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Cost-benefit analysis of Smart Grid projects: Isernia

Costs and benefits of Smart Grid pilot installations and scalability options

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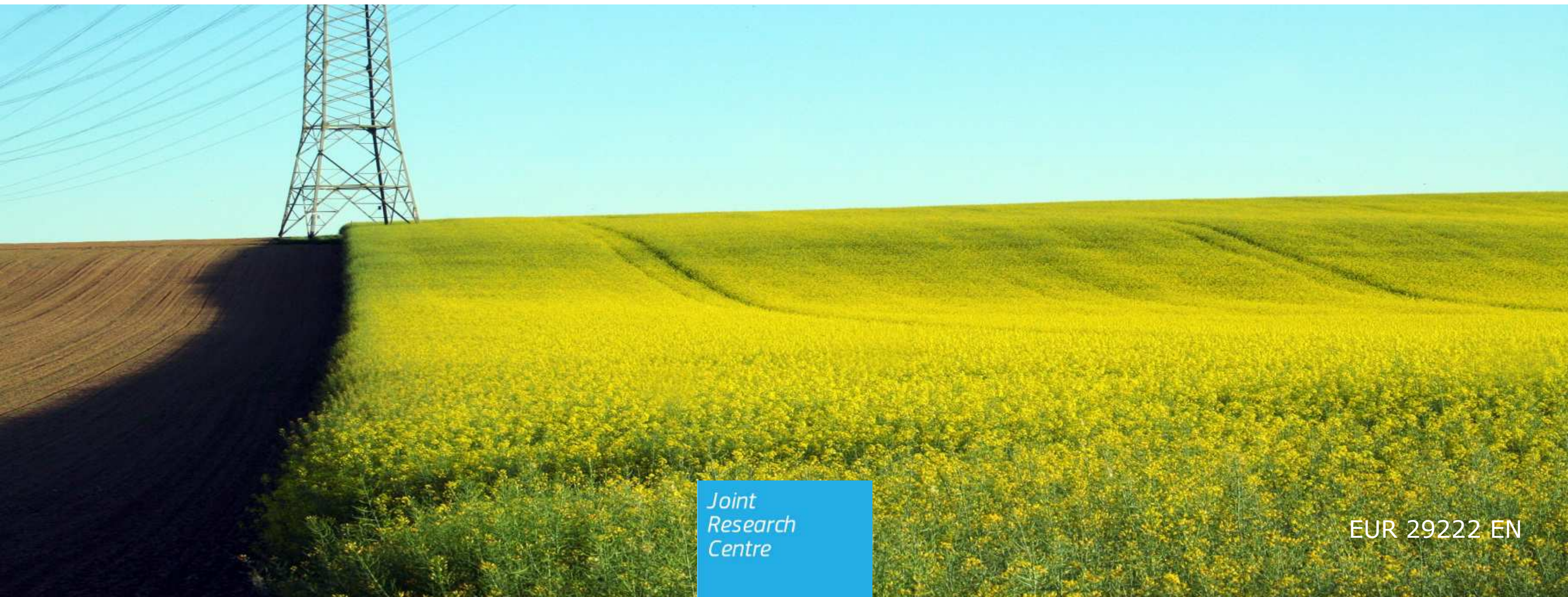

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Cost Benefit Analysis of Smart Grid Projects: Isernia - - Costs and benefits of Smart Grid pilot installations and scalability options

Smart Grid pilot projects and their assessment through a cost-benefit analysis are crucial to ensure that Smart Grid and Smart Metering roll-out are economically reasonable and cost-effective. Analysing the Isernia pilot project, the key result of the investigation is that an extra remuneration for such ambitious projects has been crucial in turning the Distribution System Operator's Return on Investment (RoI) positive.

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Executive summary

Policy context

Smart Grid projects are crucial to enable the energy transition towards Renewable Energy Sources (RES). Already in 2011, the European Commission laid down the principles to promote Smart Grids (SG) and Smart Metering throughout the EU with the Communication "Smart Grids: From innovation to deployment".

A thorough quantification of all the potential impacts stemming from a SG project is crucial for large scale SG deployment: in a first methodological effort towards this aim, the Joint Research Centre (JRC) of the European Commission has developed a comprehensive framework of Cost-Benefit Analysis (CBA) of SG projects, and is continuously testing and improving the methodology with real SG instances.The recent proposal by the European Parliament and the Council for a new Directive on common rules for the internal market in electricity (December 2016) explicitly mentions the up-take of smart distribution grids and demand response as necessary to empower consumers.

In addition, the proposal maintains the pre-existing recital requiring member states to "encourage the modernisation of distribution networks, such as through the introduction of smart grids, which should be built in a way that encourages decentralised generation and energy efficiency".

Key conclusions

The assessment of Smart Grid (SG) pilot projects through a Cost-Benefit Analysis is crucial to ensure that Smart Grid and Smart Metering roll-outs are economically reasonable and cost-effective.

The key outcome of the (ex-post) analysis of the Isernia pilot project[1] is that, for such ambitious Smart Grid projects, a dedicated incentive such as the extra Weighted Average Cost Of Capital (WACC) remuneration granted by the Italian Regulatory Authority was crucial in ensuring a positive return on investment (RoI) for the Distribution System Operator. If the regulatory extra-incentive were not in place, the investment's Net Present Value would be negative.

In other words, while pilot smart grid investments may not yield positive returns for the investor in the absence of a SG-specific regulatory remuneration, they may well benefit society and the power system as a whole

When assessed from a societal perspective, the SG projects assessed up to now by JRC and partners have proven to be beneficial, that is, each euro invested in smart grid technologies generates a higher return in terms of societal benefits.

Main findings

The decision on smart metering roll-out at the national level should be based on an economic assessment which explores if it can be economically cost-effective, given the potential benefits of Smart Metering for both end consumers and Distribution System Operators thanks to consumer engagement.

Within the Italian regulatory context, Smart Grids pilot projects (such as the one in Isernia) have benefited from generous rate-of-return regulation guaranteeing an extra-return for Smart Grids investments (under specific conditions).

The JRC's work on Smart Grids assessment involved the cost-benefit analyses of candidates for the status of Projects of Common Interest (2015 and 2017 rounds), and of

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[1] The Cost-Benefit Analysis of the Isernia project has been carried out considering the regulatory and market framework in the project's timeframe.

the SG project in Malagrotta, Rome, also targeted by the Italian Regulator's dedicated SG incentivisation. Considering the relative size of these two projects, it may be said that most of Italy's SG pilot applications were monitored and assessed by the Joint Research Centre.

This has blazed the trail for what is foreseen in the new proposal for a Directive, i.e. the national assessment of the performance of Transmission System Operators (TSOs) and Distribution System Operators (DSOs) in developing and spreading Smart Grid solutions.

This analysis identified the main beneficiaries and highlighted their costs and benefits. Two main perspectives were taken into account: the one of the DSO, and a societal perspective reflecting the standpoint of the various impacted stakeholders.

A natural question is whether SG investments would be financially viable under the standard remuneration scheme of the Italian electricity regulation, or whether a targeted one is instead indeed preferable. This is particularly relevant given that a trial regulatory framework (ARG/elt 39/2010 (2)) specifically targeted SG investments.

The Isernia project benefitted from this scheme, being awarded with an extra +2% regulated Weighted Average Cost of Capital (WACC) by the Italian Regulator, on top of the regular WACC remuneration for investments on the distribution network.

When estimating the societal benefits, the Isernia project features a positive societal benefit/cost ratio, between 1.2 and 1.8, according to the approach followed, despite it being one of the first smart grid pilots conducted by ENEL.

Related and future JRC work

JRC developed the first guidelines for Cost-Benefit Analysis of European Smart Grid projects back in 2012.

As already mentioned, the guidelines have since been applied in various contexts, s.a. the assessment of EU-wide Projects of Common Interest in the field of Smart Grids, the evaluation of national Smart Metering roll-out plans, and of specific pilot projects and their scalability options.

In line with European Commission's recommendations on applying CBA for investment projects, the JRC devotes significant resources in assessing Smart Grid deployment throughout Europe and beyond.

Quick guide

This work builds upon JRC's expertise in evaluating infrastructural projects. Smart Grid projects present some specific uncertainty related to the identification of benefits, which hinders the roll-out of Smart Grids solutions at wide scale.

The already mentioned Cost-Benefit Methodology developed by the JRC to tackle this issue involves seven steps. It drives the investors and policy makers through disentangling the various project benefits and eventually quantifies the return on investment.

In addition, a sensitivity analysis explores the results' robustness to the variation of key input parameters. The CBA itself is complemented by a quantitative evaluation of non-monetary aspects, through Key Performance Indicators, and a qualitative appraisal to estimate those benefits that, although relevant, cannot be monetised or quantified with sufficient accuracy.

1 Introduction

Smart Grid (SG) projects have been representing key enablers towards a low carbon energy scenario. Despite requiring substantial investments over many years, smart grids technologies and developments generate significant benefits for several stakeholders.

The Joint Research Centre (JRC) of the European Commission has developed a comprehensive framework of Cost-Benefit Analysis (CBA) of SG projects to test that actual benefits are generated, and continuously tests and improves the methodology based on real SG instances. A thorough quantification of all the potential impacts stemming from a SG project is necessary for large-scale SG deployment.

On the other hand, e-distribuzione SpA (hereinafter ENEL) was interested in an independent assessment of significant SG investments, as tested in an ambitious pilot project realised in Isernia, southern Italy. Such an assessment can provide valuable information on the timing, the applications, and especially on the quantification of impacts of the pilot project from both the Distribution System Operator's (DSO's) perspective and that of society at large, in view of its potential replication on increasingly large portions of ENEL's grid in Italy or other countries.

This led ENEL and the JRC to collaborate in applying the JRC CBA framework on the Smart Grid project in Isernia, resulting in this joint report. This project, funded under ARG/elt 39/10 by the Italian Regulator (ARERA), covers a wide range of SG technologies aimed at securely and reliably integrating Distributed Energy Resources (DERs) in the Medium Voltage distribution networks, empowering customers with information on electricity consumption, and enabling new services such as electrical mobility.

ENEL and the JRC cooperated on this topic, implementing a set of joint activities serving as scientific basis for the assessment and further development of the Cost-Benefit Analysis (CBA) of SG projects. Within this cooperation, the CBA step-by-step framework has been applied and validated on a real case study in Italy, both in terms of qualitative and of quantitative analysis. Evaluation criteria and formulae have been defined. Final results and conclusions have been drawn, leading to further extensions and refinements of the CBA methodology. On the other hand, the application of the JRC's methodology on a real case study, in particular the analysis of the potential benefits of SG technologies, provided with insights for future applications on the actions necessary for benefit measurements from the early stage of a project.

The Isernia project (carried out by ENEL) was chosen for this report for the wide range of SG technologies covered in a real-world user environment. The project was funded under ARG/elt 39/10 [1] by the Italian Regulator (ARERA), started in 2011 and ended in 2015. This report constitutes then a backtesting exercise on the data gathered throughout the project.

Following the JRC CBA methodology, a step-by-step analysis was carried out based on the available project results and under the regulatory and market conditions applicable in the project timeframe. Fine-tunings of the methodology to the context have been highlighted in the perspective of application to future projects.

The goal of this report is twofold: a) to gather important insights on the real costs and benefits of a SG pilot project, including the societal ones, collecting crucial information for replication at large scale of the solutions tested; and b) to continue implementing the JRC CBA methodology on real projects, in order to build a solid case for its application to the most diverse variety of SG projects as a solid decision-making tool for public and private investors in SG.

In addition, useful metrics to monetise SG benefits have been provided in this report, thus contributing to the definition of evaluation criteria that could be used in further applications.

1.1 The Isernia Project

The Isernia project started in 2011 for an overall duration of three years. Its objective was the realisation of a new model of protection, automation and management of energy distribution and generation, based on Smart Grids principles, under conditions of real-world operation. The pilot project involved several thousands of customers, and an overall investment of about 7.4 million euros.

The city of Isernia was chosen due to the area's geographic and climate characteristics which create optimal conditions for the development of PV, hydro, and biogas generation, and therefore of a system that may allow for the full integration of RES in the distribution grid.

The project's innovation contents may be summarised as follows:

- Forecasting and advanced monitoring infrastructure for RES generation and power network variables;
- Interaction with generators for the advanced regulation of network flows;
- Storage based on Li-Ion battery technology for the modulation of energy flows;
- EV chargers;
- Home energy consumption monitoring equipment.

Through such newly installed infrastructure, the traditional and distributed energy generation is integrated with modern communication and protection systems that allow maintaining the highest quality standards by managing faults in an efficient, targeted and timely manner.

The project enabled a new approach to Distributed Generation, by monitoring it through the active involvement of distributors and clients. For the first time, Isernia's customers were involved in an experimental programme on consumer awareness. Participants in this programme received from ENEL the Smart Info+ kit with the innovative Smart Info, an integrated intelligent device providing energy consumption data in real time. Through Smart Info, customers received alerts and advice every time energy employment exceeded predefined levels, so to foster more rational energy employment patterns.

The municipalities involved in the project were Isernia, Carovilli, Carpinone, Castelpetroso, Castelpizzuto, Chiauci, Civitanova del Sannio, Fornelli, Longano, Miranda, Monteroduni, Pesche, Pescolanciano, Pettoranello del Molise, Roccasicura, Sant'Agapito, Santa Maria del Molise, Sessano del Molise, and Vastogirardi. At the end of the project, the households participating in the experiment ENEL Info+ were invited to assess the initiative's effectiveness and offer their suggestions for improvement.

In parallel, Italy's first energy storage appliance was installed in Isernia. It is a 1MW device, capable of storing and releasing energy for approximately 500 kWh directly on the MV grid. The storage equipment was integrated with a recharging station for electric vehicles, which could also be supported by a PV plant directly connected to it.

The operating teams of ENEL experimented directly with the EV recharging infrastructure implemented thanks to a fully electric fleet of industrial vehicles substituting the customary diesel vans during daily maintenance activities.

The Isernia project was funded under Resolution ARG/elt 39/10 [1] of the Italian Regulator (ARERA). Following a competitive process, the regulation provided to the selected smart grids projects two additional percentage points on top of the basic regulatory tariff remuneration of 7.4% WACC, for a period of twelve years.

The total budget of the project was about EUR7.4 million, as per the final cost accounting at the end of the project. Details on costs are provided later on in section 6.

2 Application of the CBA methodology to Isernia

The main objective of the Isernia project was the implementation of innovative solutions under real operating conditions, aimed at optimally managing the bi-directional energy flow on the MV distribution networks, while integrating Distributed Energy Resources (DERs) and ensuring high system reliability and security.

Advanced regulation of input flows was provided by optimising power exchanges between the nodes and the feeder. A broad-band communication system connecting a HV/MV primary substation, MV/LV secondary substations and DERs, was implemented alongside an innovative automation system for fault detection and isolation, and a reliable protection system in the presence of DERs. A multi-functional storage facility was installed and used mainly for voltage control and power flow modulation. A system for data exchange on DER production forecast and active and reactive power measurement with the TSO system was implemented, to improve the distribution network observability.

The installation of innovative electric vehicles recharging infrastructures for the field crew of the territorial department of Isernia was carried out in the project.

The ENEL Smart Info device was also installed, providing LV consumers with information on electricity consumptions, addressing more efficient energy consumption patterns while enabling further integration of smart home appliances.

2.1 Setting boundary conditions

The main assumptions and input data employed in the CBA of the Isernia project are listed in Table 1 and Table 2. As recommended by the JRC methodology, some input data (such as CO_2 and oil price, discount rate, etc.) have been considered for sensitivity analysis against different scenarios, as they may be subject to variation through the evaluation period, possibly introducing uncertainty. References have been specified for each input data, except those known to the project experts also thanks to previous experience and activities. Explanations for the main assumptions are provided in the following.

Table 1 Financial and economic assumptions used in Isernia CBA

Parameters	Unit	Reference Value	Source
TIME HORIZON	# years	10	Asset life time
REGULATED WACC (basic tariff remuneration)	%	7.4%	ARERA (2)
EXTRA WACC (RESOLUTION ARERA ARG/elt 39/10)	%	+2%	ARERA (1)
CO_2 AVERAGE PRICE	EUR/tonne	15	JRC (3)
REAL SOCIAL DISCOUNT RATE	%	2.5%	JRC (2)
REAL FINANCIAL DISCOUNT RATE	%	4%	EC (4)
OIL AVERAGE PRICE (*)	EUR/boe	65	EC (5)
NOx EMISSION FIGURATIVE COST FOR THE SOCIETY	EUR/tonne	5,700	CAFÉ (6)
SOx EMISSION FIGURATIVE COST FOR THE SOCIETY	EUR/tonne	6,100	CAFÉ (5)
AVERAGE ELECTRICITY ENERGY TARIFF (**)	EURcent/kWh	0.15	ARERA
DEPRECIATION PERIOD 1	Years	5	Asset life time
DEPRECIATION PERIOD 2	Years	10	Asset life time
AVERAGE INVESTMENT PER RES CAPACITY UNIT	EUR/kW	1,000	ARERA
ENERGY CONSUMPTION INCREASE RATE (***)	%/year	1.1%	TERNA (http://www.terna.it/)

(*) considering an average conversion factor EUR/USD of 1.35

(**) tariff energy component (i.e. excluding taxes and non-energy components) accounting for the yearly consumptions in the project area.

(***) compound annual growth rate in Italy over the period 2012 – 2023

Source: JRC and ENEL elaborations, 2018

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[2] [1].
[3] [2].
[4] [5].
[5] [3].
[6] [7].

Table 2 Input data for benefit calculations (Business-as-Usual)

Parameters	Unit	Reference Value	Source
CO_2 EMISSION PER MWh	tonne/MWh	0.41	TERNA[7]
CO_2 EMISSION SAVING PER KM (LCA APPROACH)	tonne/km	0.00008	RSE[8]
PV EQUIVALENT FUNCTIONG HOURS PER YEAR	h/year	1,312	GSE[9]
WIND EQUIVALENT FUNCTIONING HOURS PER YEAR	h/year	1,858	GSE[9]
OTHER ENERGY SOURCES EQUIVALENT HOURS	h/year	3,000	GSE[9]
CONVERSION ELECTRICITY ENERGY TOE	toe/MWh	0.187	ARERA
TOE PER BARREL OF OIL	toe/boe	7.3	ENI[10]
NOx EMISSION PER MWh	tonne/MWh	0.00124	(*)
SOx EMISSION PER MWh	tonne/MWh	0.000985	(*)

* *Source: JRC and ENEL elaborations, 2018*

2.1.1 Time Horizon

The time horizon is a crucial parameter. One approach to set it is to consider the future benefits' duration. However, this estimation is typically affected by uncertainty, which may well be amplified by changes in the regulatory framework and/or the market setting.

An alternative setup considers the project assets' life time (typically from five to ten years): this led to the choice of a time horizon of ten years for this analysis.

2.1.2 Price of carbon emissions

As in [2], the working assumption on the price of carbon emissions is EUR15/tonne.

Unlike other externalities, EU CO_2 emission permits are traded on a dedicated market. However, long-run forecasting is not straightforward, as it is also influenced by actions taken by the EU Parliament. Quotations of CO_2 have been lately around EUR 12 /tonne, which are distant from what is envisaged in the European Commission's (EC) Roadmap to a competitive low-carbon economy, requiring in the baseline scenario carbon prices of 16.5, 20 and 36 /tonne respectively in 2020, 2025, and 2030.

Furthermore, the EC has proposed a Market Stabilisation Reserve Mechanism expected to stabilise the prices above EUR20-EUR30, so that it can be stated that EU policy decisions are expected to drive prices upwards and far from the current values. However, a conservative value of EUR 15/tonne was assumed in this report, so to keep the analysis robust to low parameter realisations. This is subjected it to sensitivity analysis in a range from EUR 5/tonne to EUR 50/tonne to account for uncertainty.

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[7] [9].

[8] [12].

[9] [17].

[10] [18].

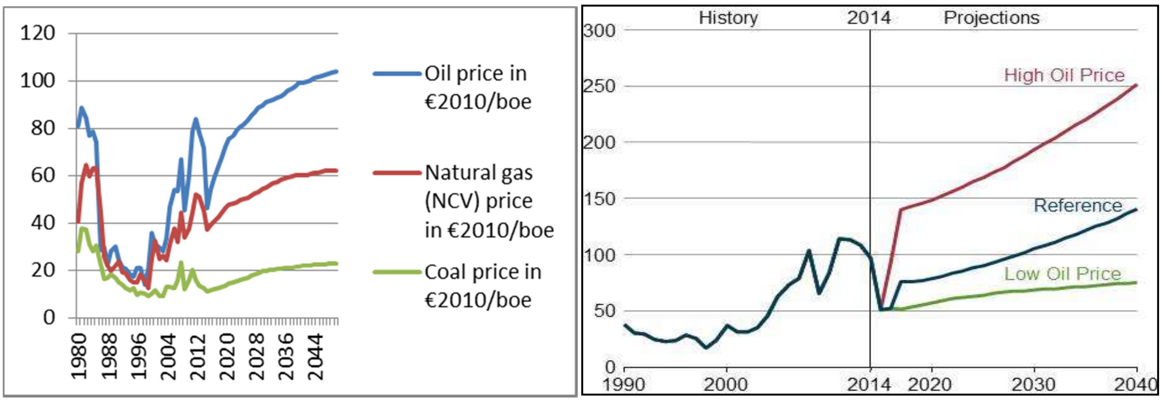
2.1.3 Oil price

As regards the oil price, the trends within the analysis' time horizon (2011-2020) have been borrowed from the EC report on EU energy, transport, and GHG emissions [3], which estimates an average value of about USD(2010) 82.5/boe as from Figure 1(a) below.

For the same time horizon, this value is not far from what is found in the International Energy Outlook of the International Energy Agency (IEA) [4], which estimates an average value of about USD 100/boe in a reference scenario (Figure 1(b)). The IEA report makes three different projections for the considered time horizon, with average values ranging from ca. USD 85/boe to ca. USD 130/boe in a low and high price scenario respectively.

In order to reflect price volatility over the years, oil price has been subjected to sensitivity analysis.

Figure 1 Oil price outlook and trends



Source: left, European Commission, 2016 [3] and right, International Energy Agency, 2016 [4]

2.1.4 Discount rate

Different discount rates could be used in calculating the Net Present Value (NPV), depending on the perspective adopted and the stakeholders considered: (i) the financial discount rate (FDR) for the case of a financial CBA, carried out exclusively from the viewpoint of the DSO as a private investor; (ii) the social discount rate (SDR) for a societal CBA, which instead takes a wider system perspective also considering the societal value of Smart Grid investments.

A real financial discount rate of 4% is adopted here, the value recommended in [5], p. 42.

With regard to the real social discount rate (SDR) applied, a working assumption of 2.5% has been considered for Italy in accordance with [2]. The discount rate takes into account the time value of money and the uncertainty of future cash flows, and has a relevant impact on the assessment of Smart Grid projects, which typically feature high investments at the beginning, with benefits accruing over the long run.

Moreover, [2], p. 16, recommends that the discount rate be subjected to a sensitivity analysis in a 1%-5% range, considered as the appropriate choice for it runs the full gamut from a zero growth scenario to the Italian local authorities' official SDR value (proposed by the Conference of the Presidents of Regions and Autonomous Provinces in [6]).

2.1.5 Figurative cost for the society of air pollutants

The figurative cost for the society of pollutant emissions has been also considered in the CBA. In particular, conservative values of EUR 5,700/tonne and EUR 6,100/tonne have been assumed respectively for NOx and SOx emissions in Italy. The assumptions were derived from the report on the damage per tonne of emissions from EU member states (excluding Cyprus) and surroundings, issued by the AEA Technology and commissioned by the European Commission under the Clean Air For Europe (CAFÉ) programme [7].

2.1.6 Emission rate per electricity energy unit

The emission factor is a country-specific coefficient that translates a unit of electricity generated into the corresponding amount of greenhouse gas emissions is the emission factor, and is expressed in tonnes of CO_2 / MWh. The Covenant of Mayors provides country-specific emission rates, obtained through both a Standard and a Life Cycle Assessment (LCA) methodology [8]. The emission rates estimated for Italy are respectively equal to 0.48 tonneCO_2/MWh (following a standard approach) and 0.71 tCO_2/MWh (following an LCA approach). In the former approach, the emission rate from renewables is considered equal to zero, while in the latter, the emission factor is always positive but differs according to the type of RES source.

As a general consideration, Smart Grid technologies can enable favourable changes in the generation mix. This may in principle modify assessments of CO_2 emissions variations, since the CO_2 intensity of power generation also varies (esp. in the long run), so that CO_2 decreases per unit of energy saved are not fixed. However, given the relatively short time span of the SG project under consideration, this subtle effect is here considered as minimal and disregarded.

In its report on international comparisons [9], the Italian Transmission System Operator (TERNA) provides an estimate of 0.41 tonCO_2/MWh with respect to Italy's overall electricity generation fleet (without LCA considerations). In this report, it was hence adopted as a working assumption, since it also represents a rough average of other available estimates cited in the sensitivity analysis section.

2.1.7 Equivalent hours of production

A value of 1,540 h/year was conservatively assumed as a working assumption for the yearly equivalent hours of production from RES, taking into account the energy mix in the project area (excluding traditional generation). Such value influences the valorisation of the traditional energy production displaced by renewable energy, which mostly depends on the hosting capacity enabled in the project.

2.1.8 Regulatory framework

Both costs and benefits have been evaluated according to the regulatory framework applicable in Italy in the project timeframe and with respect to the solutions and approaches tested in the project. The benefits of SG investments are primarily realised at customer and system level, whereas their costs were in charge of the network operator in the Isernia project. With the standard remuneration scheme (Business-as-Usual scenario), the SG investments undertaken by the Distribution System Operator (DSO) ENEL, which is responsible in Italy for MV and LV distribution network as well as for metering service activities, would not have received full remuneration.

Thus, a competitive selection process led the Italian Regulator (ARERA) to award the Isernia project with an extra WACC remuneration of +2% for up to twelve years, as foreseen by Resolution ARG/el 39/2010 [1] for the incentivising SG project investments.

A full smart meter roll-out was completed in Italy in 2006, enabling the introduction of Time of Use tariffs for all customers in the Universal Supply Regime. In 2006, the Italian Regulator (ARERA) disposed the mandatory installation of electronic meters in Italy, with minimum functional requirements for all DSOs and LV customers. Nevertheless, the smart meter roll-out had already been completed on ENEL's network under the Telegestore project. Time of Use tariffs for residential customers under the universal supply regime have also been in place in Italy since 2010.

As regards the Italian regulatory framework, the market was deregulated in 1999 with the Legislative Decree n. 79/99, providing customers with the ability to choose their own energy provider, increasing the competition between energy providers and requiring improvements in the electric distribution system performance levels for higher reliability and power quality to meet the customer demand. Before that, the whole electricity market was under the monopoly of a single vertically integrated and state-owned company.

Nowadays, energy production, transmission, distribution, and retail are under the responsibility of distinct actors (i.e. producers, TSO, DSOs, and retailers). According to the above-mentioned decree, electricity is supplied to consumers either through the open market, where traders (retailers) sell energy to consumers through supply contracts, or through the protected market, where the Single Buyer trades electricity in the wholesale market on the best possible terms and resells it to standard offer retailers in accordance with the directions given by the regulator.

In order to respond to the challenges posed by the management of recent electricity system evolutions, as well as to improve customer experience, SG technology and solutions for more active customer involvement have been developed and tested under several projects. With respect to this, it has to be mentioned that a regulatory framework allowing the participation of (active and passive) customers to the electricity market and the management of the electricity system is not in place in Italy.

As a consequence, some of the benefits activated by the implementation of the SG solutions (such as demand response, modulation of active/reactive power injections, etc.), tested in the project although potentially enabled, could not be fully assessed as they rely on the evolution of both market and regulatory conditions. Moreover, it has to be mentioned that some of the technologies tested in Isernia under Resolution ARG/el 39/2010, such as the Smart Info device and the EV charging infrastructure, do not longer fall in the DSO’s remit in Italy. The benefits enabled can be however evaluated in a wider system perspective.

In the following sections, a step-by-step CBA is described in detail. Whenever relevant, considerations aimed at highlighting possible fine-tunings and extensions of the methodology have been provided.

The seven steps of the JRC CBA methodology are:

1. Review and describe the methodologies
2. Map assets into functionalities
3. Map functionalities into benefits
4. Establish the baseline
5. Monetise the benefits and identify the beneficiaries
6. Identify and quantify the costs
7. Compare costs and benefits

2.2 CBA Step 1 Review and describe the technologies, elements and goals of the project

As a first step of the CBA, we proceed to expose the main aspects of the project, both in terms of specific goals and of engineering features (adopted technologies, functionalities of the main components).

To better understand the impact of the above-mentioned technologies, a summary of the main project functions with evidence of the principal assets activating them is provided in Table 3.

FAULT DETECTION

Remote control and automation have been deployed in Italy on the MV network since 2001. Nowadays, 100% of the HV/MV substations are remotely controlled and equipped with automation, along with 25% to 30% of the MV/LV substations. In the occurrence of faults, two techniques are used to automatically detect the grid section affected by a fault, isolate it and resupply the healthy sections without any human intervention, entailing both the trip of the circuit breaker in the HV/MV primary substation located upstream of the involved MV line. Fully programmable Remote Terminal Units (RTU) - installed in the MV/LV Substations and connected to the Central System mainly by public GSM - enable to open and close motorised disconnectors (IMS) on the MV network, according to a specific set of rules on the basis of the voltage absence measured by fault detectors (RGDAT).

Table 3 The Isernia Smart Grid project description

PROJECT GOAL	**Demonstrating new telecommunication technologies aimed at testing a series of Smart Grid technologies under real field conditions**
PROJECT SPECIFIC OBJECTIVES	Integrating RES and increasing the hosting capacity of the MV distribution network, while assuring a secure and reliable management of the MV distribution network in presence of DER; moreover, enhancing customer awareness and promoting energy-efficient behaviour, while enabling active customer participation in the management of the electricity system; finally, enabling the diffusion of electric mobility.
START AND END DATES	2011 – 2015
FUNDING SCHEME	AEEG ARG/el 39/10
LOCATION	Isernia area (Molise Region, Central Italy)

Source: JRC and ENEL elaborations, 2018

Table 4 Isernia project features

LV CONSUMERS INVOLVED	**5.840**
NUMBER OF HV/MV PRIMARY SUBSTATIONS	1
Transformer [MVA] (green busbar)	25
POWER AT LV LEVEL [KW] (green busbar)	18.540
POWER AT MV LEVEL [KW] (green busbar)	12.970
NUMBER OF MV/LV PRIMARY SUBSTATIONS	157
NUMBER MV LINES INVOLVED	5
STORAGE	1
Power [MW]	1

Energy [kWh]	500

Source: JRC and ENEL elaboration, 2018

Within the Isernia project, the portion of the grid affected by the fault was isolated without tripping the MV circuit breaker in the HV/MV substation, irrespective of the type of fault (thus also in case of short circuit). The motorised disconnectors (IMS) were replaced with feeder circuit breakers through the MV line (referred to as DY800). Such circuit breakers are able to trip faster than the IMS by acting in the presence of fault current; furthermore, they are equipped with new fault detectors (RGDM) with communication embedded. It is worth mentioning that the fault detection implemented in the project can be extended both to MV generation plants (equipped with a Generator Protection Interface Device) and to passive MV customers, so to limit the impact of the fault only to the grid portion actually affected, and the users connected to it.

The installation of new fault detectors with the possibility of real-time network measurement and monitoring, joint with the use of more reliable circuit breakers on the MV grid and of the always-on IP broad band connection over the current GSM, allows for a prompt and reliable isolation of the faulty section irrespective of the type of fault.

REMOTE DISCONNECTION IN CASE OF ANTI-ISLANDING

With the progressive increase of DG connected to the distribution network, the possibility of occurrence of unwanted islanding might pose severe safety and security issues in particular on the MV network. In fact, whenever load and generation balance in an area, generators might keep supplying loads even in the absence of supply from the HV/MV substation (as in case of outages): this would cause a network to become an unwanted island. Under this situation, for security and safety reasons it is recommended not to maintain the network in the islanding mode of operation.

A set of innovative devices was installed in the project in order to successfully detect and accordingly disconnect any islanding situation. In fact, undesired islanding operation can result in several problems, including safety issues as in the case of staff unconsciously working on a grid portion still fed by generators in islanding mode. Moreover, on the equipment side, loads may be supplied with uncontrolled and inadequate power quality. Furthermore, operation voltage and frequency might be different with respect to the main power grid, resulting in serious issues when reconnecting to the main system.

In the event of possible occurrence of undesired islanding operations, the logic implemented in the project envisages the DSO systems to send a remote signal to the Generator Protection Interface Device commanding the disconnection.

INNOVATIVE VOLTAGE REGULATION AT MV LEVEL

The network hosting capacity was primarily limited in the project area by overvoltage determined at the DG connection point in condition of reverse power flows, especially in case of large DG plants located at the end of a MV line. Nowadays, voltage regulation is implemented at MV busbar level by acting on the On Load Tap Changer (OLTC) of the transformer. Although the EN 50160 evolution introduced a ± 10% voltage tolerance - average of the effective values in ten minutes -, it is still necessary to implement advanced solutions in the presence of DERs in order to respect such technical standards without requiring network reinforcements or extensions.

HV/MV

Within the Isernia project, an innovative voltage regulation was implemented following a hybrid local and centralised logic. The reactive DG power injection (increase/decrease) is regulated according to predefined voltage regulation functions set through an algorithm: the Distributed Management System (DMS), located in the Central System and running advanced grid calculations, sets the optimal voltage set points at the level of MV busbar within the HV/MV primary substations and the new HV/MV RTU acts on the OLTP according to the defined voltage set points. When a given voltage threshold (measured

by the RGDM) is reached at a DG connection point, the generator is asked through the RGDM to operate at a given cosφ to regulate its reactive power injections by the Energy Regulator Interface.
In case a local approach is not sufficient to avoid voltage violations, a signal is sent through the RGDM to the DSO's Central System, which can act on the OLTC to regulate the voltage level of the entire grid portion of interest, or might ask other generators connected to a MV line to operate at a given cosφ (while minimising the number of generation units involved), or potentially limit the active power injections of generators while respecting technical limits.

Moreover, an always-on broad-band communication between all the main nodes of the MV network was implemented in the project. This allowed the implementation of reliable high-performance smart grid operations that would not be feasible using an on-request communication on GSM. As a matter of fact, in the business-as-usual scenario (i.e. without the implementation of Smart Grid solutions as later defined in this report), a public GSM communication is in use through the MV network: while HV/MV substations are connected to the central systems by an IP-based communication infrastructure, MV/LV substations mainly use public GSM, and there is no communication between them.

Finally, a multifunctional storage system was installed in the project: voltage control in the presence of distributed generation was tested, together with further functions such as power flow optimisation and black start of small portions of MV network.

LIMITATION/MODULATION OF ACTIVE POWER INJECTION IN CRITICAL SITUATIONS

As things stand, DG (active/reactive) power injections are not controllable by DSOs, and a regulatory framework allowing the participation of DG to the electricity market is not in place. However, the transmission system operator (TSO) can ask the DSO to curtail the generation connected to the distribution network in case of critical situations for network stability.

Solutions for DG power modulation (increase/decrease) were enabled in the Isernia project: the HV/MV RTU can receive emergency alerts from the TSO through the SCADA and, according to specific algorithms, identifies the generations connected on a MV line on the basis of their relevant technical features (e.g. min/max power) to eventually define the appropriate modulation options. Modulations potentially carried out would be tracked in the SCADA. Modulation signals possibly sent to the generator's systems through the RGDM follow a progressive approach (expressed as % of the nominal power) up to disconnection.

MONITORING OF DG POWER INJECTIONS

Alongside the advanced smart grid functions detailed above, the always-on broad band communication implemented in the project also allows for tighter monitoring of the generation connected to the MV network: generation data were collected in real time through the Energy Regulator Interface, sent to the RGDM, and then acquired at central system level. Data, such as active and reactive power, were aggregated in the project at HV/MV transformer level, sorted by type of source and made available to the TSO, with the effect of both increasing distribution network observability for the TSO and supporting a better planning of necessary actions on the grid.

ELECTRIC VEHICLE RECHARGING

Smart EV recharging stations, both public and private, fully integrated with the distribution network and remotely managed, were developed by ENEL to enable to diffusion of electric mobility (no longer in the DSO domain). In particular, EV recharging points were installed in the project to support the local field crew in their daily work activities in the area of Isernia.

CUSTOMER AWARENESS AND ELECTRICITY CONSUMPTION MONITORING

As earlier observed, the smart meter roll-out was already completed in Italy in 2006 with the Telegestore project. Consumptions are billed on a monthly basis.

Leveraging on this experience, a local meter interface named ENEL Smart Info was developed by ENEL and tested within the Isernia project: (today, no longer in the DSO domain) by communicating with the electronic meter, the ENEL smart info kit enables customers to have easy local access to metering data directly inside their premises, and allows to transmit metering data close to real time to the other devices and players under customer consent. Residential and small commercial customers were provided in the project with information of higher quantity and quality on their electricity energy consumptions, addressing higher awareness on their energy behaviour and paving the way towards a more active participation to the management of the electricity energy system. Potential flexibility from customers is in fact considered one of the largest untapped energy resources, mainly due to still insufficient consumer awareness on energy consumption.

Table 5 List of the main assets deployed in the pilot project and their main functions

Assets	Description	Location	Main functions
SCADA	Supervisory control and data acquisition system, allowing collecting and exchanging information with the MV distribution devices, together with information and signal exchange with the TSO.	Central System	Information and signal collection, transmission, and exchange with the TSO.
DISTRIBUTED MANAGEMENT SYSTEM (DMS)	Distributed management system able to calculate and analyse electricity network parameters (e.g. voltage, frequency and power) both in real time and offline. It allows evaluating network status, performances and conditions also through event simulations, thus supporting grid management, optimisation and reconfiguration.	Central System	Network analysis and management; optimal voltage set points at HV/MV primary substation level and for DG regulation according to network needs.
HV/MV SUBSTATION REMOTE TERMINAL UNIT (RTU)	System for remote monitoring, management and control of the MV network, collecting all the information coming from protection, DG monitoring and regulation systems (also in the perspective of TSO/DSO information exchange through the SCADA).	HV/MV primary substation	DG regulation and control according to the DMS set points; DG disconnection in case of fault or islanding operation; Information collection and exchange; Parameter setting for fault selection also in case of faulty communication system.
MEASUREMENT DEVICE AND FAULT DETECTOR (RGDM)	Fault detectors with possibility of real time network measurement and monitoring, able both to measure and transmit alarms and power flows values by using IEC 61850 standard protocol. With the associated RTU, RGDM allows the implementation of automated outage detection and recovery techniques.	MV/LV primary substation; Delivery substations	Outage detection and recovery; DG disconnection in case of fault or unwanted islanding; signals and information exchange.
IEC 61850 ROUTER/MODEM	Routers collecting and transmitting information between the main nodes of the distribution network by a VPN network using a Broad Band (BB) communication infrastructure, able to prioritise messages in order to guarantee a proper latency.	HV/LV and MV/LV substations	Communication and information exchange between all the main nodes.
BROAD BAND COMMUNICATION	Always-on IP broad band connection, connecting all the relevant nodes in the network over GSM communication solutions.	Project area	Communication and information exchange between all the main nodes.
IEC 61850 STANDARD PROTOCOL INTERFACE	References standard protocol for automation, control, monitoring and information exchange functionalities.	-	Communication and information exchange among substations.
USER SWITCH ETHERNET (USE)	Terminal unit of the telecommunication system at the MV active customer premises, able to receive and transmit signals sent through the router at the MV/LV or the delivery substation.	MV active customer premises	Communication and information exchange for DG monitoring, regulation and control.
HEAD LINE PROTECTION SYSTEM (LPS)	Protection relays with communication system, able to record and notify relevant events and send remote disconnection signals.	HV/MV primary substation	Feeder protection; outages detection and recovery; directional current monitoring.
CIRCUIT BREAKERS (DY800)	Circuit breakers along MV lines. In combination with fault detectors, these allow for fault isolation irrespective of the type of fault without tripping of the LPS.	MV/LV substation	Outage detection and recovery.
GENERATOR PROTECTION INTERFACE DEVICE	Protection relay with communication system, which receives disconnection signals, manages them, and sends feedbacks to the RGDMs in case of fault at the customer's premises. Furthermore, it is able to act on the generation unit when disconnection is required (e.g. in case of unwanted islanding conditions).	MV active customer premises	Outage detection and recovery (at customer premise); DG disconnection in case of fault or unwanted islanding; signals and information exchange.
ENERGY REGULATOR INTERFACE	Device endowed with communication system and interfaced with the generation power controller, the RGDMs and the HV/MV substation RTU, which is able to regulate the generator's reactive and possibly active power injection according to the signals received.	MV active customer premises	DG regulation, control and monitoring.
STORAGE	Multi-functional Li-Ion storage	MV/LV substation	Ancillary services (e.g. local voltage regulation, power flow optimisation, black start of small portion of MV network).
EV CHARGING INFRASTRUCTURE	EV recharging infrastructures	LV network	Electric vehicles recharging.
SMART INFO	Customer awareness device able to communicate with the smart meter via PLC and provide with metering data in a non-discriminatory way.	LV customer premises	Enhanced customer awareness on energy consumption behaviour, while enabling in-home energy control and active demand.

Source: JRC and ENEL elaboration, 2018

The representative sample of families equipped with energy monitoring devices including the ENEL Smart Info kit (along with dedicated interfaces) were provided with the following three levels of functionalities:

- "SEE": easy and continuous access to customer household energy use pattern through a display. Near real-time and historical information on energy consumption, shown in bar graphs and pie charts to highlight mean value and distribution throughout tariff bands over different time slots (i.e. day, week, month, two months, year) are provided, in particular to the customer. Consumption habits are displayed together with the measured consumption data in the graphs, helping consumers identify variations. Historical data is stored for about three years. The instantaneous power is reported together with a scatter plot of its maximum historical values for different periods of time (a single day, a week, a month) allowing consumers to check whether its supply electricity contract is consistent with actual needs. The instantaneous power values can be refreshed automatically as well as on demand. Tariff time bands are displayed, together with the date and time of tariff time bands switching; colours settings can be modified to be consistent with the user's tariff structure. When the contractual power is exceeded, an alarm is automatically generated, so that load shedding is prevented. Through a dedicated wizard the customer can also measure the power used by a specific appliance. Besides pure information, additional feedback and alarms at pre-defined, modifiable thresholds (for example with reference to contractual power capacity limit) are also notified for the customers, along with DSO announcements and contractual data;
- "ANALYSE": a software application (smart info manager) is provided to the consumers in order to assist energy consumption data analysis directly on a personal computer. For prosumers, energy consumption is shown alongside generation to facilitate analysis of their net energy consumption;
- "EXPLORE": customers can also remotely access their energy data on their smartphone through the smart info mobile application.

Alongside advanced energy monitoring, further functionalities were potentially enabled (entailing the implementation of further technologies and the involvement of additional stakeholders), although not tested within the Isernia project. Based on relevant meter data that can be provided close to real time by the DSO under customer consent, other market players may add information (e.g. electricity prices and tariffs) to provide customers with innovative services such as in-home energy management, active demand programmes, and other energy efficiency solutions.

All the above mentioned functions fall into the list of the functionalities provided in the JRC's guidelines. For example, the integration of users with new requirements is facilitated by the innovative voltage regulation at MV level, the monitoring of DG power injections, and the implementation of new services such as EV recharging infrastructures. Similarly, the fault detection solutions adopted, together with the power injection control and the DG monitoring, can contribute to "enhance efficiency in day-to-day grid operation". "Network security, system control and quality of supply" can also be enhanced through the power injection and voltage control, together with solutions for remote disconnection in case of anti-islanding. An "improvement of the market functioning and customer service" can be enabled, and a "more direct involvement of consumers" implemented through customer awareness and electricity consumption monitoring.

However, as better discussed at the end of this section, it might happen that a project function such as "monitoring of DG power injections" can be equally well interpreted as falling under the functionalities "Integrate users with new requirements", "Enhancing efficiency in day-to-day grid operation" or "Better planning of future network investment", as a result of broad and partially overlapping domains (see list of functionality details in Annex 1).

As a consequence, the process of mapping project assets onto functionalities may involve a certain degree of discretion, and the peculiarities of distinctive project functions may be lost in some cases.

2.3 CBA Step 2 – Map assets onto functionalities

As stated in the JRC methodology, determining which Smart Grid functionalities are enacted by which assets installed within the project is an important early step in a CBA for Smart Grid projects. To complete this step, the project assets have been mapped against thirty-three functionalities as listed by the EC Task Force for Smart Grids 2010, grouped into the six main categories below for the sake of simplicity (the full table is provided in Annex 1). In particular, all functionalities potentially or actually activated have been considered, even though they may not be fully exploited yet in the project, e.g. for regulatory reasons. The dots in the cells represent the functionalities provided and/or potentially enabled by the project - assuming that the necessary market or regulatory conditions are in place -, and show which assets activate them.

As observed in the JRC guidelines, some of the functionalities identified in Step 2 - even though enabled by the project - are likely not to be mapped onto any of the benefits in Step 3. Others, although mapped, may not be subject to reliable assessment.

As a general consideration, benefit calculation is neither a straightforward nor an easy task to perform. As experienced in other CBA applications (such as the InovGrid project), possible reasons for this may lie in (i) the size and scope of the project, (ii) benefit measurability in relation to the type of organisation involved (for instance, a DSO may be unable to assess deferred capacity investments at transmission level); (iii) inherent difficulty of the appraisal of benefits, as in the case of customer satisfaction; (iv) missing regulatory and/or market conditions at the time of project implementation, introducing a high level of uncertainty in the formulation of basic assumptions for calculation, etc.

2.4 CBA Step 3 – Map functionalities onto benefits

The purpose of this second mapping is to link the above-identified functionalities to the benefits they enable (actually or potentially). As earlier observed, even though some benefits might not be directly activated (e.g. due to regulatory constraints, the size of the project, or various boundary conditions), they shall however be considered as enabled, at least potentially, by the solution tested in the project. For this purpose, the twenty-two Smart Grid Benefits set forth by the EPRI methodology have been taken into account, grouping them into four main benefit categories: economic, environmental, reliability, and security benefits.

Table 6 Mapping of project assets onto functionalities provided/enabled

		Functionalities					
		A. Integrate users with new requirements	B. Enhance efficiency in day-to-day grid operation	C. Ensure network security, system control and quality of supply	D. Better plan of future network investment	E. Improve market functioning and customer service	F. More direct involvement of consumers in their energy usage
Assets	SCADA	•	•	•	•	•	
	Distributed Management System (DMS)	•	•	•		•	
	HV/MV substation Remote Terminal Unit (RTU)	•	•	•	•	•	
	Measurement device and fault detector	•	•	•	•	•	
	IEC 61850 router and modem	•	•	•	•	•	
	Broad Band (BB) communication	•	•	•	•	•	
	IEC 61850 Standard Protocol Interface	•	•	•	•	•	
	User Switch Ethernet (SEU)	•	•	•	•	•	
	Head line protection system (SPL)		•	•			
	Circuit Breakers (DY800)		•				
Assets	Generator protection interface device	•	•	•		•	
	Energy Regulation Interface	•	•	•	•	•	
	Storage	•	•	•		•	
	EV charging Infrastructure	•				•	
	Smart Info system					•	•

Source: JRC and ENEL elaboration, 2018

Table 7 Mapping of each functionality onto the benefits

		Functionalities					
		A. Integrate users with new requirements	**B. Enhance efficiency in day-to-day grid operation**	**C. Ensure network security, system control and quality of supply**	**D. Better plan of future network investment**	**E. Improve market functioning and customer service**	**F. More direct involvement of consumers in their energy usage**
Economic benefits	Optimised Generator Operation						
	Deferred Generation Capacity Investments						
	Reduced Ancillary Service Cost						
	Reduced Congestion Cost						

		Functionalities					
		A. Integrate users with new requirements	B. Enhance efficiency in day-to-day grid operation	C. Ensure network security, system control and quality of supply	D. Better plan of future network investment	E. Improve market functioning and customer service	F. More direct involvement of consumers in their energy usage
	Deferred Transmission Capacity Investment	•	•	•	•	•	
	Deferred Distribution Capacity Investment	•				•	
	Reduced Equipment Failures						
	Reduced Distribution Equipment Maintenance Cost						
	Reduced Distribution Operation Cost						
	Reduced Meter reading cost						
	Reduced Electricity Losses		•				
	Detection of Anomalies Related to Contracted Power						
	Reduced Electricity cost					•	•
Reliability Benefits	Reduced sustained outages						
	Reduced major outages						
	Reduced restoration cost						
	Reduced momentary outages						
	Reduced sags and swells						
Environmental Benefits	Reduced CO2 emissions	•	•	•		•	•
	Reduced SOx, NOx and PM10 Emissions	•	•	•		•	•
Security Benefits	Reduced Oil Usage	•	•	•		•	•
	Reduced Wide-scale blackouts	•	•	•			

Source: JRC and ENEL elaboration, 2018

2.5 CBA Step 4 – Establish the baseline

The project baseline formally defines the control state against which other scenarios of the analysis are compared. Therefore, any evaluation in the CBA of the project is assessed as an incremental value based on the difference between the costs and benefits associated with a Business-as-Usual (BaU) scenario and those associated with the implementation of the project, here referred to as Smart Grid (SG) scenario. Following the guidelines, the two mentioned scenarios have been defined below:

- **Scenario BaU,** meant as the baseline conditions that reflect what the system would have been without the Smart Grid system, considering only planned maintenance (also in accordance with Smart Grids Task Force Expert Group 4 [10]).
- **Scenario SG**, meant as the realised and measured conditions with the Smart Grid system installed.

As recommended in the guidelines, control groups were used to evaluate the impacts at LV customer level on the behaviour of electricity consumers stemming from the installation of ENEL's smart info devices. Final results were therefore calculated, taking into account a control group of customers to maximise the reliability and accuracy of data analysis, which in this way was cleaned of any contingency effect. In fact, as a general principle, even where historical data provide good indications, some factors having impact on the final results are likely to vary over time, which raises the importance of working with control groups.

To assess the baseline for the calculation of project benefits, historical, forecasted and/or simulated data were used, complemented in some cases by the experience from other similar projects and/or expert knowledge. Table 9 below provides with a few examples, where the main metrics used to estimate the benefits have been specified.

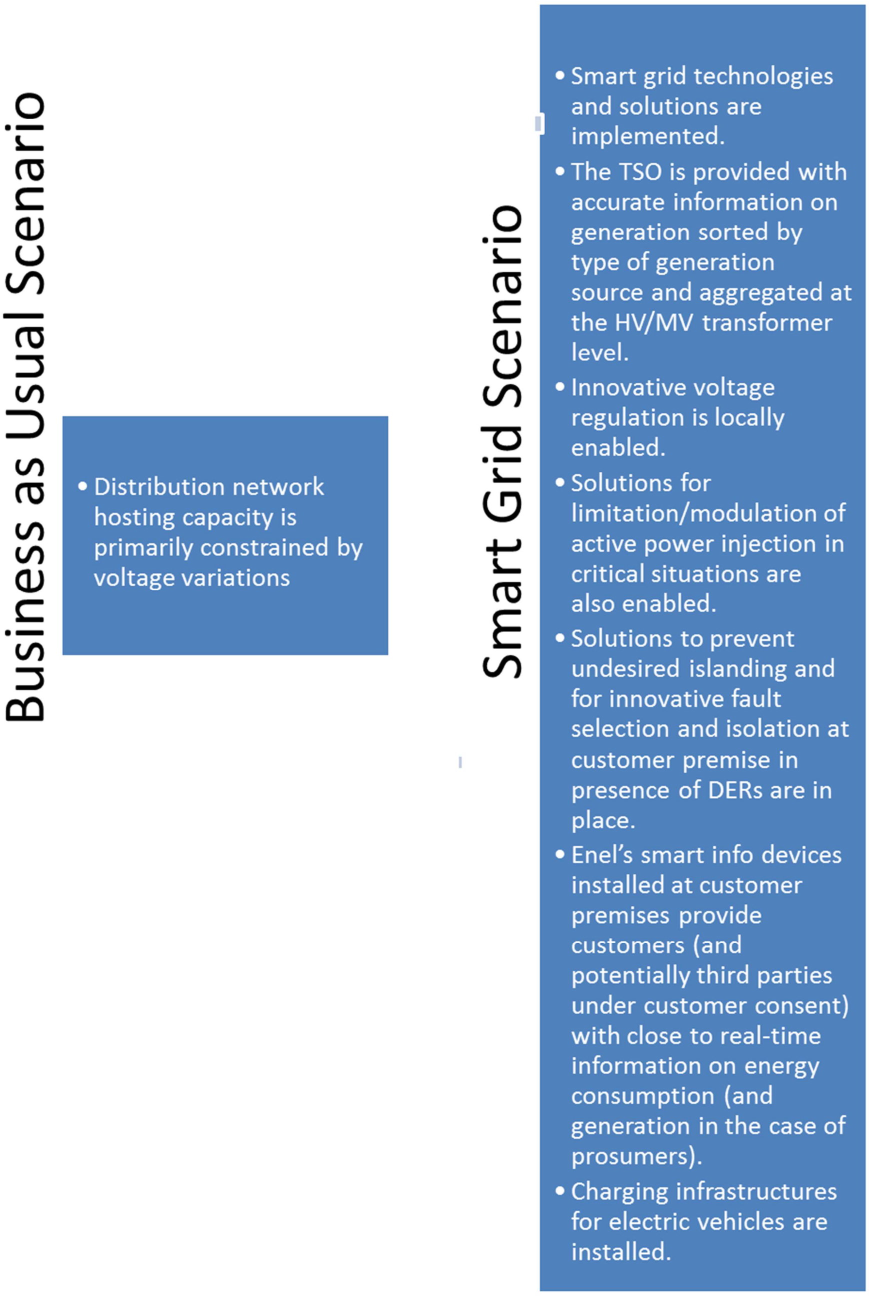
Alongside those cited above, other benefits enabled by the project can be mentioned. The detailed description of the benefits quantitatively and qualitatively estimated and/or formulated in the analysis is provided in the following sections.

Let us remark that the approaches and methods implemented under the project for the innovative voltage regulation (and, potentially, the limitation/modulation of active power injection from DG in critical situations) may contribute to increase network flexibility. This would allow them to support power system stability, provided that the necessary regulatory framework is in place. In the future, this could be measured by the fraction of generation capacity in the project area potentially controllable through the adoption of such systems.

Additionally, the project's DER production monitoring and exchange of measurement data with the TSO allows reducing the unpredictability of intermittent generation. At a larger scale, this has the potential to assist the TSO in the operation of the transmission network, and in planning the necessary actions for power system stability without requiring the disconnection of all or part of the generation capacity in a given area. This would result in lower RES curtailment for any given level of electricity system security.

Finally, close-to-real time data accessibility through ENEL's smart info kit installed in the project can be considered as an enabling factor of active customer involvement in the energy market. This would allow moving progressively from higher customer awareness (which is fully in the scope of the Isernia project) to local energy control and a more complex interaction with the management of the electricity system.

Figure 2. Business-as-Usual vs. Smart Grid scenario



Business as Usual Scenario

- Distribution network hosting capacity is primarily constrained by voltage variations

Smart Grid Scenario

- Smart grid technologies and solutions are implemented.
- The TSO is provided with accurate information on generation sorted by type of generation source and aggregated at the HV/MV transformer level.
- Innovative voltage regulation is locally enabled.
- Solutions for limitation/modulation of active power injection in critical situations are also enabled.
- Solutions to prevent undesired islanding and for innovative fault selection and isolation at customer premise in presence of DERs are in place.
- Enel’s smart info devices installed at customer premises provide customers (and potentially third parties under customer consent) with close to real-time information on energy consumption (and generation in the case of prosumers).
- Charging infrastructures for electric vehicles are installed.

Source: JRC own elaboration, 2018.

2.6 CBA Step 5 – Monetise the benefits and identify the beneficiaries

The benefits of a project represent the positive changes and externalities activated by the smart solutions implemented. Depending on the project, changes can occur at the level of cost reduction, greenhouse gas emissions, etc. We calculated the monetary values of some project benefits in consideration of the existing and/or foreseeable boundary conditions, providing brief explanations for the calculation options and assumptions. It can be observed that most of the benefits refer to the system and society as a whole, while (as better detailed in the section on Step 6) costs are mainly born by the system operators.

Benefit formulation, as detailed above, has been carried out with the prospect of generalisation to further smart grid projects, aiming at the widest possible applicability. The perspectives of different stakeholders (e.g. DSOs, residential consumers, the society as a whole, etc.) have been accounted for, building on the experience of other smart grid related projects such as GRID+, Grid4EU, iGreenGrid, ADVANCED, etc. The availability of a set of benefit metrics will strengthen the robustness of the findings from smart grid demonstration projects. Further, it will help to better understand their potential contribution to solve some of electricity’s future issues and meet the EU’s ambitious energy strategy.

However, it should be pointed out that the way the metrics are measured in practice, even when they are formulated in a common way, has an influence on benefit evaluation. As a consequence, the comparison between projects is neither obvious nor straightforward: the identification of the measurement points, for instance, may well introduce relevant differences case by case. The same applies to the status of the existing grid: this is never identical from network to network and from project to project, due to the technologies in place and to other factors (which may also be country specific).

Table 8 Example of metrics used to monetise benefits (where: *(F) Forecasted/simulated value, (H) historical value, (M) measured, (E) Estimate)*

Benefits	BaU Conditions	Metrics	Smart Grids conditions	Metrics
CO_2 EMISSIONS SAVING	CO_2 emissions considering country power energy mix, with respect to electricity energy consumptions and fuel usage	Carbon emission rate per kWh produced with the current energy mix *(E)*	Reduction in CO_2 emissions due to the implemented solutions for: increasing network hosting capacity (replacing conventional energy production with green energy); enabling the diffusion of electric vehicles over gasoline ones (reducing oil usage); increasing customer awareness on electricity energy use (turning in lower energy consumptions).	Increased DG hosting capacity [MW] *(F)*
		km driven by using gasoline fuelled vehicles *(H)*		Number of enabled EVs *(E)* and reduced CO_2 per kilometre *(E)*
		Electricity energy (EE) consumed by LV customers *(H)*		%EE reduction *(M)*
ELECTRICITY COST SAVING	Customer average electricity energy (EE) bill a year	EE yearly consumptions *(M)*	Lower EE bill due to a more efficient energy use stemming from increased customer awareness	EE yearly consumptions *(M)*
		Number of LV customers *(M)*		Number of LV customers *(M)*
				%EE reduction *(M)*
OIL USAGE SAVING	Oil usage in terms of tonnes of oil equivalent (toe) considering country power energy mix, with respect to electricity energy consumptions and fuel usage	Toe emission rate per kWh produced with the current energy mix *(E)*	Reduction in oil usage and accordingly primary energy consumptions due to the implemented solutions for: increasing network hosting capacity (replacing conventional energy production with green energy); enabling the diffusion of EVs over gasoline ones (reducing oil usage); increasing customer awareness on EE use (determining lower energy consumption).	Increased DG hosting capacity [MW] *(F)*
		km driven using gasoline fuelled vehicles *(H)*		Number of enabled EV *(E)* and reduced toe per kilometre *(E)*
		Electricity energy consumed by LV customers *(H)*		%EE reduction *(M)*

Benefits	BaU Conditions	Metrics	Smart Grids conditions	Metrics
AIR POLLUTANT EMISSIONS SAVING (NOx, SOx)	Air pollutant emissions saving in terms of NOx and SOx considering country power energy mix and the figurative air pollutant emission cost for customers	NOx and SOx per kWh produced with the current energy mix *(E)*	Reduction in NOx and SOx emissions due to the implemented solutions for: increasing network hosting capacity; enabling the diffusion of electric vehicles over gasoline ones; increasing customer awareness on electricity energy use.	Increased DG hosting capacity [MW] *(F)*
		km driven by using gasoline fuelled vehicles *(H)*		Number of enabled EVs *(E)* and reduced NOx and SOx per kilometre *(E)*
		Electricity energy consumed by LV customers *(H)*		%EE reduction *(M)*

Source: JRC and ENEL elaboration, 2018

Table 9 Energy efficiency benefits

BENEFIT	EE COSTS SAVING FROM EFFICIENT CONSUMPTION BEHAVIOUR
DEFINITION	Billing cost reduction as a result of energy efficiency stemming from higher customer awareness on electricity energy consumptions
DESCRIPTION	Energy consumption rationalisation can be pursued by enabling higher customer awareness: as a higher quantity and quality of information on energy consumption is provided to the customers, behavioural changes towards more efficient energy consumption patterns can be leveraged. Smart grids solutions implemented in the project (i.e. ENEL's smart info kit) contributed to a reduction of total energy consumption. Accordingly, customers could benefit from billing cost reduction.
FORMULA	Billing cost reduction can be monetised as follows: $\Delta B = \%EE * EE_{BAU,TOT} * t_e$ ▪ *%EE* = total net yearly energy reduction per customer (accounting for contingency factors through a control group) ▪ $EE_{BAU, TOT}$ = total yearly energy consumption [kWh] ▪ $t_e = {}_{average}$ electricity energy tariff (country specific) (EURcent/kWh) In particular, total energy consumption was monitored in comparison with the BaU scenario, taking into account the influence of contingency and other conditions by referring to a control group of customers. Actual energy reduction can be calculated as follows: $\%EE = \frac{\sum_{N}\sum_{M}(E_{m,SG} - E_{mi,BAU})}{\sum_{N}\sum_{M} E_{m,BAU}} * 100\,\%$ ▪ $E_{m, SG}$= total monthly energy consumption measured in the presence of ENEL's smart info kit per customer ▪ $E_{m, BaU}$ = total monthly energy consumption measured in the absence of ENEL's smart info kit per customer ▪ N = number of customers involved For the sample of customers that were equipped with the smart info kit, an energy consumption reduction in the range 2% - 6% was observed. Such range already considers the effect of possible contingency factors, which have been cleaned out by considering a control group of customers. In this analysis, an average reduction of about 3% has been considered for calculation, mostly accounting for residential customers. In order to monetise cost savings for the customer, only the electricity tariff components that are sensitive to the variation of energy consumption have been considered (some grid tariff components, such as power coefficient, are not proportional to energy volumes). As a general rule, features of local tariff schemes shall be considered as far as relevant in benefits evaluation. It is important to observe that given the same reduction of energy consumption in a project, differences in national tariff schemes may strongly influence billing reduction, accordingly enhancing or limiting the monetary benefit for customers.
METHODOLOGY	Methodology of calculation for Business-as-Usual conditions might strongly affect the results of the monetisation of billing cost reduction. Therefore, a clear definition should be provided. In fact, while the methodology for energy consumption monitoring is quite straightforward in the SG scenario, different methodologies can be followed for the BaU conditions, leading to possibly different results. Yearly energy consumption was calculated to determine yearly business-as-usual conditions before the installation of ENEL's smart info kit for the selected sample of customers. The same customers' consumptions were monitored afterwards (thanks to SG conditions) to calculate the energy reduction percentage. However, since other (e.g. climate or macroeconomic) conditions might influence energy reduction, a control group was considered in order to clean the results of the effects of contingent factors and increase their reliability and accuracy
NOTE	As the majority of customers in Italy fell under the universal supply regime [11], for the sake of simplicity, the regulated tariff has been used to estimate savings, and all the customers in the project area assumed to belong in the regulated market.

Source: JRC and ENEL elaboration, 2018

Table 10 CO_2 emission savings

BENEFIT	CO_2 EMISSIONS SAVINGS
DEFINITION	Carbon emissions savings
DESCRIPTION	CO_2 emission could be avoided as a consequence of the implementation of several smart grid solutions in the project. In particular, *(i)* the integration of renewable energy sources, resulting from higher network hosting capacity, would result into greener energy production; *(ii)* more efficient energy consumption behaviour, stemming from higher customer awareness enabled by ENEL's smart info kit, would bring about lower energy consumption (and therefore production); *(iii)* the diffusion of electric mobility, enabled by the installation of EV charging infrastructures in the LV distribution network, would allow to reduce fossil fuel usage.
FORMULA	Carbon emission saving can be monetised as follows: $\Delta CO_2 = \mathrm{pCO}_2 * (\Delta CO_{2,RES} + \Delta CO_{2,EV} + \Delta CO_{2,EE})$ [EUR/year] Where: ▪ pCO_2= carbon emission price [EUR/tonne] ▪ ΔCO_{2RES} = carbon emission savings from RES [tonne] ▪ ΔCO_{2EV} = emission savings from electric mobility [tonne] ▪ ΔCO_{2EE} = emission savings from customer awareness [tonne]
	CO_2 EMISSION SAVING FROM RENEWABLES CO_2 emissions saving from RES connections have been calculated by accounting for the additional hosting capacity enabled by the smart grid solutions. In general, the expected RES penetration scenario should be defined in the project area within the CBA time horizon, constrained by the RES connections enabled by the Smart Grid solutions (considering, in other words, only the project's merit in terms of enabled hosting capacity w.r.t. the forecasted one). Therefore, benefits can be formulated as follows: $\Delta CO_{2,RES} = tonne_{CO_2/MWh} * \Delta EE_{RES,year}$ ▪ $tonne_{CO2/MWh}$ = tonnes of carbon emissions per MWh of electricity energy (country specific) [tonnes CO_2 /MWh] ▪ $\Delta EE_{RES,\ year}$ = renewable energy generated from the additional RES capacity enabled on an annual basis by the project with respect to BaU conditions. It represents the amount of fossil-based energy displaced by renewable energy sources. The total amount of fossil fuel based energy, displaced by renewable energy sources, can be calculated starting from the additional hosting capacity enabled through the smart grid solutions implemented: $\Delta EE_{RES,TOT} = h_{eq} * \Delta \mathrm{HC} * \mathrm{HC}_{\mathrm{BAU}}$ [MWh/year] ▪ ΔHC= increased DER hosting capacity in the project area when SG solutions are implemented over BaU scenario [%] ▪ HC_{BAU} = additional hosting capacity that can be connected on top of the baseline in BaU scenario [MW]. ▪ h_{eq}= equivalent hours of production [h/year] The hosting capacity increase enabled through the advanced solutions tested in the project (i.e. MV busbar voltage centrally set in the HV/MV Primary Substation through the DMS together with the local DG reactive power modulation) can be assumed as equal to 19%. More details on the calculation method have been provided in the following (see section 'Increased DER hosting capacity' below). It can be observed that in order to achieve increased renewables production, additional investments would be required on the generation side alongside with the smart grid investments carried out in the project. Given that, a reduction coefficient can be prudentially applied by considering the ratio between expenditure on the smart grid investment and total investment expenditures (considering generation cost per MW installed). $r_i = Inv_{SG} / (Inv_{SG} + \Delta HC * HC_{BAU} * EUR/MW)$ [%] ▪ Inv_{SG} = smart grid investment enabling an increased hosting capacity ▪ ΔHC = increased hosting capacity enabled in the project ▪ HC_{BAU} = additional hosting capacity that can be connected above the baseline in BaU scenario (MW). ▪ EUR/MW = generation investment per unit of capacity installed
	CO_2 EMISSION SAVING FROM ELECTRIC MOBILITY CO_2 saving from electric mobility can be estimated by considering the average number of kilometres daily driven per vehicle and factoring in the expected diffusion scenario of electric mobility within the CBA time horizon. The number of EVs potentially supported by the installed EV charging infrastructures can be considered for calculation. A Life Cycle Assessment (LCA) approach has been used in order to account for carbon emission stemming from the whole vehicle life cycle beyond the usage phase (i.e. from production to disposal). Data on average carbon mission per kilometre are estimated in [12]. $\Delta CO_{2,EV} = km_{year} * N * CS * (tonne_{CO_2/km,\ EV} - tonne_{CO2/km,\ ff})$ ▪ km_{year} = average number of kilometres yearly driven on average by the field crew (historical value can be used) ▪ CS = number of EV charging stations installed in the SG scenario ▪ N = number of EVs enabled per charging station installed in the project ▪ $tonne_{CO2/km,\ EV}$ = average tonnes of CO_2 emissions per kilometre driven by an EV (LCA approach) ▪ $tonne_{CO2/km,\ ff}$= average tonnes of CO_2 emission per kilometre driven by a fossil fuelled vehicle (LCA approach) Carbon emission savings could be also enhanced by considering EV charging within the time frame with higher energy production from RES.

BENEFIT	CO_2 EMISSIONS SAVINGS

CO_2 EMISSION SAVINGS FROM CUSTOMER AWARENESS

Reduced electricity consumption turns into carbon emission savings according to the national energy production mix, which is country specific. Therefore, benefit can be formulated as follows:

$$\Delta CO_{2,EE} = \%EE * E_{BAU,TOT} * tonne_{CO2,MWh} * 10^{-3}$$

- $\%EE$ = reduction of yearly energy consumption in the SG scenario [%]
- $EE_{BAU,\ TOT}$ = total yearly energy consumption in the BaU scenario [kWh]
- $tonne_{CO2/MWh}$ = tonnes of carbon emission per MWh of electricity energy (country specific) [$tonnes_{CO2\ /MWh}$]

INCREASED DER HOSTING CAPACITY [ΔHC]

The increased DER hosting capacity [ΔHC] has been defined as the additional capacity [MW] of DER that could be connected through smart grid investments without conventional network reinforcements and extensions (such as new lines and substations).

The network hosting capacity is the total capacity that can be installed, in compliance with all the required technical and quality standards and rules (e.g. EN 50160).

Given the network's technical limits, the network hosting capacity in the project area was primarily affected by slow voltage variation phenomena, due to a high share of renewable energy sources with respect to the minimum requested load. Smart grid solutions can contribute to avoid voltage violations, thus allowing to better exploit the existing hosting capacity up to the technical network constraints, and to connect additional capacity.

ΔHC is calculated as additional DER capacity that can be connected to the grid, over and above the one that could be connected in the BaU scenario, without need for further network investments (such as grid extensions and reinforcements):

$$\Delta\mathrm{HC} = \frac{HC_{SG} - HC_{BAU}}{HC_{BAU}}$$

- ΔHC: increased DER hosting capacity (in %) in the project area when SG solutions are implemented over the BaU scenario.
- HCSG: additional hosting capacity that could be connected above the baseline in SG scenario (MW)
- HCBaU: additional hosting capacity that could be connected above the baseline in the BaU scenario (MW).

A calculation option is provided in the following on the basis of methods refined in other smart grid projects and/or applications. ΔHC in particular has been calculated using the Distribution Management System (DMS), while simulating the potential increase in network hosting capacity of DER in the worst node (in terms of limited hosting capacity) in the project area.

Hosting capacity in the BaU scenario will be limited by the maximum amount of DER that could be connected without violating technical operation limits under minimum load conditions. The MV busbar voltage in Primary Substation is set to a value (derived from historical measurement data) relative to a maximum generation period, e.g. during the summer, if significant PV power is installed in the grid. In the accounting of generation capacity, the connected DER is considered with the standard power factor (in most cases equal to one).

Similarly, the hosting capacity in the SG scenario will be the amount of DER that could be connected once smart operation criteria have been implemented, while respecting network technical limits under minimum load conditions.

In order to calculate this HC, the MV busbar in the Primary Substation is set to the set-point suggested by the smart operation criteria implemented in the DMS. The connected DER is considered with a power factor equal to 0.9 because the local voltage regulation effect is considered.

The theoretical hosting capacity of all the lines in the project area would be computed as follows:

$$HC_{SG} = \sum_{i=1}^{N} HC_{MVline,i}$$

In particular, the hosting capacity increase enabled through the advanced solutions tested in the project (i.e. MV busbar voltage centrally set in the HV/MV Primary Substation through the DMS together with the local DG reactive power modulation) can be assumed as equal to 19%.

Source: JRC and ENEL elaboration, 2018

Table 11 Reduced NOx, SOx benefits

BENEFIT	REDUCED AIR POLLUTANTS (i.e. particulate matters, NOx, SOx)
DEFINITION	Saving of air pollutant emissions resulting from the implementation of smart grid solutions
DESCRIPTION	Air pollutant emission reduction results from the integration of low carbon generation sources, a more efficient energy consumption behaviour, together with the diffusion of electric mobility. Similar considerations can be made as for the reduction of carbon emissions.
FORMULA	Air pollutant emission saving can be monetised as follows: $\Delta AP = pAP * (\Delta AP_{RES} + \Delta AP_{EV} + AP_{EE})$ [EUR/year] Where: ▪ p_{AP} = air pollutant emission value (type specific) [EUR/tonne] expressed in terms of figurative (damage) cost for the society ▪ ΔAP_{RES} = air pollutant saving from RES [tonne] ▪ ΔAP_{EV} = air pollutant saving from electric mobility [tonne] ▪ ΔAP_{EE} = air pollutant saving from customer awareness [tonne]
	AIR POLLUTANT EMISSION SAVINGS FROM RENEWABLES $\Delta AP_{RES} = tonne_{AP/MWh} * \Delta EE_{RES,year}$ ▪ $tonne_{AP/MWh}$ = tonnes of air pollutant per MWh of electricity energy (country specific) [tonnes AP /MWh] ▪ $\Delta EE_{RES,year}$ = renewable energy generated from the additional RES capacity enabled by the project with respect to BaU conditions *(*starting from the additional hosting capacity enabled [ΔHC] and the equivalent hours of production). It represents the amount of fossil-based energy displaced with renewable energy sources. A reduction coefficient (r_i) has been applied (as earlier mentioned) in order to account for the additional investments required on the generator side.
	AIR POLLUTANT EMISSION SAVING FROM ELECTRIC MOBILITY $\Delta AP_{EV} = km_{year} * N * CS * (tonne_{AP/Km,EV} - tonne_{AP/Km,ff})$ ▪ km_{year} = average number of kilometres yearly driven by the field crew (historical value can be used) ▪ *CS* = number of EV charging stations installed in the SG scenario ▪ *N* = number of EVs enabled per EV charging station installed in the project ▪ $tonne_{AP/km,EV}$ = average tonnes of air pollutant per kilometre driven by an EV ▪ $tonne_{AP/km,ff}$= average tonnes of air pollutant per kilometre by fossil fuelled vehicle
	AIR POLLUTANT EMISSION SAVING FROM CUSTOMER AWARENESS $\Delta AP_{EE} = \%EE * E_{BAU,TOT} * tonne_{AP/MWh} * 10^{-3}$ ▪ *%EE* = reduction of yearly energy consumption in the SG scenario ▪ $EE_{BAU,TOT}$ = total yearly energy consumption in the BaU scenario [kWh] ▪ $tonne_{AP/MWh}$ = average tonnes of air pollutant per MWh of electricity energy (country specific)
NOTE	Air pollutant emission price can be valued by referring to the report from the AEA Technology entitled "Damages per tonne emission of PM2.5, NH_3, SO_2, NOx and VOCs from each EU25 Member State (excluding Cyprus) and surrounding seas" [7], for carrying out cost-benefit analysis of air quality issues in the Clean Air For Europe (CAFE) programme. As seen from the title, the report provides an estimate of the damage per tonne of several pollutants, accounting for variation in the site of emission in each EU country.

Source: JRC and ENEL elaborations, 2018

Table 12 Energy savings

BENEFIT	REDUCED TONNES OF OIL EQUIVALENT
DEFINITION	Primary energy saving
DESCRIPTION	Lower primary energy usage would eventually result from the implementation of smart grid solutions: a higher percentage of demand satisfied through renewable generation, as well as a larger diffusion of electric mobility, would in fact translate into lower use of conventional fossil fuel. In order to account for the project's impact, the equivalent amount of oil consumption corresponding to each of the main implemented technologies can be estimated. Additionally, it has to be observed that - alongside environmental benefits - oil usage reduction would also improve oil security at the country level (by lowering the need for imports) so to also represent a benefit at the societal, macroeconomic, and geopolitical level.
FORMULA	Primary energy saving can be monetised per year as follows: $\Delta Toe = pToe^{*}(\Delta Toe_{RES} + \Delta Toe_{EV})$ *[EUR/year]* Where: - $pToe$= price of a tonne of oil equivalent [EUR/tonne] - ΔToe_{RES} = saving of tonnes of oil equivalent from RES - ΔToe_{EV} = saving of tonnes of oil equivalent from electric mobility
	REDUCED OIL USAGE FROM RES $\Delta Toe_{RES} = \Delta EE_{RES,year} * toe / MWh$ - ΔToe_{RES} = total amount of yearly saving of tonnes of oil equivalent from RES in the SG scenario - $\Delta EE_{RES,year}$ = renewable energy generated from the additional RES capacity enabled by the project with respect to BaU conditions *(*starting from the additional hosting capacity enabled [ΔHC] and the equivalent hours of production). It represents the amount of fossil-based energy displaced with renewable energy sources [MWh]. - *toe/MWh* = conversion factor expressing the tonnes of oil equivalent per MWh of energy produced (country specific) As earlier mentioned, a reduction coefficient (r_i) can be applied to account for the additional investments required by generation.
	REDUCED OIL USAGE FROM ELECTRIC MOBILITY Oil usage reduction through electric mobility over conventional fossil fuelled vehicles: $\Delta Toe_{EV} = FF * toe / l - EE_{EV} * toe / MWh$ - ΔToe = total amount of yearly saving of tonnes of oil equivalent from EV charging in the SG scenario [toe] - *FF* = litres of fossil fuel saved yearly by using EV over conventional vehicles - *toe/l* = average tonnes of oil equivalent per litre of fossil fuel - EE_{EV} = total yearly electricity consumption for EV charging in the SG scenario [MWh] - *toe/MWh* = conversion factor expressing the tonnes of oil equivalent per MWh of energy produced (country specific) In particular, ΔToe_{EV} accounts for the fossil fuel yearly replaced with electricity energy by using EVs over conventional fossil fuelled ones: $FF = N * CS * km_{year} * l / km$ - *FF* = litre of fossil fuels saved yearly by using EV over conventional vehicles - *l/km* = average performance of gasoline fuelled vehicles (litres per kilometre) - km_{year} = average yearly number of kilometres driven - *CS* = number of EV charging stations installed in the SG conditions - *N* = number of electric vehicles enabled per EV charging station On the other hand, EE_{EV} accounts for the amount of electricity consumption for electric mobility: electricity energy, unless fully generated by renewable energy sources, corresponds to a given equivalent (country-specific) amount of oil considering an LCA approach. As a consequence, when estimating the benefit corresponding to the fossil fuel usage reduction, the equivalent amount of oil per unit of electricity energy used should be considered as well. $EE_{EV} = N * CS * P_{EV} * 10^{-3} * t_{charge} * \frac{km_{year}}{b_{cycle}}$ - EE_{EV} = total amount of yearly electricity energy consumptions for EV charging in the SG scenario [MWh] - P_{EV} = EV battery power [kW] - t_{charge} = average time per EV charge [h /charge] - km_{year} = average yearly number of kilometres driven - b_{cycle} = average number of kilometres allowed per charge [km/charge] - *CS* = number of EV charging stations installed in the SG conditions - *N* = number of electric vehicles enabled per EV charging station As earlier mentioned, the number of EVs potentially supported by the installed EV charging infrastructures has been considered for calculation.

Source: JRC and ENEL elaborations, 2018

2.7 CBA Step 6 – Identify and quantify the costs

The costs incurred for the implementation of the smart grid solutions in the project have been considered and detailed in the table below. Given the life time of the project assets (mainly five and ten years), as already mentioned, a time horizon of ten years was chosen for the CBA.

Table 13 Costs of the project

	Investment costs (million EUR)
Equipment installed for the activation of electrical nodes and interface with the TSO	~ 2.2
Broad band communication	~ 0.4
Infrastructure and devices for smart services, testing and software developments (*)	~ 2.6
Other ad hoc developments	~ 2.2
Total Investment	**~ 7.4**

(*) Including EV charging infrastructures (optimised station and storage) and smart info devices

Source: ENEL and JRC elaborations, 2018

For the sake of simplicity, it has been assumed that the installation of the project components was completed at the beginning of the project (year 0), considering the flow of project benefits to begin from year 1.

2.8 CBA Step 7 – Compare costs and benefits

As recommended in the guidelines, when comparing and evaluating costs and benefits of a smart grid project, it is important to accurately identify the main beneficiaries and highlight the cost/benefit ratios for them.

For this project, like for the previous investigation dedicated to the Smart Grid project in Malagrotta (Rome) [2], two distinct Cost-Benefit Analyses have been carried out: a private-investor CBA where the DSO (incurring the costs in the Isernia project) is considered as the sole beneficiary of the investment, and a societal CBA where the pros and cons of the project are assessed from the wider perspective of the whole of power system participants.

In this study, the comparison of costs and benefits takes place according to the standard Net Present Value approach, whereby their present discounted value is algebraically summed to obtain a measure of the project's net worth. For the sake of simplicity, in both cases it has been assumed that all costs are incurred at the beginning of the project (year 0) while benefits only arise later, beginning with year 1. Details on the methodology and assumptions for each CBA are provided in the following section.

2.9 Application of the methodology

As regards the private-investor CBA, one should start from the consideration that DSOs are regulated entities. Consequently, the remuneration rate for the private-investor CBA (referred to as "regulated WACC") is set by the National Regulatory Authority. It is used to determine the investment recovery through the tariff.

In the time horizon analysed in this report, the basic tariff remuneration is considered equal to 7.4% ('regulated WACC'), which applies to the DSO's investments in a Business-as-Usual (BaU) scenario. In particular, under Resolution ARG/elt 39/10, the Isernia project was selected through a competitive process to be awarded with an extra remuneration of +2%. This higher rate is applicable also to those SG assets generally not remunerated in a Business-as-Usual scenario.

Therefore, the private-investor CBA was doubled to take into account both (i) the BaU situation (where the extra remuneration is not applied and some assets are not remunerated) and (ii) the project-specific case, where the incentive is considered.

In both cases, externalities are not taken into account, as they are not quantified and remunerated as such by the Regulator; however, evidently the Regulator additional remuneration of SG investments may well aim at making the private investor align with the SG expected societal benefits i.e. positive externalities, at least in part.

Since what is investigated here is purely the profitability of private investment, which is obviously affected by taxes on capital returns, the latter have been taken into account: it will be seen presently that, as recommended by the JRC guidelines, the opposite approach was followed for the societal CBA. The real financial discount rate (FDR) used is 4%, the benchmark recommended in the EC guidelines on CBA of investments [5].

For the societal CBA (which, again, considers a wider system perspective and the impact of SG investments on externalities), the investor's benefits are summed up with those accruing to other social parties, such as the consumers of electricity and the citizens at large. As a consequence, the various benefits were grouped in two great categories: economic benefits, which – beside the investor's benefits just mentioned – account for the billing savings enabled for final customers; and environmental benefits, which include carbon emissions, air pollution and primary energy savings enabled by the project (as quantitatively estimated below).

As recommended in the JRC CBA guidelines [13], pre-tax profits were considered, so to effectively disregard taxes: this is due to the reasoning that taxes are payments for public services, hence essentially transfers from one part of the society to another. The investment-generated wealth allowing the investor to make such payments should therefore be included in the computation of benefits.

The issue arises as to whether it is the Business-as-Usual (case A) or incentivised (case B) investor remuneration that should be considered in the frame of this analysis. Let us bear in mind the above remark, i.e. that the regulator's targeted rate for Smart Grid investments under Resolution ARG/el 39/2010 [1] aims precisely at letting the DSO internalise (part of) the societal benefits of this infrastructure. It should therefore be the case that, if this extra remuneration at least partially aligns the investor's and the society's incentives, the monetised positive externalities, which are the specificity of the societal CBA, are at least in part already incorporated into its value. On the other hand, it may well be that some externalities targeted by the Resolution are still disregarded by the societal CBA presented here.

For robustness, both cases were considered. The results are presented and discussed in the following section.

3 Discussion of results

Let us first consider those for the private-investor CBA, which considers the DSO bearing the Isernia project's investment costs as its only beneficiary. They may be found in Table 14.

Table 14 Summary of the Cost Benefit Analysis considering only the DSO as beneficiary (Business-as-Usual (A) and incentivised (B) tariff remuneration under Resolution ARG/el 39/2010) [1]

	0	1	2	3	4	5	6	7	8	9*
(A) Total cash flows (million EUR)	-7.4	0.4	1.0	0.7	0.7	1.0	0.4	0.1	0.2	0.8
(B) Total cash flows (million EUR)	-7.4	0.4	2.2	1.4	1.4	1.6	1.0	0.1	0.4	1.2
(A) NPV (million EUR)	-3.04									
(A) IRR	-6.7%									
(B) NPV (million EUR)	+0.79									
(B) IRR	6.5%									

** including actualised cash flows after the tenth year*

Source: JRC and ENEL elaborations, 2018

As detailed in Table 14, a non-negative private return on investment would only be observed in the presence of the incentivised remuneration scheme applied under Resolution ARG/elt 39/2010 [1], (i.e., under case B). On the contrary, in the absence of such a scheme (i.e., in case A), a negative return would be expected. This highlights the need to support and incentivise the SG investments carried out by DSOs. In fact, while from a private-investor perspective smart grid investments might not yield positive returns if a proper regulatory remuneration mechanism is not in place, missing this investment opportunity would be suboptimal when considering the impact of the adoption of such solutions on the society and the system as a whole.

The latter assessment is borne out in Table 15, which instead displays the outcomes of the societal CBA according to both the Business-as-Usual (case A) or incentivised (case B) investor remuneration. As clarified above, the former is considered here in the case that the full amount of regulatory extra-remuneration for Smart Grids captures those externalities that have been monetised; the latter, instead, covers the possibility that it only captures benefits other than such externalities. The correspondingly resulting figures, therefore, should be interpreted as setting the limits of the range wherein a reasonable estimate of the societal Net Present Value may lie. Predictably, including the extra (incentivised) remuneration yields higher figures than excluding it (EUR 6.6 million against EUR 1.2 million), but the qualitative results are entirely analogous.

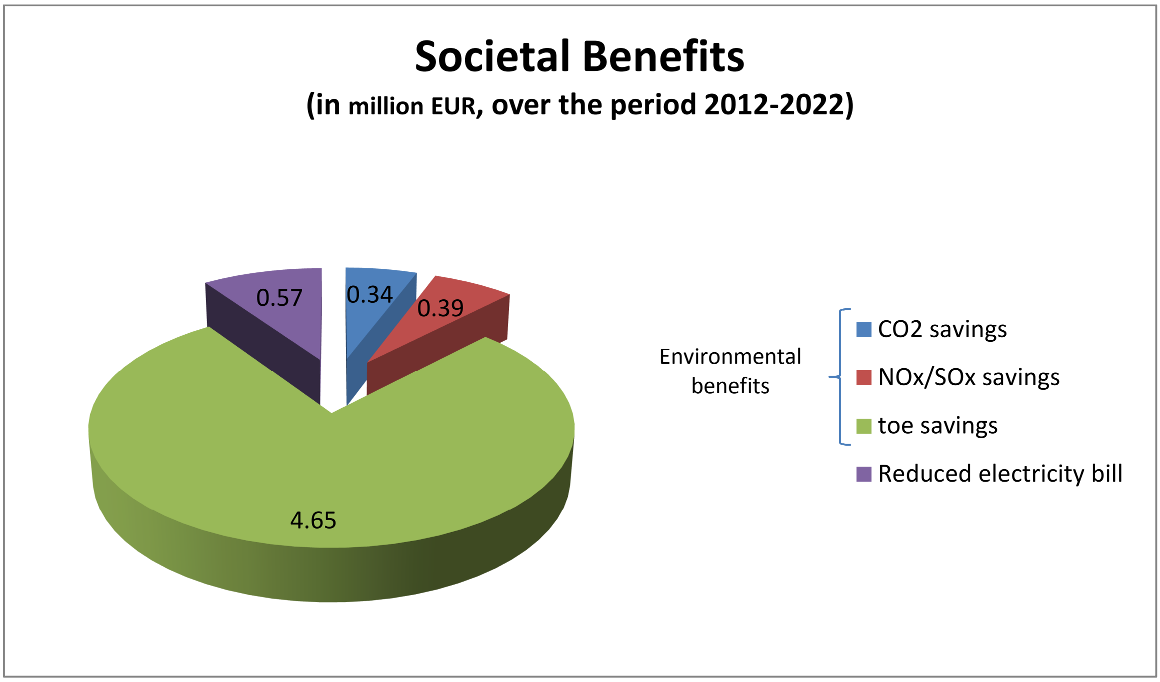
From a wider societal perspective, although being just a small pilot project and one of the pioneering experiments with SG, the project still features a positive benefit/cost ratio (>1), meaning that each euro invested in smart grid technologies generates more than one euro of monetised benefits for the main involved stakeholders in return, so to display a positive NPV (>0) and a IRR higher than the (societal) discount rate applied. Figure 3 below display the total societal cost-benefit breakdown according to the two different approaches (incentivised and BaU): naturally, given this CBA's construction, these also include the (pre-tax) investor benefits which constituted the focus of the private-investor CBA.

Table 15 (societal) Cost-benefit analysis considering a societal perspective (Business-as-Usual (A) and incentivised (B) tariff remuneration under Resolution ARG/el 39/2010) [1]

	0	1	2	3	4	5	6	7	8	9*	NPV
Costs (million EUR)	-7.4										**-7.4**
Social Benefits (million EUR)		0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	**5.95**
- Of which: Environmental benefits		0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	**5.38**
Of which: CO_2 savings		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.34
Of which: NOx/SOx savings		0.06	0.06	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.39
Of which: toe savings		0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	4.65
- Of which: Reduced electricity bills		0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	**0.57**
Tot. cash flow (A)	-7.4	0.8	1.4	1.4	1.4	1.3	1.3	1.3	1.0	1.0	**1.2**
Tot. cash flow (B)	-7.4	0.8	2.7	2.6	2.5	2.4	2.3	1.4	1.4	1.4	**6.6**

Source: JRC and ENEL elaborations, 2018

Figure 3 Break down of the sources of societal benefits of Isernia's smart grid project



Source: JRC and ENEL elaborations, 2018

Table 16 Summary of Cost Benefit Analysis results

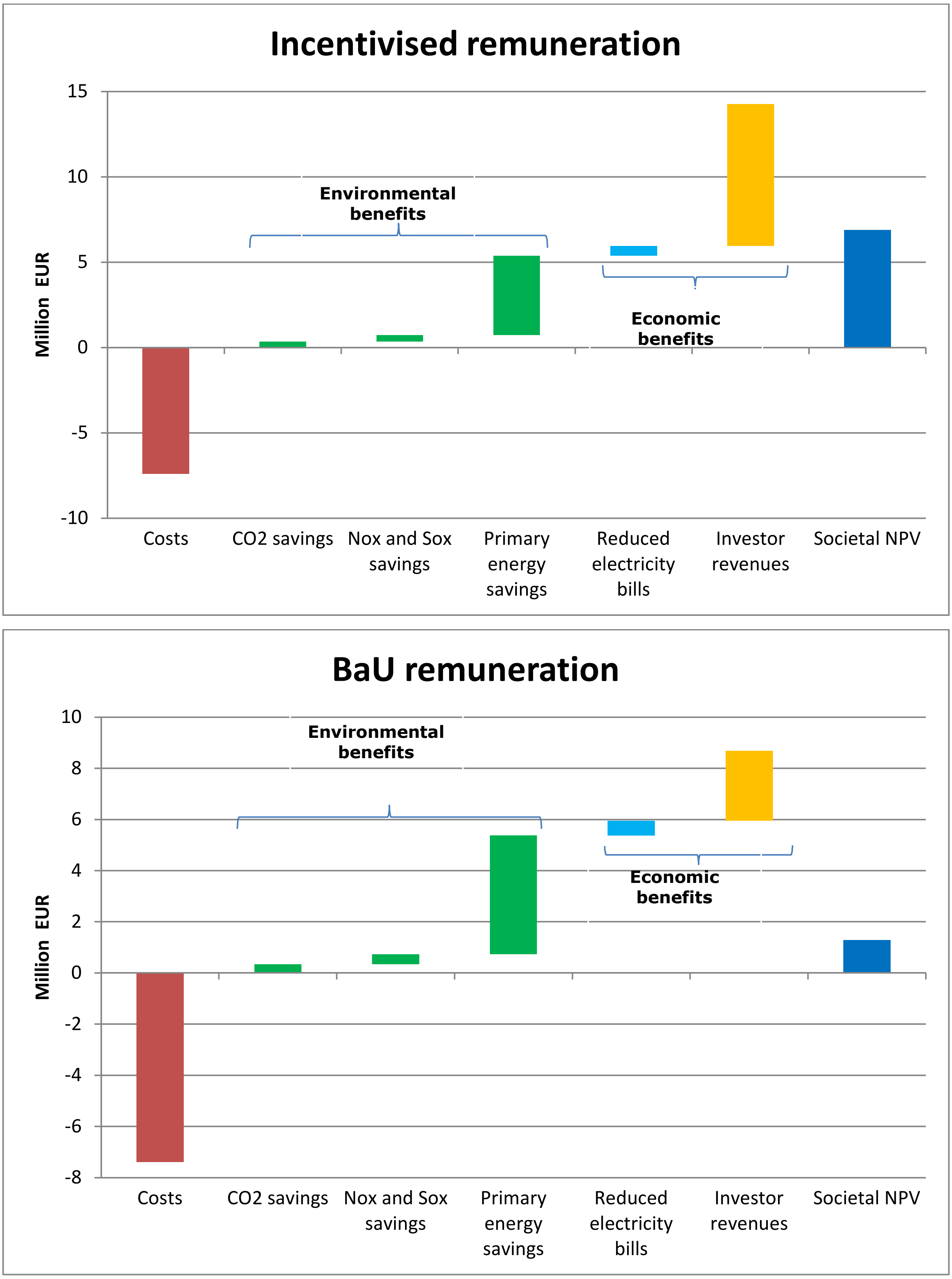
CBA results	Value
NPV (A) (million EUR)	1.2
IRR(A)	8.2%
B/C RATIO (A)	1.1
NPV (B) (million EUR)	6.6
IRR (B)	22.4%
B/C RATIO (B)	1.8

Source: JRC and ENEL elaborations, 2018

As earlier mentioned, beyond a handful of pilot projects (including Isernia and Malagrotta), Smart Grid investments in general did not receive a specific remuneration in Italy when this project was initiated. Therefore, from a DSO's strictly financial standpoint, it could well happen that the investments carried out - despite benefitting the system and/or the customers in general – would not yield a positive return for the investor bearing their costs, due to the regulation in place. On the other hand, SG investments typically have a positive cost/benefit ratio if seen from a wider societal perspective, i.e. one that includes more stakeholders than just the actor(s) actually performing the investment. Therefore, the results from this exercise, corroborate the view that sizable externalities can be generated from SG investments, and thus they should be supported and incentivised.

Such situation led the Regulator to issue the new Resolution 646/2015/R/eel [14] to turn around Italy's Smart Grids incentive scheme towards an output-based incentive regulation, whereby improvements in output due to Smart Grids technologies (initially to those pertaining network observability and MV voltage control) are rewarded as such in a systematic fashion.

Figure 4. Scenarios with regulatory incentives vs. BaU



Source: JRC and ENEL elaborations, 2018

4 Sensitivity Analysis

Sensitivity analysis is a necessary component of a CBA. Its aim is to highlight the influence of parameters, which may be subject to variation over time, and take care of the uncertainty that they introduce. The parameters that have been considered for sensitivity analysis are detailed in Table 17:

Table 17 Parameters subject to sensitivity analysis

INPUT PARAMETERS FOR SENSITIVITY	UNIT	VALUE	SENSITIVITY RANGE
REAL SOCIAL DISCOUNT RATE	%	2.5%	1 % - 5%
AVERAGE CO_2 PRICE	EUR/tonne	15	5 - 50
AVERAGE OIL PRICE	EUR/boe	65	50 - 100
CO_2 EMISSION PER MWh	tonne/MWh	0.41	0.3 - 0.55
NOx EMISSION FIGURATIVE COST	EUR/tonne	5,700	3,000 - 16,000
SOx EMISSION FIGURATIVE COST	EUR/tonne	6,100	4,000 - 18,000
EQUIVALENT HOURS OF PRODUCTION	h/year	1,540	1,312 - 2,057
INCREASE OF THE HOSTING CAPACITY	%	19%	16% - 25%
ENERGY CONSUMPTION REDUCTION	%	3%	2% - 6%

Source: JRC and ENEL elaborations, 2018

The ranges of variations assumed are explained in the following:

Real social discount rate: The social discount rate is one of the most relevant assumptions in performing a CBA and a sensitivity analysis is therefore strongly recommended. As mentioned above, a value of 2.5% has been assumed for Italy and subjected to a sensitivity analysis in a range from 1% to 5%. As from the results shown in Figure 5, this influences the project's social NPV, whose value stays positive throughout the analysed timeframe.

Carbon emission price: the afore-mentioned value of EUR 15/tonne has been used as a working assumption. A sensitivity analysis has been implemented in a range from EUR 5/tonne (closer to the recent trend) to EUR 50/tonne (which tops the market analyses and forecasts, as better argued in [2]). The carbon emission price determines the monetisation of the environmental benefits in terms of GHG emissions reductions, and thus influences the social NPV. In consideration of the expected growth in carbon emission prices, argued in [2], an even higher value of the social NPV can be expected in the future from the technologies implemented.

Oil price: the high and low price projections made by the EC and the IEA have been considered in the period 2011-2020. Values range from an average of ca. USD 85/boe, in a low price scenario, to ca. USD 130/boe, in a high price projection. Assuming a conversion rate of EUR 1.35/USD in 2013, this corresponds to a range from ca. EUR 50/boe to EUR 100/boe, which has therefore been used for the sensitivity analysis.

Oil price influences the monetisation of the environmental benefits stemming from toe savings and, as it can be observed in Figure 4, it turns out to be a relevant factor in the variation of the social NPV. However, the lowest NPV value attained (EUR 0.2 million in the BaU case with EUR 100/boe) is still in the positive range.

Emission rate: a standard approach has been used for the carbon emission rate in relation to the total energy mix in Italy. The value of 0.41 tonneCO_2/MWh provided by

TERNA has been adopted as a working assumption. ISPRA gauges a value of 0.337 tonneCO_2/MWh, whereas the Italian Ministry of Environmental Affairs' indication is 0.531 tonneCO_2/MWh. This value has been subjected to sensitivity analysis within a range spanning from 0.3 (under the hypothesis that an increase in renewable energy may reduce the emission rate in the future) to 0.55 tonneCO_2/MWh, roughly covering the span from the values provided.

The emission rate is one of the coefficients determining the amount of CO_2 emission displaced through the increase of renewable energy. However, the sensitivity analysis shows it to have a low effect on the variation of the social NPV.

Figurative cost for the society of air pollutant emissions (NOx, SOx): working assumptions have been deduced for Italy from the CAFE report [7]. The results of a sensitivity analysis are discussed therein, taking several factors into account (health effects, and others); the corresponding ranges are used here to estimate the impact on the social NPV. Figurative costs of air pollutant emissions determine the estimation of some environmental benefits as well. However, as seen from Figures 4, only NOx can be considered a relevant factor, while the social NPV appears fairly robust to the variation of SOx emissions.

Equivalent hours of production from renewables: by considering the energy mix in the project area, and excluding traditional energy sources, a baseline assumption has been made of 1,540 h/year. A sensitivity analysis has been carried out in a range from 1,312 h/year to 2,057 h/year, corresponding respectively to the equivalent hours of production from PV (under the conservative hypothesis of new connections only from solar sources) and the average value of solar, wind and other renewables' equivalent hours of production. Such value influences the calculation of the traditional energy production displaced by the renewables connections enabled. According to the sensitivity analysis' results, it represents a relevant factor on the variation of the social NPV.

Hosting capacity increase: a value of 19% has been calculated in the case of MV busbar voltage centrally set in the HV/MV Primary Substation through the Distribution Management System, together with the modulation of the local DG reactive power. The sensitivity analysis has been carried out in a range of 16% to 25%: in the Isernia project, the first figure corresponds to the use of the DMS to optimally set the voltage at HV/MV substation level without the regulation of the DG reactive power, while the second is assumed from other projects.

The hosting capacity increase is indeed one of the most relevant results with respect to the project objectives. It determines the amount of additional connections from renewables enabled by the project without traditional network reinforcements, and strongly influences the calculation of the main benefits estimated in the report.

The social NPV always results in values above zero over the range explored, and it should be observed that in the low scenario considered it may be even higher: in fact, when the value of 16% is assumed, lower investment levels should be considered as well. Since in such a case the advanced regulation would be carried out at the HV/MV substation level without contribution from DG, the costs associated with the latter could be disregarded, thus increasing the social NPV.

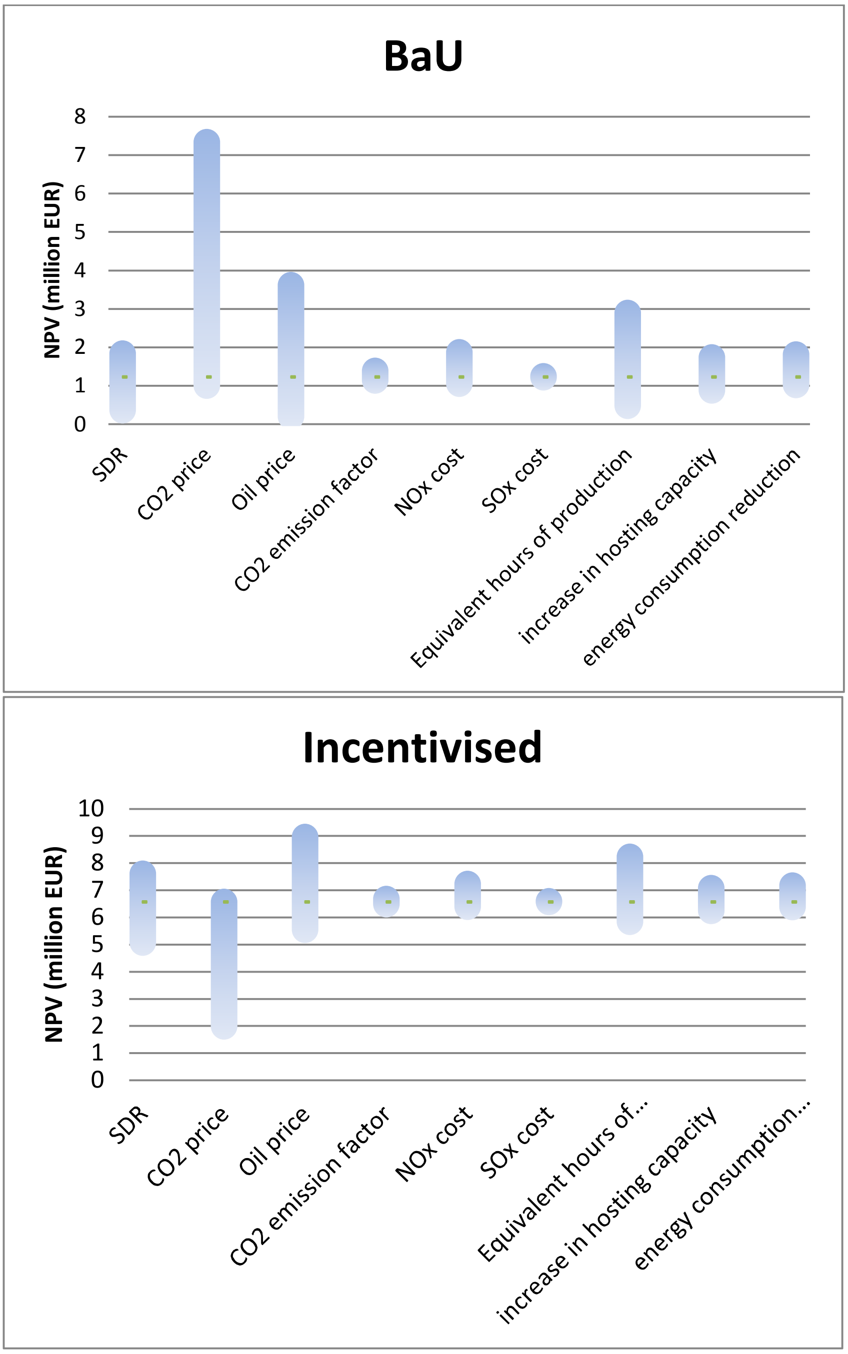
Energy consumption reduction: a sensitivity analysis has also been carried out on the variation in energy consumption reduction. For the sample of customers that were equipped with the smart info kit, a net energy consumption reduction in a range from 2% to 6% was observed, primarily depending on the type of customers. The range has been used for the sensitivity analysis.

Energy savings are also one of the main results enabled by the project. They influence the estimation of both the environmental benefits stemming from energy consumption reduction and the economic savings in terms of energy bill reduction. As seen from Figure 4, they do influence the social NPV.

It should be mentioned that, for sake of simplicity, the average yearly energy consumption and tariff of residential customers have been considered to assess the value of the corresponding benefits. These may well be higher in case of small commercial consumers (also involved in the project): as a consequence, the estimation of the social NPV should be considered prudential.

Figure 4 (a) and (b) show the results of the sensitivity analysis on the parameters discussed above in the BaU (A) and incentivised (B) case, where predictably the latter case's values stand consistently above the former's. While nominal Social Discount Rate, oil price, CO_2 price, and equivalent hours of production stand out as the most relevant factors, no parameter variation within the considered ranges is able to drive the project's NPV in the negative field.

Figure 5. Societal NPV variation by input parameters in the BaU case vs. incentivised case



Source: JRC and ENEL elaborations, 2018

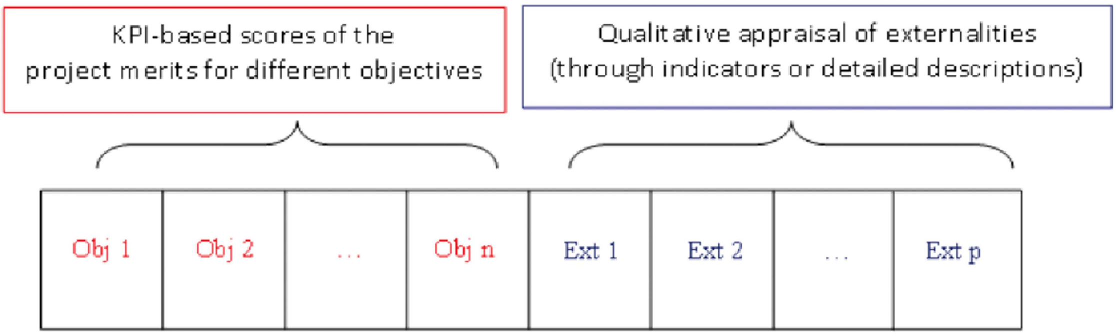
5 Quantitative (non-monetary) appraisal

As recommended in the JRC guidelines on Smart Grids CBA [13], there are benefits that are difficult to monetise and thus be considered. This may be due to a variety of reasons, ranging from contingent data deficits, to structural unobservability, to the evaluation's dependence on policy goals, to project potentials yet to be fulfilled. For example, the benefits deriving from the present enabling of future applications and functionalities are by definition still virtual, and hence generally not included in the quantitative (monetary) analysis. Such additional indirect benefits may result, for instance, from the set-up of a service platform on top of the infrastructure provided via the project, available for energy efficiency applications and demand response.

The project's contribution to each objective will be evaluated via a set of Key Performance Indicators (KPIs) as listed in the JRC Guidelines, together with examples of externalities, to account for the contribution of the project's measures and solutions in terms of social or market impact. The project size has been accounted for, without scaling the benefits at a national (or regional) level, in order to ensure coherence with the quantitative (monetary) analysis earlier performed.

As recommended in the guidelines, the outcome of the overall qualitative impact analysis will include (1) KPI-based scores of the project's merits for different objectives, and (2) qualitative appraisal of foreseen externalities. The final outcome will be a vector.

Figure 6. Qualitative outcome vector [JRC guidelines]



Source: JRC, ENEL, 2018

This section discusses the qualitative appraisal of some effects of the Isernia project that are especially difficult to monetise. In particular, the project is expected to have side-effects - whether specific to the project or global (e.g. policy related) - that will eventually result into further benefits alongside those already monetised. Objective evaluation expressed through properly defined metrics has been preferred. Calculation options have been accordingly provided in the following, in the perspective of generalisation and applicability to other smart grid projects. Where the definition of indicators/KPIs has not been possible, evaluation was expressed in some cases through a scale of five levels of relevance from 0 to 1 [low (0), medium/low (0.25), medium (0.5), medium/high (0.75), high (1)] relying on the knowledge of project experts. However, as already pointed out, some benefits - although activated and/or enabled - have not been evaluated, f.i. because the market and regulatory conditions necessary for reliable estimation are not yet in place, or the estimation of a benefit relies on actors other than those involved in the project, etc.

As envisaged in the JRC methodology, the provision of weights could be used to enhance the importance of one or more KPIs in the overall impact evaluation in case of specific objectives linked to particular local or e.g. pre-existing conditions. However, this approach was not applied in this report.

KPI-based scores of the project merits for different objectives

In the attempt to define an assessment approach linking KPIs and functionalities, and to capture the merit of the project deployment, the JRC guidelines present a comprehensive set of non-easy-to-monetise benefits and corresponding KPIs. The assessment framework proposed is based on a merit deployment matrix where benefits and corresponding KPIs are given in the rows, whereas functionalities (which are grouped into homogeneous clusters called services) are given in the columns. For each cell, the link between benefits/KPIs and functionalities achieved in the project has been evaluated by assigning a weight (in the range 0-1) to quantify how strong and relevant the link is.

In the absence of well-defined calculation methods, KPI assessment through the merit deployment matrix might be strongly affected by the subjectivity of the evaluator. Providing objective explanations and assessment methods is therefore fundamental, in the CBA's monetary and non-monetary appraisals alike. Examples of KPI calculation have been provided in this report.

However, where (indirect) benefits rely on further developments on top of the ones that are provided in the project, and/or the regulatory/market changes necessary to elicit them have not taken place yet, KPI evaluation might not be accurate or even possible. By way of example, the solutions concerning customer awareness that are provided in this project enable the adoption of intelligent in-home automation, and thus facilitate consumer participation in the electricity market (which falls under the "Improving market functioning and customer service" category below). Although enabled through the solutions implemented, some benefits will therefore not be quantified, for example because they depend on an additional set of technologies besides the ones installed for the project. This is for example the case of CO_2 emission savings stemming from in-home automation already enabled through the project.

The merit deployment matrix for the project is provided below, with calculation options for the qualitative appraisal of benefits.

Table 18 Merit Deployment Matrix

		SERVICES (i.e. group of functionalities)						
		INTEGRATE USERS WITH NEW REQUIREMENTS	ENHANCING EFFICIENCY IN DAY-TO DAY GRID OPERATION	ENSURING NETWORK SECURITY, SYSTEM CONTROL AND QUALITY OF SUPPLY	BETTER PLANNINGOF FUTURE NETWORK INVESTMENT	IMPROVING MARKET FUNCTIONING AND CUSTOMER SERVICE	MORE DIRECT INVOLVEMENT OF CONSUMERS IN THEIR ENERGY USAGE	TOTAL SUM
BENEFIT	**KPI**							
Adequate capacity of transmission and distribution grids to collect and bring electricity to the consumer	Hosting capacity for distributed energy resources in distribution grids	Integration of RES (0.19)						0.19
BENEFIT	**KPI**							
Satisfactory levels of security and quality of supply	Share of electrical energy produced by renewable sources	Integration of RES (0.22)						0.22
	Power system stability			Integration of RES (0.79)				0.79
BENEFIT	**KPI**							
Enhanced efficiency and better service in electricity supply and grid operation	Ratio between minimum and maximum electricity demand within a defined time period (e.g. one day, one week)					Installation of ENEL's smart info kit (0.13)		0.13
	Demand-side participation in electricity markets and in energy efficiency measures					Installation of ENEL's smart info kit (0.13)		0.13
BENEFIT	**KPI**							
Enhanced consumer awareness and participation in the market by new players	Demand side participation in electricity markets and in energy efficiency measures					Installation of ENEL's smart info kit (0.13)		0.13
	Measured modifications of electricity consumption patterns after new (opt-in) pricing schemes						Installation of ENEL's smart info kit (0.03)	0.03
BENEFIT	**KPI**							
Enable consumers to make informed decisions related to their energy to meet the EU Energy Efficiency targets	Consumers can comprehend their actual energy consumption and receive, understand and act on free information they need/ask for						Installation of ENEL's smart info kit (0.95)	0.95
	Consumers are able to access their historic energy consumption information for free in a format that enables them to make like-for-like comparisons with deals available on the market					Installation of ENEL's smart info kit (1)		1
	Ability to participate in the relevant energy market to purchase and/or sell electricity					Installation of the ENEL's smart info kit (0.25)		0.25
BENEFIT	**KPI**							
Create a market mechanism for new energy services such as energy efficiency or energy consulting for customers	Simple and/or automated changes to consumers' energy consumption in reaction to demand response signals are enabled					Installation of ENEL's smart info kit (0.5)		0.5
	Data ownership is clearly defined and data processes in place to allow for service providers to be active with customer consent					Installation of ENEL's smart info kit (1)		1

Source: JRC and ENEL elaborations, 2018

KPI: hosting capacity for distributed energy resources in distribution grids

The KPI has been defined as the additional capacity [MW] of DER that can be connected through smart grid investments without conventional network reinforcements and extensions (such as new lines and substations). Details on the calculation method have been discussed in the section on monetised indicators.

KPI: share of electrical energy produced by renewable sources

This KPI can be quantified in terms of percentage variation of the share of electricity generated from renewable sources that can be safely integrated in the system in the SG and in the BaU scenarios (over a defined period of time, e.g. a year), assuming the same total amount of electricity generated in both the scenarios:

$$KPI_{EE,RES} = \frac{h_{eq} * \Delta\mathrm{H}C * \mathrm{HC}_{\mathrm{BAU}}}{EE_{BAU,TOT}}$$

$\mathrm{heq} * \Delta\mathrm{HC} * \mathrm{HC}_{\mathrm{BAU}}$ is the equivalent energy [MWh] representing the amount of fossil-based energy displaced via additional renewable energy sources capacity achievable in the project area through the implementation of smart grid solutions, while $\mathrm{EE}_{\mathrm{BAU,TOT}}$ is the total energy consumption [MWh] in the distribution grid under consideration in the defined period (possible impacts of the project on energy consumption levels have been disregarded, as a rough approximation to have a comparable basis for evaluation).

KPI: power system stability

Techniques and methods for the control of reactive and also active power injection from the distributed generation were in place in the Isernia project. As detailed above, the current Italian regulation does not yet fully allow for the participation of DG to the management of the electricity system. However, the technical rules for connection (CEI 0-16, 2012-12) [15] establish that all the generators (connected to the grid above 100 kW after 2012) shall be equipped with systems for the regulation (increase/decrease) of reactive and active power injection.

It can therefore be assumed that, whenever regulation on DG participation will be fully adopted, the approaches and methods implemented in the project can contribute to increased network flexibility and hence potentially support power system stability, as follows:

$$KPI_{PS} = \frac{MW_{2012} + MW_{F,area}}{MW_{area} + MW_{F,area}}$$

MW_{2012}= generation capacity connected in the project area after 2012

$\mathrm{MW}_{\mathrm{F,AREA}}$= generation capacity forecast in the project area or alternatively the enabled hosting capacity (HCSG) net of the generation currently installed

$\mathrm{MW}_{\mathrm{AREA}}$ = total generation connected in the project area

KPI: demand-side participation in electricity markets and in energy efficiency measures

Flexibility is a measure of the ability of the electricity system to respond to and eventually balance supply and demand variations. To this extent, demand side management represents one of the flexibility resources that can be used for a better management of the electricity energy system. This KPI expresses potential demand side participation, as the amount of load enabled to participate in demand side management, i.e. able to be shifted in time and/or modulated (e.g. demand capacity corresponding to interruptible or shiftable white goods installed). This relies on the assumption that further technologies for local energy control be available, enabled by the accessibility of Smart Metering data through installation of ENEL's smart info kit within the project. This KPI accounts only for the contribution of active loads (demand), primarily at LV level, in the assessment of both the BaU and SG scenarios:

$$P_{DSM} = \frac{P_{DSM,SG} - P_{DSM,BAU}}{P_p}$$

$P_{DSM,\ BAU}$ = the amount of load capacity enabled for DSM in the BaU scenario (no smart info kit installed – it corresponds to the amount of interruptible loads in the project area, if any).

$P_{DSM,\ SG}$ = the amount of load capacity enabled for DSM in the SG scenario (i.e. the sum of the potentially interruptible/shiftable loads in the project area such as from some white goods at LV customer premises)

P_p = the maximum electricity demand in the area under evaluation in the BaU

Given the size of the demonstration and/or the localisation of the project itself (as f.i. in the case of projects featuring customers spread over a large territory), P_p could be referred just to the sample of customers involved in the demonstration.

A contemporary coefficient of use has been considered while accounting for the potential amount of load capacity enabled for DSM in the SG scenario. The main interruptible/shiftable loads (e.g. white goods) available at the premises of the involved sample of customers have been considered.

On the contrary, no interruptible/shiftable loads have been considered in a BaU scenario.

KPI: ratio between minimum and maximum electricity demand within a defined time period

The KPI calculates the variation in the ratio between minimum (P_{min}) and maximum (P_{max}) electricity demand (within a defined time period) as a consequence of higher customer awareness resulting into the shifting and/or modulation of energy consumption from peak to off-peak hours:

$$KPI_P = \frac{\Delta P_{BAU} - \Delta P_{SG}}{P_p}$$

P_{BAU} = difference between minimum and maximum demand within a predefined period of time in the BAU scenario

P_{SG} = difference between minimum and maximum electricity demand within a predefined period of time in the SG scenario

P_P = the peak electricity demand in the BaU over the predefined period of time.

To measure this KPI, in particular, the amount of (enabled) "demand-side participation in electricity markets and in energy efficiency measures" (earlier detailed) may be used. This assumes that the difference (ΔP_{BAU} – ΔP_{SG}) is the capacity corresponding to interruptible and/or shiftable white goods potentially enabled.

KPI: measured modifications of electricity consumption patterns

As described above, efficient energy behaviour can be pursued by enabling consumption rationalisation stemming from higher customer awareness. As higher quantity and quality of information on energy consumption is provided to the customers, a behavioural change can be expected in order to achieve higher energy efficiency.

In particular, the total energy consumption resulting from the adoption of ENEL's smart info kit was monitored in comparison with the BaU scenario (where no local meter interface for customer awareness is installed). Therefore, the KPI measures the effect of energy efficiency in terms of total yearly volume reduction, as in the following:

$$KPI_{\%EE} = \frac{\%EE * EE_{BAU,TOT}}{EE_{TOT}}$$

%EE = total net yearly energy reduction (cleaned of contingency factors)

$EE_{BAU,\ TOT}$ = total yearly energy consumption for the customers involved in the project

EE_{TOT} = total yearly energy consumption in the portion of grid involved in the project

In consideration of the size of the demonstration (and, more generally, of the features of the project as in the case of customers spread over a large territory), the formulation of the KPI had better refer to the project performance regardless of project size and/or geographical features, by relating the achieved energy consumption reduction to the total energy consumption of the customers involved, as follows:

$$KPI_{\%EE} = \frac{(\%EE * EE_{BAU,TOT})}{EE_{BAU,TOT}}$$

For the sample of customers that have been equipped with the smart info kit, an energy consumption reduction in the range 2% - 6% was observed. Such range already considers the effect of possible contingency factors, which were cleaned out by considering a control group of customers. In this analysis, an average reduction of about 3% has been assumed in the calculation, mostly accounting for residential customers.

KPI: Consumers can comprehend their actual energy consumption and receive, understand and act on free information they need/ask for

Duly prepared questionnaires have been distributed to the customers in order to assess whether they find the technology useful and are aware of their energy consumption on the basis of the free information they have received. Answers to the questionnaire can be used to evaluate such KPI as follows:

$$KPI_{QA} = (positive\_answers)/(number\_of\_\mathrm{int}erviews)$$

KPI: consumers are able to access their historic energy consumption information for free in a format that enables them to make like-for-like comparisons with deals available on the market

ENEL’s smart info kit provides with information on both historical and near real-time energy consumption, made available to the customers through a display, a personal computer or e.g. a smart phone, and shown in bar graphs and pie charts to highlight mean values and distributions over different time slots (i.e. day, week, month, two months, year). Consumption habits were displayed together with the measured consumption data in the graphs, helping consumers identify variations. A software application was also provided to the consumers in order to assist energy consumption data analysis directly on a personal computer. For prosumers who are generating electricity themselves, the energy production was shown alongside their consumption to facilitate analysis of their net energy consumption.

Meter data could also be provided to third parties under customer consent for them to add further information (such as tariff, price signals and/or further information) and provide new services to the customers on the basis of data accessibility made available by the DSO. Therefore, a relevant weight has been assigned to this KPI (1).

KPI: ability to participate in the relevant energy market to purchase and/or sell electricity

Smart Grids play a crucial role towards low carbon energy scenarios. Consumers are at the centre of these changes, as they are expected to evolve from being passive recipients of energy services into more active participants in the energy market. For this to happen, they must be provided with better information as well as appropriate ICT tools and services. In fact, it has been recognised by the European Commission that data from smart meters on energy consumption as well as other relevant measurements are essential to massively deploy new functionalities and services. As data accessibility and exchange become crucial topics, the provision of metering data through ENEL's smart info kit can be considered as an enabling factor. Nevertheless, since the ability of customers to participate in the market relies on market and regulatory conditions alongside with the attitude of the customer him- or herself, a weight of 0.25 has been assigned to this KPI.

KPI: simple and/or automated changes to consumers' energy consumption in reaction to demand response signals are enabled

ENEL's smart info kit permits the development of a platform for a bidirectional communication with the DSO's systems, enabling solutions for demand response. As a matter of fact, a domestic platform for the provision of Value Added Services (VAS) based upon information exchange was tested in Central Italy under the Energy@home project, employing the smart info kit as a bridge between devices in the Home Area Network (HAN) and the DSO's systems upstream. An integrated management of distributed generation and customer loads was performed locally, while potentially contributing to the security and stability of the whole electricity system.

In fact, alongside customer energy awareness and monitoring, cases where automated control at customer premises could be used were defined and developed during the testing phase of Energy@home, and such as: load flexibility through the coordinated management of appliances, energy generation, and consumption coordinated management as in the case of prosumers (who may either consume or sell energy by accounting for network needs, tariff schemes, price signals and incentives, and shift their consumption accordingly). Therefore, as the smart info kit can be considered a key enabling factor, a high weight has been assigned to this KPI (0.5).

KPI: data ownership is clearly defined and data processes are in place in order to allow service providers to take necessary action with customer consent

Data ownership and privacy issues, also in relation to data collection and processing, were addressed in ENEL's project terms and conditions. The involved parties' rights and liabilities were also stated hereby, always in agreement with the customers. Moreover, the customers' right to opt-out was guaranteed, and participation arranged on a voluntary basis with no cost for the involved customers. To this extent, and considering that no relevant concerns rose from the customer side on these aspects, the project can be awarded with a high weight assigned to this KPI (1).

The summary table of the qualitative appraisal is shown below.

Table 19 Summary Table of KPIs scores

KPIs based score per (qualitative) benefit					
Adequate capacity of grids to collect and bring electricity	Security and quality of supply	Enhanced efficiency and service in electricity supply and operation	Enhanced consumer awareness and participation in the market by new players	Enable consumers to make informed decisions	Create a market mechanism for new energy services
0.19	1	0.26	0.16	2.2	1.5

Source: JRC and ENEL elaborations, 2018

6 Qualitative appraisal of foreseen externalities

Customer satisfaction

As earlier mentioned, duly prepared questionnaires were distributed to the customers to collect their feedbacks on the technologies demonstrated. Customer satisfaction can be assessed as the number of positive answers out of the total number of interviews concerning the level of appreciation of the solution provided and whether they would recommend it to others. In particular, customer satisfaction can be evaluated considering that about the 93% gave a positive answer to the question "Would you recommend your relatives and/friends to participate to ENEL's smart info project?" and that about the 89% of the people interviewed expressed satisfaction at the end of the project, and expressed their availability to repeat the experience.

Enabling new services and applications and market entry for third parties

New services and applications were enabled by making DSO meter data available close to real-time in a discriminatory way to third parties, in order for them to provide innovative services to the customers. This element of the project turns out to have a positive impact in creating new opportunities for third parties (e.g. aggregators) to enter the electricity market, as well as for currently existing players (retailers, ESCOs, etc.) to provide advanced and innovative services in the market (such as energy efficiency services). As data accessibility can be considered crucial for the provision of energy services and applications (both at a customer and system level), while opening up a market for services also fosters new entry, the project can be awarded with a high score (1) on this regard.

Noise impact

Further environmental benefits of enabling the massive diffusion of electric vehicles over conventional fossil-fuelled ones are due to the reduction of noise. The following indicator has been formulated in order to express the positive environmental impact enabled by the installation of EV recharging infrastructures in the project. The corresponding indicator is expressed in physical units [decibels] as follows:

$$EI_{EV} = \frac{N * CS * (dbA_{FF} - dbA_{EV})}{M * dbA_{FF}}$$

N = number of electric vehicles enabled per EV charging infrastructure

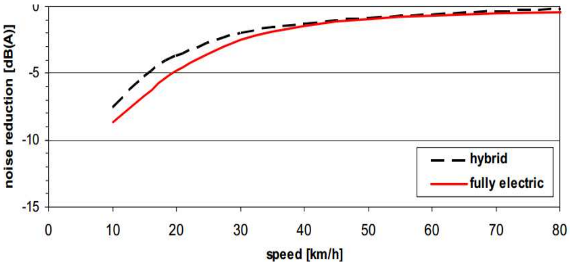
CS= number of EV charging stations installed in the project

M= number of conventional vehicles (potentially replaced by EVs)

dbA_{FF} = noise emission expressed in decibel from conventional fossil-fuelled vehicles

dbA_{EV} = noise emission expressed in decibel from conventional electric vehicles

Figure 7. Noise reduction of hybrid and electric passenger cars compared to conventional passengers cars



Source: RIVM National Institute for Public Health and the Environment (Effect of electric cars on traffic noise and safety, 2010)

According to the Dutch National Institute for Public Health and the Environment [16], hybrid and electric cars are more silent than conventional cars, at speeds below 30 km/h - in particular for hybrid vehicles as powered electrically under that speed. Above 50 km/h there is no significant difference in noise emission left as the tyre-road noise starts dominating the sound emission. As low speeds can be assumed, a reduction range from 3 to 4 dbA per EV can be attributed to the project as a consequence of electric mobility enabled by the charging infrastructures installed within the Isernia project. An average noise emission of 45 dB has been considered for fossil fuelled vehicles (below 30km/h) according to http://www.auto-decibel-db.com/

The summary table of the externalities appraisal is shown below.

Table 20 Results of the qualitative benefit appraisal

QUALITATIVE APPRAISAL OF EXTERNALITIES		
Customer satisfaction /Recommend to others	Enabling new services and applications and market entry for third parties	Environmental impact
0.93	1	0.1

Source: JRC and ENEL elaborations, 2018

7 Conclusions

ARERA, the Italian energy authority (ARERA), has devoted considerable effort in incentivising investment in Smart Grids, by competitively selecting a handful of pilot projects and awarding them with two extra percentage points on top of its standard WACC electricity investment remuneration scheme (applied, furthermore, to a much wider Regulatory Asset Base). This has provided the JRC with the opportunity to field-test its dedicated the Cost-Benefit Analysis methodology for Smart Grids, first on ACEA's project in Malagrotta, Rome, and now on e-distribuzione's project in Isernia. Considering the relative size of the projects, it may be said that most of Italy's SG pilot applications were monitored and assessed by the Joint Research Centre.

As well known, Smart Grids are a comprehensive concept covering a broad set of assets and technologies, with a general reference to advanced network monitoring and control, and deeper RES and especially DER penetration. Prominently, and characteristically, both aspects involve larger bidirectionality in the flows of energy and data, and an enhanced role for the diffuse management of the power system.

Both analyses have confirmed the methodology's merits, and fully proven its applicability to a wide variety of Smart Grid setups, technologies, and conditions. The ACEA project had a strong focus on advanced grid management, considering the three sub-projects of advanced MV-grid automation (through automatic fault detection and selective disconnection), monitoring and remote control of the MV/LV grid, and the introduction of innovative management algorithms of the MV grid; user-centred Smart Grid applications, such as for instance electro-mobility, better user information, and demand rationalisation, were largely left aside in that exercise.

As well known, though, Smart Grids have the potential to completely turn around the roles traditionally assigned to customers within an energy system, by greatly enhancing their relevance both in energy generation and management. This implies that previous work left ample room for the investigation of significant aspects of the Smart Grids' impact on the energy system, through a fuller application of the analytical panoply predisposed by the JRC in its 2012 methodological document [13]. The Isernia study, then, starts to fill this gap by taking a comprehensive perspective on Smart Grids technologies, including enabled expansion of RES penetration, electric mobility, storage, SG-related energy consumption reduction: aspects, which generally feature strong user orientation, and often prominently involve deeper first-person user involvement. The analysis, then, makes a remarkable effort towards carrying out an accurate quantification and monetisation of such benefits, by proceeding head-on to assess a number of KPIs involving distributed resources and consumer engagement.

Specific attention is devoted to the estimation of the monetary value deriving from the expansion of the grid's ability to securely absorb energy generated by renewable sources; to the measurement of the potential benefits of electro-mobility; and to consumption savings thanks to enhanced usage awareness on the consumers' side. Furthermore, the (by now conventional) monetisation exercise devoted to CO_2 is extended here to much less-frequented territories such as the assessment of NOx and SOx emission savings. "Soft" benefits regarding consumer information, awareness, and compliance, as well as the enabling of larger perspective LV-level participation into demand side management activities through dedicated market instruments, are considered and measured also by the elaboration of user feedback obtained through questionnaires. Finally, an earnest attempt is made at measuring noise pollution reduction due to the spread of electric vehicles (whose full-blown monetisation of noise reduction benefits, however, is not attempted here).

From the point of view of the Regulator's stated goals, it is reassuring to find a positive outlook for both the projects; in particular, the externalities constituting the key rationale for ARERA's active policy targeting are clearly relevant and sizable. While in Malagrotta's case a positive NPV was only obtained for the planned extension of the SG infrastructure to the whole of Rome's grid, the crucial result of the present CBA is that, for the Isernia exercise, positive NPVs are already to be found for the pilot project itself, when it is duly assessed through a societal approach.

The second key result of our investigation is that the project's NPVs is positive from the point of view of the individual investor (i.e., the DSO) if and only if the Italian Regulator's dedicated extra remuneration for SG investments is taken into account. However, if only the standard regulatory WACC on electricity assets were applied, the NPV would be negative. As a consequence, ARERA's targeted Smart Grids investment remuneration scheme seems fully warranted: it is able to reach its stated goal, and correctly align the society's and the investors' incentives, so to allow the latter to consider to a sufficient degree those sizable Smart Grid-related environmental externalities, that the JRC CBA methodology allows to identify and measure.

References

[1] AEEGSI, "Deliberazione 25 marzo 2010 – ARG/elt 39/10 Procedura e criteri di selezione degli investimenti ammessi al trattamento incentivante di cui al comma 11.4 lettera d) dell'Allegato A alla deliberazione dell'Autorità per l'energia elettrica e il gas 29 dicemb," 2010.

[2] S. Vitiello, G. Flego, G. Fulli, S. Liotta, S. Alessandroni and L. Esposito, "A Smart Grid for the city of Rome - A Cost Benefit Analysis," European Commission, Brussels, 2015, JRC95273.

[3] P. Capros and e. alii, "EU Reference Scenario 2016: Energy, transport and GHG emissions trends to 2050," European Commission, Brussels, 2016.

[4] US Energy Information Administration, "International Energy Outlook 2016," Washington, 2016.

[5] D. Sartori , G. Catalano, M. Genco, C. Pancotti, E. Sirtori, S. Vignetti and C. Del Bo, "Guide to Cost-benefit Analysis of Investment Projects Economic appraisal tool for Cohesion Policy 2014-2020," European Commission, Brussels, 2014.

[6] Conferenza dei presidenti delle regioni e delle province autonome, "Studi di fattibilità delle opere pubbliche - Guida per la certificazione da parte dei Nuclei regionali di valutazione e verifica degli investimenti pubblici (NUVV)," 2003.

[7] AEAT, "Damages per tonne emission of PM2.5, NH3, SO2, NOx, VOCs from each EU25 Member State (excluding Cyprus) and surrounding seas," 2005.

[8] Covenant of Mayors, "Technical annex to the SEAP template instructions document: The emission factors," 2010.

[9] TERNA, "Confronti internazionali," 2015.

[10] V. Giordano, S. Vitiello and J. Vasiljevska, "Evaluation of Smart Grids Projects within the Smart Grid Task Force Expert Group 4 (EG4)," European Commission, Brussels, 2013.

[11] AEEGSI, "Relazione annuale sullo stato dei servizi e sull'attività svolta - Volume I: stato dei servizi," Milan, 2015.

[12] RSE, "Ibridi plug-in e veicoli elettrici: vantaggi e svantaggi secondo un approccio LCA," Milan, 2012.

[13] V. Giordano, I. Onyeji, G. Fulli, M. Sanchez Jimenez and C. Filiou, "Guidelines for conducting a cost-benefit analysis of Smart Grid projects," European Commission, Brussels, 2012.

[14] AEEGSI, "Testo integrato della regolazione output-based dei servizi di distribuzione e misura dell'energia elettrica, per il periodo di regolazione 2016-2023," 2016.

[15] AEEGSI, "Reference technical rules for the connection of active and passive consumers to the HV and MV electrical networks of distribution company," 2012.

[16] RIVM, “Effect of electric cars on traffic noise and safety,” 2010.

[17] GSE, “Rapporto statistico 2012: Impianti a fonti rinnovabili Settore Elettrico,” 2012.

[18] ENI, “Tabella di conversione dell'energia”.

[19] EPRI, “Guidebook for Cost/Benefit Analysis of Smart Grid demonstration projects,” Palo Alto, 2012.

[20] EPRI, “Estimating the costs and the benefits of the smart grid,” Palo Alto, 2011.

[21] European Commission, “Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee, and the Committee of the Regions: Smart Grids: from innovation to deployment. SEC(2011) 463 final,” Brussels, 2011.

[22] European Commission, “Benchmarking smart metering deployment in the EU-27 with a focus on electricity,” Brussels, 2014.

[23] V. Giordano, S. Vitiello and J. Vasiljevska, “Definition of an assessment framework for Projects of Common Interest in the field of Smart Grids,” European Commission, Brussels, 2014.

[24] C. Marnay, J. Mauzy, B. Shaffer, W. Agate, S. Vitiello and N. Karali, “White Paper on Benefit Analysis of Smart Grid Projects,” 2016.

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Annexes

Annex I: Detailed assets-functionalities-benefits maps according to JRC methodology

Table 21. Complete map of assets into functionalities

FUNCTIONALITIES→	**A. INTEGRATE USERS WITH NEW REQUIREMENTS**				**B. ENHANCING EFFICIENCY IN DAY-TO-DAY GRID OPERATION**						**C. ENSURING NETWORK SECURITY, SYSTEM CONTROL AND QUALITY OF SUPPLY**					
ASSETS↓	1. Facilitate connection at all voltages / locations for any kind of devices	2. Facilitate the use of the grid for the users at all voltages locations	3. Use of network control systems for network purposes	4. Update network performance data on continuity of supply and voltage quality	5. Automated fault identification / grid reconfiguration, reducing outage times	6. Enhance monitoring and control of power flows and voltages	7. Enhance monitoring and observability of grids down to LV levels	8. Improve monitoring of network assets	9. Identification of technical and no-technical losses by power flow analysis	10. Frequent information exchange on actual active/reactive generation/consumption	11. Allow grid users and aggregators to participate in ancillary services market	12. Operation schemes for voltages/current control	13. Intermittent sources of generation to contribute to system security	14. System security assessment and management of remedies	15. Monitoring of safety, particularly in public areas	16. Solutions for DR for system security in the required time
SCADA				●		●	●			●		●	●			
DMS	●	●				●	●			●		●	●			
HV/MV RTU)				●	●	●	●			●		●	●			
MEASUREMENT DEVICE AND FAULT DETECTOR (RGDM)	●	●		●	●	●	●			●		●	●			
IEC 61850 ROUTER + MODEM	●	●		●	●	●	●			●		●	●			
BB COMMUNICATION	●	●		●	●	●	●			●		●	●			
IEC 61850	●	●		●	●	●	●			●		●	●			
USER SWITCH ETHERNET (SEU)	●	●			●	●	●			●		●	●			
HEAD LINE PROTECTION SYSTEM (SPL)					●		●						●			
CIRCUIT BREAKERS (DY800)					●											
GENERATOR PROTECTION INTERFACE DEVICE	●	●			●								●			
ENERGY REGULATOR INTERAFACE	●	●		●		●	●			●		●	●			
STORAGE	●	●				●						●				
EV CHARGING INFRASTRUCTURES	●	●														
SMART INFO																

Source: JRC and ENEL, 2018

Table 22 Complete map of assets into functionalities, part II

FUNCTIONALITIES →	**D. BETTER PLANNING OF FUTURE NETWORK INVESTMENT**			**E. IMPROVING MARKET FUNCTIONING AND CUSTOMER SERVICE**								**F. MORE DIRECT INVOLVEMENT OF CONSUMERS IN THEIR ENERGY USAGE**					
ASSETS↓	17. Better models of DG, storage, flexible loads, ancillary services	18. Improve asset management and replacement strategies	19. Additional information on grid quality and consumption by metering for planning	20. Participation of all connected generators in the electricity market	21. Participation of VPPs and aggregators in the electricity market	22. Facilitate consumer participation in the electricity market	23. Open platform (grid infrastructure) for EV recharge purposes	24. Improvement to industry systems (for settlement, system balance, scheduling	25. Support the adoption of intelligence home /facilities automation and smart devices	26. Provide grid users with individual advance notice for planned interruptions	27. Improve customer level reporting in the case of interruptions	28. Sufficient frequency of meter readings	29. Remote management of meters	30. Consumption/ injection data and price signals by different meters	31. Improve energy usage information	32. Improve information on energy sources	33. Availability of individual continuity of supply and voltage quality indicators
SCADA	●			●													
DMS				●													
HV/MV RTU)	●			●													
MEASUREMENT DEVICE AND FAULT DETECTOR (RGDM)	●			●													
IEC 61850 ROUTER + MODEM	●			●													
BB COMMUNICATION	●			●													
IEC 61850	●			●													
USER SWITCH ETHERNET (SEU)	●			●													
HEAD LINE PROTECTION SYSTEM (SPL)																	
CIRCUIT BREAKERS (DY800)																	
GENERATOR PROTECTION INTERFACE DEVICE				●													

FUNCTIONALITIES →	**D. BETTER PLANNING OF FUTURE NETWORK INVESTMENT**			**E. IMPROVING MARKET FUNCTIONING AND CUSTOMER SERVICE**								**F. MORE DIRECT INVOLVEMENT OF CONSUMERS IN THEIR ENERGY USAGE**					
ASSETS↓	17. Better models of DG, storage, flexible loads, ancillary services	18. Improve asset management and replacement strategies	19. Additional information on grid quality and consumption by metering for planning	20. Participation of all connected generators in the electricity market	21. Participation of VPPs and aggregators in the electricity market	22. Facilitate consumer participation in the electricity market	23. Open platform (grid infrastructure) for EV recharge purposes	24. Improvement to industry systems (for settlement, system balance, scheduling	25. Support the adoption of intelligence home /facilities automation and smart devices	26. Provide grid users with individual advance notice for planned interruptions	27. Improve customer level reporting in the case of interruptions	28. Sufficient frequency of meter readings	29. Remote management of meters	30. Consumption/ injection data and price signals by different meters	31. Improve energy usage information	32. Improve information on energy sources	33. Availability of individual continuity of supply and voltage quality indicators
ENERGY REGULATOR INTERAFACE	●			●													
STORAGE				●													
EV CHARGING INFRASTRUCTURES							●										
SMART INFO					●	●			●						●		

Source: JRC and ENEL elaborations, 2018

Table 23 Map of functionalities into benefits

FUNCTIONALITIES →	**A. INTEGRATE USERS WITH NEW REQUIREMENTS**				**B. ENHANCING EFFICIENCY IN DAY-TO-DAY GRID OPERATION**						**C. ENSURING NETWORK SECURITY, SYSTEM CONTROL AND QUALITY OF SUPPLY**					
BENEFITS↓	1. Facilitate connections at all voltages/locations for any kind of devices	2. Facilitate the use of the grid for the users at all voltages locations	3. Use of network control systems for network purposes	4. Update network performance data on continuity of supply and voltage quality	5. Automated fault identification / grid reconfiguration, reducing outage times	6. Enhance monitoring and control of power flows and voltages	7 Enhance monitoring and observability of grids down to LV levels	8. Improve monitoring of network assets	9. Identification of technical and no-technical losses by power flow analysis	10. Frequent information exchange on actual active/reactive generation/consumption	11. Allow grid users and aggregators to participate in ancillary services market	12. Operation schemes for voltages/current control	13. Intermittent sources of generation to contribute to system security	14. System security assessment and management of remedies	15. Monitoring of safety, particularly in public areas	16. Solutions for demand response for system security in the required time
Optimised Generator Operation																
Deferred Generation Capacity Invest.																
Reduced Ancillary Service Cost																
Reduced Congestion Cost																
Deferred Transmission Capacity Invest.	•					•	•			•			•			
Deferred Distribution Capacity Invest.	•															
Reduced Equipment Failures																
Reduced Distribution Equipment Maintenance Cost																

FUNCTIONALITIES →	**A. INTEGRATE USERS WITH NEW REQUIREMENTS**				**B. ENHANCING EFFICIENCY IN DAY-TO-DAY GRID OPERATION**						**C. ENSURING NETWORK SECURITY, SYSTEM CONTROL AND QUALITY OF SUPPLY**					
BENEFITS↓	1. Facilitate connections at all voltages/locations for any kind of devices	2. Facilitate the use of the grid for the users at all voltages locations	3. Use of network control systems for network purposes	4. Update network performance data on continuity of supply and voltage quality	5. Automated fault identification / grid reconfiguration, reducing outage times	6. Enhance monitoring and control of power flows and voltages	7 Enhance monitoring and observability of grids down to LV levels	8. Improve monitoring of network assets	9. Identification of technical and no-technical losses by power flow analysis	10. Frequent information exchange on actual active/reactive generation/consumption	11. Allow grid users and aggregators to participate in ancillary services market	12. Operation schemes for voltages/current control	13. Intermittent sources of generation to contribute to system security	14. System security assessment and management of remedies	15. Monitoring of safety, particularly in public areas	16. Solutions for demand response for system security in the required time
Reduced Distribution Operation Cost																
Reduced Meter reading cost																
Reduced Electricity Theft																
Reduced Electricity Losses						•										
Detection of anomalies relating to contracted power																
Reduced Electricity cost																
Reduced sustained outages																
Reduced major outages																
Reduced restoration cost																
Reduced momentary outages																

FUNCTIONALITIES →	**A. INTEGRATE USERS WITH NEW REQUIREMENTS**				**B. ENHANCING EFFICIENCY IN DAY-TO-DAY GRID OPERATION**						**C. ENSURING NETWORK SECURITY, SYSTEM CONTROL AND QUALITY OF SUPPLY**					
	1.	2.	3.	4.	5.	6.	7	8.	9.	10.	11.	12.	13.	14.	15.	16.
BENEFITS↓	Facilitate connections at all voltages/locations for any kind of devices	Facilitate the use of the grid for the users at all voltages locations	Use of network control systems for network purposes	Update network performance data on continuity of supply and voltage quality	Automated fault identification / grid reconfiguration, reducing outage times	Enhance monitoring and control of power flows and voltages	Enhance monitoring and observability of grids down to LV levels	Improve monitoring of network assets	Identification of technical and no-technical losses by power flow analysis	Frequent information exchange on actual active/reactive generation/consumption	Allow grid users and aggregators to participate in ancillary services market	Operation schemes for voltages/current control	Intermittent sources of generation to contribute to system security	System security assessment and management of remedies	Monitoring of safety, particularly in public areas	Solutions for demand response for system security in the required time
Reduced sags and swells																
Reduced CO_2 emissions	•	•				•						•				
Reduced SOx, NOx and PM - 10 Emissions	•	•				•						•				
Reduced Oil Usage	•	•				•						•				
Reduced Wide-scale blackouts	●	●				•	•					•	•			

Source: JRC and ENEL elaborations, 2018

Table 24 Map of functionalities into benefits, part II

FUNCTIONALITIES →	**D. BETTER PLANNING OF FUTURE NETWORK INVESTMENT**			**E. IMPROVING MARKET FUNCTIONING AND CUSTOMER SERVICE**								**F. MORE DIRECT INVOLVEMENT OF CONSUMERS IN THEIR ENERGY USAGE**					
BENEFITS↓	17. Better models of DG, storage, flexible loads, ancillary services	18. Improve asset management and replacement strategies	19. Additional information on grid quality and consumption by metering for planning	20. Participation of all connected generators in the electricity market	21. Participation of VPPs and aggregators in the electricity market	22. Facilitate consumer participation in the electricity market	23. Open platform (grid infrastructure) for EV recharge purposes	24. Improvement to industry systems (for settlement, system balance, scheduling	25. Support the adoption of intelligence home /facilities automation and smart devices	26. Provide grid users with individual advance notice for planned interruptions	27. Improve customer level reporting in the case of interruptions	28. Sufficient frequency of meter readings	29. Remote management of meters	30. Consumption/ injection data and price signals by different meters	31. Improve energy usage information	32. Improve information on energy sources	33. Availability of individual continuity of supply and voltage quality indicators
Optimised Generator Operation																	
Deferred Generation Capacity Invest.																	
Reduced Ancillary Service Cost																	
Reduced Congestion Cost																	
Deferred Transmission Capacity Invest.	•			•		•			•								
Deferred Distribution Capacity Invest.						•			•						•		
Reduced Equipment Failures																	
Reduced Distribution Equipment Maintenance Cost																	

FUNCTIONALITIES →	**D. BETTER PLANNING OF FUTURE NETWORK INVESTMENT**			**E. IMPROVING MARKET FUNCTIONING AND CUSTOMER SERVICE**								**F. MORE DIRECT INVOLVEMENT OF CONSUMERS IN THEIR ENERGY USAGE**					
BENEFITS↓	17. Better models of DG, storage, flexible loads, ancillary services	18. Improve asset management and replacement strategies	19. Additional information on grid quality and consumption by metering for planning	20. Participation of all connected generators in the electricity market	21. Participation of VPPs and aggregators in the electricity market	22. Facilitate consumer participation in the electricity market	23. Open platform (grid infrastructure) for EV recharge purposes	24. Improvement to industry systems (for settlement, system balance, scheduling	25. Support the adoption of intelligence home /facilities automation and smart devices	26. Provide grid users with individual advance notice for planned interruptions	27. Improve customer level reporting in the case of interruptions	28. Sufficient frequency of meter readings	29. Remote management of meters	30. Consumption/ injection data and price signals by different meters	31. Improve energy usage information	32. Improve information on energy sources	33. Availability of individual continuity of supply and voltage quality indicators
Reduced Distribution Operation Cost																	
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Detection of anomalies relating to contracted power																	
Reduced Electricity cost						•			•						•		
Reduced sustained outages																	
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Reduced restoration cost																	
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FUNCTIONALITIES →	**D. BETTER PLANNING OF FUTURE NETWORK INVESTMENT**			**E. IMPROVING MARKET FUNCTIONING AND CUSTOMER SERVICE**								**F. MORE DIRECT INVOLVEMENT OF CONSUMERS IN THEIR ENERGY USAGE**					
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Reduced sags and swells																	
Reduced CO_2 emissions							•		•						•		
Reduced SOx, NOx and PM - 10 Emissions							•		•						•		
Reduced Oil Usage							•		•						•		
Reduced Wide-scale blackouts	•																

Source: JRC and ENEL elaborations, 2018

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