place.

In order to appropriately assess a possible solution, several scenarios are defined: (i) the Business as Usual (BAU) scenario and (ii) the "with solution" scenario.



Scenario A shows the baseline conditions that reflect what the system would have been ***without*** the defined solution.

Scenario B shows the conditions, defined using metrics, that reflect the system ***with*** the implementation of the defined solution.

In order to define any particular benefit, it is necessary to define scenarios A and B and the assumptions used to define it, and measure the difference in that benefit metric between scenarios A and B.

Type of Benefit	Assumptions - Scenario A (baseline scenario)	Expected results	Assumptions - Scenario B (estimated scenario)	Expected results

The assumptions and values used to define the two scenarios may refer to both historical values and predictions made.

Analysis methodology

Step 5: Monetise benefits and identify beneficiaries

Once the baseline and solution scenarios have been defined, **it is necessary to identify, collect and report the data required for the quantification and monetisation of the benefits.** This step, in turn, consists of five sub-steps.

Identify and compile the data

The benefits identified (in Step 3) and the various scenarios (identified in Step 4) determine the type of data needed for the evaluation.

Quantify the benefits

The benefits of a solution will represent the change between the baseline conditions and the hypothetical conditions following implementation of the solution. Depending on the solution to be implemented, changes can occur at different levels.

Monetise the benefits

This sub-step involves monetising (i.e. expressing in equivalent economic terms) the benefits quantified in the previous sub-step so that the quantifiable benefits can be compared using a common unit of measurement.

Identify the beneficiaries

The analysis will attempt to identify the various beneficiaries in the electricity system for each of the benefits (users, system operators and, ultimately, society).

Assess uncertainty

Additionally, the level of precision in the quantification and monetisation of the benefits will be identified, since it is more difficult to assess certain benefits based on environmental or social factors, for instance, than it is to assess technical benefits.

Analysis methodology

Step 6: Quantification of costs

The costs of the solution are those incurred throughout the implementation thereof with respect to the baseline scenario. This step requires each cost component to be meticulously broken down to provide a faithful reflection of the actual investment made.

Identification of costs

To identify the main costs that will be incurred in the solution, they will be evaluated:

- Internally by the company.
- On the basis of the information provided by the suppliers.
- Using estimates for similar solutions that may already exist in the market.
- By means of any other mechanism that enables the costs associated with the solution to be identified.

The cost types that will be identified for subsequent quantification can be classified under either of the following two categories:

Capital expenditure (CapEx)

Operating expenditure (OPEX)

Quantification of costs

The quantification of the costs of the solution is a key process for ascertaining the return on investment, which shows whether it is positive.

Analysis methodology

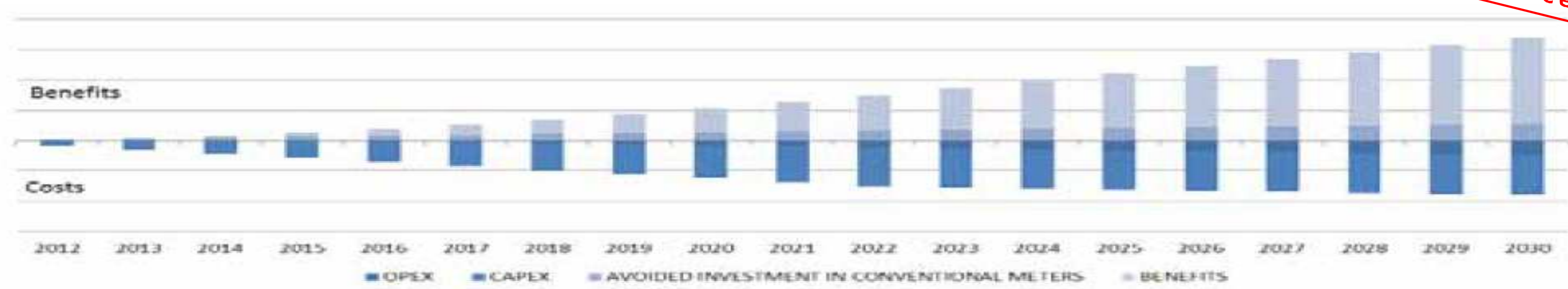
Step 7: Comparison of cost and benefits

Once the costs and benefits of the solution have been estimated, they must be compared and evaluated to determine the cost-effectiveness of the implementation of the solution.

Cumulative comparison

This method presents costs and benefits cumulatively. This approach is useful in identifying the point in time when the break-even point is passed, i.e. when benefits exceed costs.

Illustrative example



Benefit-cost ratio

This method consists of representing the value of the solution as a ratio of benefits to costs, either on an annual basis or on a present value basis.

This is a simple way of representing the size of the benefits relative to that of the costs. If the ratio is greater than one, the solution is cost-effective.

Analysis methodology

Step 8: Qualitative evaluation of the contribution of the solution to the regulatory criteria

Certain benefits are difficult to assess in economic terms, and they cannot therefore form part of the cost-benefit analysis. The qualitative evaluation performed in this step **enables, through the definition and assessment of a series of KPIs, various solutions to be differentiated in qualitative terms on the basis of their merits**, which **serves to supplement the economic analysis conducted in previous steps.**

The **benefits of the solution defined in step 3** are considered, **and KPIs associated with each benefit are established.**

The **specific criteria established by the regulation** setting out the framework of the solution and defined in step 2 are considered.

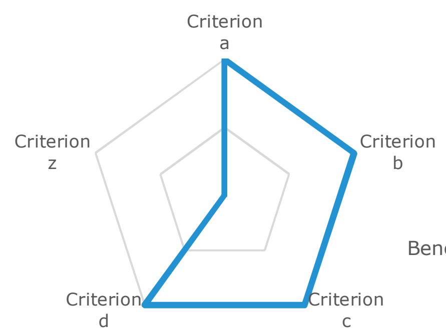
Relationships between the specific criteria established by the regulation and the KPIs associated with the benefits are identified, and discrete weights (0-1) enabling the significance of the criterion-KPI relationship to be quantified are allocated. The analysis must include the allocation of an element that constitutes a "link" between a given criterion or regulatory objective and a specific benefit.

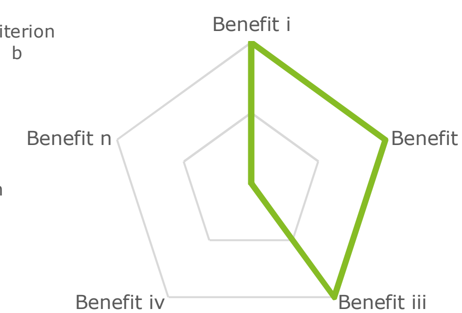
Illustrative example

		Criterion a	Criterion b	Criterion z	
Benefit i	KPI_1^i	Weight 1	-	Weight 13	Σ Weights
	KPI_2^i	-	Weight 7	Weight 14	
Benefit ii	KPI_1^{ii}	Weight 2	Weight 8	-	Σ Weights
	KPI_2^{ii}	Weight 3	-	-	
	KPI_3^{ii}	-	Weight 9	Weight 15	
	KPI_4^{ii}	-	Weight 10	Weight 16	
Benefit n	KPI_1^n	Weight 4	Weight 11	-	Σ Weights
	KPI_2^n	Weight 5	Weight 12	Weight 17	
	KPI_3^n	Weight 6	-	Weight 18	
		Σ Weights	Σ Weights	Σ Weights	

Each solution can be analysed on two planes (criteria and benefits), so that **the impact of the solution will be greater the larger the area in the diagram.**

Illustrative examples





Cost-benefit analysis

Step 9: Identification and estimation of other aspects and qualitative impacts

In addition to the qualitative evaluation of the solutions performed in step 8, **the qualitative analysis must identify and evaluate all the costs and benefits of a given solution for society, which cannot be monetised or therefore included in the economic analysis conducted in previous steps (the externalities of the solution).**

1. The **externalities must be listed** and **preferentially expressed in physical units, so that the analysis can be as rigorous and objective as possible.**
2. **The establishment of indicators for each externality is recommended**, and the **choice and calculation of each indicator should be appropriately motivated.**
3. **Where the calculation of an indicator is not possible, a detailed description of the estimated impacts of the solution** should be provided.

Possible externalities of a solution (illustrative examples)

- **…in terms of employment**
- **…in relation to safety**
- **…through possible environmental impacts**
- **…in terms of social acceptance**
- **…in relation to the possible time savings for consumers**
- **…creating an innovative market ecosystem**
- **…in relation to privacy**

Appendix II: Others

Appendix II

Characteristics of the electrical network where the solution would be implemented.

A high-voltage underground cable is composed of various elements, in contrast to its aerial equivalent, which only has the conductor cable. Due to its greater complexity, and the difficulties involved in an underground electricity cable, the ongoing monitoring of its state is very important.

Insulation

This is a critical component of the cable, since **it must be capable of withstanding the electrical field that it surrounds.** The maximum voltage that can be withstood by a cable will depend on the material and the thickness of the insulation.

Terminal

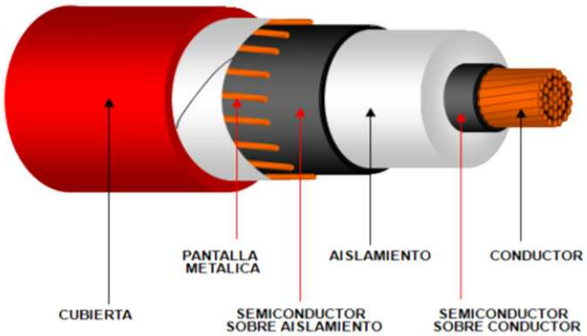
The terminals are the **ends of the** underground high-voltage cable that ensure **electrical continuity** to other elements of the system (aerial lines, substations, transformation centres, etc.).

Cable joint

Cable joints are **unions between conductors that ensure electrical and mechanical continuity. They are considered to be "critical points" of the underground high-voltage networks,** since **most faults occur in this part of the facilities.**

Conductor cable

This is the **element that enables the transmission of electricity through the conductor** (aluminium or copper). A typical blueprint for a conductor cable in underground high-voltage facilities is as follows:



Earth cable

This enables **the elements of the facilities to be earthed,** making it possible to **protect elements that should not be live from becoming electrically charged.**

Connection

Connections are **cable unions that ensure electrical continuity,** although there is less mechanical resistance than in the cable joints. A connection cannot be subjected to mechanical forces or increase the electrical resistance of the conductor.

Image source: Condumex

Appendix III: References

Appendix III

References

Sources of reference information
Workshop on the localisation of faults in insulated underground and underwater cables, organised by CIGRE Spain (September 2019)
Thorne & Derrick International (https://www.powerandcables.com/)
HV Technologies (https://hvtechnologies.com/)
Baur (https://www.baur.eu/es/home)
Hawk Measurement (http://www.hawkmeasure.com/)
AP Sensing (https://www.apsensing.com/)
Lumiker (http://www.lumiker.com/)
Arteche (https://www.arteche.com/es)
Maintenance of high-voltage underground electricity networks, Germán Coca López (2013)

General considerations regarding the document

In order to put this document into the correct context the following considerations should be taken into account.

Our work was based mainly on the use of technical descriptions and economic, technical and financial information provided by Lumiker Aplicaciones Tecnológicas, S.L. (the Company) or published by third parties which, due to its nature, is not audited in many cases. Given the nature of our work, we have assumed that the aforementioned information is accurate and complete, and have not performed any reviews thereof.

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Our work was not an audit of financial statements or a review of historical or prospective economic information and, accordingly, did not include all the procedures considered necessary under generally accepted professional standards for the performance of an audit of financial statements and, therefore, we do not express a professional opinion on the financial information used. Had we performed an audit of the financial statements in accordance with generally accepted auditing standards or had we performed additional procedures or procedures with a different scope, other additional matters of interest might have been disclosed which would have been reported to you.

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