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Statement of Originality

This deliverable contains original unpublished work except where clearly indicated otherwise. Acknowledgement of previously published material and of the work of others has been made through appropriate citation, quotation or both.

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1 Executive Summary

Projects concerning the performance of distribution grids are gaining importance in Europe. The integration of decentralized renewable energy sources in the distribution grid means not only new needs for regulatory circumstances but also for technical adaptations of the grid and of the grid users acting as consumers, either producers or prosumers. However, projects on the distribution grid like Net2DG have to be analysed concerning their profitability for the stakeholders and their economic impact. This task appears to be difficult, as profits and costs cannot be seen on the first attempt. To get a full assessment of all benefits and costs that are part of Net2DG's prospect, cost-benefit analyses (CBA) for the individual, relevant stakeholders have to be conducted. These can be merged in the end to do a customer-benefit-analysis that acts as a summary for Net2DG's prospects for the contracted customers.

In the literature regarding smart grid projects in general, there are mainly two different approaches for Distribution Systems Operators (DSOs) to do a CBA, the Electric Power Research Institute Method (EPRI, 2010) and the Joint Research Center Method (Giordano et al., 2012). The EPRI method was the first step-by-step approach developed. As an advancement, the JRC method can be seen as an adjustment of the EPRI method to fit on the European market.

The development of an adjusted concept for conducting the CBA as part of the Net2DG project is the main background why it is important to explain the two methods in detail. However, the adjusted approach will be mainly based on the JRC method following the suggested steps, as it incorporates more extensive and useful steps for Net2DG. The choice of relevant use-cases is conducted as a first part. After this, the concept incorporates a use-case-specific cost-benefit analysis following JRC's steps. Robustness and plausibility checks are planned to be performed after the individual CBAs finish.

The developed concept yields a good estimation of benefits and costs, and therefore of the profitability of Net2DG. This information can be used to provide convincing arguments for implementing the proposed system. However, since this deliverable's topic is only to define an approach for the CBA, an application will not take place yet. Also this deliverable gives an outlook of how and when the CBA's concept will be applied in the later stage of Net2DG. Therefore, we conclude the deliverable with a proposition of a time table for the first iteration of the CBA.

2 Introduction

The purpose of this deliverable is threefold:

(1) Chapter 3 defines the aim of the cost-benefit analysis in the context of the Net2DG project.

(2) We give insights about the prominent methods in literature applied to smart grid applications in chapter 4. Hereby, we refer to focus on two relevant methods developed in the US (4.1) and Europe (4.2). These methods are described in a step-by-step approach in order to ensure applicability in the Net2DG project. We provide a comparison of those two methods in section 4.3. An example for the application of the JRC method in section 4.4 concludes this chapter.

(3) Based on the results of chapter 4, we describe the method of the cost-benefit analysis chosen for Net2DG in chapter 5.

Overall, this deliverable marks the cost-benefit analysis conducted in the Net2DG project.

3 Aim of a Cost-Benefit Analysis

In this context, a cost-benefit analysis (CBA) is an analytical tool for the assessment of economic advantages and disadvantages of (smart) grid projects that result in a welfare change (Sartori and EC, 2015). Welfare changes are important to measure in the context of Net2DG, since "Welfare is an often-used metric in electricity markets, as it describes the producers and consumers perspective. The definition of social welfare is the sum of gross consumers' surplus minus producers' costs" (Willems, 2004). The grid as part of the project has to be defined as all infrastructure and devices that either directly interact with each other or indirectly influence the project's attributes and goals, but can still be accounted as part of Net2DG. This means on the opposite, that the usage of devices that have an impact on the grid, but cannot be accounted, is not included in the CBA. An example for this is prosumer-activity. Since this aspect has an impact on the grid operation, but cannot be accounted for as part of the project, it would not be relevant. (See project vs. baseline condition! -> would cancel out).

CBAs offer a transparent way to provide a consistent and profound quantification of a project's prospects. The chosen CBA can be flexibly adjusted to changed circumstances of the project, as it is based on a general structure that has been applied in different undertakings.

4 Methods of Cost-Benefit Analysis in the Literature

Mainly two methods for conducting a CBA are most prominent in the literature. The first one is the Electric Power Research Institute method (EPRI, 2010). Since it was originally developed in the US, it is mainly applied to American projects. The US Department of Energy, for example, chose the guideline as a basis for their demonstration projects in the context of renewable and distributed systems integration. In order to better fit the EPRI method to European projects, the second method, the Joint Research Centre Method, was developed (Giordano et al., 2012). The basic concepts of the two methods are coherent. However, JRC adds some further steps in their CBA framework and also makes some improvements.

4.1 Electric Power Research Institute Method – EPRI (EPRI, 2010)

EPRI introduces a step-by-step framework for conducting a CBA. The basic goal of the method is to provide the first standardized approach for estimating costs and benefits for (smart) grid projects from a DSO's perspective. The basic concept consists of three steps: The general characterization of the project, the estimation of benefits, and finally the comparison of costs and benefits. In the next part, these three major steps are explained in detail.

4.1.1 Characterizing the Project

The CBA starts by a three step approach, from revision, to identification towards an assessment.

Step 1: *Revision of the project's technologies/elements/goals*.
The first step in the EPRI-method is the description of all technological elements or assets that are used in the new project and clearly are accountable to be relevant for the project's performance. On the one hand, these technological elements, like devices (e.g. new meters or cable installations), may be provided by the DSO. On the other hand, the DSO may conclude contracts with third parties for services (e.g. data providers such as measurements by smart PV inverter). For the sake of simplicity, third party services are included as elements in the project. The performance of the project's elements usually can be quantified with some metrics. Consequently, the first step concludes with an enumeration of all elements, its performance goals, and the metrics associated.

Step 2: *Identification of functions provided by the project*.
The technological assets of the grid fulfill a specific function in the grid. The second step therefore is to link the technological elements or assets from the first step to their function in the network. Also, public policies that are implemented and affect these functions may be considered in this identification. An example would be a different consumer behavior because of policies concerning demand response.

Step 3: *Assessment of grid characteristics*.
The grid under consideration offers different principal characteristics. These general characteristics can be chosen from a commonly agreed-on list for smart grids, like in EC Task Force for Smart Grids (2010) or individually. Afterwards, metrics regarding these characteristics are drawn. An example for Net2DG would be the function of identifying disturbances and the consequently reduced outages of the grid. This function could be linked to the metric of number of outages, which is the corresponding measurement. Thus, the characterization of the project ends with a complete description of all assets, its functions and the assessment of the proposed grid.

4.1.2 Estimate the Benefits

The main part of a CBA is the estimation of benefits. In order to provide this estimation, the previously defined functions and grid characteristics are going to be linked to specific benefits. Afterwards, the benefits following the product implementation are quantified and monetized.

Step 1: *Map functions to benefits*.
In a first step, the benefits of the proposed project are qualified and quantified. A default list of grid benefits with classification can be found in the corresponding part of EPRI (2010). The already identified functions of the proposed grid (including the changes due to the project) are linked to these benefits. A table can be used, as many benefits are linked to different functions.

Step 2: *Establish project baselines*.
In the second step of the estimation of benefits, a determination of a baseline state that reflects the system condition in terms of functionalities, costs and benefits **without** the project is conducted. A comparison to the conditions **with** the project's attributes can be done to obtain changes in benefits between the baseline and the new system.

Step 3: *Identification of needs for data and quantification of economic benefits*.
The parameters needed to quantify and monetize benefits of the project have to be based on obtained data from the project realization. Assets and functions of the proposed gridgrid usually offer this data to identify a clear relevant progress. This progress then can be expressed in terms of economic benefits. Some general approximating formula for the quantification of benefits may not be sufficient.

Step 4: *Quantification of other benefits*.
Besides economic benefits that can easily be calculated in monetary units, there may exist relevant technical or environmental benefits without a given quantification scheme. There exist different ways to monetize these benefits and include them in the analysis. They can be found in a literature review or surveys.

Step 5: *Monetisation of benefits*.
Economic estimations can be used to monetize technical and other benefits that are usually not calculated with monetary units. Examples would be the monetisation of increased reliability or the reduction of external costs (e.g. from pollution), by the transition towards renewable energy. Costs of externalities can be various, which means parts of it have to be estimated to assess the environmental impact of a grid project like Net2DG.

4.1.3 Comparison of Costs and Benefits

Step 1: *Estimation of costs*.
The first step of the cost-benefit-comparison is the identification and estimation of costs. Cost data coming from implementing the project has to be distinguished from costs that would occur in the baseline scenario without the proposed grid infrastructure to enable a clear identification. In addition to that, operational, maintenance and capital costs have to be regarded. Also, costs directly connected to the project administration are relevant. It is useful to arrange the costs in a temporal order of incurrence.

Step 2: *Comparison of costs and benefits*.
There exist different ways of comparing the existing costs and benefits. These range from annual comparisons or cumulative comparisons to the calculation of net present values or the benefit-cost ratio. Exact approaches and examples again can be found in Giordano et al. (2012).

4.2 Joint Research Centre Method – JRC (Giordano et al., 2012)

The JRC method was used in *InovGrid project* (EDP Distribuição, 2017) or *InspireGrid* project (InspireGrid, 2013) for example. The JRC method is based on the EPRI method. The intention of this method is to add relevant details and include typical market characteristics in regard of the application to the European market. Therefore, major details are similar to the EPRI method. An overview over the general approach and its components can be seen in figure 1.

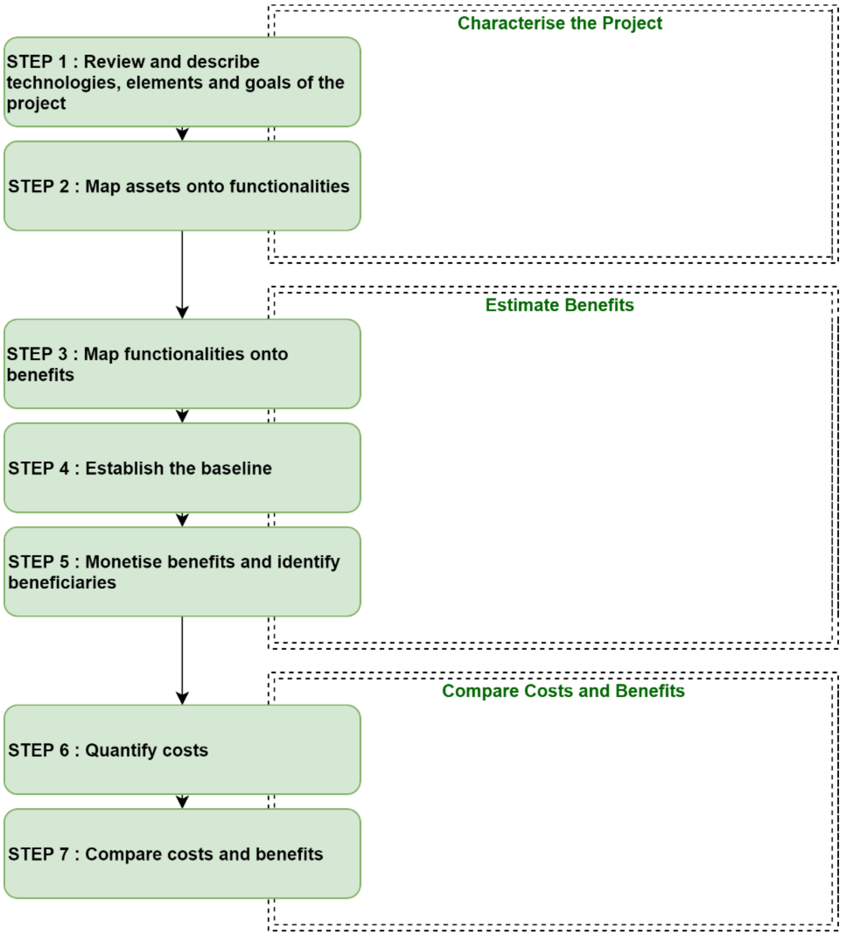

Figure 1: Work flow following the steps

4.2.1 Definition of Boundary Conditions

The JRC method starts with the definition of the project's framework conditions. This input is relevant for the later definition of benefits and costs. Firstly, we have to analyze discount rates. The discount rate is necessary to assess the time value of future costs and revenues. In addition, the time horizon is relevant for the time value of costs and benefits. It is a definition of how long costs and benefits will occur. Usually the time horizon ranges from 20 to 30 years for projects on the distribution grid level. In addition to the definition of time aspects, relevant general economic developments have to be identified. An example for this is the growth of demand for electricity or the deployment of renewable energy sources. Since the Net2DG project is concerning the distribution grid, the input parameters in terms of boundary conditions can be limited to the size of the relevant networks. All DSOs should be aware of the boundary conditions within their network for the short-term future. Therefore, no whole assessment of the energy market processes is necessary.

The next aspect is the schedule of implementation of the project. Macroeconomic parameters may change with the time of implementation, such as inflation and energy prices. Also, the spatial extent of the project has an influence on these parameters. Especially the size of the project and its possible impact on relevant market aspects like prices is relevant. The boundary conditions include the choice of technology parameters, e.g. communication technology or automation systems. A comparison of different technology options can be done in terms of costs. Basically, the choice of all technological aspects has to be well-known on this step of the CBA.

4.2.2 Cost-Benefit Analysis

After the boundary conditions to the project are defined, the CBA can be conducted. The sequence of steps is similar to the EPRI method.

Step 1: *Revision and description of technologies, elements and goals*.
The first step of the CBA-procedure is the overall description of the technologies and the grid characteristics. This includes the scale of the project, the engineering features, the relevant stakeholders and the regulatory context incorporating the goal of the project.

Step 2: *Overview over all assets used in the project*.
The second step has to provide an overview over all technological assets. These assets are used in the proposed grid (with an implemented project) and include technological devices with critical functionality as well as information systems used for the project. The overview has to provide a detailed description of the grid itself including the assets.

Step 3: *Assessment of functionalities and resulting benefits*.
First, the assets' functionalities have to be identified, just like in the EPRI method. Then, the formulation of possible benefits has to be conducted. The determined functionalities of the assets are linked to these benefits. One may consider aspects like measurability, applicability and monetization of the benefits already.

Step 4: *Establishing baseline and project conditions*.
The next step after the identification of functionalities and their benefits is the definition of a control state that reflects the system condition without the project (maybe a counterfactual status). A comparison to the project system condition has to be done, e.g. the treated system. The relevant changes induced by the scenario are obtained and can later be used to clearly identify the costs and benefits.

Step 5: *Monetizing of benefits and beneficiaries.*
For each previously identified benefit and baseline condition, the relevant data has to be collected and reconditioned. Which metric does influence the baseline conditions? A possible sequence is: *identified benefit - baseline status-quo - metrics used for describing the baseline* vs. *new condition by project - metrics used to quantify benefits*. The used metrics have to be monetized, this includes the identification of beneficiaries and the impacts of uncertainty. A possible approach for the whole process of monetizing benefits of an asset can be seen in figure 2, taking smart metering as an illustrative example. Thus, a comparison between baseline scenario and implementation takes place and the differences between the two states are formulated as benefits with a monetized metric.

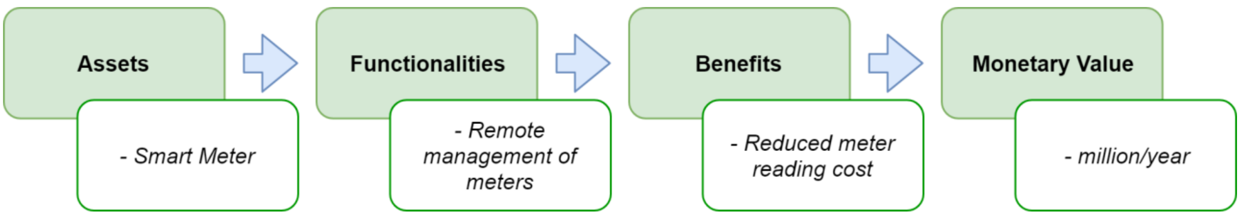

Figure 2: Possible mappings in the analysis

Step 6: *Identification and monetization of costs*.
In order to conduct a CBA, also the costs have to be identified and listed. This again includes implementation costs of the project in the analyzed timeframe, running costs, capital costs and project costs. Cost-effectiveness can be reviewed on this stage.

Step 7: *Comparison of costs and benefits*.
The last step of the CBA involves the comparison of the defined costs and benefits, often on an annual basis. Also, cumulative comparisons towards the end of the timeframe can be done as well as a net-present value calculation depending on the timeframe of decisions.

4.2.3 Sensitivity Analysis

In addition to the pure CBA, JRC suggests to conduct a sensitivity analysis for relevant parameters. Usually, a long timeframe is considered in the CBA analysis. This means that many variables are based on forecasts or scenarios. Therefore, the sensitivity for those variables has to be analyzed within the sensitivity analysis. Basically, the threshold of variables leading to a positive outcome should be determined. Possible aspects for sensitivity are demand growth, losses due to transmission and distribution, share of renewable generation, the estimation of lost load and non-supplied minutes or the discount rate used.

4.2.4 Qualitative Impact Analysis

Finally, also qualitative aspects may not be ignored within the JRC method. Social impacts can exceed the project's scope or can be difficult to quantify. Examples are possible job creation or know-how extensions. Nevertheless, they should also be included in the CBA. The project's contribution to different policy objectives can be drawn and quantified to a certain extent. So, key performance indicators for social impact can be defined or derived from the literature and the project's impact on these can be analysed. Non-monetary impacts on society should be expressed as physical units – as much as possible. If that is impossible, a detailed description of the expected impacts is sufficient.

4.3 Methods of CBA in Comparison

Joint Research Center method can be seen as an advancement of the Electric Power Research Institute method. It was developed to fit the EPRI method to the European context better. The following table gives an overview over the relevant steps in both methods and examples for needed data.

EPRI	JRC	Data needed for the CBA
-	General boundary conditions	*Discount rates, time horizon, economic scenarios/ parameters, grid data*
Technological assets, elements and goals	Technological assets, elements and goals	*Technological parameters, quantity of used assets, system components*
Functions and functionalities	Functions and functionalities	-

Grid characteristics and resulting metrices	-	*Grid characteristic data*
Mapping of functions and benefits	Mapping of functions and benefits	*Reduced outages, information transmission time improvement, relevant cost reductions*
Baseline scenarios	Baseline scenarios	*Usual (screened) outage number, outage costs, time needed for identification*
Project condition scenarios	Project condition scenarios	*Foreseen outage number, outage costs, time needed for identification*
Cost estimation	Cost estimation	*Implementation costs, running costs, project costs, capital costs*
Comparison of costs and benefits	Comparison of costs and benefits	-
-	Assessment of qualitative impact: quantification of non-monetary units	*Possible pollution reduction, necessary employment / employment reduction*
-	Sensitivity analysis	*Scenario data: prosumer development, network inputs*

Table 1: Overview of CBA aspects and needed data

Since the JRC method modifies and adds some aspects to the EPRI method, a higher demand for data may be the consequence.

4.4 Inovgrid (EDP Distribuição, 2017) as an Example of a CBA Following the JRC Method

The Inovgrid project (EDP Distribuição, 2017) is a project that performed a CBA following the steps of the JRC method. Its basic goal was to use multi-purpose EDP boxes (EBs) with an Automated Meter Management (AMM) standard instead of conventional electromechanical meters. The EBs work as a gateway to energy management and still include the functions of smart meters. In a Home Area Network, they can interact with other devices locally. Information from these EBs then can be automatically collected and redirected to the upstream system via local control equipment. Inovgrid is a useful example for the application of a CBA, since it is also concerning the distribution grid in the context of automation smart grid aspects. In the following, a CBA is conducted for the Inovgrid as an example. The figures are taken from (Giordano et al., 2012).

Step 1/2: *Revision and description of technologies, elements and goals / Overview over all assets used in the project*

First, the relevant devices are summarized. In this case for example:

- *EDP Boxes (EBs):* devices to be installed at consumers/producers to gather information
- *Distribution Transformer Controller (DTC)*: control equipment to be installed in transformers
- *Grids/Communications*: equipment for information transmission
- *Information Systems*: system for management and central data processing

Infrastructure	**EDP Box (EB)**	Device that includes a measurement module, control module and communication module and which is installed at the consumer/producer site.
	HAN Module	Communication and control module that allows reading of the records of the local EB (e.g. consumption, power consumption profile, historical events, quality of service) by connecting to other devices.
	Distribution Transformer Controller (DTC)	Local control equipment will be installed in distribution transformer stations, the main components being a measurement module, a control module and a communication module. Its main functions are: collecting data from the EB and MV/LV substation, data analysis functions and grid monitoring.
	DTC Cell Module (Distribution Automation)	Module that enables the turning on and off remotely or locally of the various independent circuits of the MV/LV substation. This is a critical component for Distribution Automation for providing new functionalities like remote management and automatic network reconfiguration.
	DTC Power Quality Module	Module that allows the recording and reporting of the quality characteristic values of the wave voltage (root mean square value, flicker, voltage dips, harmonics), providing information and generating alarm events.

Figure 3: Exemplary overview of devices in InovGrid

Step 3: *Assessment of functionalities and resulting benefits.*
The relevant devices are now linked to its functionalities, as seen in figure 4.

FUNCTIONALITIES

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

Figure 4: Exemplary mapping of assets and functionalities

After the functionalities are defined, a similar approach has to be done for the benefits. The functionalities are now linked to benefits, as seen in figure 5.

FUNCTIONALITIES

BENEFITS	Integrate users with new requirements				Enhancing efficiency in day-to-day grid operation						Ensuring network security, system control and quality of supply						Better planning of future network investment			Improving market functioning and customer service								More direct involvement of consumers in their energy usage					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
Optimised Generator Operation																	•																
Deferred Generation Capacity Investments																									•					•			
Reduced Ancillary Service Cost			•			•				•																							
Reduced Congestion Cost																																	
Deferred Transmission Capacity Investments																									•								
Deferred Distribution Capacity Investments						•	•	•								•		•	•		•				•					•			
Reduced Equipment Failures						•	•	•										•	•														
Reduced Distrib. Equipment Mainten. Cost								•										•											•				
Reduced Distribution Operations Cost					•			•																					•				
Reduced Meter Reading Cost																												•	•				
Reduced Electricity Theft									•						•									•				•					
Reduced Electricity Losses			•			•	•	•	•	•		•	•				•		•	•	•			•						•			
Detection of anomalies in Contracted Power							•																										
Reduced Electriciy Cost								•				•										•			•			•	•				
Reduced Sustained Outages			•	•	•			•					•				•			•													
Reduced Major Outages					•									•																			
Reduced Restoration Cost					•	•	•																						•				
Reduced Momentary Outages					•	•	•																						•				
Reduced Sags and Swells						•	•																										
Reduced CO_2 Emissions	•	•				•	•	•	•	•		•					•		•			•	•		•			•	•	•	•	•	
Reduced SOx, NOx, and PM-10 Emissions	•	•				•	•	•	•	•		•					•		•			•	•		•			•	•	•	•	•	
Reduced Oil Usage	•	•				•	•																•					•	•				
Reduced Wide-scale Blackouts																																	

Figure 5: Exemplary mapping of functionalities and benefits

An example for the mapping of functionalities and benefits: The benefit 'reduced ancillary service cost' is linked to the functionalities 'Integrate users with new requirements' and 'enhancing efficiency in day-to-day grid operation'.

Step 4: *Establishing baseline and project conditions.*
In this step, the baseline scenario for the Inovgrid project is defined. In order to do so, historical data was used to form a baseline condition for each benefit, as seen in figure 6. As a comparison, the project condition is drawn either by historical data or forecasts.

BENEFIT	A: BASELINE CONDITION (BaU)	METRICS USED*	B: ESTIMATED/REALISED CONDITION (InovGrid)	METRICS USED*
Reduced Meter Reading Cost	Cost with local meter readings	• Meter reading cost/ client/year (H) • Number of LV clients (H) • Inflation rate (F)	Reduced cost of obtaining local 'disperse' readings (i.e. readings from clients without smart meters or experiencing communication failures): with InovGrid infrastructure, only clients who are unable to use the EDP Box and those who experience communications failure will require local meter-reading services	• Communications success rate (H) • % of customers unable to use EDP Box (F) • Cost of 'disperse' local readings

Figure 6: Exemplary comparison of baseline and project condition for a benefit

The benefit of reducing meter reading costs can be projected with the metrics of standard reading costs, the number of clients and the inflation rate, that was defined as a part of the boundary conditions. In contrast, the reduction of metering costs can be measured by the communication success rate, the number of clients unable to use the new functionalities and the costs of additional metering.

Step 5: *Monetizing benefits and beneficiaries.*
The quantified benefits from the previous step can be monetized by a standard formula. Some examples for the Inovgrid project can be seen in the following:

- The reduced maintenance costs of devices

$$Value(€) = [Direct\ costs\ relating\ to\ maintenance\ of\ assets\ (€)]_{baseline} - [Direct\ costs\ relating\ to\ maintenance\ of\ assets\ (€)]_{project}$$

- Deferred distribution capacity investments due to asset remuneration

$$Value(€) = Annual\ DSO\ investment\ to\ support\ growing\ capacity\ \left(\frac{€}{year}\right) * Time\ deferred * Remuneration\ rate\ of\ investment$$

Step 6: *Identification and monetization of costs.*
Relevant costs were determined via a market consultation with the relevant actors. The results from this consultation were used to generate estimates of costs of action for a smart grid project. Examples were the costs of smart meters, a telecommunication system, etc.

Step 7: *Comparison of costs and benefits.*
The comparison of costs and benefits can be adjusted. An example for one calculation is the annual comparison of costs and benefits, as seen in figure 7.

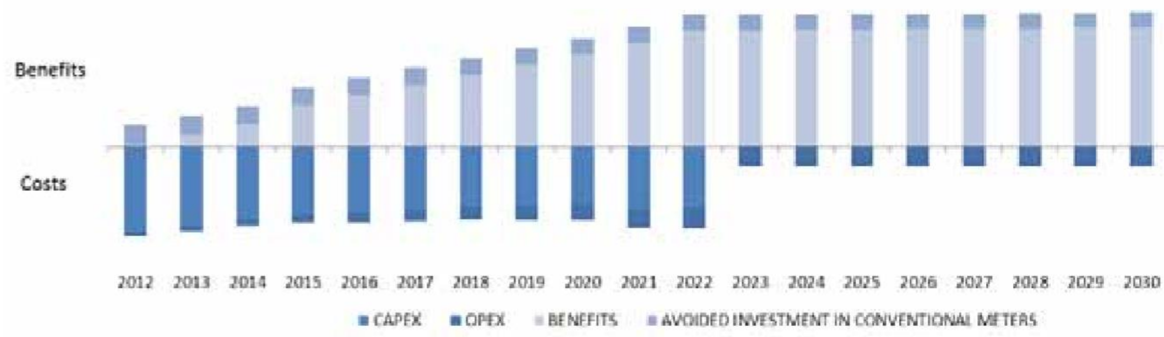

Figure 7: Exemplary comparison of costs and benefits – annual comparison

5 Cost-benefit Analysis for the Net2DG Project

Net2DG's CBA approach will be defined by three parts. The first part is the choice of relevant use-cases for the CBA as part of the definition of the project. Afterwards as a second part, for each of these use-cases, an individual CBA will be done. This individual CBA will in basic follow the steps from JRC's method and is completed by the option of mapping the use-cases in the end, if necessary. As a last part, robustness and plausibility checks will be performed. In the following, the complete adjusted approach for Net2DG will be explained in detail. This approach will be done in different iterations depending on the beneficiary. The first iteration (2019) will cover the DSOs' perspective, while the second iteration (2020) will complete the CBA for other relevant stakeholders.

Figure 8 provides an overview of the whole approach that we conceptualized for Net2DG, starting with the definition of the use cases, the use case specific CBA and ending with the robustness and plausibility check.

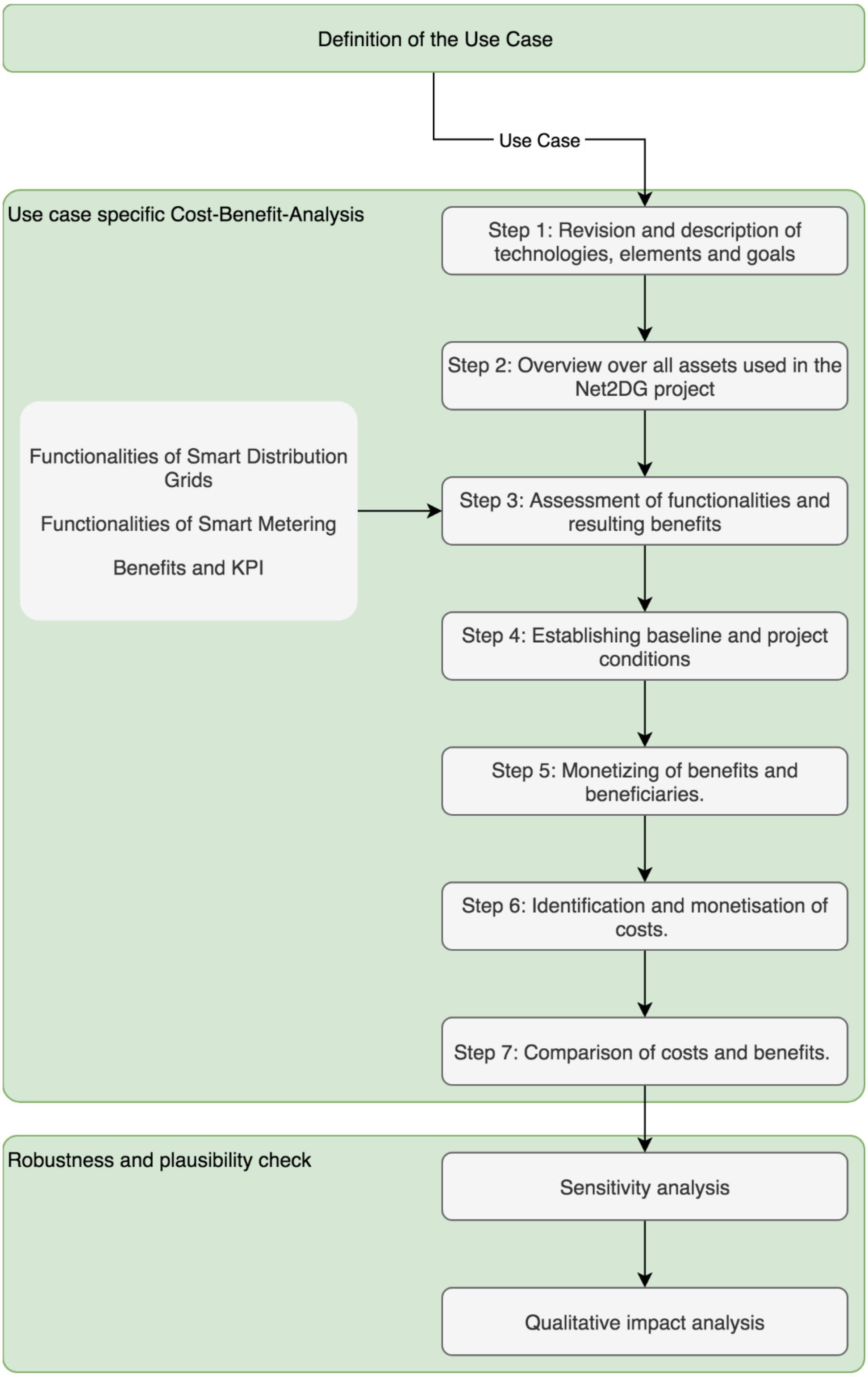

Figure 8: CBA method for Net2DG

5.1 Definition of Net2DG: Choice of Relevant Use-Cases

The first step in the CBA for Net2DG is the choice of relevant use-cases. The following use-cases were agreed on to be in focus:

1. FM-1: Outage Detection
2. FM-2: Outage Diagnosis
3. FM-3: Preventive maintenance (asset management)
4. LM-1: Loss calculation and recording
5. VQ-1: LV Grid Monitoring
6. VQ-2: Automatic Voltage Regulation

Each use-case will be analysed with a specific, independent cost-benefit analysis.

5.2 Use-case Specific Cost-Benefit Analysis

As described earlier, an individual cost-benefit analysis will be conducted to ensure flexibility and transparency. It will mainly be based on the JRC approach, which means it will be built upon seven major steps:

1. Revision and overview of technologies, elements and goals
2. Overview of all assets
3. Mapping of functionalities and benefits
4. Comparison of baseline and project conditions
5. Monetarization of benefits
6. Quantification of costs
7. Comparison of costs and benefits

5.2.1 Revision and Overview of Technologies, Elements and Goals / Overview of all Assets

For simplicity, the first two steps of the CBA can be combined, as they are both concerning the assets of Net2DG. It has to be noticed, that most grid infrastructure is already present in the system and does not have to be newly installed. Nevertheless, this existing infrastructure is relevant for the cost-benefit approach and has to be comprehended. Also new devices have to be included in the analysis.
The project's attributes demand that a special focus is put on IT-components and digital infrastructure. Information transmission as part of this digital infrastructure will be central for most of the relevant use-cases.
As a final result, a full list of all assets/devices/technological elements is necessary to proceed to the following steps.

5.2.2 Mapping of Functionalities and Benefits

The next step incorporates the mapping of functionalities and benefits. The assets derived in the first two steps now are relevant.
These assets can be linked with functionalities that reflect their role in the system. It may be noticed, that multiple functionalities can be performed by a single asset. A broad range of different possible

functionalities can be seen in table 3 in the Appendix A. The partners involved in this WP may choose functionalities from the default list, but can also add individual ones.

After the assets are linked to functionalities, another mapping takes place, which then links the functionalities to benefits. A corresponding list of possible benefits also can be seen in table 5 in the Appendix C. Again, the partners may suggest individual benefits, but the list can be used, if necessary. In the end, the list of assets should be extended by a full comprehension of all functionalities and corresponding benefits.

5.2.3 Comparison of Baseline and Project Conditions

To get a clear view on the project's benefits, a comparison between the system's condition without the project (baseline condition) and with the project is necessary (project condition). The baseline condition involves the standard approach that is used in the distribution grid to deal with the respective use-case. Since functionalities are only determined for the project condition yet, the missing baseline state functionalities have to be reworked, if necessary. The baseline condition works as a reference to the project condition that shows the improved way to deal with the use-case. In this step, the benefits that are obtained in the previous step can be linked with metrics to measure a certain system condition. The metrics then are calculated for each condition of the system and are able to show measurable differences.

5.2.4 Monetarization of Benefits

The next step includes the monetarization of benefits. From the previous step, the obtained benefits are described with metrics. From these metrics, a difference between the baseline condition and the project condition can be obtained. This difference is now complemented with a monetary value. Usually, the differences can be calculated with a standard formula, but the partners may suggest individual ones, too, if necessary.

5.2.5 Quantification of Costs

After all benefits are calculated, the costs of the project have to be identified. Following the basic JRC method, costs are somehow hard to estimate. Thus, the partners have to deliver the full cost data. This data has to incorporate both implementation costs and running costs. As big parts of the infrastructure are already existing in the grid, the implementation costs have to be reduced by this. Running costs have to cover the possible cost to provide the incentive for consumers to share their information.

As a result, a full list of all costs relevant for Net2DG have to be available.

5.2.6 Comparison of Costs and Benefits

As a conclusion, the benefits and costs obtained from the previous steps can be analysed within the comparison of both. This comparison can be conducted in different ways. The relevant option will be determined, when all CBA-steps are solved.

5.3 Robustness and Plausibility Check

After the individual CBA has been conducted, robustness and plausibility checks are necessary to ensure a valid result. As part of the DSO's perspective, relevant assumptions and input parameters that

were taken, have to varied. The respective critical aspects to vary have to be chosen, after the CBA is conducted and the partners have delivered their data. The partners may suggest, which input parameters are the most relevant for the robustness and plausibility check.
To complete the approach for Net2DG's cost-benefit analysis, a qualitative impact analysis can be conducted. However, the scope of this and the affected aspects have to be determined after the individual CBAs as well. Basically, qualitative impacts can be measured by their effect on certain key performance indicators. The relevant KPIs will be worked out during the CBA.

5.4 Example of the CBA for the Use Case "Outage Detection"

In the following, an example for a possible CBA procedure is shown. This example is the use-case "FM-1: Outage detection". Since a prioritization of use-cases is not made for the CBA, this example was drawn randomly only to show a possible application. The use-case specific CBA will now follow the steps that have been worked out earlier in chapter 5.

- **Step 1&2: Revision and overview of technologies, elements and goals / Overview of all assets used in the project**
  The assets that are linked to the use-case have to be analysed and listed up. For the given example, a special focus has to be put on the transmission of grid-information. For this use-case, the already present grid infrastructure that usually detects outage has to listed, as well as devices or infrastructure that has to be added in the context of Net2DG, if these are necessary. In the end, a full list of all relevant parts has to be built.

- **Step 3: Mapping of functionalities and benefits**
  Then, a mapping of the defined assets and its corresponding functionalities is the first part of Step 3. From Table 2: Functionalities of Smart Distribution Grids, different predefined functionalities can be drawn in order to describe the assets for use-case "FM-1: Outage Detection". For example, the functionality category "Enhancing efficiency in day-to-day grid operation" seems to be most relevant. This functionality category consists of several subcategories that can be matched to the use-case's assets. However, one has to notice, that the subcategories are not analysed in the given example, as the assets are not clearly defined. Only a possible mapping is shown.

	Enhancing efficiency in day-to-day grid operation					**(Further functionalities…)**
Asset 1	x	x	x	x		
Asset 2			x		x	
(Further assets…)						

After the mapping of assets and functionalities has taken place, these functionalities then have to be linked to its benefits as the second part of this Step 3. Basically, the same procedure can be used again. From the predefined list of benefits in Table 4: Benefits and KPI, the benefits

"Time reduction to handle customer complaints" and "Reduced time to recover from outages" seem to be relevant for the use-case.

	Enhancing efficiency in day-to-day grid operation					(Further functionalities…)
Time reduction to handle customer complaints	x			x		
Reduced time to recover from outages	x	x	x		x	
(Further benefits…)						

The final result is consequently a full list of all assets for "FM-1: Outage Detection", a mapping of its functionalities and benefits. Although this step seems to be a bit redundant, it is necessary to provide a transparent and consistent CBA.

- **Step 4: Comparison of baseline and project condition**
  For the given example "FM-1: Outage Detection", a baseline condition has to be established to cover the present and standard way to deal with outage detection. In case needed, this Step 4 requires the Steps 1-3 as well, if the usual way to deal with outage detection is not clear on the first attempt.
  The project condition then has to cover the improved approach to deal with outage detection. The benefits, that were derived in Step 3, can be assigned to metrics that measure the improved condition. In this way, a comparison of the baseline condition and the project condition is done to get a clear effect.

Benefit	Baseline condition	Metrics used	Project condition	Metrics used
Time reduction to recover from outages	Usual time to recover from outages	Cost per time unit, average number of outages per time unit	Reduced time to recover from outages	Cost reduction per time unit

The benefit "Time reduction to recover from outages" needs the baseline condition with the usual time to recover from outages. This is usually calculated by the cost per time unit and the average number of outages per time unit. In the improved manner, the project condition shows the reduced time to recover from outages. This, of course, can be calculated by the cost reduction per time unit, which is described by the same metrics.

- **Step 5: Monetarization of benefits**
  This Step is the first one to put a monetary value on benefits. Therefore, the metrics that are corresponding to the benefits, can be actually calculated. For the given benefit "Time reduction to recover from outages", the following calculation would hold.

$$value\ of\ benefit(€) = [\hat{c} * \hat{n}]_{baseline} - [\hat{c} * \hat{n}]_{scenario}$$

with

$$\hat{c}\ \dots\ average\ cost\ of\ outage\ per\ time\ unit$$
$$\hat{n}\ \dots\ average\ number\ of\ outages\ per\ time\ unit$$

In this simple example, a difference between the baseline condition and the scenario condition results in the monetary value of the benefit “Time reduction to recover from outages”.

- **Step 6: Identification and monetarization of costs**
  For the given example “FM-1: Outage Detection”, the costs have to be identified. The costs cover the relevant costs for implementing the IT-infrastructure and devices and the running costs of the system once it is implemented. They have to be delivered by the relevant partners, an estimation from outside is difficult.

- **Step 7: Comparison of costs and benefits**
  Once, all benefits are monetized and costs are defined, a comparison of costs can be conducted. An adjustment on different timeframes offers various possibilities to calculate a comparison. In the end, this step is the most expressive, as it summarizes the whole CBA.

6 Conclusions and Outlook

This chapter concludes the deliverable on the CBA approach. It was shown that there exist different methods to conduct a CBA. However, an adjustment of the methods is always necessary to provide a fitting concept for individual distribution grid projects. On different steps of the approach, there might be difficulties to access the required information. Because of that, flexibility and transparency are central to the CBA approach to redirect information and tasks, if needed.

For the future application of the CBA, the identification of costs remains as a special aspect, because the full data is needed from the partners and an estimation is not possible. Cost data on different devices and infrastructure is not openly accessible. On the first run, this cost data might be the highest, as it is the first implementation of the proposed grid. Just like a learning curve, different cost-structures will arise, once the system is operating and can be adopted. Therefore, also the operational costs remain as a point of discussion.

In order to provide the transparency and consistency that is demanded by the project, we suggest the timetable shown in Figure 9 for the year 2019. This first iteration will cover the DSO’s perspective only. Other stakeholders’ perspectives will be included later on.

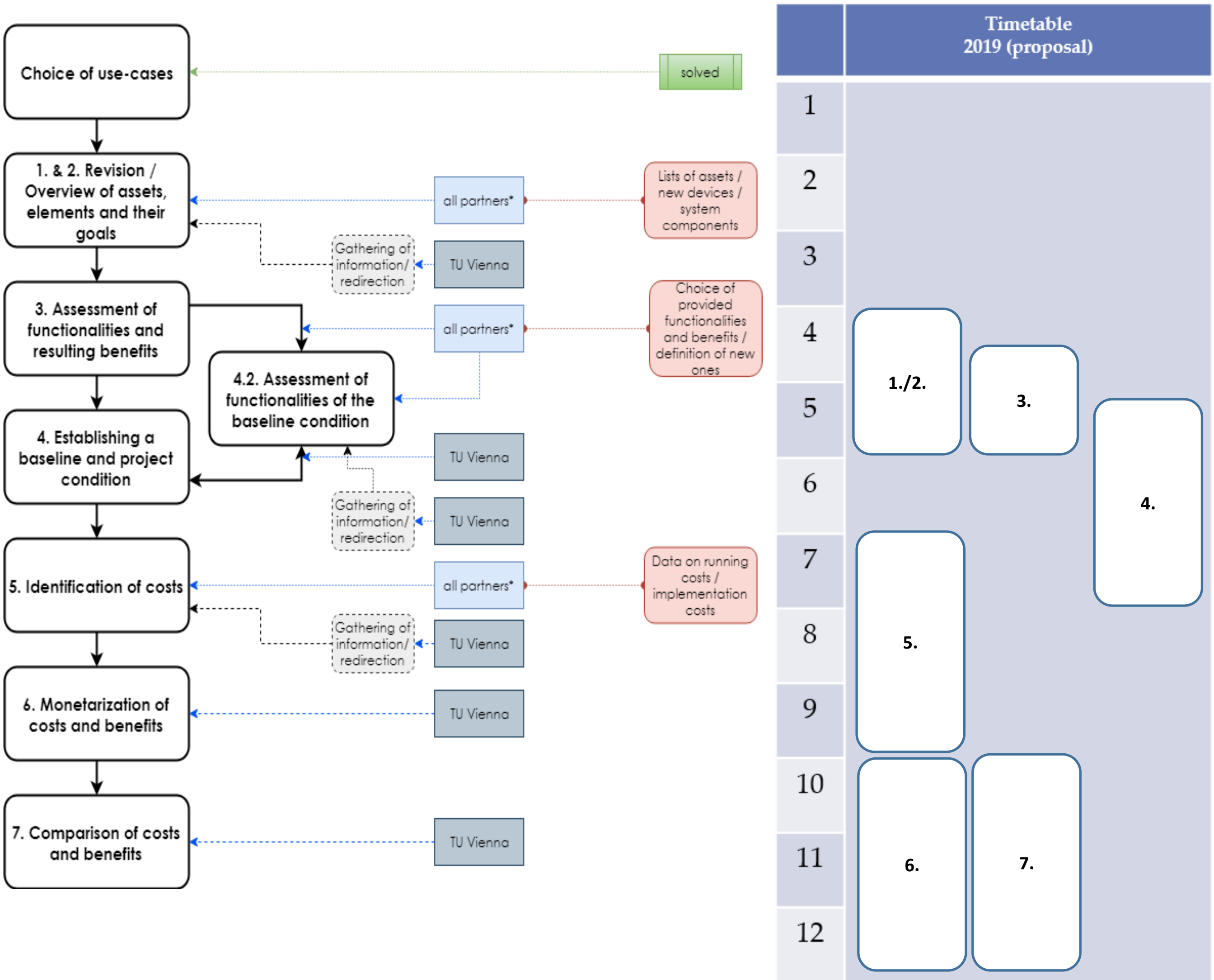

Figure 9: Outlook of the application of the CBA

Since this first iteration concerning the DSO's perspective is planned to start in April 2019, the first two steps of the individual CBAs have to be finished until the end of May 2019, as well as step 3. The information regarding these steps have to be provided by all relevant partners. After this, step 4 will be performed by TU Vienna until end of July. Afterwards, the partners are responsible to deliver the cost data until end of September. TU Vienna will gather the relevant information to conduct the two last steps until the end of the year 2019. As the WP-leader, TU Vienna will also be responsible for the gathering of information in between the steps and redirection, where necessary.

7 Literature

EC Task Force for Smart Grids, 2010. Expert group 1: Functionalities of smart grids and smart meters.

EDP Distribuição, 2017. InovGrid.

EPRI (Ed.), 2010. Methodological Approach for Estimating the Benefits and Costs of Smart Grid Demonstration Projects.

Giordano, V., Onyeji, I., Fulli, G., Sánchez Jiménez, M., Filiou, C., 2012. Guidelines for conducting a cost-benefit analysis of smart grid projects.

InspireGrid, 2013. InspireGrid - Improved and enhanced stakeholder participation in the reinforcement of the electricity grid.

Sartori, D., EC (Eds.), 2015. Guide to cost-benefit analysis of investment projects: economic appraisal tool for cohesion policy 2014 - 2020, Dec. 2014. ed. Publ. Office of the Europ. Union, Luxembourg.

Willems, B., 2004. Electricity Networks and Generation Market Power 186.

Appendix

Table 2 and Table 3 (in Appendix A and B) describe all the functionalities of Smart Distribution Grids and Smart Metering based on (Giordano et al., 2012). As Net2DG needs an adaption of these functionalities, the future application may require an adaptation of those tables. Additionally, Table 4 shows the benefits and Key-Performance-Indicators (KPI) achievable by Net2DG.

Appendix A: Functionalities of Smart Distribution Grids

Table 2: Functionalities of Smart Distribution Grids

Category A: Enabling the network to integrate users with new requirements	
	(1) Facilitate connections at all locations through the availability of data and information
	(i) simplify and reduce costs of connection process to maintain network safety (ii) facilitate an 'open platform' approach (iii) make connection options transparent (iv) facilitate connection of new load types (v) ensure that most efficient connection strategies can be persued from a system perspective
	(2) Better use of the grid for users at all locations, including renewable generators
	(3) Registers of the technical capabilities of connected devices with an improved network control system to be used for network purposes
	(4) Updated performance data on continuity of supply and voltage quality to inform connected/perspective users
Category B: Enhancing efficiency in day-to-day grid operation	
	(5) Improved automated fault identification and optimal grid reconfiguration after faults reducing outage times
	(i) using dynamic protection and automation schemes with additional information where disributed generation is present (ii) strengthening Distribution Management Systems of distribution grids
	(6) Enhanced monitoring and control of power flows and voltages
	(7) Enhanced monitoring and observability of network components down to low voltage levels, potentially using the smart metering infrastructure
	(8) Improved monitoring of network assets in order to enhance efficiency in day-to-day network operation and maintenance
	(9) Identification of technical and non technical losses through power flow analysis, network balances calculation and smart metering information
	(10) Frequent information on actual active/reactive injections/withdrawals by generation and flexible consumption to system operator
Category C: Ensuring network security, system control and quality of supply	

	(11) Solutions to allow grid users and aggregators to participate in an ancillary services market to enhance network operation
	(12) Improved operation schemes for voltage/current control taking into account ancillary services
	(13) Solutions to allow intermittent generation sources to contribute to system security through automation and control
	(14) System security assessment and management of remedies, including actions against terrorist attacks, cyber threats, actions during emergencies, exceptional weather events and force majeure events
	(15) Improved monitoring of safety particularly in public areas during network operations
	(16) Solutions for demand response for system security purposes in required response times
Category D: Better planning of future network investment	
	(17) Better models of DG, storage, flexible loads (including EV), and the ancillary services provided by them for an improvement of infrastructure planning
	(18) Improved asset management and replacement strategies by information on actual/forecasted network utilization
	(19) Additional information on supply quality and consumption made available by smart metering infrastructure to support network investment planning
Category E: Improving market functioning and customer service	
	(20) Solutions for participation of all connected generators in the electricity market
	(21) Solutions for participation of VPPs in the electricity market, including access to the register of technical capabilities of connected users/devices
	(22) Solutions for consumer participation in the electricity market, allowing market participants to offer
	(i) time of use energy pricing, dynamic energy pricing and critical peak pricing; (ii) demand response / load control programmes
	(23) Grid solutions for EV recharging
	(i) open platform grid infrastructure for EV recharge purposes accessible to all market players and customers (ii) smart control of the recharging process through load management functionalities of EV
	(24) Improved industry systems for settlement, system balance, scheduling and forecasting and customer switching
	(25) Grid support to intelligent home/facilities automation and smart devices by consumers
	(26) Individual advance notice to grids users for planned interruptions
	(27) Customer level reporting in event of interruptions (during, and after event)
Category F: Enabling and encouraging stronger and more direct involvement of consumers in their energy usage and management	
	(28) Sufficient frequency of meter readings, measurement granularity for consumption/injection metering data (e.g. interval metering, active and reactive power, etc)
	(29) Remote management of meters

	(30) Consumption/injection data and price signals via the meter, via a portal or other ways including home displays, as best suited to consumers and generators
	(31) Improved provision of energy usage information, including levels of green energy available at relevant time intervals and supply contract carbon footprint
	(32) Improved information on energy sources
	(33) Individual continuity of supply and voltage quality indicators via meter, via portal or other ways including home displays

Appendix B: Functionalities of Smart Metering

Table 3: Functionalities of Smart Metering

Category G: Remote reading of metrological registers and provision of these values to designated market organisations
Category H: Two-way communication between the metering system and designated market organisations
Category I: Meter supporting advanced tariffing and payment systems
Category J: Meter allowing remote disablement & enablement of supply
Category K: Communciation with (and where appropriate directly controlling) individual devices in the home/building
Category L: Meter providing information via portal/gateway to an in-home/building display auxiliary equipment

Appendix C: Benefits and KPI

Table 4: Benefits and KPI

Benefit	*Possible KPIs*
Increased sustainability	Quantified reduction of carbon emissions
	Environmental impact of electricity grid infrastructure

	Quantified reduction of accidents and risk associated with generation technologies (during mining, production, installations, etc.)
Adequate capacity of transmission and distribution grids for 'collecting' and bringing electricity to the consumers	Hosting capacity for distributed energy resources in distribution grids
	Allowable maximum injection of power without congestion risks in transmission networks
	Energy not withdrawn from renewable sources due to congestion and/or security risks
	An optimised use of capital and assets
Adequate grid connection and access for all kinds of grid users	First connection changes for generators, consumers and prosumers
	Grid tariffs for generators, consumers and prosumers
	Methods adopted to calculated changes and tariffs
	Time to connect a new user
	Optimisation of new equipment design resulting in best cost/benefit
	Faster speed of successful innovation against clear standards
Satisfactory levels of security and quality of supply	Ratio of reliably available generation capacity to peak demand
	Share of electrical energy produced by renewable sources
	Measured satisfaction of grid users with the 'grid' services they receive
	Power system stability
	Duration and frequency of interruptions per consumer
	Voltage quality performance of electricity grids (e.g. volatge dips, volatge and frequency deviations)
Enhanced efficiency and better service in electricity supply and grid operation	Level of losses in transmission and in distribution networks (absolute and percentage)

	Ratio between minimum and maximum electricity demand within a defined time period
	percentage utilisation of electricity grid elements
	Demand-side participation in electricity markets and in energy efficiency measures
	Availability of network components (related to planned and unplanned maintenance) and its impact on network performances
	Actual availability of network capacity with respect to its standard value
Effective support of transnational electricity markets by load flow control to alleviate loop flows and increased interconnection capacities	Ratio between interconnection capacity of one region and its electricity demand
	Exploitation of interconnection capacities (ratio between monodirectional energy transfers and NTC), particularly related to maximisation of capacities according to the regulation of electricity cross-border exchanges and congestion management guidelines
	Congestion rents across interconnections
Coordinated grid development through common European, regional and local grid planning to optimise transmission grid infrastructure	Impact of congestion on outcomes and prices of regional markets
	Societal benefit-cost ratio of a proposed infrastructure investment
	Overall welfare increase, i.e. always running the cheapest generators to supply the actual demand
	Time for licensing/authorisation of a new electricity transmission infrastructure
	Time for construction (i.e. after authorisation) of a new electricity transmission infrastructure
Enhanced consumer awareness and participation in the market by new players	Demand side participation in electricity markets and in energy efficiency measures
	Percentage of consumers on (opt-in) time-of-use/critical peak/real-time dynamic pricing

	Measured modifications of electricity consumption patterns after new (opt-in) pricing schemes
	Percentage of users available to behave as interruptible load
	Percentage of load demand participating in market-like schemes for demand flexibility
Enable consumers to make informed decisions related to their energy to meet the EU Energy Efficiency targets	Base-to-peak load ratio
	Relation between power demand and market price for electricity
	Consmuers can comprehend their actual energy consumption and receive, understand and act on free information they need/ask for
	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
	Ability to participate in relevant energy market to purchase and/or sell electricity
	Coherent link is established between the energy prices and consumer behaviour
Create a market mechanism for new energy services such as energy efficiency for energy consulting for customers	Simple' and/or automated changes to consumers' energy consumption in reply to demand/response signals are enabled
	Data ownership is clearly defined and data processes in place to allow for service providers to be active with consumer consent
	Physical grid-related data are available in accessible form
	Transparency of physical connection authorisation, requirements and charges
	Effective consumer complaint handling and redress. This includes clear lines of responsibility should things go wrong

Consumer bills are either reduced or upward pressure on them is mitigated	Transparent, robust processes to assess whether the benefits of implementation exceed the costs in each area where roll-out is considered, and a commitment to act on the findings by all the involved parties
	Regulatory mechanisms that ensure that these benefits are appropriately reflected in consumer bills and do not simply result in windfall profits for the industry
	New smart tariffs (energy prices) that deliver tangible benefits to consumers or society in a progressive way
	Market design is compatible with the way consumers use the grid