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Deliverable D2.2: Key Performance Indicators (KPIs)

Work Package 2
iDistributedPV: Solar PV on the Distribution Grid: Smart Integrated Solutions of Distributed Generation based on Solar PV, Energy Storage Devices and Active Demand Management

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Content

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Introduction

In order to identify the most promising solutions, a technical and economical assessment is necessary. The technical solution will cover a simulation of the decentralized energy system and a grid analysis of the surrounding grid. The following Key Performance Indicators (KPIs) will be applied to quantify the benefits of the solution. The indicators are grouped in economic, technical and environmental indicators. The technical KPIs describe the system performance on two levels. First the technical performance of the onsite system is evaluated. Afterwards the interaction with the surrounding electricity grid is analysed.

Economic – on site

The following KPIs assess the single solutions by economic terms. The system border is the onsite system including electric loads, PV system and battery system.

1. Reduced network usage fee

In most European countries, the grid fee is paid per kWh of electricity consumed. Prosumers therefore pay less network usage fees. The reductions are calculated by multiplying the amount of PV own consumption by the amount of network usage fee. The reductions are calculated over the system's lifetime.

$$network\ usage\ fee\ reduction = PV\ own\ consumtion\ [kWh]\ \cdot network\ usage\ fee\ [€/kWh]$$

2. Net present value (NPV)

Difference between the present value of cash inflows and the present value of cash outflows.

$$NPV = \sum_{t=1}^{T} \frac{C_t}{(1+i)^t} - C_0$$

Where C_t is net cash inflow during the period t, C_0 is the total initial investment cost and i is the discount rate.

3. Internal rate of return (IRR)

Measure of the profitability of potential investments.

The IRR is found by setting the NPV equation equal to zero. The IRR then describes an average interest rate for the invested capital. If the IRR is equal to or larger than the minimal expected cost of capital, the investment is considered profitable. The IRR is calculated by using a goal seek function as are available in Excel.

$$0 = \sum_{t=1}^{T} \frac{C_t}{(1+IRR)^t} - C_0$$

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4. Payback time

Length of time required to recover the cost of an investment.

$$PB = \frac{C_0}{\sum_{t=1}^{T} \frac{C_t}{(1+i)^t}}$$

Where C_t is net cash inflow during the period t, C_0 is the total initial investment cost and i is the discount rate.

5. Reduced exposure to volatility of electricity prices

PV systems produce electricity mainly during daytime. In the case that the consumer has a variable electricity price, own consumption during daytime may have a positive effect on the cost of electricity for the consumer. The amount of high price electricity saved due to own consumption is therefore analyzed. The reduced exposure to volatility of electricity prices is calculated by dividing the amount of energy consumed from the PV and/or storage system during periods in which the electricity price is high by the total energy demand of the consumer during the periods in which the electricity price is high.

$$\frac{energy\ consumed\ from\ solution_{price\ max}}{energy\ demand_{price\ max}}$$

6. Levelized Cost of Electricity (LCOE)

Method used to rank different power-generating technologies according to its lifetime costs.

$$LCOE = \frac{I_0 + \sum_{t=1}^{n} \frac{A_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{M_{t,el}}{(1+i)^t}}$$

Where:

LCOE	Levelized cost of electricity in Euro/kWh
I_0	Investment expenditures in Euro
A_t	Annual total costs in Euro in year t
$M_{t,el}$	Produced quantity of electricity in the respective year in kWh
i	Real interest rate
n	Economic operational lifetime in years
t	Year of lifetime (1, 2, ...n)

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Technical – on site

Every solution can be evaluated by its technical KPI that are influenced only by the operation of the onsite system. The system border is the system containing electric loads, PV and battery system.

7. Degree of self-sufficiency

The extent to which the consumer is self-sufficient – using electricity produced by his or her own electricity generation system.

$$selfsufficiency = \frac{PV\ own\ consumption}{total\ electricity\ consumption}$$

8. Reduction peak demand ratio

Percentage relation of the resulting demanded energy (residual load) in the peak hours of a day between the PV solution scenario and the reference scenario.

$$Reduction\ peak\ demand\ (\%) = \frac{Peak\ demand_{solution}[kWh]}{Peak\ demand_{bs}[kWh]}$$

Technical – grid

Every solution will have an effect on the grid infrastructure it is connected to. The adapted building load profile will change the loading of the grid. A representative number of simulations with varying level of penetration of distributed energy generation will be carried out to evaluate the behavior of the grid under different conditions.

Table 1: Criteria that can be evaluated depending on the simulation carried out

	Load flow (quasi stationary)	dynamic	dynamic ENSO-E System (transmission)
Nodal voltage	Yes	Yes	Yes
Current, thermal violations	Yes	Yes	Yes
Outage times	(yes) with statistical outage	(yes) with statistical outage	(yes) with statistical outage
Flickers, harmonics	No	Yes	Yes
Frequency	No	No	Yes

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Depending on the type of the simulation (e.g. quasi stationary or dynamic) it is possible to assess different units, which are summarized in Table 1. All simulations allow calculating nodal voltages and loading of grid components. For the analysis of outages statistical models for all grid components are needed. This leads to highly probabilistic models. For assessing the influence on the frequency dynamic models of the full European transmission system are necessary.

9. Energy exchange with the grid

Savings by the network because of reduction in electricity transmission and distribution losses are possible when consumption is replaced by onsite generation. In case the PV system produces more electricity than is consumed, losses in the transmission and distribution system may be increased. To evaluate this, the energy exchange with the grid is evaluated in both directions for feed-in and consumption.

$$\Delta_{feed} = \frac{W_{feed,solution}}{W_{feed,bs}}$$

$$\Delta_{cons} = \frac{W_{cons,solution}}{W_{cons,bs}}$$

10. Hosting capacity of solar PV

The hosting capacity of solar PV describes the total amount of photovoltaic $\max(\ PV\ energy\ feed\_in)$ that can be fed into the grid without causing voltage band violations and thermal overloading. This KPI needs to be calculated in iteration between plant operation and grid simulation. Depending on self-consumption schemes different amounts of feed-in can be realized. For comparing KPI it is necessary to regard equal time periods.

$$Hosting\ capacity = \max(\ \ PV\ Energy\ feed\_in_{solution})$$

11. Reduction in solar PV production cut-off due to congestion

Quantify the energy that is not generated due to the low robustness of the grid.

When the storage is full, the prosumer's demand is low and the grid is congested, the PV production is lost.

The KPI measures the relationship between the energy that was planned during a cut-off (energy that is finally not produced) and the energy generated.

$$Reduction\ due\ to\ congestion = \frac{Energy\ not\ sold\ because\ of\ the\ cut\ off\ [kWh]}{Solar\ PV\ generated\ [kWh]\ -solar\ PV\ self\ consumed\ [kWh]}$$

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12. Voltage stability Vmax

The maximum voltage in the scenario is divided by the maximum voltage in baseline scenario. This KPI should be performed on per unit voltages.

$$stability_{Vmax} = \frac{max\ V_{solution}}{\max V_{bs}}$$

13. Voltage stability Vmin

The minimum voltage in the scenario is divided by the minimum voltage in baseline scenario. This KPI should be performed on per unit voltages.

$$stability_{Vmin} = \frac{min\ V_{solution}}{\min V_{bs}}$$

14. Reduction of over voltage in the grid

Number of time steps of the solution in which at any node the upper voltage band is violated is divided by the number of violations in the baseline scenario.

$$reduction_{Vmax} = \frac{\sum violation\ V_{max,solution}}{\sum violation\ V_{max,bs}}$$

15. Reduction of under voltage in the grid

Number of time steps of the solution in which at any node the lower voltage band is violated is divided by the number of violations in the baseline scenario.

$$reduction_{Vmin} = \frac{\sum violation\ V_{min,solution}}{\sum violation\ V_{min,bs}}$$

16. Increase frequency quality performance

Reduction in the variations with respect to the reference distribution frequency of the country, enhanced due to the availability of distributed energy when facing frequency system variations.

$$\Delta f = \sqrt{\frac{1}{n}\sum_{n=1}^{N}\left(f_n - f_{ref}\right)^2}$$

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17. Time of a certain frequency variation

Average amount of time in which, the main frequency of a certain grid varies from the reference distribution frequency of each country, with respect to the variation limits for a chosen period of time.

$$t_{\Delta f} = \frac{\sum tperiod_{fn \neq fref}}{tperiod_{\ total}}$$

18. Average outage duration for each customer served (SAIDI).

Also referred to as the System Average Interruption Duration Index, it is the average period duration in which each consumer supply is interrupted.

$$SAIDI\ [s] = \frac{sum\ of\ all\ customers\ interruption\ durations\ [s]}{total\ number\ of\ consumers\ served}$$

The SAIDI is measured in units of time, minutes or hours, over the course of a year.

19. Average number of interruptions in the supply of a customer (SAIFI)

Also named as the System Average Interruption Frequency Index, it is the average amount of interruptions each consumer would experience.

$$\frac{total\ number\ of\ customer\ interruptions}{total\ numer\ of\ consumers\ served}$$

The SAIFI is measured in units of time, minutes or hours, over the course of a year.

20. Increased efficiency in preventive control and emergency control

Related to SAIDI and SAIFI, it is the measurement of the improvement in the increased capacity related to risk prevention and emergency control for the TSOs and DSOs.

Being "Reaction capacity$_{PV\ solution}$" the capacity of prevention and reaction to any emergency that happens when PV solutions have been included in the grid and "Reaction capacity$_{bs}$" the capacity of prevention and reaction to any emergency under baseline conditions.

$$Reaction\ capacity = \left(\frac{(SAIDI \cdot SAIFI)_{bs}}{(SAIDI \cdot SAIFI)_{solution}} - 1\right) \cdot 100$$

21. Increased demand side participation

Increased demand participation of the solution due to the Energy Management System (EMS) installed and operation of the PV system.

$$Demand\ side\ participation = \frac{nº\ EMS_{solution} - nº\ EMS_{bs}}{nº\ EMS_{bs}}$$

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22. Actual availability of network capacity

Relationship between the total power of the solution installed and the power capacity available in the network that allows the maximum power injection without risk of congestion.

Constraint: grid not congested.

$$Energy\ not\ sold\ because\ of\ the\ cut\ off = 0$$

KPI:

$$\frac{Total\ capacity\ of\ the\ grid[MW] - \sum Capacity\ of\ solutions\ installed\ [MW]}{Total\ capacity\ of\ the\ grid[MW]}$$

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Regulative

After analyzing the legislative rules per country different measure KPI concerning the regulative flexibility can be evaluated:

23. Reduction in time to connect new user

Average period of time, expressed in days, needed for getting the required permission to connect a new prosumer into the grid. iDistributed will propose new procedures to reduce the period of time that currently exists as technical and administrative barriers.

$$Av\ time\ [days] = \frac{\frac{\sum t_{permission}}{Total\ nº\ of\ prosumers}_{bs} - \left(\frac{\sum t_{permission}}{Total\ nº\ of\ prosumers}\right)_{solution}}{\left(\frac{\sum t_{permission}}{Total\ nº\ of\ prosumers}\right)_{bs}}$$

24. Increase in coordinated operation between TSOs and DSOs

Measurement of the improved communication between TSO and DSO, due to the installation of advance metering equipment related to prosumer's installation. It is the measurement of the increased visibility of the TSO on the distribution grid and the increased visibility of the DSO on the transmission grid.

$$Communication = \frac{nº\ smart\ metering_{solution} - nº\ smart\ metering_{bs}}{nº\ smart\ metering_{solution}}$$

Environmental

The impact in environmental terms is assessed using the following method.

25. Quantified reduction of carbon emissions

Amount of energy produced by the solution multiplied by the mean value of the emission factor of fossil fuel technologies in the country.

$$avoided\ CO_2\ emissions = \ Solar\ PV\ energy\ \ [kWh] \cdot emission\ factor\ [{}^{CO_2}/_{kWh}]$$

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