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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This deliverable contains original unpublished work except where clearly indicated otherwise.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 regarding smart grid applications grow in importance in Europe. They are considered to be a main driver to make distribution grids on the low voltage level ready for the challenges of integrating renewable energy sources. Smart grids' performance can even be enhanced regarding the daily grid operation, if data from the smart meter infrastructure are made available, accessible and processable to a DSO. This is being implemented by the Net2DG project. However, the financial benefits regarding profitability and economic impacts of smart grid projects is not clear on the first hand. Comprehension of benefits is not a straightforward task in this context, since there is no direct payment in many cases. For this purpose, a Cost-Benefit-Analysis (CBA) is conducted to fully assess the benefits and costs for a DSO. This information can then be used to formulate a business model for the customer group of DSOs. In previous work regarding the CBA, a basic concept was derived from prominent approaches in the literature. This concept was defined as a step-by-step approach, whose steps were conducted over the year in intense coordination with the relevant partners of DSOs and research institutions. This deliverable summarized the first run of the CBA approach by giving first reference results. They are expected to widen and expand in the future, as more research and work will be conducted in the rest of the project.

For each of the use-cases, that were defined in previous work, a summary of the derived benefits for a DSO are presented first. The calculations then are done by defining these benefits with Key Performance Indicators (KPIs). Since for some use-cases the benefits are closely related to each other, they could be combined to get a joint analysis of benefits. Thus, "Outage Detection" and "Outage Diagnosis" were combined, because their benefits almost entirely come from the time reduction in processing and removing outages in a distribution grid. "Grid Monitoring" and "Loss Calculation" could be combined, because their benefits are arising from the new information, that is accessible and processible with the Net2DG solution. "Automatic Voltage Regulation" is being analysed by its own, whereas "Preventive Maintenance" is not yet fully implemented and the analysis will depend on future work. Thus, a reference example is not yet calculated for this single use-case, but some formulations are already projected.

The benefits, that were obtained in this first CBA, are then used to define a business case for the services of Net2DG. A business consists of three components: The proposition of a unique customer value, a profit formula for providing the Net2DG services and the consideration of the key resources and processes from the Net2DG application. In all these steps, the results from the CBA are applicable and integrable. This constitutes the CBA as a core work for achieving economic impact both from a sellers' and customers' perspective.

2 Introduction and Overview

International climate change mitigation demands the worldwide reduction of CO2-emissions. A main contribution has to be done by the electricity sector and also other energy sectors as a big driver for emissions. Thus, the European Union formulated three main goals for the development of the electricity sector. The market harmonization has to be increased as well as RES[1]-penetration while keeping up security of supply. These goals do not only cause problems on the transmission grid, but also on the distribution low-voltage grid level (e.g. outage problems, power quality). Still, the integration of RES in the form of DER[2] and the security of supply stay relevant on the low-voltage grid. The Net2DG solutions provide practically relevant service for DSOs, that can help to incorporate these goals and their consequences into the daily grid operation.

In previous work (D6.8), the basic principle of the Cost-Benefit-Analysis (CBA) was already introduced. It was based on two prominent examples from literature [1] [2], but was formed as an individual concept to fit onto the specific project attributes. It was planned to incorporate the use-cases of "Outage Detection", "Outage Diagnosis", "Grid Monitoring", "Loss Calculation", "Automatic Voltage Regulation" and "Preventive Maintenance" into the CBA and conduct individual CBA for each of these. In the following, the CBA approach is applied to each of these use-cases. In the beginning, the benefits and corresponding KPIs are explained. After that, a reference example with initial values for a first comparison is calculated and monetarized as far as possible. Then, future steps for the next years' work is described and how the CBA is planned to be refined in the future. This means, the values obtained in this document are not the final ones and may change in future analyses. The document concludes with a definition of the business model. Again, a sophisticated way of characterizing the components of a business model is applied.

3 Cost-Benefit-Analysis for the use-cases

3.1 *Outage Detection & Outage Diagnosis*

3.1.1 Description of achievable benefits

The benefits arising from the use-cases "Outage Detection" and "Outage Diagnosis" arise mainly from the time reduction in either finding the outage in the grid or identifying the reason for the outage, apart from recovery time. If these two time-benefits can be identified clearly, it is possible to determine quantitative improvements in notifiable figures like the System Average Interruption Duration Index (SAIDI) or later on the System Average Interruption Frequency Index (SAIFI). These values are central figures for a Distribution System Operator (DSO), as they have to be notified towards a respective regulator. Another aspect is the savings in personnel costs. From a time-reduction to identify and/or diagnose faults in the grid, personnel can be dispatched more efficiently. The time, a respective staff member has to spend on these issues can be reduced and the personnel costs directly aligned to the task are reduced.

[1] RES – renewable energy source

[2] DER – distributed energy resource

Due to the time reduction in identifying and diagnosing faults in a grid, also benefits regarding the grid itself can be determined. An improved availability of grid assets can be achieved, when considering the reduced outage time for the respective grid asset. Consequently, a higher overall efficiency in the grid can be observed. This aspect becomes even more clear, when not delivered energy (energy not supplied = ENS) during the time of the outage is considered. A clear benefit to a DSO and therefore also for the customer, if this value can be reduced.
Also, a qualitative perspective can be added when considering an improved outage detection. As status-quo in the grid, not all types of faults can be determined without problems [3]. If a DSO is able to easily identify all outages, also the significance of reported values of SAIDI or SAIFI do improve. Now, all outages, that occurred in the grid, can be included in these key figures. This allows a DSO to gain more knowledge about their grid and therefore increases the controllability. Another qualitative benefit is the improved customer perception due to automatic notifications regarding faults and decreased outage duration time.

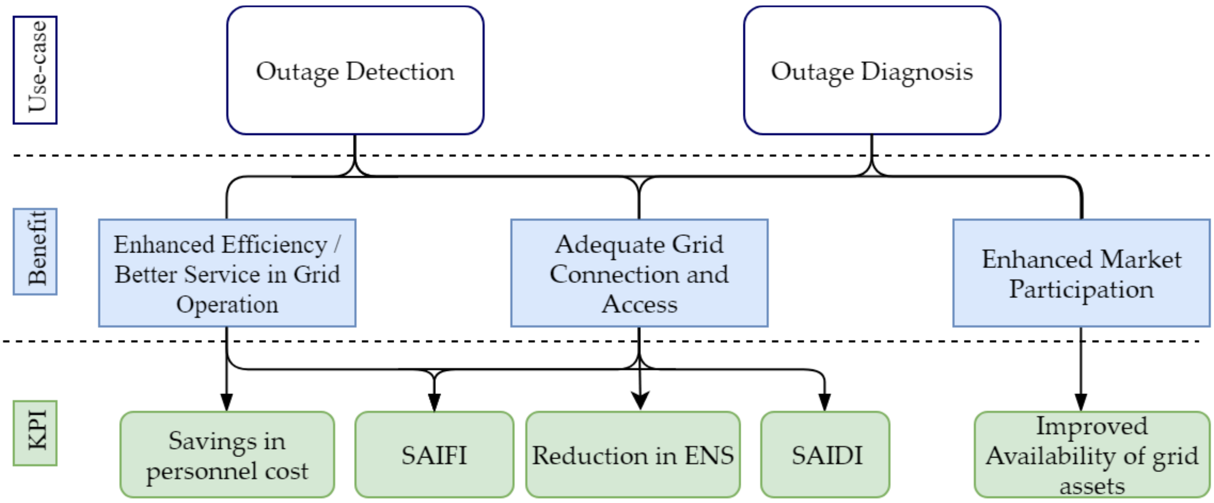

Figure 1: Benefits and KPIs from "Outage Detection" and "Outage Diagnosis", source: TU Vienna

Figure 1 gives an overview of the current most important benefits and linked KPIs that are analyzed within the Cost-Benefit-Analysis. In the next chapter, it is described, how these KPIs can be calculated and where the data can be obtained from.

3.1.2 Determination of necessary data and calculation of reference example

For the clear identification of the benefits linked to the use-cases “Outage Detection” and “Outage Diagnosis”, the specific time reductions need to be determined. Since this can only limitedly be determined in the real grids, an experiment needs to be conducted to identify the benefits.

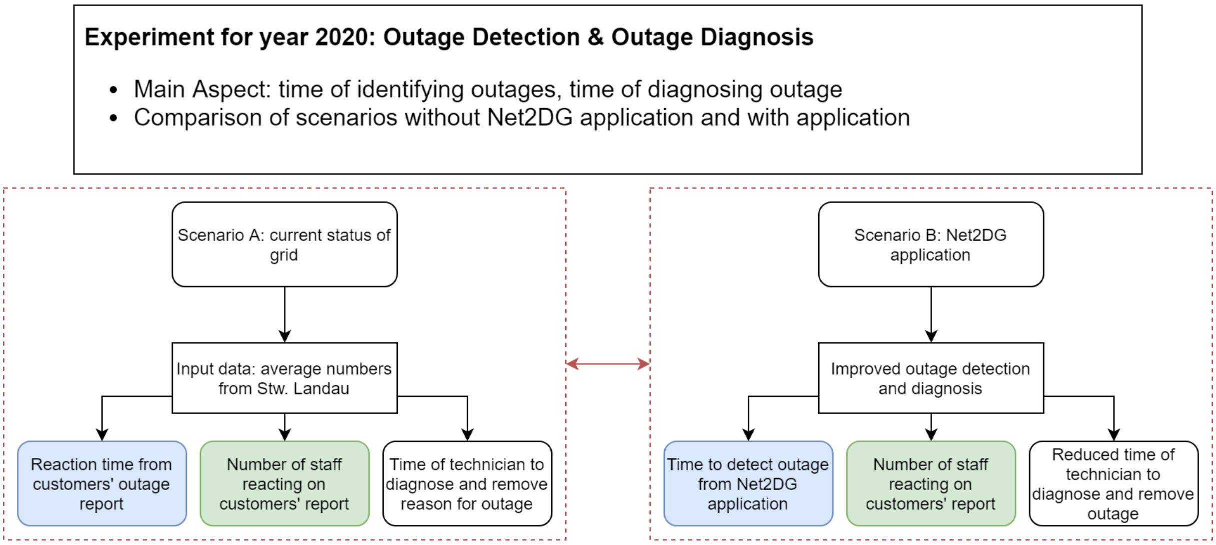

Figure 2: Basic setup for the experiment regarding "Outage Detection" and "Outage Diagnosis", source: TU Vienna.

The basic setup for the planned experiment can be seen in Figure 2. A comparison between the two states (Scenarios) needs to be conducted: Scenario A represents the current status of the grid, whereas Scenario B represents the grid with the usage of the Net2DG solution. In both cases, an artificial outage needs to be induced to see how fast the network reacts. Basically, an outage can be defined as an "unpermitted deviation from its standard operating conditions" [4]. This means, many different things can act as an outage and one specific example case needs to be formed for the experiment. First of all, a distinction has to be made regarding the duration of the outage. There are temporary outages and permanent outages that can occur in the grid [5]. Since a temporary outage is solved by itself within a short time period of some minutes, it only makes sense to analyze for the CBA a permanent outage, that needs to be fixed manually. In most cases, outages are caused by insulation failures induced by material aging leading to short-circuits [6].

In literature it is described, that an outage in the grid leads to the disconnection of the main feeder cable and the source of the outage [4]. From this, a number of customers that is connected by the main feeder cable loses grid connection for a certain duration.

In the grid simulation for each case, the following parameters as seen in Table 1 need to be drawn.

Parameter	Scenario A: Current status	Scenario B: Net2DG solution
Reaction time	Time from an outage to the identification	Time to notice an outage, its location in the grid and the affected customers by Net2DG
Time to diagnose outage	Time to find the location of an outage, identify the affected customers and determine an outage reason by a technician	Time to find reason for outage and initiate resolution within Net2DG
Time to remove outage	Repair time + Switching time	Repair time

Table 1: Parameters from the grid simulation experiment, source: TU Vienna.

There are initial parameters that can be used as reference values. The average manual fault identification time is set to 45 minutes. The reason for a fault can be found within 15 minutes by a technician (assumed). After that, the outage needs to be dealt with by repairing the respective grid asset and initiating a switch for the affected consumers to be supplied in a different way. In general, switching can be defined as the process of transferring load, when possible, to a different feeder in order to achieve energy balance [7]. Thus, it can be assumed that the load is supplied in an alternative way after switching. In Table 2, the assumed values are summarized. The data is partially taken from the literature [8] and from Stw. Landau's[3] grid statistics. However, these values may be adjusted with further input that is provided by DSOs.

Parameter (Scenario A)	Value	Additional information
Fault identification time (h)	0.75	$T_i = T_0(L_j / \sum L_j)$
Time for Diagnosis (h)	0.25	-
Repair time (h)	2	-
Switching time (h)	0.5	-

Table 2: Baseline values assumed for Scenario A, source: [8], Stw. Landau.

With these values, a useful initial comparison for the time demand can be conducted. Figure 3 shows the process of removing a fault in the grid, as it is comprehended within the Cost-Benefit-Analysis.

[3] https://www.swlandau.de/news/artikel/news/2018/10/15/eu-projekt-net2dg/

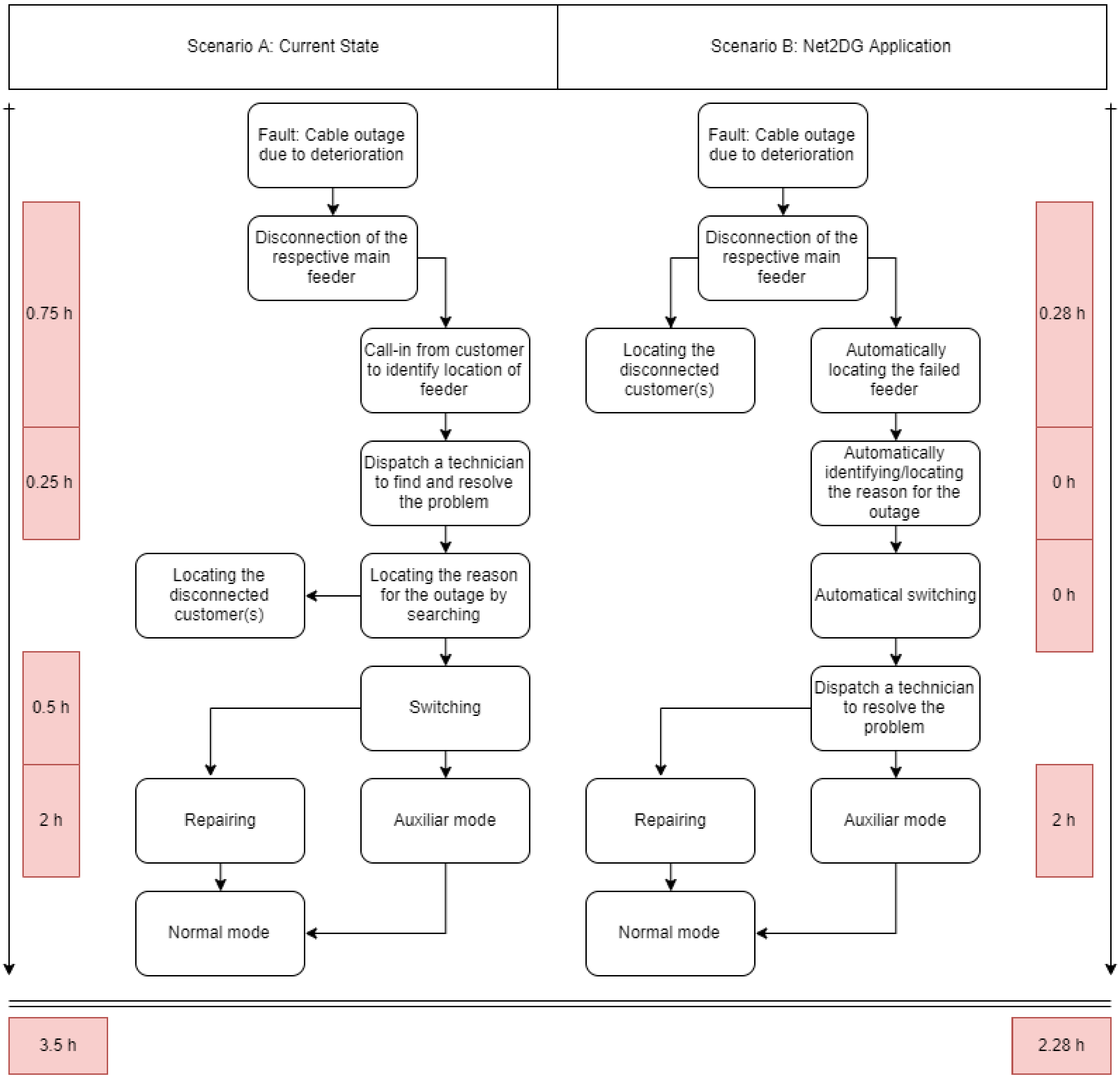

Figure 3: Scenario A vs. Scenario B in time, source: TU Vienna.

Overall, a time reduction of more than one hour per outage can be achieved. The outage detection time can be reduced from 0.75 hours down to 0.28 hours. The time for diagnosing an outage can be completely eliminated from approximately 0.35 hours to zero, as the Net2DG solution provides automatic information about the reason of the outage. In the current state, a technician needs to be dispatched to search the reason for the outage.

3.1.2.1 Reductions in Energy Not Supplied & SAIDI

From these time savings, multiple financial benefits can be calculated. The first one is the reductions in ***Energy Not Supplied (ENS)*** per customer in an average outage as described before.

$$\Delta ENS = (C \cdot T^{Base} \cdot D) - (C \cdot T^{Net2DG} \cdot D) = C \cdot D \cdot (T^{Base} - T^{Net2DG})$$

To calculate this, D represents the average energy demand of a single customer per hour. The time benefit is the difference between T^{Base} and T^{Net2DG}. For the calculation, it is necessary to determine the costs C induced by outages in terms of ENS. As this value is not easily accessible, [9] provides a profound estimation with cost values for different load types in the USA (no newer values found). These values can easily be converted from Dollar into Euro[4].

Category		Momentary	0.5 hours	1 hour	4 hours	8 hours
Residential	Per Event (€)	2.457	3.003	3.549	7.098	9.737
	Per kW (€)	1.638	2.002	2.366	4.641	6.461
	per kWh unserved (€)	19.656	4.004	2.366	1.183	0.819
Small C&I	Per Event (€)	399.49	555.1	744.38	2453.36	4338.88
	Per kW (€)	182.091	253.071	339.612	1118.572	1978.158
	per kWh unserved (€)	2184.91	506.233	339.521	279.643	247.247
Medium C&I	Per Event (€)	10697.96	14295.19	18527.6	53861.08	85439.9
	Per kW (€)	13.104	17.563	22.75	66.066	104.832
	per kWh unserved (€)	157.521	35.035	22.75	16.562	13.104

Table 3: Cost values for outages of different durations for specific load types, source: [9].

Another way to estimate the costs of an outage C is the determination of the Value of Lost Load (VoLL). Different estimates are present in literature. Compared to the presented values in Table 3, even higher values can be found for the different specific load types [10], like seen in Table 4.

	VoLL (€/kWh)
Households (Residential)	16.38
Agriculture	3.90
Manufacturing	1.87
Construction	33.05
Transport	12.42
Services	7.94

Table 4: VoLL for different load types, source: [10].

From these values, a baseline estimation of costs, that currently occur in the grid, can be conducted. For this, the data on the appearance of faults in a grid as well as their affected number of customers and their type is needed. The average yearly electricity demand of an Austrian household is approximately 3559.9 kWh per year [11], when using the value for the year 2016. This value can be seen as a reference value for Europe. Per hour, an energy demand D of 0.406 kWh per hour can be calculated. Small industry customers, that are assumed to be present in the distribution grid as well, are referenced with a yearly average energy demand of 19214 kWh, respective 2.193 kWh per hour. Table 5 shows the demand values for different load types.

Year 2016	**Energy Demand (kWh/y)**	**Power (kWh/h)**
Residential	3559.9	0.406
Small	19214	2.193
Medium and large	7140501	815.126

Table 5: Assumed energy demand of load types, source: [11].

[4] The exchange rate is assumed to be 0.91 Dollar per Euro

An example is drawn from Thy-Mors Energi's[5] statistics regarding their outages for the year 2018. An outage covering four assets with a total number of 232 disconnected customers occurred, whose duration was 1.5 hours in total. Excluding the time for repair, the values from literature in chapter 3.1.2 can be seen as a good reference, because the concluded time for an outage was in fact 1.5 hours and 2 hours of repair.

	Scenario A: Current State	Scenario B: Net2DG	ΔENS
Cost per residential customer (Detection)	0.72 € - 4.99 €	0.27 € - 1.86 €	0.45 € - 3.13€
Cost per residential customer (Diagnosis)	0.24 € - 1.66 €	0 €	0.24 € - 1.66 €
Cost per small industry customer (Detection)	558.67 €	208.57 €	350.10 €
Cost per small industry customer (Diagnosis)	186.22 €	0 €	186.22 €

Table 6: Cost per customer for "Outage Detection" and "Outage Diagnosis", source: TU Vienna.

Therefore the ENS was calculated with the equation above and taking the values as lower (Table 3) and upper (Table 4) bound, the cost per customer for outage detection for this example outage can range from 0.72 € to 4.99 € in the Scenario A case, just like seen in Table 6. For the outage diagnosis, the cost ranges between 0.24 € and 1.66 €. With the Net2DG application, the costs might reduce to a range of 0.27 € to 1.86 € for the detection and zero for the diagnosis.
From the time benefits, that are shown in Figure 3, also improvements regarding the ***SAIDI***, in this case covering only the example outage from Thy-Mors Energi's data, can be drawn.

$$SAIDI = \frac{N^{Dis} \cdot T^{Dis}}{\sum N}$$

The calculation of SAIDI needs the number of disconnected users N^{Dis}, the time of disconnection T^{Dis} in minutes and the total number of customers $\sum N$.

Number of customers disconnected	**232**	**232**
Number of customers total	43814	43814
Duration of interruption (min)	90	16.8
$\boldsymbol{SAIDI}$	0.47656	0.08896

Table 7: Improvements in SAIDI for an example outage, source: TU Vienna.

Intuitively, this value for the SAIDI is not covering all outages of the respective grid, but only this single one. When calculating the improved SAIDI for a whole year, also temporary outages, which do not

[5] https://www.tme-elnet.dk/om-os/forskningsprojekter

require the dispatchment of a technician, and therefore are not directly affected by Net2DG's solution for an accelerated outage detection and diagnosis, should be considered.

3.1.2.2 Savings in personnel cost

Also, the expenses for personnel can be decreased by reducing the time for outage detection and outage diagnosis. Personnel can be dispatched more efficiently and the needed time for solving the problem of faults can be reduced. By applying an opportunity cost approach, it can be seen, that costs occur, if personnel cannot be assigned to different tasks.

$$\Delta C^P = W \cdot \Delta T$$

The ***savings in personnel costs*** for a single staff member ΔC^P can be calculated by simply multiplying the average wage W with the time reduction ΔT induced by the Net2DG solution.

	Average salary (€/h)	Total saving in outage detection per staff (€)	Total saving in outage diagnosis per staff (€)
Germany	14.32	6.73	3.58
Denmark	19.27	9.06	4.82

Table 8: Average salary in comparison, source: [12].

For the calculation of the benefit in monetary values, the average salary per hour is needed. For this, Table 8 gives an overview of the average wages for certain countries. Taking the German average hourly wage of 14.32 € [12] as an example, a comparison between Scenario A and Scenario B can be conducted. Following the time partition in Figure 3, 0.47 working hours of a single staff member can be avoided within the detection during a normal fault process. Additional 0.25 hours will be avoided during the diagnosis. Summed up, 0.72 hours per staff member can be avoided in total by applying the Net2DG solution. In order to apply these findings on an example of a DSO, it is necessary to know how many people are working on the revision of faults and which wage is used for personnel.

3.1.2.3 Qualitative Aspects: SAIFI and Availability of Network Assets

Furthermore, qualitative improvements can be discussed, although some quantification is not accessible in the process of the first CBA. An example would be the value for the SAIFI. The determination of SAIFI depends on the number of customer interruptions X in a certain time period.

$$SAIFI = \frac{\sum \mu \cdot X}{\sum N}$$

In addition to that, the failure rate μ is needed to calculate the value for SAIFI. However, there is no direct relation between a faster outage detection and diagnosis and the number of occurring faults, as neither the failure rate nor the number of outages can be improved. Still, a qualitative enhancement can be achieved by implementing the Net2DG solution. A clearer outage detection and diagnosis enables a better determination of faults, that are occurring in the distribution grid. Especially for very short-term temporary outages, even the notification is not always possible in a standard grid. Net2DG helps by improving the notification statistics and therefore improves the quality of SAIFI. When solely looking at this qualitative benefit in an isolated way, of course a KPI like SAIFI would initially be worse compared to a standard procedure. However, a better assessment of outages is in the general interest of a DSO, as this information can be processed further to achieve other benefits. Since also SAIDI is dependent on the outage statistics, that a DSO is able to measure in their grid, a qualitative improvement can be expected here as well. Besides, DSOs are obliged to report a precise measure of their individual SAIFI and SAIDI to regulators. The improvement of these KPIs is therefore of great value for a DSO.

Another aspect is the increase in the availability of network assets. When time for dealing with faults is overall reduced, the statistics for average network asset availability improve. However, this value is not obvious to be calculated. For a detailed analysis, comprehensive data on network assets, that are affected by faults, is needed. It would be necessary to categorize assets and observe the fault statistics for each category. Then, improvements could be measured. Since only a representative fault without a detailed list of affected assets is presented, the improvements in the availability of network assets cannot be quantified yet. Still, it can be definitely claimed, that this benefit is taking place with the Net2DG application. With further simulations taking place in the next year, a clearer view on these qualitative benefits will be achieved.

3.1.3 Future steps

A realization of the experiment, that has been defined in this chapter, will be conducted on the test site grid in 2020. With this, a more precise determination of time improvements for outage detection and diagnosis can be achieved. The data from the experiment can then be used in future grid models to simulate a standard grid operation. The results will not only affect the determined time benefits, but also the values for monetarization as well. Project partners will be able to include their individual data and values into the experiment. Therefore, a more individualized result for the savings in personnel cost, ENS and SAIDI will be determined. Since the distribution grid in Denmark, that is included as test site grid in the project Net2DG, is having smart meter deployment, the grid is most useful to draw outage statistics. Thus, a good representative image of outage durations and frequencies can be extracted from the smart meter. The test site grids are suitable to draw clear information about the durations and time frames, when detecting, diagnosing and removing outages in the distribution grid. The reason for this is the size of the grid and the DSO's willingness and ability to exactly measure time intervals in outage detection and diagnosis. The precise data, that is gathered both for the outage statistics and the time intervals of outage detection, diagnosis and removing, will enable the calculation of further KPIs. An example is the overall availability of grid assets. DSOs can expect to improve the overall availability of network assets in their grid. When outage durations are reduced, this value will improve not only regarding the timely availability, but also the availability of capacities over a year for example. Improvements cannot necessarily be monetarized directly, but are definitely in a DSO's interest and necessity (for example in benchmarking processes with special consideration of overall cost efficiency aspects).

Outage statistics can be very heterogenous between different distribution grids in different countries. Although permanent faults are quite rare in the test sites' grids in Denmark and Germany, outages can take a number of up to 140 per year, all taking a time of several hours including two whole teams for removing the outage [13]. Additionally, the affected customers can be very heterogenous, also influencing the cost of lost load. Thus, the benefits from increasing speed in detecting and diagnosing outages can add up to a substantial amount of money depending on the grid. The results presented here can be seen as a reference, which can be adjusted to different grid characteristics, as all values are calculated down to single customers.

3.2 Loss Calculation and Grid Monitoring

3.2.1 Description of achievable benefits

An advancement in the calculation of losses in the distribution grid helps the DSO to get a more detailed knowledge about the present grid assets. The advanced calculation of losses is therefore very closely related to a better grid monitoring, as the accessibility of information in the grid is increased and can be used for the same purposes.

In the first place, loss calculation is solely about the determination and calculation of losses in the grid. Subsequent benefits can then arise from processing the knowledge about these losses for example in order to increase the system efficiency. This, of course, would be implemented in the loss recovery, which is not directly implemented in the Net2DG solution yet. However, there are some benefits, that can be obtained from the calculation already, and also from the possibility to monitor the grid. An overview of all benefits and the corresponding KPIs arising from "Loss Calculation" and "Grid Monitoring" can be found in Figure 4.

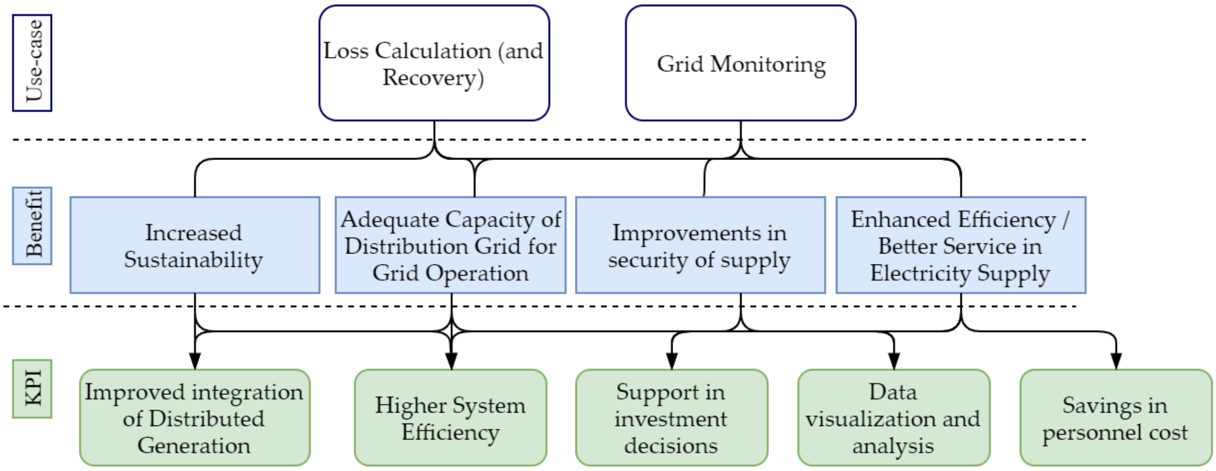

Figure 4: Benefits and KPIs from "Loss Calculation" and "Grid Monitoring", source: TU Vienna

The knowledge about losses in the grid within an advanced loss calculation can result in a better usage of the grid assets. The DSOs receive a better basis for planning and grid adjustments, if their knowledge about particular assets, that are causing losses, is broadened. From a qualitative point of view, the DSOs will gain a better accessibility to data. Visualization and the better analysis of the data are additional aspects of this accessibility. These benefits additionally are based in the advanced grid monitoring. Specific data for operating, maintaining and planning are made available for DSOs through Net2DG application. Consequently, the DSOs can apply ambitious plans like increasing the overall system efficiency. Also, by having knowledge about the grid losses, the integration of renewable energy sources can be fostered, as DER can be spread. The information and calculation of losses can help in this matter by identifying weak parts of the system, that can be adjusted. In combination with a better visualization, the DSO will get to use more existing information from the grid and can process it to do changes. Thus, both the enhanced loss calculation and the improved grid monitoring can be utilized in order to get a better plan for investment decisions. These investment decisions can either be interpreted as adjustments, that can be conducted immediately or as long-run grid reinforcements. More precisely, a DSO can adjust the grid in two possible ways:

(1) Grid reinforcements, like the replacement of lines can be conducted. Also, grids can be reinforced by adding new lines [14]. This procedure represents the long-run grid adjustments. However, grid reinforcements are expensive and cost-efficiencies can be achieved, if they are avoided.
(2) Concepts like grid reconfiguration [15] [16] as an example can be applied by the DSOs without directly reinforcing the grid. A necessary requirement for this is an advanced way of data collection and data processing. New communication, monitoring and control infrastructure is needed to apply these control schemes [17]. Therefore, the Net2DG solution is most appropriate to help DSOs conducting them. These adjustments would not require an advanced loss recovery, but can be applied with a more advanced calculation of losses and a better visualization of the grid.

Under the assumption of growing DER in the distribution grids in the future, adjustments in the grid, as defined here, need to be done to increase the hosting capacity of the grid.

3.2.2 Determination of necessary data and calculation of reference example

The first benefit is the improved integration of renewable energy sources which is seen as DER on the distribution grid level. This is closely linked to the support in investment decisions, as the hosting capacity can either be increased by reconfiguration based on data accessibility and visualization, or grid reinforcements, like long-term investments. In this chapter a reference example is defined how the hosting capacity of a distribution grid can be increased by a DSO's adjustments based on advanced data accessibility. For this purpose, it is necessary to define how the hosting capacity can be measured. The hosting capacity for DER of a distribution grid is defined as the maximum possible overall capacity of DER, that can be installed in the grid without having operational violations like security or voltage stability issues [18]. For this, it is again necessary to be able to make a comparison between two states of the grid mode:

- Standard operational mode of the grid without a DSO's adjustments
- Data collection, data visualization and loss calculation implemented in the grid in order to make adjustments like grid reconfiguration

Although other concepts can be applied, grid reconfiguration by a DSO is dependent on the access to data about losses and an advanced monitoring application. Therefore, it is chosen as a reference example to measure the benefits regarding hosting capacity and grid expansions or reinforcements. The reference distribution grid, that is used for the comparison, is a simple distribution grid consisting of 33 busses and covering peak load of 3715 MW and 2.3 MVar [19]. It can be declared as a reference distribution grid, as it can be found anywhere. There are eight spots (G1-G8) at these busses with distributed generation. According to these spots, the maximum hosting capacity can be determined.

The grid has been used widely in literature to do analyses. A graphical depiction of the grid can be seen in Figure 5.

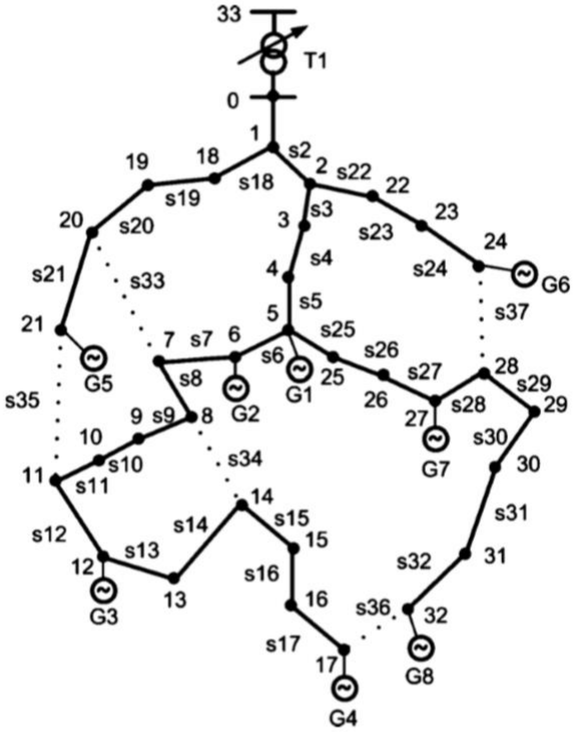

Figure 5: Reference grid used for the reconfiguration application, source: [17].

3.2.2.1 Improved Integration of DER

Within this baseline grid, the gains in hosting capacity for DER can be observed by comparing the two operational modes. It is assumed that all spots for distributed generation are included. However, there are two different possibilities for grid reconfiguration. The static reconfiguration allows only a single reconfiguration for the whole optimization period, whereas the dynamic reconfiguration allows for a dynamic adjustment of the grid in each timestep. Table 9 shows the results for the maximum hosting capacity within the test network in Figure 5.

	No reconfiguration (reference)	Static reconfiguration	Dynamic reconfiguration
Hosting capacity (MW)	7.154	7.228	7.483
Change (%)	-	+1.034	+4.599

Table 9: Maximum hosting capacity for DER under different reconfiguration schemes, source: [17].

The grid reconfiguration, which demands advanced knowledge about losses and the grid assets, enables an increase in the maximum hosting capacity for DER. With the information provided by the Net2DG application, advanced configuration schemes can be performed, that allow an increase in the hosting capacity. However, the exact values on how much the hosting capacity can be increased depends very much on the grid. The values provided in Table 9 can be declared as reference values for comparison in future applications of the Net2DG project. The financial benefit regarding the hosting capacity comes from the curtailment of energy that can be avoided. Following an opportunity cost approach, the generated energy of DER, that has to be curtailed, inherits a monetary value. Literature shows, that grid reconfiguration based on advanced data access enables reductions in curtailments of renewable energy on the distribution grid, which is a clear indicator for a higher hosting capacity [20]. When renewable energy from DER is curtailed because of the missing hosting capacity and would not be curtailed in any other case, it has to be delivered from a different source. Thus, the monetary value of the curtailed energy can be determined. The energy sources, that would not have been producing, if the hosting capacity was sufficient, inherit a marginal cost structure, that can be used as a value for the curtailment. Based on the merit order of each grid, the price setting power plant can be considered with and without the amount of spillage.

3.2.2.2 Higher System Efficiency

Another aspect of the improved loss calculation and grid monitoring is the improved system efficiency. This indicator is usually measured by the ratio of energy input and energy output. One could argue, that this value is somehow not directly related to a better loss calculation and a better grid monitoring, but rather a part of loss recovery (which is not yet implemented). Nevertheless, the information provided by the Net2DG solution is helpful again for grid adjustments, as data accessibility is increased. A useful example is again the grid reconfiguration, that can be conducted by DSOs in their grid, because it is dependent on the determination of losses and the data accessibility. To identify the grid efficiency, it is necessary to determine the losses in a grid. The improvement and consequently the benefits are obtained by comparing these two states:

- The grid and its losses without any adjustment like grid reconfiguration
- The grid and its losses including adjustments like grid reconfiguration

Therefore, the benefit of an increased system efficiency can be calculated as follows, whereas the financial benefit is entirely based on the reduction of losses.

$$\Delta Eff = \left(\frac{E^{Delivered}}{E^{Input}}\right)_{Adj} - \left(\frac{E^{Delivered}}{E^{Input}}\right)_{NoAdj}$$

In a usual distribution grid, the losses can take a value of about 10.6 % [21], which shows, that there is a big potential for possible savings. Nevertheless, the magnitude of losses depends on the individual grid and the magnitude of losses is heterogenous [22]. The physical losses are the difference between the energy input and the energy delivered.

$$Losses = E^{Input} - E^{Delivered}$$

Again, just like in the case of increasing the hosting capacity, the system efficiency can be examined based on the grid seen in Figure 5 in order to ensure maximum comparability. Losses can be reduced by allowing grid reconfiguration [23].

	No reconfiguration (reference)	**Static reconfiguration**	**Dynamic reconfiguration**
Physical losses (MWh)	481.8	340.9	340.2
Change (%)	-	-29.2	-29.4

Table 10: Loss reduction under different reconfiguration schemes, source: [23].

Again, just like for the increasing of the grid's hosting capacity, the reduction of losses via grid reconfiguration can be compared for the cases of a static reconfiguration, allowing one adjustment, and of dynamic reconfiguration, allowing several adjustments after each time step. In this example, losses could be reduced by more than 29 %. The losses inherit a financial value, which can be calculated by the average spot market price for electricity [24] for the months between August 2018 and August 2019 in order to get a contemporary approximation of the monetary value, as seen in Table 11. The spot market price for one MWh of electricity is widely used as a monetary value for the losses [25].

Month	Average price per MWh DE (€)
08/18	56.19
09/18	54.83
10/18	53.12
11/18	56.68
12/18	48.13
01/19	49.39
02/19	42.82
03/19	30.62
04/19	37.06
05/19	37.84
06/19	32.52
07/19	39.68
08/19	36.85
Average	***44.29***

Table 11: Average spot market prices for electricity, source: [24].

Taking this average value of 44.29 € per MWh as an approximation, the monetary value for a small part of the distribution grid can be calculated.

	No reconfiguration (reference)	Static reconfiguration	Dynamic reconfiguration
Physical losses (MWh)	481.8	340.9	340.2
Value of losses (€)	21338.92	15098.46	15067.46
Saving (€)	-	6240.46	6271.46

Table 12: Cost benefit from loss reduction via configuration, source: TU Vienna.

As it can be seen in Table 12, the value of losses for this specific example [23] without any usage of data from the grid to do adjustments like reconfiguration, can take a monetary value of over 21338 €. With grid reconfiguration, it can be reduced to about 15067 €, which makes savings possible. The cost of losses can therefore be reduced by more than 6271 €. Of course, the losses heavily depend not only on the grid topology, but also on the method to avoid them. The example of grid reconfiguration shown here can be seen as a first reference example to show the potential of Net2DG's solution to help reducing losses. It does not represent the value for any test site like Landau's or Thymors' grid yet.

3.2.2.3 Support in Investment Decisions

The advanced accessibility of smart grid data for the DSOs can help with investment decisions for the grid. Without the use of intelligent, leveraged network data, the investments like grid reinforcements are merely uncontrolled and can end up in overinvestment and excessive cost [26]. On the other side, the usage of data leveraged by the Net2DG solution can help to make better investment decisions. This benefit can be identified as savings in necessary grid expansions under an expected growth of DER in the grid in the future.

$$\Delta Cost = InvC_{ref} - InvC_{Net2DG}$$

The difference between necessary investment cost that would occur without any usage of smart meter data and the reduced cost including the usage of smart meter data results in financial benefits. The scenario is central in this case: By an increase of DER in the distribution grid (and possibly a change in demand for electricity), grid expansions will be necessary, if the potential of managing the present grid is exhausted.

Cost saving potential very much depends on the overall data accessibility that is possible in the network. A comprehensive example is shown in the literature [27]. The Net2DG solution is able to leverage smart grid data and use it, but it is dependent on the grid users' willingness to provide the individual smart grid data. In the optimal case, all smart grid data is available to the DSO, but a smaller amount is realistic. It therefore makes sense to define scenarios with different levels of data availability to the DSO. Since grid reinforcements are necessary due to the evolution of demand and generation, the scenarios need to analyze grid expansion costs under different levels of data availability for a comprehensive future scenario. Under the assumption of a 30-year scenario, the usage of DER, electric vehicles, batteries and heat pumps play an important role in the future and are included in the scenario.

As different levels of data availability, a 50% case and a 100% case can be analyzed. The latter one is the case for the optimal assumption, that every household provides the full smart meter data for the Net2DG solution. A more realistic version is the case with 50% of the data available to the DSO.

The total cost of the simulated network reinforcements can be calculated down to a single feeder cable, assuming a cable cost of 45000 € per km and a time frame of 40 years.

	Discounted cost in €	**Percentage change**
Reference	774	-
50 % data availability	680	-12.2
100 % data availability	520	-32.8

Table 13: Discounted costs for feeder cable reinforcements for different levels of data accessibility, source: [27].

As seen in Table 13, the discounted cost per feeder cable in the context of grid reinforcements can be reduced in total numbers from 774 € down to 520 €. From these total numbers, a percentage reduction of costs can also be obtained and transferred to different grids and cost estimations for whole grid expansion plans. In terms of grid models, a distribution network under the stepwise expansion of DER up to 750 kWp can be analysed regarding the necessary total grid reinforcements [28].

	Total cost in €	**Cost reductions in €**

Reference	168625	-
50 % data availability	148052.75	-20572.25
100 % data availability	113316	-55309

Table 14: Total cost of grid reinforcement with a DER expansion scenario grid, source: [28], TU Vienna.

For this example, total grid reinforcement costs of 168625 € would arise to deal with the growth in DER (in this case PV). Taking the relatively possible reduction values [27], cost savings up to 55309 € can be possible. This value is relevant for the whole expansion of 750 kWp.

	Cost per kWp in €	**Cost reductions per kWp in €**
Reference	224.83	-
50 % data availability	197.40	-27.43
100 % data availability	151.09	-73.75

Table 15: Cost of grid reinforcement per kWp with a DER expansion scenario grid, source: TU Vienna

Normalized per kWp DER expansion, the cost for expansion in the reference case are calculated as roughly 225 €, as seen in Table 15. The reduction can be down to 73.75 €, which results in a cost estimate of 151.09 € per kWp. With these values, every distribution grid can be analysed and the cost can be estimated. Thus, the benefit of “Support in Investment Decisions” can be characterized as clear cost reduction in necessary network expansions for the integration of DER.

3.2.2.4 Qualitative Aspects: Data Visualization and Analysis & Savings in Personnel Cost

Apart from the financial benefits that can be linked to an advanced loss calculation and grid monitoring, also some qualitative aspects, that cannot be measured yet, have to be mentioned.
The availability of data and especially its improved accessibility is of qualitative value for a DSO. The possibility to control the grid better can be mentioned as one characteristic of that. Also, leveraged data can be used for more detailed statistics and evaluation of grid data. Obviously, there is no direct monetary value for this benefit.
Personnel cost can be reduced from a better grid monitoring in combination with improved loss calculation. The identification time for grid assets, that cause losses, is not only a time-spending, but also a difficult task. Staff members’ work efficiency would be increased substantially by the implementation of a better grid monitoring. It is possible, to get a monetary estimation for the benefit. However, the time reduction itself is hard to be determined. The task is very much dependent on the grid and on the DSO. An approximation in literature is not available either.

3.2.3 Future steps

To determine the individual potential of grid monitoring and loss calculation, grid models are needed in future work. A detailed grid model incorporating the Danish test site grid is already in work in the current project status. This model will be further expanded in the next year and could be complemented with considerations of grid monitoring and the options for loss calculation. This would be necessary in order to progress from the arbitrary example network towards the individual distribution grids on the test sites. It is necessary to put a special focus on the grid’s hosting capacity for DER and also overall efficiency. Also, other options than grid reconfiguration can easily be applied as an extension or refinement of the benefits obtained from “Grid Monitoring” and “Loss Calculation”. However, it is not exactly clear yet, how the grid model is extended with respect to these use-cases. The central aspect is, that benefits need to be based on the acquisition of information on the grid (losses) and the direct options that arise from this data availability. Therefore, a data-based ex-ante determination of benefits from a grid perspective is necessary.

A clear connection to the use-case of “Automatic Voltage Regulation” is given. Grid adjustments like grid reconfiguration can also solve voltage stability issues [29]. In addition, proactive investigations and the gathered information in the grid can be used to do adjustments. By this, clear cost reductions can be achievable in terms of voltage events [30]. It therefore makes sense to use the same grid model for the named use-cases. Consequently, there needs to be some more specification and coordination in the future, on which aspects are being measured in the grid models. The results in this chapter show a possible solution to measure and monetarize benefits from the use-cases of “Grid Monitoring” and “Loss Calculation”. It will be checked in the near future, how these solutions are applicable in the planned grid models or whether other aspects will be measured.

3.3 Automatic Voltage Regulation

3.3.1 Description of achievable benefits

The integration of renewable energy sources as DER on the distribution grid level imposes different challenges for the grid. In certain time periods, network congestion can occur [31], if the hosting capacity is not sufficient. However, not only the transportation of electricity within the network is affected, but also the security and continuity of supply [32]. Classical measures for the security of supply under the integration of renewable energy sources is the voltage quality, which in the end is a proxy for the hosting capacity of a distribution grid. Basically, voltage quality can be measured in different ways. The absolute number of voltage level violations can be considered to be such a measure. Also, the relative voltage violation, in case such a violation takes place, can be named. By automating voltage regulation, the number of voltage violations are expected to get less, because the system can dynamically adjust. In consequence to that, the relative size of still possible voltage violations is expected to be reduced as well. By applying automatic voltage regulation, it is expected, that DERs’ integration in the distribution grid can be enhanced. With the existing grid, more renewable energy sources can be used without causing serious congestions and voltage problems. Necessary grid reinforcement and grid expansions can be deferred or avoided for the closer future, if voltage regulation can be enhanced. In the end, the benefits for the DSOs come from that. There are no clear, direct financial benefits from integrating more DER into the distribution grid. However, grid reinforcements can cause substantial cost for a DSO. Reducing the necessity for grid expansions is also resulting in clear financial benefits. Figure 6 gives an overview of the achievable benefits and KPIs resulting from an automatic voltage regulation.

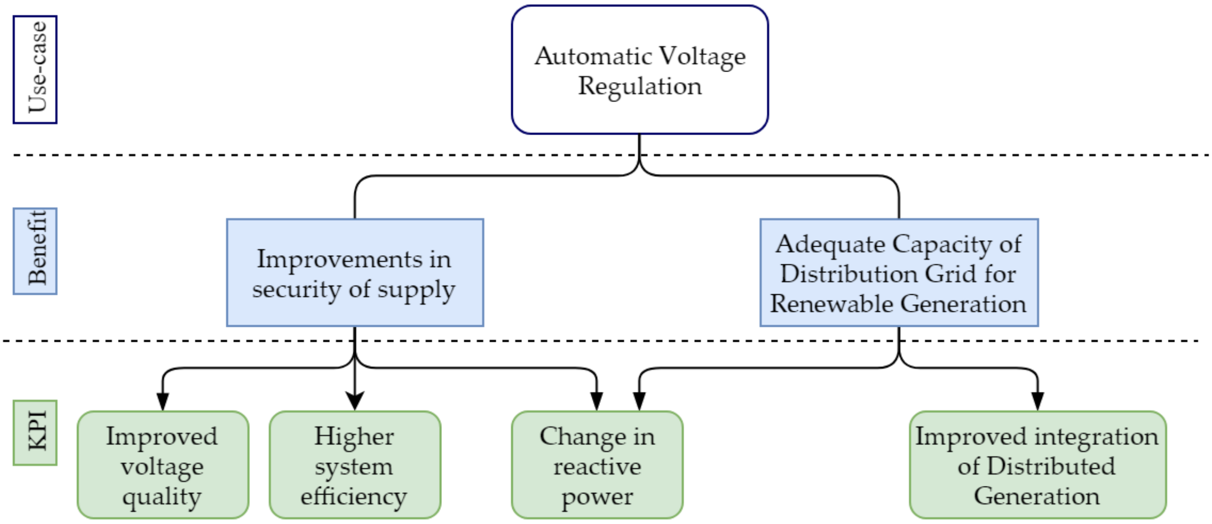

Figure 6: Benefits and KPIs from "Automatic Voltage Regulation", source: TU Vienna

The Net2DG approach helps to implement advanced voltage control mechanisms by leveraging more network data, that can be extracted from smart meter infrastructure in the grid. More information about voltage and frequency can be obtained in a more detailed time resolution.

3.3.2 Determination of necessary data and calculation of reference example

Various voltage regulation methods currently exist. A commonly used method is the utilization of tap-changing transformers, however, several drawbacks are present, such as a large demand for thyristors and poor transient voltage rejection [33]. Another example is the Dynamic Voltage Restorer (DVR), which is a custom power device used in order to resolve voltage issues. The efficiency of the DVR distinguishes the device from other custom power devices [34]. The implementation of AC-AC voltage-voltage converters can solve problems related to voltage sags and extended undervoltages [33]. Fault Current Limiters (FCL) are another method of voltage regulation. FCLs are normally utilized in order to limit large fault currents. However, the FCLs can also reduce voltage sags, thus lessening economic losses caused by production outages [35]. Lastly, implementing energy storage systems in distribution grids could potentially reduce voltage quality issues related to the increasing implementation of distributed energy resources (DER) [36].

Voltage controllers are relying on accurate information regarding the voltage at each network node in order to ensure adequate voltage quality. Currently, most distribution grids only have measuring points at primary substations [37]. By utilizing leveraged data from Net2DG solutions, advanced voltage regulation mechanism can therefore be implemented or improved.

3.3.2.1 Improved voltage quality

The first benefit to calculate is the cost benefit, that arises from reduced or weakened voltage violations. The following equation can be used in order to find the monetary benefit of automatic voltage regulation and the utilization of leveraged data from Net2DG solutions.

$$\Delta C_{violation} = \left(\sum_{x}^{X} M_x * C_x\right)_{ref} - \left(\sum_{x}^{X} M_x * C_x\right)_{Net2DG}$$

The total cost benefit $\Delta C_{violation}$ regarding voltage violations and voltage quality issues can be calculated by building the difference between the reference cost in the current grid status and the improved cost from the status with Net2DG implementation. For this, the sum over the occurring voltage violations X has to be built. Since these violations are very heterogenous, they have to be analyzed individually regarding the size or intensity of violation M and the cost C that is attached to this. A possible measure for the cost could be spot market prices for electricity, if the voltage violation leads to a lower system efficiency for example, as shown in Table 11.
Further information regarding monetary values is still needed to calculate the benefits of automatic voltage regulation. It mostly depends on the consequences that voltage violations mean to the distribution grid. Sufficient data for this calculation is expected to be provided next year, as a grid model will be implemented and relevant voltage values will be measured.

3.3.2.2 Higher system efficiency

Improved voltage quality is crucial to reduce losses in the power grid. Automatic voltage regulation is a measure to increase the quality of the voltage, and thereby also the security, quality and efficiency of power systems. Several reasons for reduced voltage quality exist. Increased implementation of distributed energy resources, operation of transmission grids close to maximum capacity [38] and faults on the distribution level could result in voltage sags or swells, which again could lead to equipment failure and shut downs [34]. Consequently, improved voltage regulation could result in significant economic savings.
The voltage level of distribution grids must remain within a given range of + 10% and – 6% for 230 V grids and ± 6% for 11 kV grids, in order to enable proper functionality of equipment and power systems [37]. Unregulated line voltages can lead to significant issues, such as overheating and complete process shutdown. Consequently, efficiencies are reduced, power demand is increased and the cost for power is higher [33]. An average distribution grid costumer will normally experience around 70 instances with a voltage drop below 70% of the nominal voltage per year. Using an AC voltage-voltage converter corrected the voltage sag by 60% from the nominal line [33]. The largest voltage drops usually occur during winter peak load. During this period, automatic voltage regulation must aim for a voltage level that ensures that the minimum costumer voltage still exceeds the lower statutory limit [37].

3.3.2.3 Improved Integration of Distributed Generation

The rapidly increasing amount of DER implemented in distribution grids could be a benefit both for consumers and for the environment. However, the rising amount of DER could also lead to voltage violations, depending on the size, location and operation mode of the distributed generators [39]. Wind turbines and CHP plants are examples of distributed energy generators commonly implemented in the distribution grid. Traditionally, wind turbines were connected to low-voltage networks. However, larger turbines and clustered windmills result in more power being generated, hence DER often need to be connected to medium-voltage or even high-voltage networks [40].

An experiment was performed in order to evaluate the possible cost savings related to automatic voltage regulation and implementation of DER in a distribution grid [41]. The amount of maximum generated power by DER was increased stepwise and the corresponding average cost for grid expansion was calculated. The average costs from grid expansion for 750 kWp and 1 kWp are shown in Table 16. Significant cost savings can be made by implementing automatic voltage regulation. Utilizing Net2DG solutions could increase the hosting capacity of the distribution grid, thus allowing for more DER to be implemented. Additionally, grid reinforcements can be deferred or avoided, resulting in significant cost savings.

	power	*Average cost of grid expansion*
No automatic voltage regulation	750 kWp	168.625 Euro
	1 kWp	225 Euro
$cos\ \varphi$ (P)-regulation	750 kWp	83.925 Euro
	1 kWp	112 Euro
Q(U)-regulation without power factor limitation	750 kWp	56.552 Euro
	1 kWp	75 Euro

Table 16: Cost of grid expansions based on voltage control mechanisms, source: [41].

The impact of DER on the voltage profile in distribution grids is subject to the power flow in the grid. Depending on the X/R ratio, feeder load and injected power by the DER, power flows can change directions and voltage levels can rise. Injected power that is lower than or equal to the load of the feeder does not have a considerable impact on the voltage profile. A large quantity of injected power could however lead to voltage rises within the grid. The voltage rise stems from reversed power flow. Additionally, implementing DERs in the distribution grid can have transient effects on the voltage level, due to rapid changes in the output of the DERs. This could lead to voltage drops, voltage flicker, harmonics and resonances [40].

Active voltage regulation in distribution grids can increase the implementation capacity of DER. By controlling the target voltage of automatic voltage control relays at primary substations, distributed generation capacity in distribution grids can increase significantly [37]. Constraining the DER generation in times of low demand could be an operational approach to lowering the voltage, and thus avoiding costly grid expansions [40].

3.3.3 Future steps

A grid model representing Thymors' grid is planned within WP4. The model will measure all aspects related to automatic voltage regulation and technical results for reductions in voltage violations etc. is therefore awaited in the next year. The data will be used in order to provide precise cost estimations. Additionally, grid extensions to the other test side grid is possible, and further KPIs could be added in the case that the grid model provides any further insight.

3.4 Preventive Maintenance

3.4.1 Description of achievable benefits

The key benefits within "Preventive Maintenance" come from a reduction in necessary maintenance works both for grid elements like feeder cables and other network assets like substations or transformers etc. With a preventive approach, outages and corresponding excessive maintenance work can be avoided. From this procedure, multiple benefits arise. The determined benefits and corresponding KPIs that are going to be measured in the CBA can be seen in Figure 7. It has to be clearly noted, that the approach for preventive maintenance is not yet fully determined, as it is a work planned for future work packages. Still, the KPIs, that are going to be relevant within the CBA, can be clarified in advance. Thus, the respective data and results necessary for a benefit calculation can be drawn.

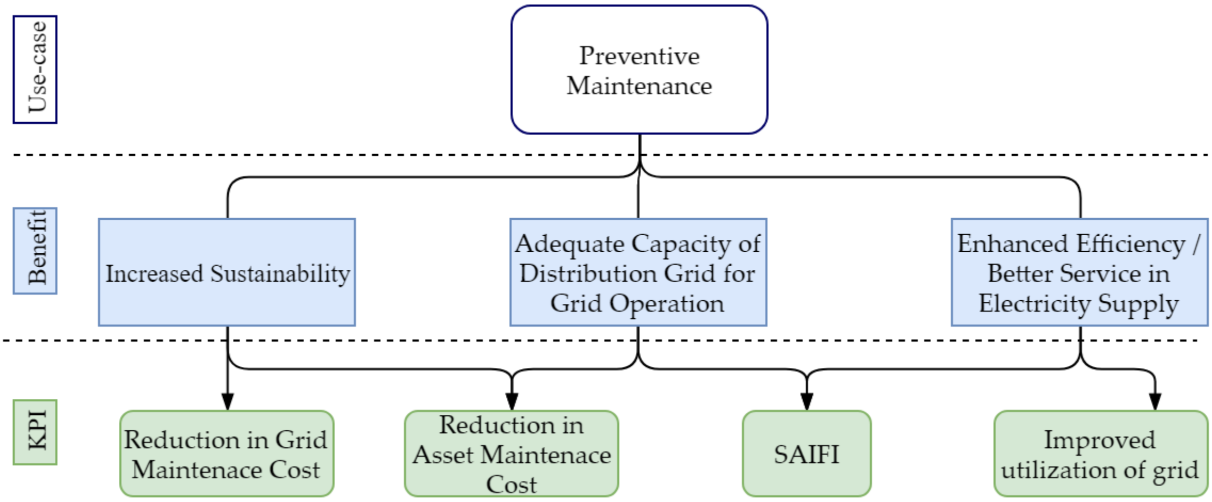

Figure 7: Benefits and KPIs from "Preventive Maintenance", source: TU Vienna.

A preventive approach to find assets in the grid that are close to an outage can result in a reduction in maintenance cost. The basic precondition for that is extensive maintenance cost and also secondary cost resulting from outages in the grid, that are arising, if the fault cannot be foreseen. By a preventive approach, the cost could be reduced, as excessive maintenance works are avoided. As described in 3.1, there are also costs arising during the duration of outages in the grid. If outages can be avoided, the resulting value can be calculated by comparing the cost of the preventive maintenance with the cost resulting from a fault, that was not possible to be discovered without the Net2DG application. This advantage is twofold: Either a feeder in the grid is affected (in this case, only permanent feeder faults would be relevant) or an asset working in the grid, e.g. substations. The avoidance of outages directly affects the value for SAIFI of a DSO. This value is highly relevant, as it is notifiable towards a regulator. With the usage of a preventive maintenance, the frequency of outages can be reduced. Consequently, also the SAIFI value decreases.

From the enhanced continuity of supply, an improved utilization of the grid can be achieved. With an increased number avoided of faults by preventive maintenance, the availability of grid elements increases. With reduced unavailabilities over a certain time period, the utilization of the grid is enhanced.

3.4.2 Determination of necessary data and possible calculation options

The benefits in the use-case of “Preventive maintenance” will mainly be based on the avoidance of larger maintenance works by determining weak points in the grid, that might need a replacement or repair. Therefore, the reduction in maintenance cost is the central benefit. It is twofold: A distinction has to be made between parts of the grid and assets. By grid parts, mainly lines and feeder cables are meant. On the other hand, grid assets are merely objects like a transformer or a substation. Since both their replacement works and their lifetimes can be considered different, the distinction makes sense. The reduction in grid maintenance cost demands the choice of a central device, in this case it would be the choice of a feeder cable. When it comes to maintenance, feeder cables are the most affected grid part [6]. The central reason for the faults is deterioration.

3.4.2.1 Reduction in grid maintenance cost

With a preventive maintenance approach, the looming fault could be identified and fixed, before an outage with all its consequences occurs. It is therefore necessary to compare the cost arising from maintenance work in the standard way, the grid is operated at the moment, and the advanced way including the preventive maintenance work.

$$\Delta C_{grid} = C_{usual} \cdot N_{outage} - C_{preventive} \cdot N_{preventive}$$

Since the overall benefit is aimed to be determined, the number of outages N_{outage} is also necessary, if preventive maintenance work $N_{preventive}$ needs to be performed more frequently in comparison over a certain time period. The difference between the two values is giving the financial benefit then.

3.4.2.2 Reduction in asset maintenance cost

The same approach fully holds for the obstructed assets in the grid. Only the devices, that are looked at are different. For network assets, the lifetime might be different to cables, especially in the context of different load patterns as part of DER [42].

$$\Delta C_{asset} = C_{usual} \cdot N_{outage} - C_{preventive} \cdot N_{preventive}$$

Again, the difference between the two values is giving the financial benefit. The determination of exact values will be part of future research.

3.4.2.3 SAIFI

The system average interruption frequency index (SAIFI) is again affected by the use-case of “Preventive Maintenance”. SAIFI is a highly relevant measurement for DSOs, that has to be reported and is used for different company-internal strategies. If the Net2DG solution is able to reduce the number of outages by applying preventive maintenance, that leads to a total avoidance of some faults in the grid, the SAIFI will take a much better value for specific DSOs.

$$SAIFI = \frac{\sum \mu \cdot X}{\sum N}$$

Just like before, the failure rate μ, the number of customer interruptions X in a certain time period and the total number of customers N is needed to calculate the SAIFI. Basically, the number of customer interruptions and the failure rate would both improve (the value would reduce) and SAIFI would reduce. The important values for the calculation of the market-relevant benefit will be used in the future CBA after completion of the use-case.

3.4.2.4 Qualitative aspects: Improved utilization of grid

Another benefit, that was used in different use-cases before, is the qualitative benefit of an increased utilization of the grid. By increasing the availability of network assets over a certain time period, in which no outages occur because of preventive maintenance, the utilization of the grid can increase. If the utilization of the grid can be increased, also the efficiency of the grid can be improved. This benefit is relevant, as the results and statistics can be used by DSOs in different ways. An example would be a benchmarking process regarding cost-efficiency. If the higher utilization can be measured and quantified, this can result in higher overall efficiency values. A clear monetarization of this benefit is rather difficult, as there are no direct financial consequences arising for "Preventive Maintenance".

3.4.3 Future steps

As from the project plan, the use-case "Preventive Maintenance" is not quantified within this deliverable. For a proper analysis, necessary information such as reference vaues from literature shall be available. A future deliverable regarding the CBA will contain more elaborate calculations of the named benefits.

4 Formulation of a business model

The first CBA reference for the project Net2DG, as presented in this deliverable, is the base for the definition of a business model regarding the Net2DG solution. First of all, it is necessary to define, what a business mode is. As presented in the literature, three components are necessary for a complete business model [43]:

(1) **Customer value** proposition
(2) **Profit** formula
(3) **Key resources** and **processes**

For defining a customer value proposition, it is initially relevant to define the group of customers for the Net2DG solution. Since the project aims to leverage network data from smart meter infrastructure in the distribution grid, the customer group is clearly European DSOs. However, smart meter infrastructure is not yet fully deployed in Europe [44]. In addition, the developments of the deployment in the future are not clear [45]. Also, within the project status, the German test site distribution grid in Landau does not have full deployment of smart meters yet, whereas the Danish grid at Thy-Mors has full smart meter infrastructure already. The current status of smart meter deployment is indeed required to fully exploit the benefits of the Net2DG solutions, but full Europe aims to install a smart meter infrastructure in the future. Thus, not only the DSOs with a Net2DG-ready infrastructure are potential customers, but also DSOs that plan to implement smart meters in the closer future, as is demanded from institutional side [46].

Since this CBA's first run has the clear perspective of benefits for DSOs, the **customer value** is clearly defined. The determination of the customer value proposition is the central aspect and purpose of the CBA. Although the exact values for a benefit estimation are not yet fully clear, the general arguments supporting the implementation of the Net2DG-solution in the grid can be named as customer values. A short summary is shown in Table 17.

Use-Case	Benefit / Relevant KPI	Additional aspects
Outage Detection & Diagnosis	Reduction in ENS	
	SAIDI improvement	
	Reduction in personnel cost	Higher work efficiency
	SAIFI qualitative improvement	

	Higher availability of network assets	
Loss Calculation & Grid Monitoring	Improved Integration of DER	
	Higher system efficiency	
	Support in investment decisions	Reduction in grid reinforcements
	Data visualization	
	Savings in personnel costs	
Automatic Voltage Regulation	Improved voltage quality	
	Higher system efficiency	
	Change in reactive power	
	Improved integration of distributed generation	
Preventive Maintenance	Reduction in maintenance cost	Grid and network assets
	SAIFI improvement	
	Improved utilization of the grid	

Table 17: Customer value proposition of Net2DG solutions for a DSO, source: TU Vienna.

As written in this deliverable, for most of these benefits, a financial comprehension already exists now as explained in the respective chapters. The exact costs have to be individualized on certain DSOs' grids, however. This means, an exact general solution for the value of benefits for all DSOs' grids cannot be provided. The KPIs are defined in accordance to DSOs' input. This means they are all highly relevant for DSOs and all represent an innovative approach to support daily grid operation. Assuming a fully rational acting DSO, the Net2DG solution provides financial and also qualitative improvements. The Net2DG solution does not imply any operational costs to a DSO, thus infrastructure development costs (such as the smart meter roll-out) is independent from the concept. Cost for the DSO will certainly arise from receiving the services of data processing and the software costs within the Net2DG solution. Another aspect, that must not be neglected, is the role of consumers and prosumers in the end. The information from smart meters is to a large extent in property of this group. To build up a working customer relationship between DSO and consumers/prosumers as the main source of data procurement, financial incentives have to be set. In particular, consumers and prosumers have to be incentivized to share data from smart meters with the respective DSO.

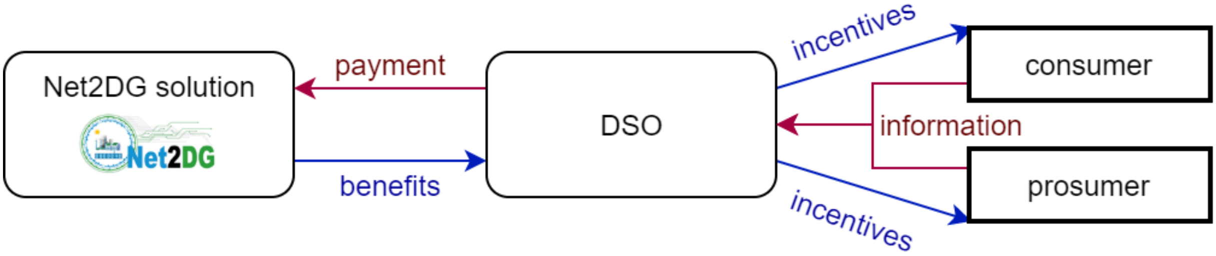

Figure 8: Marketing channels of the Net2DG solution, source: TU Vienna.

A first overview of the respective marketing channels can be seen in Figure 8. The graphs summarize the two stages of customer interaction. It is not clear yet, how consumers and prosumers will be incentivized and by whom.
Apart from the customers of Net2DG, also the provision of the Net2DG solution has to be profitable as well. Therefore, a profit formula has to be defined for the respective partners included in the Net2DG project, that are providing the services in the future. This profit formula is the basic idea, on how the project results are being utilized for market implementation in the end. It gives the intuitive concept for generating profits.

$$\pi^{Net2DG} = R - C$$

Basically, the profits π^{Net2DG} of implementing the Net2DG solution into the market, are calculated as the difference of revenues R and costs C. Revenues can be defined as the payment by the respective DSO for the services provision. To identify this value, the maximum willingness-to-pay (WTP) can be used as an approximation. By assuming a rationally acting DSO, the maximum WTP is the equivalent to the customer value, that has already been defined. The CBA results presented in this deliverable serve as a first impression of this customer value. Therefore, the revenues R can be considered as the summary of benefits from the CBA. When applying the maximum WTP, profits are maximized, as revenues are maximized as well. However, it has to be assumed, that each DSO can be offered an individual Net2DG concept, that incorporates the specific grid characteristics. The cost C is the cost of providing the Net2DG services. This value is not reliably determinable in the current status of the project, but is planned to be covered in future work.
As a final aspect of the business model definition, it is necessary to define **key resources**, **processes and partners**. These three are considered the central components of the business model to work in the end. The key resource for the Net2DG solution to work as a business case is the provision of the respective infrastructure. This is twofold: On the one hand, DSOs and consumers need to be included in a smart grid. This requires the roll-out of smart meters in the distribution grid. On the other hand, the Net2DG infrastructure has to be able to process the data from the smart grid. For this, mainly a functioning ICT is necessary. Key processes are directly linked to the working infrastructure provided by the Net2DG project and its partners. Basically, they can be defined as the theoretical implementation of the Net2DG solution into grid models and also test sites. The functions of these processes are being researched and tested within the project and described in the other WPs' deliverables. Relevant for this is the integration of key partners from the practical grid operation into the theoretical research aspect. Especially manufacturing companies and DSOs are to be named in this context. By integrating them as providers of key resources into the definition and testing of key processes, the applicability of the project results is ensured. Thus, all other WPs' work as well as the CBA define the character of the business model. Since all these attributes are already implemented in the project structure, the business model has sufficient potential to be refined in the future steps of the project by including individual and more precise project results.

5 Conclusions and outlook

In this deliverable the concept for the CBA was first applied. For this, the use-cases of "Outage Detection", "Outage Diagnosis", "Grid Monitoring", "Loss Calculation", "Automatic Voltage

Regulation" and "Preventive Maintenance" were discussed with the project partners in order to determine their functions and corresponding benefits for a DSO as potential customer. The benefits were then attached to specific KPIs, that can work as a way of calculating and monetarizing the benefits. In the context of these, some of the use-cases could be grouped together because of the similarity of the identified benefits.

It could be shown, that the challenges induced by a growth of renewable energy input even into the distribution grid, can be dealt with by applying the innovative concepts of the Net2DG project. These concepts help realizing the EU targets for the closer future. Thus, overall economic and ecologic targets can be met by the implementation of Net2DG solutions in the distribution grid. Grid operation can be adjusted to the advanced demands of security of supply requirements by reducing outage probabilities and minimizing grid losses. The integration of renewable energy sources is fostered by utilization of network data and increasing the grids' hosting capacity. Therefore, the concepts of Net2DG solutions are consonant with the European goals for the market for electricity and the CO2 neutral society.

As a potential service for distribution grid operation is being analyzed, the DSOs' economic interests are being considered. The overall individual benefits can sum up to a substantial monetary value depending on the individual grid characteristics. A blanket calculation for distribution grids is neither possible nor useful. However, it is planned for the future to use refined results from experiments and reference grid models covering the Danish and German distribution grids. Thus, it can be possible to provide a comprehensive CBA for a full distribution grid. Also, the business model application is dependent on the future results. With a precise CBA, the business model can be applied and an excellent estimation for the financial aspects of the project like WTP of consumers and the DSO as well as the retail price of the services can be defined.

Further analyses and calculations will be conducted in the further months of the project. This CBA was mainly driven by the DSOs' perspective. In the next runs, also the customers' perspective is going to be included. If all marketing levels and channels of the business model are considered, the results will have the highest importance and major impacts.

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