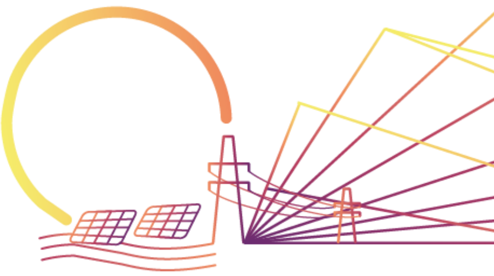
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement Nº 953016

D1.5 Mid-term follow-up on KPIs progress on PV reliability, performance and profitability, and grid integration – Public version

T1.5 Follow-up on KPIs progress on PV Reliability, Performance and Profitability and grid integration

Grant Agreement nº:	**953016**
Call:	H2020-LC-SC3-2020-RES-IA-CSA / LC-SC3-RES-33-2020
Project title:	**Smooth, REliable aNd Dispatchable Integration of PV in EU Grids**
Project acronym:	SERENDI-PV
Type of Action:	Innovation Action
Granted by:	European Climate, Infrastructure and Environment Executive Agency (CINEA)
Project coordinator:	Fundación TECNALIA Research & Innovation
Project website address:	*www.serendi-pv.eu; www.serendipv.eu*
Start date of the project:	October 2020
Duration:	48 months
Document Ref.:	SERENDI-PV-D1.5_ Mid-term follow-up on KPIs progress on PV reliability, performance and profitability, and grid integration - PU version.docx
Lead Beneficiary:	Lappeenranta-Lahti University of Technology
Doc. Dissemination Level:	**PU** – Public
Due Date for Deliverable:	30/09/2022 (M24)
Actual Submission date:	30/12/2022 (M27)
Version	V1



Summary

The purpose of this report is to provide a mid-term follow-up on the progress of the **K**ey **P**erformance **I**ndicators (KPIs) considered in the SERENDI-PV project as per task 1.1 of the working package WP1 and publicly shared in D1.1 [1]. These KPIs span the reliability, performance, profitability, and grid integration of solar PV.

The report first recaps the selected KPIs as well as the planned innovations to be developed by the project partners. Then, the main section of the report outlines the project partners' expert opinion on the nature of the impact of these innovations on each KPI. This mid-term follow-up is only considered as a hypothesis that will be confirmed by actual measurements at the end of the project.

This deliverable is an output of task T1.5 of WP1 of the SERENDI-PV project.

Document Information

Title	D1.5 Mid-term follow-up on KPIs progress on PV reliability, performance and profitability, and grid integration - Public version
Lead Beneficiary	Lappeenranta-Lahti University of Technology (LUT)
Contributors	TEC, CEA, FHG, BI, FIB
Distribution	Public
Report Name	SERENDI-PV-D1.5 Mid-term follow-up on KPIs progress on PV reliability, performance and profitability, and grid integration - PU version

Document History

Date	Version	Prepared by	Organization	Approved by	Notes
30/12/2022	V1	Mai ElSayed, Dmitrii Bogdanov, Christian Breyer	LUT	Monica Aleman (BI)	

Acknowledgments

The work described in this publication has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement Nº 953016.

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1 EXECUTIVE SUMMARY

1.1 Description of the deliverable content and purpose

This is the first report in a series of two reports that form the output of task 1.5 of working package 1 (WP1) of the SERENDI-PV project. This report constitutes a mid-term follow-up, based on expert opinion, on the progress of the key performance indicators (KPIs) defined and selected in task 1.1 of the same WP1. The second report would be the final follow-up, based on demonstration results, on the progress of these KPIs and is scheduled to be submitted at the end of the project.

The purpose of this report is to compile partners' opinions about the potential impact of the developed innovations as part of the SERENDI-PV project on the KPIs related to solar PV reliability, performance, profitability, and grid integration. The introduction first recaps the list of selected KPIs in T1.1 of WP1, published as public deliverable D1.1 [1]. It also summarises the innovations and tools that are being developed by the SERENDI-PV project partners for which the impact is monitored. Furthermore, an overview of the survey used to collect expert opinion on the matter is given.

Sections 3 to7 form the main body of this report. Each section corresponds to one of the five identified KPI categories: performance, reliability, power modelling and forecasting, monitoring, and profitability. These are then divided into sub-sections corresponding to the included KPIs within this category. Each of the sub-sections first defines the KPI in question. Then, it lists the innovations and categorizes them based on whether they are expected to have an impact on this KPI or not. Lastly, it discusses in greater detail the innovations with a potential impact based on the integral view of the owners of each innovation. The main findings and outlook of this report are concluded in the last section.

1.2 Reference material

The first part of this document is based on another report published earlier as part of the project where more details on the selected KPIs for the scope of SERENDI-PV can be found: **"SERENDI-PV_D1.1 KPIs on state of the art PV reliability, performance, profitability and grid integration_submitted.pdf"** [1]. It is also based on the planned innovations as part of the original SERENDI-PV project proposal.

1.3 Relation with other activities in the project

Table 1.1 depicts the main links of this deliverable to other activities (work packages, tasks, deliverables, etc.) within the SERENDI-PV project. The table should be considered along with the current document for further understanding of the deliverable contents and purpose.

Table 1.1: Relation between current deliverable and other activities in the project

Project activity	Relation with current deliverable
D1.1	The current deliverable feeds from the defined KPIs as an output of task T1.1 of working package WP1.
WP2-6 & WP8	The current deliverable feeds from and to all the innovations developed as part of working packages WP2-WP6 as well as their demonstration as part of WP8. It compiles partners' opinions on the potential impacts of the developed innovations on the selected KPIs. These impacts will be revised and concluded in another report at the end of the project based on the results from WP8.
WP9	The results presented in this report are strongly linked to the exploitation of the innovations developed in SERENDI-PV. These results have been used as input to develop the business cases for the innovative solutions in the project in D9.12.

1.4 Abbreviation list

Table 1.2 outlines all the abbreviations used throughout the report.

Table 1.2: Abbreviation list

Abbreviation	Meaning
BAPV	Building Attached PV
BIPV	Building Integrated PV
C	Temperature Adjustment Factor
CAPEX	Capital Expenditures
CLS	Controllable Local System
CPR	Temperature-corrected performance ratio
DA	Data Availability
DSO	Distribution System Operator
DQ	Data Quality
E_{out}	Output AC Electricity
EMS	Energy Management System
EPI	Energy Performance Index
FSS	Forecast Skill Score
G_{ref}	Reference Irradiance
H	Total In-Plane radiation
iMsys	Integrated Management System
KPI	Key Performance Indicator
LCoE	Levelised Cost of Electricity
MAE	Mean Absolute Error

Abbreviation	Meaning
MBE	Mean Bias Error
(M)IRR	(Modified) Internal Rate of Return
NPV	Net Present Value
NWP	Numerical Weather Prediction
OPEX	Operational Expenditures
P_0	Rated DC Power
P2P	Peer-to-Peer
PF	Profile Factor
PO	Observed PV Power
PP	Predicted PV Power
PPA	Power Purchase Agreement
PR	Performance Ratio
PR_{exp}	Expected Performance Ratio
PLR	Performance Loss Rate
PV	Photovoltaic
RMSE	Root Mean Square Error
$RMSE_{ref}$	Reference Root Mean Square Error
SoC	State-of-Charge
SoH	State-of-Health
SR	Soiling ratio
STC	Standard Testing Conditions
T	Task
T_{mod}	Module Temperature
T_{ref}	Reference Temperature under STC
TRL	Technology Readiness Level
TSO	Transmission System Operator
WACC	Weighted Average Cost of Capital
WP	Working Package
Y_E	Expected Yield
Y_f	Final Yield
Y_r	Reference Yield

2 Introduction

All the major world regions have witnessed an increase in installed solar PV capacities over the previous years, with solar PV surpassing installed wind capacities in 2021 [2], [3]. This uptake in solar PV installations has been mainly driven by the decreasing costs of the technology as well as the more equal distribution of solar resources worldwide compared to other renewable resources. In anticipation of the major role that solar PV will play in future energy systems, the SERENDI-PV project proposes several innovations to improve the performance and utility-friendliness of solar PV.

Task 1.1 of the SERENDI-PV project identified and compiled a list of KPIs spanning the performance, reliability, power modelling and forecasting, monitoring, and profitability of solar PV systems of different scales. The selected KPIs were deemed the most relevant and informative about the impact of the developed innovations during SERENDI-PV on the different aspects of solar PV performance. Table 2.1 outlines the selected KPIs as per **"D1.1 KPIs on state of the art PV reliability, performance, profitability and grid integration"** [1].

Table 2.1: SERENDI-PV project key performance indicators (KPIs)

Category	Key performance indicator
Performance	Performance ratio (PR)
	Temperature-corrected performance ratio (CPR)
	Soiling ratio (SR)
Reliability	Performance loss rate (PLR)
Power modelling and forecasting	Root mean square error (RMSE)
	Mean absolute error (MAE)
	Mean bias error (MBE)
	Forecast skill score (FSS)
Monitoring	Energy performance index (EPI)
	Data availability (DA)
	Data quality (DQ)
Profitability	Levelised cost of electricity (LCoE)
	Profile factor (PF)
	Weighted average cost of capital (WACC)
	Net present value (NPV)
	(Modified) Internal rate of return ((M)IRR)

As part of the original project proposal, a list of existing tools and innovations at a technology readiness level (TRL) of 6-7 are planned to be developed to reach a TRL of 7-8. These developments are part of working packages WP2-6. Their demonstration and integration are part of WP8, where the impacts of such developments on the selected KPIs are monitored. The impacts are then reported as part of this task, T1.5 of WP1. Table 2.2 below lists all the innovations included in the impact assessment by working package. The innovations are indexed based on the working package number and their order within each package. These indices will be used later when referring to innovations for the sake of brevity. Real partner names are substituted by aliases throughout the rest of this report.

To conduct the mid-term progress follow-up, a survey was designed to collect owners' and project partners' opinions about the potential direct and indirect impacts of the proposed innovations on the selected KPIs. A direct impact is a direct result of the use/implementation of an innovation. An indirect impact is achieved because of a secondary action triggered by the innovation in question. The participants were asked to respond to four questions regarding the impact of each innovation on each of the KPIs. These questions are:

- How does an innovation influence a certain KPI?
- If there is an impact, is it positive or negative, and how significant is it?
- If applicable, what is the expected value of the change?
- Where is the innovation introduced, and when will the results be available?

In total, **14** owners and project partners responded to the survey. The responses were then collected, sorted, and analysed to extract an integral view of the expected impact of every innovation on each of the KPIs. The results are summarised and reported here.

The rest of the report goes over the selected KPIs by category. Each of the KPIs is first briefly explained as per **"D1.1 KPIs on state of the art PV reliability, performance, profitability and grid integration"** [1]. Then, the impact of different innovations on it according to expert opinion is outlined and discussed. Finally, the main findings are highlighted and concluded.

Table 2.2: SERENDI-PV innovations

WP	ID	Innovation
WP2	2.1	Modelling of bifacial PV systems
	2.2	Modelling of floating PV systems
	2.3	Modelling of small PV systems, including building attached PV (BAPV)
	2.4	Modelling of building integrated PV (BIPV) systems, any size
	2.5	Modelling of soiling
	2.6	Modelling of snow
	2.7	Modelling of degradation
WP3	3.1	Specific data analytics for bifacial PV systems
	3.2	Specific data analytics for floating PV systems
	3.3	Specific data analytics for small PV systems, including BAPV
	3.4	Specific data analytics for BIPV systems, any size
	3.5	Specific data analytics for soiling
	3.6	Specific data analytics for snow
	3.7	Specific data analytics for degradation
	3.8	IV curve data analytics
	3.9	IR imaging data analytics
	3.10	Failure detection and diagnosis methods
	3.11	Fault detection/diagnosis toolbox for small PV
	3.12	PV inverter efficiency characterisation
	3.13	PV inverter digital twin
	3.14	PV battery digital twin
	3.15	BIPV digital twin
WP4	4.1	Specific procedures for bifacial PV systems
	4.2	Specific procedures for floating PV systems
	4.3	New procedures for PV inverters field testing
	4.4	New procedures for batteries field testing
	4.5	Quality control procedures for solar radiation and meteorological measurements
	4.6	Soiling measurement kit
	4.7	Capacitive I-V tracer at 1,500V

Table 2.3 (continued): SERENDI-PV innovations

WP	ID	Innovation
WP5	5.1	Short-term PV power forecasting based on the integration of satellite data and Numerical Weather Prediction (NWP) models with PV power production data (small and medium-sized PV systems)
	5.2	PV power nowcasting by merging satellite data with sky-camera data and methods for PV power output aggregation
	5.3	Improved power forecasting in presence of snow, dust, fog, and other extreme events
	5.4	Forecasting applied to bifacial PV systems
	5.5	Forecasting applied to floating PV systems
	5.6	Forecasting applied to residential PV systems
	5.7	Forecasting for spatial averaging and PV aggregation
WP6	6.1	Characterisation of PV inverters using generic IEC 61850 data model as a fundamental element for telecommunication and control of PV systems
	6.2	Acquisition of PV measurements/status data using Smart/Advanced-Metering-Infrastructure with high resolution in DSO SCADA
	6.3	Curtailment of PV system from DSO SCADA via secured CLS-channel provided by Smart Meter Gateway and delivery of evidence for performed curtailments
	6.4	Algorithms for automatic PV data integration in DSO SCADA using IEC 61850 data model
	6.5	Algorithms for automatic PV data integration in PV meta-data registry using IEC 61850 data model
	6.6	Integration of algorithms for automatic PV data integration in smart grid data systems of participating project partners, using IEC 61850 data model or Common Information Model
	6.7	Service system for aggregating anonymous data for the monitoring and management of distributed generation systems (residential, commercial, and small industry)
	6.8	Digital twin of the grid (down to low voltage), real-time state estimation based on load and PV-measurements[1]
	6.9	Real-time congestion management of the grid based on the Digital twin of the grid and different algorithms for PV-control[1,2]
	6.10	Advanced grid operation and control of PV systems based on PV forecast (cooperation with WP5, ISE)[1,2,3]
	6.11	Integration of V2G & G2V into self-consumption optimisation software
	6.12	Further integration of virtual batteries into self-consumption optimisation software
	6.13	Predictive control-based EMS for PV storage self-consumption optimisation
	6.14	Operation and planning of PV for the provision of ancillary services to the grid operators (large commercial) – standalone
	6.15	Operation of PV ensuring active power reserve available to provide ancillary services - grid connected

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[1] Minimum 3 measurement points per grid feeder, optimal 10

[2] Minimum 1 CLS

[3] Minimum 1 PV forecast method

3 Impact of innovations on performance KPIs

Performance KPIs include the performance ratio (PR), the temperature-corrected performance ratio (CPR), and the soiling ratio (SR). These KPIs help to capture and differentiate the factors that can affect the performance of solar PV plants. This section first briefly explains each KPI as per T1.1, then outlines the expected impacts of SERENDI-PV innovations on each of these KPIs according to expert opinion. Table 3.1 summarises which innovations affect performance KPIs. More detailed information about the KPIs, their influencing factors, and their state-of-the-art values can be found in **“D1.1 KPIs on state of the art PV reliability, performance, profitability and grid integration”** [1].

Table 3.1: Summary of the impact of SERENDI-PV innovations on performance KPIs

ID	Innovation	PR	CPR	SR
2.1	Modelling of bifacial PV systems	X	X	X
2.2	Modelling of floating PV systems	X	X	X
2.3	Modelling of small PV systems, including BAPV	X	X	X
2.4	Modelling of BIPV systems, any size	X	X	X
2.5	Modelling of soiling	X	X	X
2.6	Modelling of snow	X	X	X
2.7	Modelling of degradation	X	X	X
3.1	Specific data analytics for bifacial PV systems	X	X	X
3.2	Specific data analytics for floating PV systems	X	X	X
3.3	Specific data analytics for small PV systems, including BAPV	X	X	X
3.4	Specific data analytics for BIPV systems, any size	X	X	X
3.5	Specific data analytics for soiling	X	X	X
3.6	Specific data analytics for snow	X	X	X
3.7	Specific data analytics for degradation	X	X	X
3.8	IV curve data analytics	X	X	X
3.9	IR imaging data analytics	X	X	X
3.10	Failure detection and diagnosis methods	X	X	X
3.11	Fault detection/diagnosis toolbox for small PV	X	X	
3.12	PV inverter efficiency characterisation	X	X	
3.13	PV inverter digital twin	X	X	X
3.14	PV battery digital twin	X	X	X
3.15	BIPV digital twin	X	X	
4.1	Specific procedures for bifacial PV systems	X	X	X
4.2	Specific procedures for floating PV systems	X	X	X
4.3	New procedures for PV inverters field testing	X	X	
4.4	New procedures for batteries field testing	X	X	X
4.5	Quality control procedures for solar radiation and meteorological measurements	X	X	X
4.6	Soiling measurement kit	X	X	X
4.7	Capacitive I-V tracer at 1,500V	X	X	
5.1	Short-term PV power forecasting based on integrating satellite data and NWP models with PV power production data	X	X	

ID	Innovation	PR	CPR	SR
5.2	PV power nowcasting by merging satellite data with sky-camera data and methods for PV power output aggregation	X	X	
5.3	Improved power forecasting in presence of snow, dust, fog, and other extreme events	X	X	X
5.4	Forecasting applied to bifacial PV systems	X	X	X
5.5	Forecasting applied to floating PV systems	X	X	
5.6	Forecasting applied to residential PV systems	X	X	
5.7	Forecasting for spatial averaging and PV aggregation	X	X	
6.1	Characterisation of PV inverters as a fundamental element for telecommunication and control of PV systems			
6.2	Acquisition of PV measurements using Smart/Advanced-Metering-Infrastructure with high resolution in DSO SCADA			
6.3	Curtailment of PV system from DSO SCADA via secured CLS-channel and delivery of evidence for performed curtailments			
6.4	Algorithms for automatic PV data integration in DSO SCADA			
6.5	Algorithms for automatic PV data integration in PV meta-data registry			
6.6	Integration of algorithms for automatic PV data integration in smart grid data systems of participating project partners			
6.7	Service system for aggregating anonymous data for the monitoring and management of distributed generation systems			
6.8	Digital twin of the grid, real-time state estimation based on load and PV-measurements	X		
6.9	Real-time congestion management of the grid based on the Digital twin of the grid and different algorithms for PV-control	X		
6.10	Advanced grid operation and control of PV systems based on PV forecast	X		
6.11	Integration of V2G & G2V into self-consumption optimisation software			
6.12	Further integration of virtual batteries into self-consumption optimisation software			
6.13	Predictive control-based EMS for PV storage self-consumption optimisation			
6.14	Operation and planning of PV for the provision of ancillary services to the grid operators	X	X	
6.15	Operation of PV ensuring active power reserve available to provide ancillary services			

3.1 Performance ratio

The performance ratio is one of the most widely used performance metrics for solar PV plants. It is a ratio between the final yield and the reference one. The reference yield (Y_r) is the total in-plane radiation (H) relative to the reference irradiance (G_{ref}), which is 1000 W/m^2 under standard testing conditions (STC). The final yield (Y_f) is the actual output AC energy from the PV array (E_{out}) divided by its peak DC power (P_0). In that sense, the PR accounts for both array losses, like shading and soiling, as well as system losses, like inverter losses during the conversion from DC to AC. The PR can be calculated at the inverter level or the delivery point. In SERENDI-PV, high-accuracy ground measurement instruments as well as quality-controlled solar radiation data are used to calculate the PR yearly at the delivery point. The formula below shows how the PR is calculated:

$$PR = \frac{Y_f}{Y_r} = \frac{E_{out}}{P_0} / \frac{H}{G_{ref}} \qquad (1)$$

Many of the SERENDI-PV project innovations are expected to have an impact on the PR. Table 3.1 gives an overview of influential and non-influential innovations according to expert opinion. An innovation is considered to be potentially influential if at least one of the project partners deems it as such. The impact of influential innovations is discussed in more detail below.

3.1.1 Impact of WP2 innovations on PR

Partners 2A, 2B, and 2C all expect the modelling of bifacial PV systems (2.1) to lead to better estimation of and less uncertainty about the PR of bifacial systems. Partner 2C elaborated that the current tools on the market do not enable a proper evaluation of backside irradiation of bifacial PV array. That makes it difficult to obtain a reliable estimation of the PR. Partner 2C is also going to propose a new definition for the calculation of the PR for bifacial PV, as the standard definition often results in a PR greater than 100%, especially with vertical bifacial modules. The impact is expected to be significant, i.e. few percentage points difference compared to current estimations. Partners 2D and 2E, however, do not anticipate any impact from innovation 2.1 on the PR.

Similarly, partners 2A, 2B, and 2C expect the modelling of floating PV systems (2.2) to improve the knowledge and accuracy of the PR of such systems, thereby decreasing uncertainty in PV plant analysis and evaluation. Partner 2A highlighted that it will improve yield modelling and offer better estimates for the reference PR in particular. Partner 2F pointed out that innovation 2.2 can lead to the adaptation of the design, e.g. the height of the floaters and albedo considerations. This would improve the PR of the system. Regarding the significance of the impact, different partners had different opinions. Partner 2B said that it is still unquantifiable while partner 2C expects a slight improvement and partners 2A and 2F expect a significant impact. Partner 2F’s justification is that no market standard for floating PV exists yet, thus, the impact is expected to be significant. Partner 2C, however, expects only a slight impact because there is still much to be developed in this area. Nevertheless, partners 2D and 2E envision no impact at all from innovation 2.2 on the PR.

Modelling of small and BAPV systems (2.3) is expected to decrease uncertainty in the analysis and evaluation of such systems independent of the size, according to partner 2A. In that sense, the impact anticipated for utility-scale systems should be transferable to smaller systems as well, i.e. an improvement in reference PR estimations. Partner 2C also expects that better modelling of such systems in an urban environment will improve the knowledge about shading losses from surrounding objects and buildings, thereby improving the accuracy of the PR. Partner 2B concurs while adding that innovation 2.3 can improve the short time accuracy of thermal behaviour as well. As for the significance of the impact, partner 2A anticipates a difference of few percentage points while partner 2B expects it to be strongly dependent on local surroundings. Partner 2E, however, expects no impact at all.

When it comes to modelling BIPV systems (2.4), partner 2C has similar expectations as to those reported for innovation 2.3. In this case, partner 2C also expects additional improvements from the modelling of curved surfaces. Partner 2A has similar expectations to the ones reported for innovation 2.2, i.e. improved yield modelling and better estimates for the reference PR. Partner 2E considers innovation 2.4 to be non-influential.

Partner 2A reported that modelling of soiling (2.5) would help in shifting from the current status of using rough guesses to using local estimates based on the data available from weather databases. This reduces uncertainty in PV power plant analysis and evaluation, including the PR, with an expected impact of tens of percentage points. Partner 2G expects better accuracy because of innovation 2.5 as well. However, the direction and significance of the impact are said to be still unclear. Partner 2F expects the modelling results to lead to adaptations in the plant design, e.g. tilt angle, and maintenance procedures, e.g. cleaning campaigns. This can significantly increase the PR by up to 5%, according to partner 2F. Nevertheless, partner 2D anticipates no impact from this innovation.

Modelling of snow (2.6) is expected to improve yield modelling and reference PR estimation, according to partner 2A. That would decrease the uncertainty in PV plant analysis and evaluation. Partner 2A anticipates a difference of few percentage points in the PR due to this innovation. However, the direction of change was not indicated. Partner 2G also expects the PR to be more accurate, but the magnitude and direction of change are said to be unclear. Partner 2B expects innovation 2.6 to help in differentiating between the effect of snow and other system failures on the PR. Partner 2B expects this development to reduce the average PR, but the magnitude would strongly depend local conditions. Partner 2F expects this innovation to impact the system design in terms of the tilt angle. This can also impact soiling and cleaning procedures. The expected change in PR could be positive or negative by up to 2%, according to partner 2F. Still, partner 2D expects no impact at all.

Lastly, degradation modelling (2.7) is expected to have only an indirect impact on the PR, according to partner 2A, and no impact at all, according to partner 2D. Partner 2A reported that innovation 2.7 does not directly estimate the degradation. Alternatively, the resulting maps show which regions have a higher probability of increased degradation of PV system components in order to support the decision-making process. The indirect impact on the PR would be in terms of lower productivity, shorter component lifetime, and increased maintenance costs in such regions. Partner 2B anticipates the accurate modelling from innovation 2.7 to decrease the uncertainty in estimating the PR and to help in differentiating between reversible and irreversible degradation losses. The significance of the impact, however, is said to be unquantifiable at the moment.

3.1.2 Impact of WP3 innovations on PR

Specific data analytics for bifacial PV systems (3.1) would help in detecting conditions that result in underperformance and require maintenance, according to partner 3A. This helps in improving electricity production and mitigating losses, thus, increasing the PR. The magnitude of the impact is expected to be a few percentage points depending on the location and the system type, among other factors. Partner 3B also anticipates innovation 3.1 to be influential if noticeable underperformance has been detected. However, they anticipate a more significant impact of at least +20% per year depending on regional characteristics, irradiation level, and system topography. Partner 3C expects this innovation to reduce the uncertainty in the calculated PR for bifacial systems. This could result in an increase or decrease in the PR up to 1-2% due to the more accurate estimates of impinging irradiance. Partner 3D envisions a similar impact from this innovation as to that stated earlier for innovation 2.1 by partner 2C.

Partner 3A anticipates the same impact on the PR from specific data analytics for floating PV systems (3.2) as that outlined for innovation 3.1. Partner 3B also expects innovation 3.2 to have a similar impact in nature as that of innovation 3.1. However, a lower significance (+10% per year or more) is expected. Partner 3C anticipates the same impact from innovation 3.2 as from innovation 3.1 as well while partner 3D anticipates a similar impact as that reported for innovation 2.2 by partner 2C.

Partners 3A's and 3B's expectations from specific data analytics for small and BAPV systems (3.3) are the same as outlined for innovation 3.2 in nature and magnitude. Partner 3D anticipates a similar impact as that reported for innovation 2.3 by partner 2C.

Again, partner 3A expects the same impact from specific data analytics for BIPV systems of any size (3.4) as that from innovations 3.1-3.3. Partner 3B highlighted that the aim of these developments is to have models whose applicability does not depend on the size of the system. In that sense, the impact anticipated from specific data analytics for utility-scale systems should be transferable to this innovation. Overall, innovation

3.4 would decrease uncertainties in the analysis and evaluation of PV plants. Partner 3D anticipates the same impact from innovation 3.4 as that stated for innovation 2.4 by partner 2C.

When it comes to specific data analytics for soiling (3.5), snow (3.6), and degradation (3.7), partners 3A and 3B expect the same impact as that outlined for innovation 3.2 in both nature and magnitude. For innovation 3.5, partner 3C expects that a better evaluation of soiling would enable correcting the PR with soiling losses and considering the impact of soiling on long-term productivity. The PR could increase or decrease due to better estimations of impinging irradiance by 1-2% depending on the operating environment. Partner 3D, however, deems innovations 3.5-3.7 as non-influential.

Partner 3A expects IV curve data analytics (3.8) to have a similar impact as that reported for innovations 3.1-3.7. However, in this case, the impact would be at the string level. Partner 3E anticipates that innovation 3.8 can help in detecting and correcting failures in a PV plant, thereby increasing the PR by a maximum of 1-2%.

Again, partner 3A expects IR imaging data analytics (3.9) to help in detecting conditions requiring maintenance at the module level, like underperformance quantification, fault location, and degradation type. When these conditions are fixed, electricity production improves. The significance of the impact can range from minor to high depending on the number of affected modules. Partner 3C stated that this innovation is devoted to fault detection helping in detecting string failures sooner and better. This improves electricity production and, consequently, the PR. Again, the magnitude of the impact depends on the number of affected strings with a high impact expected during the early stages of a project. Partner 3E expects a similar impact from this innovation as that stated for innovation 3.8.

As for failure detection and diagnosis methods (3.10), partner 3A anticipates that the complementarity of all the previous innovations in this WP3 would lead to the detection of conditions requiring maintenance at different levels, from module to inverter. This would improve electricity production which, in turn, improves the PR. The impact magnitude can range from insignificant to an improvement of few percentage points. Partner 3C foresees the same impact mechanism for this innovation, highlighting that the magnitude is dependent on the number of modules or strings that are affected by underperforming conditions. Partner 3C also expects the impact to be high during the early stages of a PV project. Partner 3B expects innovation 3.10 to only be influential if noticeable underperformance has been detected. In such case, energy production would be improved which can increase the PR by 10+% per year depending on the regional and project characteristics. Partner 3D expects that fault detection and diagnosis of PV system fleets via the application of the peer-to-peer (P2P) method would significantly contribute to the PR. However, the direction of change was not indicated. Partner 3F highlighted that unless the results from this innovation are utilised by a prescriptive maintenance tool, there will be no impact on the PR.

The utilisation of a fault detection/diagnosis toolbox for small PV systems (3.11) is expected by its owner, partner 3G, to enhance the accuracy of the PR. The direction of change was said to be potentially positive, but the significance was said to be still unclear. Partner 3E anticipates an increase in the PR as a result of detecting and correcting failures using this innovation. This increase can reach a few percentage points, according to partner 3E. Partner 3F, again, emphasises that innovation 3.11 would have no impact on the PR if its results are not utilised by a prescriptive maintenance tool.

Partner 3H, the owner of the PV inverter efficiency characterisation innovation (3.12), expects it to be non-influential. Nevertheless, partner 3A anticipates that it would help in detecting conditions requiring maintenance which improves electricity production and, thus, the PR by up to a few percentage points. Partner 3E envisions an indirect impact instead, stating that the data analytics from innovation 3.12 would improve the modelling. That, in turn, can improve the PR.

Partner 3I expects that utilising a PV inverter digital twin (3.13) would optimise predictive maintenance. This would reduce losses as well as the number of times of system shutdown due to malfunction and maintenance. As a result, a higher PR can be reached with high significance in some cases. Partner 3E expects this innovation to increase the understanding of inverter losses. This could then lead to design adaptations that can increase the PR by a maximum of 1%. Partner 3F maintains the view that if the results are not utilised by a prescriptive maintenance tool, there will be no impact on the PR.

The same applies to a PV battery digital twin (3.14), according to partner 3F. The other owner of innovation 3.14, partner 3J, expects little influence of low importance on the PR. Partner 3E, however, expects a similar impact from innovation 3.14 as stated earlier for innovation 3.13, where the understanding of system losses at the battery level is enhanced leading to design adaptations and improvements in the PR. This time the impact can reach a few percentage points.

Both owners of the BIPV digital twin (3.15), partners 3H and 3F, foresee no influence from this innovation on the PR. Nevertheless, partner 3E expects the same indirect impact stated earlier for innovation 3.12.

3.1.3 Impact of WP4 innovations on PR

The development of specific procedures for bifacial PV systems (4.1) is expected to be non-influential, according to its owner 4A. However, partner 4B foresees an indirect impact via the impact on modelling, such that the specific procedures enhance the modelling quality which, in turn, improves the PR. Partner 4A also expects that specific procedures for floating PV systems (4.2) would be non-influential. Partner 4C, the other owner of the innovation, expects some impact although it is currently unquantifiable. This is because the performance of floating PV systems suffers due to humidity, a salty operating environment, mechanical stresses from wind and waves, and current leakage. All of this degrades the modules resulting in significant losses of 10-20%. Innovation 4.2 would help in selecting more appropriate and resilient modules which mitigates increased degradation and improves the PR.

New procedures for PV inverters field testing (4.3) are expected by two its owners, partners 4A and 4D, to not impact the PR. Partner 4E, another owner, expects a significant improvement in the PR. This is because the new testing procedures would result in choosing inverters of a better quality. This enhances the robustness of the components and the overall system, leading to better performance and less shutdown times. As for new procedures for batteries field testing (4.4), one owner (4F) anticipates an influence of moderate importance on the PR. However, the mechanism and direction of the impact were not specified. Partner 4A, the other owner, expects no impact on the PR while partner 4B expects an indirect impact via the impact on modelling.

Partner 4G emphasises that quality control procedures for solar radiation and meteorological measurements (4.5) are of great importance. This is because these measurements are essential inputs for yield estimation. If their quality is not checked, this can lead to significant errors that affect the whole chain of PV simulation, including the final energy yield, the performance ratio, and the energy performance index. More specifically, if solar radiation is overestimated, expected electrical power production is also overestimated which leads to underestimating the PR, and vice versa. Errors in solar radiation estimations lead to errors in the final energy yield ranging from a few percentage points to over 10% per year. The magnitude of the impact depends on the type of PV technology and its operating environment. The effect is even more pronounced when analysed on a monthly basis. In that sense, innovation 4.5 can result in an increase or decrease in the PR depending on whether it was over- or underestimated to begin with. Partner 4B shares a similar view to partner 4G stating that innovation 4.5 would lead to more accurate irradiation measurements which would increase or decrease the PR, by up to a few percentage points, depending on the results of the quality control procedures.

The use of a soiling measurement kit (4.6) would provide a better estimation of soiling losses on a weekly and seasonal basis because of the more accurate and precise measurements obtained, according to partner 4A. This allows for a better estimation of the actual PR of the PV plant in question. Partner 4A anticipates an increase in the PR with a variable significance depending on the PV plant location. Partner 4C, the other owner of the innovation, foresees a positive impact on the PR as a result of soiling detection, removal, and reduction. Lower soiling means higher electricity production and a better PR. The impact can reach a few percentage points depending on location, system type, and soiling type.

Finally, the use of a capacitive I-V tracer (4.7) is expected to be non-influential, according to its owner 4A. Nevertheless, partner 4B envisions an indirect impact on the PR via the impact on modelling as explained earlier.

3.1.4 Impact of WP5 innovations on PR

Innovations 5.1 and 5.2 address PV power short-term forecasting and nowcasting, respectively. Partner 5A, one of the owners, expects a moderate impact from both innovations thanks to the results obtained from PV system neural networks which help with very short-term forecasting. Partner 5B foresees a slight positive impact only for projects with trackers if their algorithms can integrate forecasting data.

Innovation 5.3 is concerned with improved power forecasting in the presence of snow, dust, fog, and other extreme events. According to partner 5C, one of its owners, this innovation can help in forecasting events requiring on-site maintenance, making maintenance reactive enough to limit the impact of these events or its duration. This mitigates a reduction in the PR of up to a few percentage points over the event duration depending on location, system type, and meteorological event type. Partner 5B envisions that cleaning campaigns can be adapted according to the results from this innovation in such a way that the PR increases by 1-2%.

Forecasting applied to bifacial (5.4) and floating (5.5) PV systems is expected to have a direct but negligible impact on the PR, according to its owner 5C. This would be due to the ability to schedule maintenance during less disturbing timeslots, thereby decreasing the impact of maintenance times on the PR. Partner 5A, another owner, anticipates an indirect impact via the impact of modelling improvements described earlier. Partner 5B shares the same view. Partners 5A’s and 5B’s views extend to forecasting applied to residential PV systems (5.6).

Partners 5D and 5E, owners of forecasting for spatial averaging and PV aggregation (5.7), did not state any impact on the PR from this innovation. Other project partners either expect an indirect impact via the impact on modelling (5B), or no impact (5F and 5G).

3.1.5 Impact of WP6 innovations on PR

Only a few innovations from this WP are expected to influence the PR. Deploying a grid digital twin (6.8) means that all grid information will be estimated based on available measurements. As a result, less curtailment and disconnections are expected, according to the innovation owner - partner 6A. Less curtailment from the DSO means a better performance, where a maximum of 30% curtailment might be avoided in Germany, for example. Partner 6A also expects less curtailment because of real-time congestion management of the grid (6.9), resulting in the same impact described for innovation 6.8. Advanced grid operation and control of PV systems based on forecasts (6.10) is also expected to decrease curtailment as good forecast data is integrated into the grid digital twin, according to partner 6A. This would impact the PR in the same way described for innovation 6.8. Partner 6B anticipates a low negative impact on the PR as a result of the operation and planning of PV systems for the provision of ancillary services to grid operators (6.14). This is because the provision of ancillary services can affect PV inverter efficiency. The remaining innovations from this WP are expected to be non-influential by their owners as well as other project partners.

3.2 Temperature-corrected performance ratio

The temperature-corrected performance ratio is also known as PR at STC or DC-corrected PR. It utilises a similar equation as the one used for PR, except that the reference yield is corrected for temperature variations. The purpose of this correction is to account for the deviation of the actual module temperature on-site from the reference one under STC. This makes the PR of PV plants in different climatic conditions comparable. Equation (2) shows how the CPR is calculated:

$$CPR = \frac{Y_f}{Y_r} = \frac{E_{out}}{P_0} / \frac{H}{G_{ref} \cdot C} \tag{2}$$

Where:

- C: temperature adjustment factor, calculated as follows:

$$C = 1 + \gamma \cdot (T_{mod} - T_{ref}) \tag{3}$$

Where:

- γ: relative maximum-power temperature coefficient [°C^{-1}]
- T_{mod}: module temperature [°C]
- T_{ref}: reference temperature under STC [25°C]

Since the PR at STC is a variation of the PR, most of the innovations with a potential impact on the latter are also expected to influence the former, and vice versa. Table 3.1 summarised expert opinions on influential and non-influential innovations when it comes to the PR at STC.

3.2.1 Impact of WP2-6 innovations on CPR

Innovation owners and project partners envision the same impacts from working packages 2-5 on the CPR as the ones outlined earlier for the PR, assuming the module temperature is monitored and recorded. The only exception is in WP6, where partner 6A expects innovations 6.8-6.10 to be non-influential when it comes to the CPR as opposed to the potential impacts explained earlier for the PR. This is because the impact of these innovations has to do with reducing curtailment from the DSO's point of view. The temperature correction for PV modules is irrelevant in this case.

3.3 Soiling ratio

The soiling ratio is used to reflect the effect of soiling on the performance and compare PV plants in different operating conditions with different soiling degrees. It is a ratio between the actual power output of a soiled device and its expected power output if it is clean. For this purpose, two reference devices are used. A soiled PV cell or module, representative of the PV plant conditions, and a clean one, which is maintained via regular manual or automatic cleaning. The maximum power output as well as the temperature of both devices are then monitored. Alternatively, the energy output could be used to avoid errors due to calibration misalignment.

When it comes to the impact of SERENDI-PV innovations on the SR, Table 3.1 outlined all the innovations and whether they are expected to be influential or not by the project partners. Influential innovations are discussed in more detail below.

3.3.1 Impact of WP2 innovations on SR

Three of the owners (partners 2C, 2D, and 2E) of modelling of bifacial PV systems (2.1) think that the innovation does not influence the SR. Nevertheless, partner 2A stated that innovation 2.1 would help in shifting from rough estimates to ones based on the local data available from weather databases. This would reduce the uncertainty in PV plants analysis and evaluation by tens of percentage points. Partner 2A noted, however, that only a front side soiling model is being developed, and not both sides. Partner 2B, another owner, also expects an improvement in numerical assessment, but did not specify the significance of this impact. Partner 2F believes that the improved knowledge about bifacial systems gained from this innovation can lead to changes in plant design. This includes the tilt angle which would, in turn, affect the SR. The direction of the impact can be positive or negative depending on the modelling results, and the magnitude is not expected to be significant.

Partners 2C and 2D foresee no impact from the modelling of floating PV systems (2.2) on the SR. Partner 2A stated that their soiling model only covers ground-mounted systems and does not account for the specifics of the harsh environment in which floating PV operates. Partner 2B is the only innovation owner that anticipates an impact via digital twinning recognition if a system is soiled. This is important for operation and maintenance; however, the direction of the impact was not stated, and the significance was said to be very site specific. Partner 2F expects the same impact from this innovation as stated earlier for innovation 2.1.

Modelling of small and BAPV systems (2.3) is expected to be non-influential, according to partners 2C and 2E. Nevertheless, partner 2A stated that the aim of the development is to have models that are independent of system size. In that sense, the impact expected on large-scale systems is transferable to small and BAPV systems. Thus, innovation 2.3 is also expected to reduce uncertainties in overall PV plant analysis and evaluation as stated for innovation 2.1. Partner 2B also expects the same impact as of innovation 2.1.

Again, partners 2C and 2E expect no impact from the modelling of BIPV systems (2.4) on the SR. Partner 2A, however, expects this innovation to improve PV yield modelling and reference values estimation. This decreases the uncertainty associated with PV plant analysis and evaluation overall by up to 10%. Partner 2B also expects innovation 2.4 to reduce uncertainties, but the impact is expected to be insignificant.

Partner 2A, one of the innovation owners, expects a similar impact from the modelling of soiling (2.5) on the SR as that stated for innovation 2.1. Partner 2F expects this innovation to lead to changes in plant design and cleaning campaigns which can, then, decrease the SR by a few percentage points. Another owner, 2D, anticipates no impact from innovation 2.5 on the SR.

Again, partner 2A expects a similar impact from the modelling of snow (2.6) as that expected from innovation 2.1, such that only the front side is affected by snow in case of bifacial PV systems, and the rear side effects are disregarded. Partner 2F expects that the better modelling offered by this innovation can lead to changes in the design and cleaning campaigns which can, in turn, affect the SR. The direction of change can be positive or negative depending on the modelling results, but the impact is expected to be insignificant either way. Partner 2D, one of the owners, foresees no impact on the SR.

Finally, partner 2D believes that the modelling of degradation (2.7) has no impact on the SR. Partner 2A clarified that soiling is one of the factors that causes degradation as it affects the surface properties of PV modules. Together with other degradative factors, soiling has an increased effect on PV electricity production. While partner 2A stated that an impact of tens of percentage points on the SR is expected, it was not clarified how that unfolds.

3.3.2 Impact of WP3 innovations on SR

Two of the owners of specific data analytics for bifacial PV systems (3.1) expect the innovation to be influential when it comes to the SR. Partner 3C anticipates that this innovation will help in calculating the soiling ratio on both sides of a bifacial PV module more accurately. This helps in more accurately quantifying the impact of soiling on the performance of such modules. The SR could either increase or decrease by 1-2% due to this more accurate estimation. Partner 3B expects innovation 3.1 to only have an impact if noticeable underperformance that leads to lowering electricity production below a certain threshold has been detected. In that case, the SR can change by 20+% per year depending on irradiation levels, regional characteristics, and system topography. Partners 3A and 3D, however, foresee no impact from innovation 3.1 on the SR.

As for specific data analytics for floating PV systems (3.2), partner 3C envisions a similar impact on the SR as that outlined for innovation 3.1. Again, the SR may increase or decrease by 1-2% as a result of the more accurate estimation based on more robust knowledge of floating PV soiling. Partner 3B also foresees a similar impact as the one they stated for innovation 3.1, except that the magnitude of the impact is expected to be 10+% per year this time. Again, partners 3A and 3D anticipate no impact from this innovation on the SR.

Partner 3B believes that specific data analytics for small and BAPV systems (3.3) will have a similar impact in nature as that of innovation 3.1, and in magnitude as that of innovation 3.2. Partner 3C did not state any potential impacts while partner 3D deems innovation 3.3 to be non-influential when it comes to the SR. Partner 3D also stated the same when it comes to specific data analytics for BIPV systems of different sizes (3.4). Nevertheless, partner 3B clarified that the aim of the development is to create valid models that are independent of system size, so the impact seen on large-scale systems should be transferable to smaller ones. Partner 3B expects innovation 3.4 to reduce the uncertainties related to PV plants analysis and evaluation, in general, by tens of percentage points.

Partner 3D is the only owner of specific data analytics for soiling (3.5) that expects no impact from this innovation on the SR. Partner 3B predicts the same impact in nature and significance as that outlined for innovation 3.3. Partner 3C also expects a similar impact as that stated earlier for innovations 3.1 and 3.2. This means that the SR can go up or down due to more accurate estimates, but the magnitude will depend significantly on the operating environment in question. Partner 3A stated that innovation 3.5 can help in detecting conditions requiring cleaning which would, in turn, reduce the soiling losses and positively impact the SR. The magnitude of the impact is expected to be a few percentage points depending on location, system type, and soiling type. It can even reach 10-15% in soiling-prone sites, according to partner 3A.

Partners 3A and 3D expect specific data analytics for snow (3.6) and degradation (3.7) to have no impact on the SR. Nevertheless, partner 3B anticipates the same impact from both innovations as the one stated earlier for innovation 3.3.

IV curve data analytics (3.8) are expected to help in detecting extreme soiling conditions at the string level, according to its owner 3A. This would lead to a decrease in soiling losses and an improvement in the SR after cleaning. The impact can reach a few percentage points at the string level depending on location, systems type, and soiling type. Partner 3A also believes that IR imaging data analytics (3.9) can act as a soiling indicator and help in detecting conditions requiring cleaning. Again, this would decrease soiling losses and improve the SR by a few percentage points as stated earlier. However, another owner of innovation 3.9, partner 3C, deems it as non-influential.

Partner 3A anticipates that failure detection and diagnosis methods (3.10) would have a positive impact on soiling losses and the SR after cleaning by a few percentage points depending on local and project conditions. This is due to the detection of circumstances requiring cleaning thanks to the complementarity of the aforementioned data analytics tools. Partner 3B, again, expects a similar impact from innovation 3.10 as that stated for innovation 3.3. Nevertheless, partners 3C and 3D foresee no impact from this innovation on the SR.

Partner 3G, the owner of the fault detection/diagnosis toolbox for small PV systems (3.11), did not state any potential impacts on the SR. Other project partners, like 3E, 3F and 3K, deem the innovation to be non-influential. PV inverter efficiency characterisation (3.12) is believed to have no impact on the SR either, according to its owner 3H as well as other project partners.

While partner 3F envisions no impact from the PV inverter digital twin (3.13) on the SR, partner 3I foresees a significant improvement. Partner 3I clarified that innovation 3.12 can help in controlling soiling and detecting long-term slow degradation by comparing the expected and the real electricity production levels. The early detection of losses at the inverter level can, in turn, significantly improve the SR where it can almost reach unity in large-scale plants made up of a great number of small generators. As for the PV battery digital twin (3.14), partner 3J expects little influence of low importance on the SR although the mechanism of the impact was not clarified. Partner 3F, the other owner, foresees no impact at all. Finally, none of the owners or the project partners deemed the BIPV digital twin (3.15) to be influential when it comes to the SR.

3.3.3 Impact of WP4 innovations on SR

Specific procedures for bifacial PV systems (4.1) would allow a more accurate determination of the power produced by such modules, according to its owner 4A. This, in turn, enables a more accurate estimation of the soiling losses that affect them. However, partner 4A did not state the direction or magnitude of the expected impact. Another project partner, 4D, foresees no impact. Partner 4A maintains the same view when it comes to specific procedures for floating PV systems (4.2). Yet, this innovation is deemed non-influential by its other owner, partner 4C.

None of the owners (partners 4A, 4D and 4E) of new procedures for PV inverters field testing (4.3) or project partners anticipate this innovation to affect the SR. New procedures for batteries field testing (4.4) are expected to have a moderate influence of moderate importance on the SR, according to its owner 4F. The mechanism of such an impact was not clarified. Partner 4A, the other owner of innovation 4.4, deems it non-influential.

Partner 4G, the owner of quality control procedures for solar radiation and meteorological measurements (4.5), expects the innovation to change the SR by tens of percentage points. This is because wrong values of the SR, as well as other measurements, can lead to significant errors that affect the whole PV simulation chain. Quality control is, thus, crucial before any further processing of such measurements occurs. In particular, the overestimation of soiling leads to the underestimation of electrical power production and the SR, and vice versa. Other project partners, like 4B and 4D, foresee no impact from innovation 4.5 on the SR.

The utilisation of a soiling measurement kit (4.6) is expected to decrease soiling and improve the SR if an anti-soiling coating is used or cleaning actions are applied accordingly, as stated by partner 4C. The improvement in the SR can reach a few percentage points depending on location, system type, and soiling type. Partner 4A, the other owner, expects the more precise soiling kit to help in arriving at more accurate estimation of soiling losses. This means that the SR will also be more accurate with a variable significance depending on the soiling characteristics of the location in question. Partner 4B also expects a variable impact on the SR depending on the results of the soiling kit.

The use of a capacitive I-V tracer (4.7) is expected to be non-influential by its owner, 4A, as well as other project partners, like 4B and 4D.

3.3.4 Impact of WP5-6 innovations on SR

Only two innovations from this working package are considered influential when it comes to SR. The first is improved power forecasting in presence of snow, dust, fog, and other extreme events (5.3). Partner 5C, one of the owners, anticipates a positive impact of up to a few percentage points depending on location, system type, and soiling type. This is because innovation 5.3 can help in forecasting conditions requiring cleaning, like extreme soiling events, making maintenance reactive enough to limit the duration of the event impact. This rapid maintenance action reduces soiling losses and improves the SR. Partner 5B also foresees an improvement of 1-2% as cleaning campaigns can be adapted to improve the SR.

The second influential innovation is forecasting applied to bifacial (5.4). Partner 5C expects a similar impact in magnitude as that stated for innovation 5.3. Forecasting conditions requiring cleaning of the backside of the module or the ground behind it can lead to the same impact stated earlier. Partner 5A, another owner of innovation 5.4, deems the innovation as non-influential.

None of the owners of WP6 innovations or the project partners expect them to influence the SR.

4 Impact of innovations on reliability KPIs

Only one indicator has been selected in T1.1 [1] as a reliability KPI, which is the performance loss rate (PLR). This KPI is briefly explained here, followed by a summary of partners' opinions on which innovations impact it (see Table 4.1) and how they do so (see Section 4.1). More details about the KPI, the factors that affect it, and its state-of-the-art value can be found in **"D1.1 KPIs on state of the art PV reliability, performance, profitability and grid integration"** [1].

Table 4.1: Summary of the impact of SERENDI-PV innovations on reliability KPIs

ID	Innovation	PLR
2.1	Modelling of bifacial PV systems	X
2.2	Modelling of floating PV systems	X
2.3	Modelling of small PV systems, including BAPV	X
2.4	Modelling of BIPV systems, any size	X
2.5	Modelling of soiling	X
2.6	Modelling of snow	X
2.7	Modelling of degradation	X
3.1	Specific data analytics for bifacial PV systems	X
3.2	Specific data analytics for floating PV systems	X
3.3	Specific data analytics for small PV systems, including BAPV	X
3.4	Specific data analytics for BIPV systems, any size	X
3.5	Specific data analytics for soiling	X
3.6	Specific data analytics for snow	X
3.7	Specific data analytics for degradation	X
3.8	IV curve data analytics	X
3.9	IR imaging data analytics	X
3.10	Failure detection and diagnosis methods	X
3.11	Fault detection/diagnosis toolbox for small PV	X
3.12	PV inverter efficiency characterisation	X
3.13	PV inverter digital twin	X
3.14	PV battery digital twin	X
3.15	BIPV digital twin	X
4.1	Specific procedures for bifacial PV systems	X
4.2	Specific procedures for floating PV systems	X
4.3	New procedures for PV inverters field testing	X
4.4	New procedures for batteries field testing	X
4.5	Quality control procedures for solar radiation and meteorological measurements	X
4.6	Soiling measurement kit	X
4.7	Capacitive I-V tracer at 1,500V	X
5.1	Short-term PV power forecasting based on integrating satellite data and NWP models with PV power production data	X
5.2	PV power nowcasting by merging satellite data with sky-camera data and methods for PV power output aggregation	X
5.3	Improved power forecasting in presence of snow, dust, fog, and other extreme events	X

5.4	Forecasting applied to bifacial PV systems	X
5.5	Forecasting applied to floating PV systems	X
5.6	Forecasting applied to residential PV systems	X
5.7	Forecasting for spatial averaging and PV aggregation	X
6.1	Characterisation of PV inverters as a fundamental element for telecommunication and control of PV systems	
6.2	Acquisition of PV measurements using Smart/Advanced-Metering-Infrastructure with high resolution in DSO SCADA	
6.3	Curtailment of PV system from DSO SCADA via secured CLS-channel and delivery of evidence for performed curtailments	
6.4	Algorithms for automatic PV data integration in DSO SCADA	
6.5	Algorithms for automatic PV data integration in PV meta-data registry	
6.6	Integration of algorithms for automatic PV data integration in smart grid data systems of participating project partners	X
6.7	Service system for aggregating anonymous data for the monitoring and management of distributed generation systems	
6.8	Digital twin of the grid, real-time state estimation based on load and PV-measurements	X
6.9	Real-time congestion management of the grid based on the Digital twin of the grid and different algorithms for PV-control	X
6.10	Advanced grid operation and control of PV systems based on PV forecast	X
6.11	Integration of V2G & G2V into self-consumption optimisation software	
6.12	Further integration of virtual batteries into self-consumption optimisation software	X
6.13	Predictive control-based EMS for PV storage self-consumption optimisation	X
6.14	Operation and planning of PV for the provision of ancillary services to the grid operators	
6.15	Operation of PV ensuring active power reserve available to provide ancillary services	X

4.1 Performance loss rate

The PLR of a PV system is the rate of reduction of its performance over time, usually measured in percent per annum. This is measured at the system and not the module level, which differentiates it from the module degradation rate. Both irreversible module degradation as well as reversible and/or preventable system-level factors are included in the PLR. It is calculated as a ratio between the daily, weekly, monthly, or yearly PR of two subsequent years. The CPR can also be used for the calculation.

4.1.1 Impact of WP2 innovations on PLR

Three out of the five owners of modelling bifacial PV systems (2.1) expect no impact from the innovation on the PLR. These are partners 2C, 2D, and 2E. Partner 2A, another owner, expects this innovation to improve yield modelling and offer better estimates for the reference/simulated PR value. This can further used for the detection of performance loss. Innovation 2.1 is, hence, expected to decrease the uncertainty in PLR by a few percentage points. Partner 2B anticipates that innovation 2.1 can lead to a change in the operating points of PV plants which can slightly reduce the PLR by 0.25% per year but may become significant in the long run. Partner 2F believes that this innovation can lead to a better understanding of bifacial PV systems and their losses and to a slight decrease in their PLR. Partner 2F clarified that the market standard for performance loss is currently 0.5%, and innovation 2.1 can help in decreasing it by a few tenths of percentage points.

Partners 2C and 2D, on the one hand, believe that modelling of floating PV systems (2.2) has no influence on the PLR. On the other hand, partners 2A and 2B anticipate a similar impact in nature and magnitude as that stated earlier for innovation 2.1. Partner 2F expects innovation 2.2 to have an impact on the PLR for the same reasons stated for innovation 2.1. The PLR is expected to decrease slightly by less than 1%. Partner 2F also clarified that there is currently no market standard for the PLR of floating PV systems.

As for modelling small and BAPV systems (2.3), partner 2G believes that better modelling can lead to a better understanding of loss and better preventative measures against it. In that sense, the PLR would improve but the magnitude of improvement was not specified. Partner 2A clarified that the purpose of these developments is to have valid models irrespective of the system size. This means that the benefits observed for large-scale PV plants, as in innovation 2.1, are transferable to this innovation for small PV systems. Nevertheless, other owners, like 2C and 2E, deems this innovation as non-influential. Again, partners 2C and 2E believe that modelling of BIPV systems (2.4) has no impact on the PLR. Partner 2A, however, expects a similar impact from this innovation as the one stated for innovation 2.1.

Modelling of soiling (2.5) can affect the PLR, according to partners 2A and 2G. Partner 2A believes that innovation 2.5 can help in differentiating between performance losses due to soiling (weather, reversible) and degradation (technical, irreversible), and in more accurately estimating the PLR. This can decrease the uncertainty in PV plants analysis and evaluation by tens of percentage points. Partner 2G expects the same impact from innovation 2.5 on the PLR as the one stated for innovation 2.3. Still, partner 2D deems this innovation as non-influential. Partners 2A, 2D, and 2G maintain these views also when it comes to modelling of snow (2.6). In this case, the innovation can help in differentiating between snow and degradation factors affecting the PLR, according to partner 2A.

Modelling of degradation (2.7) is regarded as non-influential by one of its owners, 2D. The other owner, 2A, clarified that the developed feature does not directly estimate degradation. Rather, the resulting maps show which regions have a higher probability of increased degradation of PV plant components in order to support the decision-making process. In that sense, the innovation only has an indirect impact on the PLR. Partner 2F expects innovation 2.7 to enhance the understanding of degradation and to lead to adaptations in plant design and maintenance. This, in turn, can slightly reduce the PLR by a few tenths of percentage points from the current market standard of 0.5%.

4.1.2 Impact of WP3 innovations on PLR

Specific data analytics for bifacial PV systems (3.1) are expected to influence the PLR by several of the innovation owners. Partner 3A expects an improvement of a few tenths of percentage points per year, depending on location and system type, as a result of mitigating electricity production losses. This would be the case if on-site maintenance actions are taken when conditions requiring maintenance, such as underperformance, are detected. Partner 3B also expects innovation 3.1 to be influential if noticeable underperformance has been detected. However, they predict a much higher improvement of 20% or more per year depending on regional characteristics, irradiation levels, and system topography, among other factors. Partner 3C stated that this innovation would enable evaluating the performance of bifacial PV systems more accurately, which also means a better estimation of their performance losses. Partner 3C anticipates a reduction in PLR uncertainty of at least 2-5%. Nevertheless, partner 3D deems innovation 3.1 as non-influential.

The views of partners 3A, 3B, 3C, and 3D regarding the impact of innovation 3.1 also apply to specific data analytics for floating PV systems (3.2). The only exception is that this time partner 3B expects a lower magnitude of improvement in the PLR, 10% or more per year, as a result of innovation 3.2. Specific data analytics for small and BAPV systems (3.3) are expected to have a similar impact on the PLR as that outlined by partner 3B for innovation 3.2 and partner 3A for innovation 3.1. Partner 3C did not state any potential impacts while partner 3D deems innovation 3.3 as non-influential.

Partner 3B stated that the aim of these developments is to have models that are valid irrespective of the system size. Thus, the improvement expected in large-scale systems should be transferable to smaller ones as well. In other words, specific data analytics for BIPV systems of different sizes (3.4) can decrease the uncertainty in PV systems analysis and evaluation, including the PLR, by a few percentage points. Partner 3A anticipates a similar impact from innovation 3.4 as that outlined earlier for innovation 3.1. Partner 3E stated that this innovation can help in detecting failures leading to high performance losses. So, the PLR can decrease by a few percentage points. However, partner 3D anticipates no impact from this innovation on the PLR.

Partner 3A expects an improvement of a few percentage points per year in the PLR as a result of specific data analytics for soiling (3.5). That is in case on-site regular or one-off cleaning actions are applied when conditions requiring cleaning, like underperformance and a low soiling ratio, are detected. This mitigates electricity production losses and improves the PLR. Partner 3B envisions the same impact from this innovation as the one outlined earlier for innovation 3.2. Partner 3C clarified that innovation 3.5 would allow differentiating soiling losses from degradation losses. The soiling losses can then be subtracted from the performance evaluation to properly account for degradation. This can decrease the uncertainty in the PLR by at least 2-5%, according to partner 3C. Still, partner 3D regards this innovation as non-influential.

Partner 3A expects the same nature and magnitude of the impact from specific data analytics for snow (3.6) as that stated for innovation 3.5. That is in case on-site specific cleaning actions are applied when conditions requiring the removal of snow are detected. Partner 3B anticipates the same impact as that stated for innovation 3.2 while partner 3D considers this innovation to be non-influential. As for specific data analytics for degradation (3.7), partner 3A expects a positive impact on the PLR if maintenance actions, like the fixing or changing of devices, are carried out when degradation is detected. This can mitigate electricity production losses, especially if many inverters or modules have been affected, such that the improvement can range from a few tenths to a few percentage points per year. Partner 3B expects the same impact stated before for innovation 3.2 while partner 3D foresees no potential impacts.

IV curve data analytics (3.8) are expected to have a positive impact on the PLR, according to its owner 3A. Partner 3A clarified that performance deteriorations can be mitigated if on-site maintenance actions at the string level are carried out when degradation, in modules or connections, is detected. This can mitigate losses in electricity production, however, that may not be significant on the plant level if only a few strings have been affected and detected. Partner 3A expects an improvement in the PLR of few tenths of percentage points per year depending on location, system type, degradation type, and degradation extent. Partner 3E expects innovation 3.8 to help in detecting failures resulting in high performance losses. Thus, the PLR can slightly decrease (<1%). Other partners, like 3F and 3K, anticipate no impact on the PLR.

When it comes to IR imaging data analytics (3.9), the owners 3A and 3C envision a positive impact on the PLR. Partner 3A clarified that if different failure modes are detected and lead to on-site maintenance actions on the module or the system level, deterioration in performance can be mitigated. In that case, electricity production losses are avoided, however, it may not be significant on the plant level if only a few modules are affected and detected. Thus, an improvement of a few tenths of percentage points per year in the PLR can be expected depending on location, system type, degradation type, and degradation extent. Partner 3C stated that the convoluted analysis using data from SCADA and IR imaging allows the detection of power losses due to degradation. Innovation 3.9 detects failures early via a machine learning tool trained with IR images. The magnitude of the impact depends on the number of affected strings, but is generally expected to be high during the early stages of a project. Other project partners, like 3E, 3F and 3K, have the same expectations regarding this innovation as the ones stated for innovation 3.8.

Several owners of failure detection and diagnosis methods (3.10) anticipate a positive impact from the innovation on the PLR. Partner 3A stated that the complementarity of several approaches, like underperformance quantification, degradation type and fault location identification, can lead to detecting and fixing failures. This leads to the mitigation of electricity production losses as well as the prevention of potential escalations or catastrophic failures, such as preventing fire hazards from severe hot spots when detected at an early stage. The magnitude of PLR improvement can range from a few tenths of percentage points, such as with potential induced degradation detection and recovery, to a few percentage points, in case of the detection of severe mismatches/hot spots. Partner 3C highlighted that innovation 3.10 benefits from the aforementioned innovations from this WP and would, indeed, lead to a better understanding of the PLR of PV plants. Innovation 3.10 is expected to help in the early detection of any underperformance in a PV plant. The magnitude of improvement in the PLR strongly depends on the amount of detected and fixed failures. Partner 3C generally expects a high impact during the early stages of a project, and a moderate impact over the rest of the system lifetime. Partner 3F foresees no impact from this innovation on the PLR.

As for the fault detection/diagnosis toolbox for small PV (3.11), its owner 3G envisions a positive impact from it on the PLR. Partner 3G clarified that innovation 3.11 allows a better modelling which, in turn, leads to a better understanding of losses and better preventative measures against them. Partner 3E also expects innovation 3.11 to decrease the PLR (<1%) as a result of detecting failures or decreased efficiency that lead to high performance losses. Partner 3F deems the innovation as non-influential.

The owner of PV inverter efficiency characterisation (3.12), 3H, expects it to be non-influential when it comes to the PLR. Nevertheless, partner 3E expects a slight improvement in the PLR (<1%) as a result of detecting failures that lead to high performance losses.

One of the owners of the PV inverter digital twin (3.13), 3F, deems the innovation as non-influential. However, the other owner, 3I, expects the innovation to improve significantly the reliability of the system due to the early detection of unexpected behaviour in faulty components. Partner 3F maintains the same view for the PV battery digital twin (3.14) as the one stated for innovation 3.13. The other owner of the innovation, 3J, stated that it might have little influence of low importance on the PLR but did not clarify the mechanism of the impact. Partner 3E expects a decrease in the PLR by a few percentage points as a result of failure detection that might lead to performance losses via innovation 3.14. The owners of the BIPV digital twin (3.15), partners 3F and 3H, deem the innovation to be non-influential. Partner 3E expects a slight improvement in the PLR (<1%) for the same reason stated for innovation 3.14.

4.1.3 Impact of WP4 innovations on PLR

Partner 4A, the owner of specific procedures for bifacial PV systems (4.1), expects procedures like the in-situ measurement of bifacial modules and strings to reduce the uncertainty in the PLR by at least 2-5%. This is because such specific procedures can enable a better long-term characterisation of the performance of bifacial PV systems and a better evaluation of the performance loss they exhibit. Other project partners, like 4B, envision an indirect impact via the improved data quality utilised by WP2-3 innovations while partner 4D envisions no impact.

Partner 4A anticipates a similar impact from the specific procedures for floating PV systems (4.2) on the PLR as that stated for innovation 4.1. Partner 4C expects that procedures like choosing more appropriate and resilient modules, or measures taken against losses due to humidity, salt and mechanical stress can lead to the prevention and mitigation of performance loss. In that sense, innovation 4.2 can help in keeping the PLR below 1% for floating PV systems.

Similar to innovation 4.1, partner 4A expects that new procedures for PV inverters field testing (4.3) can decrease the uncertainty in the PLR by at least 2-5%. This is because the in-situ measurement of central and string inverters can lead to a more accurate evaluation of the conversion efficiency of said inverters, their performance, and their degradation. Partner 4E also envisions a direct and positive impact that can be very significant. This is because the main target of innovation 4.3 is to choose more reliable inverters, thus, enhancing the reliability of the overall system. Partner 4D, however, considers this innovation to be non-influential.

As for new procedures for batteries field testing (4.4), partner 4A stated that new procedures that allow measuring the state-of-health (SoH) and state-of-charge of batteries (SoC) without disconnecting them can enable the characterisation of their SoH and SoC. This enables the evaluation of their performance losses and reduces the uncertainty in the PLR by at least 2-5%. Partner 4F predicts a marginal influence of low importance from this innovation. Partner 4D expects innovation 4.4 to be non-influential.

According to partner 4G, solar radiation and meteorological measurements are essential inputs for yield estimation. Thus, the utilisation of quality control procedures for such measurements (4.5) before further processing them is crucial to prevent errors that span the whole chain of PV simulation. This includes errors in the final energy yield, the performance ratio, and the energy performance index. Since the PLR is based on the calculated performance ratios for consecutive years, innovation 4.5 can mitigate errors of up to 10% per year depending on the operating environment and the PV technology used. Partner 4B concurs stating that more detailed quality control procedures can improve the quality of obtained measurements and provide a more precise estimate of the PLR. The PLR can increase or decrease depending on the results, but the magnitude of change was not specified. Partner 4D expects no impact from innovation 4.5 on the PLR.

Partner 4C expects that the improved soiling measurements and the application of appropriate and adequate cleaning strategies as a result of utilizing a soiling measurement kit (4.6) can reduce the impact of soiling. This would lead to higher electricity production levels and improve the PLR by a few percentage points depending on location, system type, and soiling type. Partner 4A envisions that innovation 4.6 can improve the evaluation of soiling losses which enable subtracting the losses from soiled devices from the system performance. This, ultimately, allows for a better estimation of the performance loss in the rest of the devices. Partner 4A expects a decrease in the PLR uncertainty by at least 2-5% as a result of this innovation. Partner 4D anticipates no impact from innovation 4.6 on the PLR.

Finally, partner 4A also expects a reduction of the uncertainty in the PLR by at least 2-5% as a result of using an improved capacitive I-V tracer (4.7). Partner 4A clarified that the use of a tracer that is capable of monitoring string up to 1,500 V and 35 A enables the direct measurement of power loss in PV strings and enhances their characterisation. Partner 4D foresees no impact from innovation 4.7 on the PLR.

4.1.4 Impact of WP5 innovations on PLR

None of the owners of innovation 5.1, concerning short-term PV power forecasting, stated any potential impacts on the PLR. Other project partners, like 5F and 5G, expect the innovation to be non-influential. Partner 5H stated that innovation 5.1 may not necessarily improve the PLR, but it might make it more accurate via the improved forecasting of expected electricity production. The same views from the different owners and project partners also apply to PV power nowcasting (5.2).

Partner 5C, one of the owners of improved power forecasting in the presence of extreme events (5.3), predicts that the innovation will have a positive impact on the PLR. Partner 5C clarified that innovation 5.3 can lead to improvements in maintenance and production loss quantification as well as help in maintaining a good performance ratio. This can mitigate reductions in the performance ratio caused by the impact of such extreme events on electricity production. Therefore, an improvement of a few percentage points per year in the performance ratio in northern countries is expected as well as an improvement in the PLR. Partner 5F anticipates no impact on the PLR from innovation 5.3.

As for forecasting applied to bifacial PV systems (5.4), partner 5C expects a positive but negligible impact on the PLR. This is because forecasting can help in scheduling maintenance during less disturbing timeslots which reduces the impact of maintenance on performance. The other owners of innovation 5.4 did state any potential impacts and other project partners, like 5B and 5F, expect no impact. The same views of the different owners and project partners also apply to forecasting applied to floating PV systems (5.5).

None of owners of forecasting applied to residential PV systems (5.6) and forecasting for spatial averaging and PV aggregation (5.7) stated any potential impact on the PLR. As for innovation 5.6, other project partners expected either an indirect impact via the impact on WP2-3 innovations, like partner 5B, or no impact at all, like partner 5F. For innovation 5.7, only partner 5H stated that it may not necessarily improve the PLR, but it might make it more accurate via the improved forecasting of expected electricity production. Other partners, like 5B and 5F, foresee no impact.

4.1.5 Impact of WP6 innovations on PLR

Innovations 6.1-6.5 are not expected by any of their owners or the project partners to influence the PLR. The integration of algorithms used for automatic PV data integration in smart grid data systems (6.6) is expected to be influential, according to partner 6C. Partner 6C clarified that the use of the IEC 61850 standard in this innovation supports communication protocols for the automation of information exchange. Thus, the algorithms can perform an automatic performance assessment of a PV system and in case any pre-defined problems occur, pre-defined actions can be triggered automatically. Partner 6C highlighted that the use of this standard in information exchange is still not common practice but is necessary for future scale-up of solar PV and the management of distributed energy resources. Partner 6C concluded innovation 6.6 will help in reporting early information on PV systems behaviour and in managing a fleet of PV systems well. In the long run, this can save up a few tens of percentage points in performance that would otherwise be lost. Nevertheless, partner 6B deems this innovation as non-influential when it comes to the PLR.

Partner 6A stated that the use of a digital twin of the grid and real-time state estimation (6.8) gives a more realistic picture of how the grid behaves and performs. This, in turn, can increase the reliability of the grid and PV operation. The magnitude of this improvement was not mentioned. Partner 6A expects that real-time congestion management of the grid (6.9) can help in optimizing congestion management and, thus, improve the reliability of the grid and PV operation. Again, the magnitude of this improvement was not stated. Advanced grid operation and PV systems control based on PV forecasts (6.10) is also expected to improve the reliability of the grid and PV operation, according to partner 6A. This would be due to the integration of accurate PV forecasts into the digital twin of the grid. Partner 6A did not state the significance of this improvement.

As for the integration of virtual batteries into self-consumption optimisation software (6.12), partner 6B anticipates that this innovation can reduce the PLR of batteries. This is because the use of virtual batteries prevents the degradation of physical ones. Partner 6B also predicts an improvement in the PLR of batteries as a result of the use of predictive control-based energy management system (EMS) for PV storage self-consumption optimisation (6.13). This is because this innovation enables the charging of batteries more softly to get the same self-consumption rate. Finally, partner 6B believes that the operation of PV ensuring active power reserve is available to provide ancillary services (6.15) is also beneficial for the PLR of batteries. This is because the use of active power reserves for ancillary services avoids the degradation of physical batteries.

5 Impact of innovations on power modelling and forecasting KPIs

Four indicators have been selected in D1.1 [1] as power modelling and forecasting KPIs. Power modelling differs from forecasting. The former is a simulation of a PV system performance under previously measured conditions while the latter is based on future forecasts which start with an initial measured or modelled value. The selected KPIs are the root mean square error (RMSE), the mean absolute error (MAE), the mean bias error (MBE), and the forecast skill score (FSS). These are briefly described below, then the effect of SERENDI-PV innovations on them according to expert opinion is outlined in Table 5.1 and discussed in respective sub-sections. These KPIs are discussed in detail in **"D1.1 KPIs on state of the art PV reliability, performance, profitability and grid integration"** [1].

Table 5.1: Summary of the impact of SERENDI-PV innovations on power modelling and forecasting KPIs

ID	Innovation	RMSE	MAE	MBE	FSS
2.1	Modelling of bifacial PV systems	X	X	X	X
2.2	Modelling of floating PV systems	X	X	X	X
2.3	Modelling of small PV systems, including BAPV	X	X	X	X
2.4	Modelling of BIPV systems, any size	X	X	X	X
2.5	Modelling of soiling	X	X	X	X
2.6	Modelling of snow	X	X	X	X
2.7	Modelling of degradation	X	X	X	X
3.1	Specific data analytics for bifacial PV systems	X	X	X	X
3.2	Specific data analytics for floating PV systems	X	X	X	X
3.3	Specific data analytics for small PV systems, including BAPV	X	X	X	X
3.4	Specific data analytics for BIPV systems, any size	X	X	X	X
3.5	Specific data analytics for soiling	X	X	X	X
3.6	Specific data analytics for snow	X	X	X	X
3.7	Specific data analytics for degradation	X	X	X	X
3.8	IV curve data analytics	X	X	X	X
3.9	IR imaging data analytics	X	X	X	X
3.10	Failure detection and diagnosis methods	X	X	X	X
3.11	Fault detection/diagnosis toolbox for small PV	X	X	X	X
3.12	PV inverter efficiency characterisation	X	X	X	X
3.13	PV inverter digital twin	X	X	X	X
3.14	PV battery digital twin	X	X	X	X
3.15	BIPV digital twin	X	X	X	X
4.1	Specific procedures for bifacial PV systems				
4.2	Specific procedures for floating PV systems				
4.3	New procedures for PV inverters field testing				
4.4	New procedures for batteries field testing	X	X	X	X
4.5	Quality control procedures for solar radiation and meteorological measurements	X	X	X	
4.6	Soiling measurement kit				
4.7	Capacitive I-V tracer at 1,500V				
5.1	Short-term PV power forecasting based on integrating satellite data and NWP models with PV power production data	X	X	X	X

5.2	PV power nowcasting by merging satellite data with sky-camera data and methods for PV power output aggregation	X	X	X	X
5.3	Improved power forecasting in presence of snow, dust, fog, and other extreme events	X	X	X	X
5.4	Forecasting applied to bifacial PV systems	X	X	X	X
5.5	Forecasting applied to floating PV systems	X	X	X	X
5.6	Forecasting applied to residential PV systems	X	X	X	X
5.7	Forecasting for spatial averaging and PV aggregation	X	X	X	X
6.1	Characterisation of PV inverters as a fundamental element for telecommunication and control of PV systems				
6.2	Acquisition of PV measurements using Smart/Advanced-Metering-Infrastructure with high resolution in DSO SCADA				
6.3	Curtailment of PV system from DSO SCADA via secured CLS-channel and delivery of evidence for performed curtailments				
6.4	Algorithms for automatic PV data integration in DSO SCADA				
6.5	Algorithms for automatic PV data integration in PV meta-data registry				
6.6	Integration of algorithms for automatic PV data integration in smart grid data systems of participating project partners				X
6.7	Service system for aggregating anonymous data for the monitoring and management of distributed generation systems				
6.8	Digital twin of the grid, real-time state estimation based on load and PV-measurements				
6.9	Real-time congestion management of the grid based on the Digital twin of the grid and different algorithms for PV-control				
6.10	Advanced grid operation and control of PV systems based on PV forecast				
6.11	Integration of V2G & G2V into self-consumption optimisation software				
6.12	Further integration of virtual batteries into self-consumption optimisation software				
6.13	Predictive control-based EMS for PV storage self-consumption optimisation				
6.14	Operation and planning of PV for the provision of ancillary services to the grid operators				
6.15	Operation of PV ensuring active power reserve available to provide ancillary services				

5.1 Root mean square error

The RMSE is used for both power modelling and power forecasting. This metric is often used to compare a time series of modelled or forecasted values to observed ones. It measures the scatter of the simulation or forecasting model with respect to actual observations. In that sense, the lower the RMSE is, the better the forecasting, with a value of 0 corresponding to a perfect match between a model and reality. The RMSE gives a higher weight to larger errors compared to smaller ones. It is also sensitive to data outliers. The formula used to calculate the RMSE for PV power can be seen below:

$$RMSE_P = \sqrt{\sum_{i=1}^{i=N} \frac{(PP_i - PO_i)^2}{N}} \tag{4}$$

Where:

- PP_i: modelled or predicted PV power at time step i [kWh]
- PO_i: observed PV power at time step i [kWh]
- i: time step index
- N: sample size, i.e. total number of considered time steps

Other variations of the RMSE include the normalised and relative options. The first normalises the RMSE with respect to the rated power of the PV system, which makes plants of different sizes comparable. The second one divides the RMSE by the average value of observations. Relative RMSE is commonly used in solar resource modelling and is used here for PV power modelling and forecasting.

5.1.1 Impact of WP2 innovations on RMSE

All the innovations from WP2 are expected to affect the RMSE. Partner 2A believes that modelling of bifacial PV systems (2.1) will improve PV yield modelling of such systems and provide a better estimation for the reference/simulated value. This can lead to decrease in the RMSE by a few percentage points. Partner 2D highlighted that innovation 2.1 will improve the modelling of rear side collected irradiance taking into account the surrounding environment. This leads to an optimised calculation of the system power and to a lower RMSE. Rear side collected irradiation accounts for 10-15% of total collected irradiation in tilted system and to 50% of it in vertical systems, thus, the impact can be significant, according to partner 2D. The improvement in the RMSE is expected to reach a few percentage points. Partners 2C and 2E also expect an improvement in the RMSE as a result of the improved model accuracy, but the magnitude of the impact was said to be hard to quantify at the moment.

Partners 2A and 2C predict a similar positive impact from modelling of floating PV systems (2.2) as that outlined for innovation 2.1. Partner 2D expects a positive impact on the RMSE that can reach a few percentage points. Partner 2D clarified that electricity production from floating PV systems is expected to be higher due to the cooler air beneath the module (0-5°C less) depending on location, water temperature, and system configuration. Innovation 2.2 will improve the modelling of module temperature while taking into account the operating environment, leading to an optimised calculation of system power and a lower RMSE. Other project partners, like 2G and 2H, also anticipate a positive impact as a result of the better modelling of such systems.

Modelling of small and BAPV systems (2.3) is expected to lower the RMSE due to higher modelling accuracy, according to its owners 2E, 2G and 2C. Partner 2A highlighted that the aim of such developments is to have valid models for both large and small PV systems. In that sense, the positive impact expected for large-scale systems, e.g. innovation 2.1, is transferable to this innovation. Partners 2A, 2C, and 2E expect a similar positive impact on the RMSE from modelling of BIPV systems of different sizes (2.4) as the ones they stated for innovation 2.1.

Partner 2A expects modelling of soiling (2.5) to significantly decrease the RMSE by tens of percentage points. This is because the innovation entails the development of yearly and monthly average soiling rates with a global coverage based on local data available in weather databases. This will help in shifting from rough guesses, as is currently done, to more accurate location-based estimates which decreases errors, particularly in sites with higher soiling impacts. Partner 2D clarified that innovation 2.5 will lead to an improvement in the soiling ratio assessment via the analysis of power and current timeseries and their dynamics. The higher accuracy of these values can lead to better identification of soiling phases and cleaning events. Partner 2D suggested that a close comparison between the results of this innovation and those of the soiling measurement kit (4.6) can benefit the methodology. These methods will lead to an improvement in the RMSE that should be rather significant compared to the use of annual and monthly estimations. The magnitude of the impact is expected to reach a few tenths of percentage points in absolute values and be in phase with seasonal variations, according to partner 2D. Partner 2G expects the innovation to improve the modelling of BIPV systems and, thus, improve the RMSE with a moderate to high significance.

Modelling of snow (2.6) is expected by partner 2A to improve the RMSE by tens of percentage points for the same reasons stated for innovation 2.5, particularly in snow-prone locations in the winter months. Partner 2D clarified that the aim of innovation 2.6 is determine the snow cover ratio and distinguish between snow and soiling. In that sense, improvements from innovation 2.5 will benefit this innovation as well. Partner 2D also stated that the RMSE error of the snow cover ratio may also be based on data from soiling kits as a reference if on-site cameras are not available. Overall, the RMSE is expected to decrease by a few percentage points, especially in northern countries with numerous snowy days. Partner 2G anticipates the RMSE to improve by moderate to high levels as a result of the better modelling offered by innovation 2.6.

Both partners 2A and 2D highlighted that modelling of degradation (2.7) does not directly estimate degradation. Partner 2D clarified that the modelling of other factors, like temperature, soiling and snow, will improve the accuracy of estimating the remaining types of losses, like abnormal degradation and ageing. This can lead to a lower RMSE when it comes to degradation by a few tenths of percentage points. Partner 2A stated that the results of this innovation are maps showing the regions with a higher probability of increased PV components degradation. This is done to support the decision-making process.

5.1.2 Impact of WP3 innovations on RMSE

Some of the owners, like partners 3A and 3C, of specific data analytics for bifacial PV systems (3.1) foresee no impact from the innovation on the RMSE. Partner 3B, another owner, stated that innovation 3.1 can be impactful if noticeable underperformance has been detected. The change in the RMSE can reach 20+% per year depending on regional characteristics, irradiation levels, and system topography. Partner 3D, another owner, stated that a likely improvement in the RMSE is expected but is hard to quantify at the moment. Partner 3F believes that innovation 3.1 can lead to better modelling of bifacial PV systems via the available monitoring data which can result in a lower RMSE.

Partners 3A, 3C, 3D, and 3F expect a similar impact from specific data analytics for floating PV systems (3.2) as that described for innovation 3.1. Partner 3B also expects a similar impact in nature as that stated for innovation 3.1, but the magnitude is different. This time, innovation 3.2 can affect the RMSE by 10+% per year.

Partners 3A, 3B, 3D, and 3F anticipate the same impact from specific data analytics for small and BAPV systems (3.3) as that outlined for innovation 3.2. The same applies to specific data analytics for BIPV systems of different sizes (3.4), except that partner 3B highlighted that the aim of the development is to have valid models irrespective of the system size. So, the impacts expected for large-scale systems should be transferable to smaller systems as well, but the magnitude of the impact was not quantified.

Partners 3A and 3C foresee no impact on the RMSE as a result of specific data analytics for soiling (3.5). Partners 3B and 3D expect a similar impact on the RMSE as that stated earlier for innovation 3.2. Partner 3F expects a lower RMSE due to better monitoring data available for modelling of soiling. The opinions of partners 3A, 3B, 3D, and 3F regarding innovation 3.5 also apply to specific data analytics for snow (3.6) and specific data analytics for degradation (3.7).

Partner 3A, the owner of IV curve data analytics (3.8), anticipates no impact from the innovation on the RMSE. Nevertheless, partner 3F foresees an indirect improvement via the better modelling results using the IV curve. No impact is expected from IR imaging data analytics (3.9) on the RMSE, according to its owners 3A and 3C. Yet, partner 3F expects a similar indirect impact as that explained for innovation 3.8.

Failure detection and diagnosis methods (3.10) are deemed as non-influential by some of the owners, 3A and 3C. Partner 3B expects a similar impact in nature and magnitude as that stated for innovation 3.2. The same applies to partner 3D's opinion. Partner 3F expects a lower RMSE because of innovation 3.10. This is because the innovation would enable better modelling of the state-of-health of the PV system in question via the monitoring data available. The magnitude of improvement depends on the quality of monitoring data and its temporal and spatial resolutions.

As for fault diagnosis/detection toolbox for small PV (3.11), its owner 3G anticipates little to moderate improvement in the RMSE due to better modelling. Partner 3F also expects an improvement due to better modelling, but the magnitude was not specified. Partner 3K envisions no impact on the RMSE.

Partner 3H, the owner of PV inverter efficiency characterisation (3.12), foresees no impact on the RMSE from this innovation. However, partner 3F expects a lower RMSE due to better modelling of PV inverter efficiency through the monitoring data made available by this innovation.

A lower RMSE is also expected from the use of a PV inverter digital twin (3.13), according to its owner 3F. This is because of the better modelling of PV inverter internal temperature and conversion efficiency via available monitoring data. The magnitude of the improvement is still unknown. Partner 3I, the other owner, did not state any potential impacts. Partner 3F is also the owner of the PV battery digital twin (3.14). Again, an improvement of an unknown magnitude is expected for the RMSE. This is because innovation 3.14 would enable better modelling of the state-of-health, the state-of-charge, and the remaining useful life of a battery via the available monitoring data. Partner 3J, the other owner, anticipates a moderate influence on the RMSE as a result of this innovation, but the mechanism of the impact was not clarified.

Finally, both owners of the BIPV digital twin (3.15), 3H and 3F, expect an improvement in the RMSE as a result of this innovation. Partner 3H said this is because of the better accuracy expected although the magnitude of the improvement is still hard to quantify. Partner 3F also stated that the magnitude is still unknown, and the improvement would be due to better modelling of BIPV systems via monitoring data.

5.1.3 Impact of WP4 innovations on RMSE

Only two innovations from this WP are expected to influence the RMSE. New procedures for batteries field testing (4.4) are expected to have a high influence of great importance on the RMSE, according to its owner 4F. The mechanism of such an impact was not clarified. However, the other owner, 4D, deems the innovation as non-influential. Partner 4G anticipates a significant influence on the RMSE from the quality control procedures used for solar radiation and meteorological measurements (4.5). Partner 4G clarified that such meteorological measurements are essential inputs for modelling and yield estimation. If not checked before further processing, they can lead to significant errors that affect the whole chain of PV simulation, including metrics like final energy yield, performance ratio, and energy performance index. For instance, solar radiation has a direct impact on energy yield estimation. If overestimated, it will lead to the overestimation of electricity production and the underestimation of the performance ratio, and vice versa. Thus, simulations based on high quality data show a lower RMSE and allow analysing PV plants in greater detail. The improvement in the RMSE can vary from a few to over 10% annually, with a more pronounced effect monthly. The magnitude depends on the specifics of the PV technology in question and its operating environment.

5.1.4 Impact of WP5-6 innovations on RMSE

Innovations 5.1 concerns short-term PV power forecasting based on the integration of satellite data and numerical weather prediction (NWP) models with PV power production data for small- and medium-sized PV systems. Partner 5D, an owner, clarified that the goal of this innovation is to increase forecasting accuracy, particularly for intra-day and day-ahead forecasts, relative to the current solutions, which use satellite-based nowcasting and NWP. The target is an improvement in forecasting accuracy by at least 5% compared to the current solutions which, in turn, means a lower RMSE. This also means a lower uncertainty for transmission (TSO) and distributions system operators (DSO) which enables them to better manage the volumes of PV electricity delivered to the grid. Partner 5A, another owner, stated that innovation 5.1 may lead to a slight improvement in the RMSE, particularly for high density PV installations that require a high spatial resolution for nowcasting. Partners 5F and 5H also expect an improvement in the RMSE due to this innovation.

Innovation 5.2 concerns PV power nowcasting via merging satellite data with sky-camera data and methods for PV power output aggregation. Partner 5A, an owner, expects a similar impact from innovation 5.2 on the RMSE as that stated above for innovation 5.1. Other owners, 5D and 5E, did not state any potential impacts.

Again, project partners, like 5F and 5H, expect better forecasting and lower RMSE as a result of innovation 5.2.

Partner 5C, an owner, foresees no potential impacts from improved power forecasting in presence of snow, dust, fog and other extreme events (5.3) on the RMSE. Partner 5D, another owner, clarified that the target of this innovation is to develop models that account for extreme conditions and are at least 5% more accurate than current solutions. In case of dust, soiling and snow, the accurate prediction of these events can enable PV plant operators and maintenance teams to act upfront and prevent some losses via cleaning actions. In case of fog, having a model which accurately accounts for it means having improved accuracy and reliability regarding the expected lower PV power output. All in all, innovation 5.3 improves the accuracy and decreases the uncertainty and RMSE regarding PV power production. Other partners, like 5F and 5H, also envision an improvement in the RMSE as a result.

Forecasting applied to bifacial (5.4) is deemed as non-influential, according to partner 5C. Other owners, like 5A and 5D, envision and indirect impact via the impact on modelling. Partner 5D clarified that the aim of innovation 5.4 is to feed innovation 2.1 with more accurate forecasted data, e.g. solar irradiation, which helps in making accurate predictions for bifacial PV panels. An improvement of at least 5% in accuracy and, thus, in the RMSE is targeted. This improvement should help TSOs and DSOs in managing the volumes of PV electricity delivered to the grid by decreasing uncertainty. Partner 5A also stated that the improvement in the RMSE will be derived from modelling improvements because of this innovation. The opinions of partners 5A, 5C, and 5D regarding innovation 5.4 extend to forecasting applied to floating PV systems (5.5).

Partner 5D, an owner, clarified that the goal of forecasting applied to residential PV systems (5.6) is not to improve the accuracy of forecasting, i.e. no impact on the RMSE. The goal is, rather, to develop an algorithm that can derive/conclude the PV system configuration based on real measured PV power production data. This is because forecasting PV power production of such systems is not possible without first knowing the technical settings of the system. Partner 5A, another owner, expects a similar impact on the RMSE from this innovation as that stated earlier for innovations 5.4 and 5.5. Other project partners, like 5F and 5H, expect an improvement in the RMSE as a result of better forecasting methods.

Partner 5D, an owner, explained that the aim of forecasting for spatial averaging and PV aggregation is not the improvement of forecasting. The aim is to demonstrate the effects of spatial averaging of multiple PV systems of different geographical scales on forecasting. In other words, no impact is expected on the RMSE. Other project partners, like 5F and 5H, expect a lower RMSE as a result of the availability of better forecasts for PV aggregation.

None of the innovation owners or project partners expect any influence from WP6 innovations on the RMSE.

5.2 Mean absolute error

Similar to the RMSE, the MAE measures the scatter of a model with respect to the observed reality. Again, a value of 0 indicates a perfect match between the model and reality. The higher the MAE is, the less accurate a model is. Unlike the RMSE, the MAE gives equal weights to all errors, irrespective of their size, and is less sensitive to outliers. It can also be normalised to the rated power of the PV system or weighted relative to the average observed value. In general, it is more suited for forecasting applications. The MAE of PV power is calculated as shown below:

$$MAE_P = \frac{1}{N}\sum_{i=1}^{i=N}(PP_i - PO_i) \qquad (5)$$

5.2.1 Impact of WP2-6 innovations on MAE

All innovation owners and project partners expect the same impacts from all the SERENDI-PV innovations on the MAE as those stated earlier for the RMSE. This is because the MAE is merely another error metric that offers a slightly different view. In other words, whatever reduces the uncertainty and errors in solar PV systems modelling and forecasting would result in an improvement across all error metrics.

5.3 Mean bias error

The MBE is a metric used to detect systematic deviations. Thus, it is suitable for assessing the quality of PV power modelling, not forecasting, on a yearly basis or over longer periods. The MBE also indicates the direction of the deviation such that positive MBE values indicate a systematic overestimation, and vice versa. When used for one PV system, it corresponds to the long-term deviation between the mean modelled and observed values. When used for several sites, it reveals systematic deviations in the model used for these sites. Like the RMSE and the MAE, normalised and relative versions of the MBE can also be used. Equations (6) and (7) show how the MBE of PV power modelling can be calculated.

$$MBE_P = \frac{1}{N}\sum_{i=1}^{i=N} |PP_i - PO_i| = \overline{PP} - \overline{PO} \tag{6}$$

Where:

$$\overline{PP} = \frac{1}{N}\sum_{i=1}^{i=N} PP_i \tag{7}$$

5.3.1 Impact of WP2-6 innovations on MBE

All innovation owners and project partners expect the same impacts from all the SERENDI-PV innovations on the MBE as those stated earlier for the RMSE. This is because the MBE is merely another error metric that offers a slightly different view. In other words, whatever reduces the uncertainty and errors in solar PV systems modelling and forecasting would result in an improvement across all error metrics.

5.4 Forecast skill score

The FSS is widely used in meteorology and is applied here to PV power forecasting, not modelling. It compares the inaccuracy (error) of the model in question to a simple reference model. A skill score of 0 means that the evaluated and the reference forecasts have the same accuracy. A negative skill score means that the evaluated forecast performs worse than the reference one while an FSS equal to 1 indicates a perfect forecast. For short-term forecasts, the reference model used is usually persistence. However, more advanced models, like smart persistence, have been suggested recently by Task 16 of the International Energy Agency's Photovoltaic Power Systems Programme [4]. The equation used to calculate the FSS can be seen below, where $RMSE_{ref}$ is the RMSE of a simple reference PV power forecasting model.

$$FSS = \frac{RMSE_{ref} - RMSE}{RMSE_{ref}} \tag{8}$$

5.4.1 Impact of WP2-6 innovations on FSS

Since the FSS is a function of the RMSE, most innovation owners and project partners expect the impacts from WP2-6 innovation on the RMSE to also be applicable to the FSS. An improvement/decrease in the RMSE would lead to an improvement/increase in the FSS and bring it closer to unity. However, a few exceptions in expert opinion apply as explained below.

While partner 2A expects an improvement in the RMSE, the MAE, and the MBE because of different innovations across WP2-5, no potential impacts on the FSS were mentioned. Another difference is that partner 6C expects an improvement in the FSS due to innovation 6.6. This innovation concerns the integration of algorithms for automatic PV data integration in smart grid data systems of the participating project partners using the IEC 61850 data model or the Common Information Model. Partner 6C stated that there can be dramatic timely differences between available models in terms of PV electricity generation that can reach a few percentage points. In that case, the FSS can help in indicating which forecast models are better and are to be preferred.

Partner 2D also expects an improvement in the FSS as the RMSE improves because of the WP2 innovations for which they indicated an impact. However, partner 2D highlighted that the magnitude of improvement will also depend on the RMSE of the reference model. The higher the accuracy of the reference model was to begin with, the higher the impact of the newly developed and improved models will be. While partner 5C deemed improved power forecasting in presence of extreme events (5.3), forecasting applied to bifacial PV systems (5.4), and forecasting applied to floating PV systems (5.5) as non-influential when it comes to the RMSE, some impact is expected on the FSS. Partner 5C expects an indirect impact from innovation 5.3, where the improved power forecasting will result in a lower RMSE in power modelling. As the RMSE of soiling (2.5), snow (2.6), and degradation (2.7) models decreases, the FSS would become closer to 1. Again, the significance of the impact will also depend on the RMSE of the reference model. A similar indirect impact is expected for innovation 5.4 as the improved power forecasting considers variations in albedo due to soiling and snow, and backside soiling of bifacial modules resulting in a lower RMSE for power modelling (2.1). The same applies to innovation 5.5 as improved forecasting models consider air, water, and module temperature variations and reduce the RMSE of power modelling for floating PV systems (2.2).

6 Impact of innovations on monitoring KPIs

When it comes to monitoring, uncertainty arises from the different sensors and monitoring devices used in a PV plant. Nevertheless, this is usually not the only source of uncertainty as it can also arise due to other factors like how the modules were installed and how they are maintained. D1.1 [1] selected three parameters as monitoring KPIs, which are the energy performance index (EPI), data availability (DA), and data quality (DQ). The latter two are considered the most relevant when it comes to assessing the quality of a monitoring system. Each of these KPIs is briefly explained, then the expert opinion on how they are impacted by the SERENDI-PV project innovations is outlined (see Table 6.1) and discussed in corresponding sub-sections. More details about the KPIs can be found in **"D1.1 KPIs on state of the art PV reliability, performance, profitability and grid integration"** [1].

Table 6.1: Summary of the impact of SERENDI-PV innovations on monitoring KPIs

ID	Innovation	EPI	DA	DQ
2.1	Modelling of bifacial PV systems	X	X	X
2.2	Modelling of floating PV systems	X	X	X
2.3	Modelling of small PV systems, including BAPV	X	X	X
2.4	Modelling of BIPV systems, any size	X	X	X
2.5	Modelling of soiling	X	X	X

2.6	Modelling of snow	X	X	X
2.7	Modelling of degradation	X	X	X
3.1	Specific data analytics for bifacial PV systems	X	X	X
3.2	Specific data analytics for floating PV systems	X	X	X
3.3	Specific data analytics for small PV systems, including BAPV	X	X	X
3.4	Specific data analytics for BIPV systems, any size	X	X	X
3.5	Specific data analytics for soiling	X	X	X
3.6	Specific data analytics for snow	X	X	X
3.7	Specific data analytics for degradation	X	X	X
3.8	IV curve data analytics	X	X	X
3.9	IR imaging data analytics	X	X	X
3.10	Failure detection and diagnosis methods	X	X	X
3.11	Fault detection/diagnosis toolbox for small PV	X	X	X
3.12	PV inverter efficiency characterisation	X	X	X
3.13	PV inverter digital twin	X	X	X
3.14	PV battery digital twin	X	X	X
3.15	BIPV digital twin	X	X	X
4.1	Specific procedures for bifacial PV systems	X	X	X
4.2	Specific procedures for floating PV systems	X	X	X
4.3	New procedures for PV inverters field testing	X	X	X
4.4	New procedures for batteries field testing	X	X	X
4.5	Quality control procedures for solar radiation and meteorological measurements	X	X	X
4.6	Soiling measurement kit	X	X	X
4.7	Capacitive I-V tracer at 1,500V	X	X	X
5.1	Short-term PV power forecasting based on integrating satellite data and NWP models with PV power production data	X		
5.2	PV power nowcasting by merging satellite data with sky-camera data and methods for PV power output aggregation	X		
5.3	Improved power forecasting in presence of snow, dust, fog, and other extreme events	X		
5.4	Forecasting applied to bifacial PV systems	X		
5.5	Forecasting applied to floating PV systems	X		
5.6	Forecasting applied to residential PV systems	X		
5.7	Forecasting for spatial averaging and PV aggregation	X		
6.1	Characterisation of PV inverters as a fundamental element for telecommunication and control of PV systems		X	
6.2	Acquisition of PV measurements using Smart/Advanced-Metering-Infrastructure with high resolution in DSO SCADA		X	
6.3	Curtailment of PV system from DSO SCADA via secured CLS-channel and delivery of evidence for performed curtailments	X		
6.4	Algorithms for automatic PV data integration in DSO SCADA			
6.5	Algorithms for automatic PV data integration in PV meta-data registry			
6.6	Integration of algorithms for automatic PV data integration in smart grid data systems of participating project partners		X	X

6.7	Service system for aggregating anonymous data for the monitoring and management of distributed generation systems			
6.8	Digital twin of the grid, real-time state estimation based on load and PV-measurements		X	X
6.9	Real-time congestion management of the grid based on the Digital twin of the grid and different algorithms for PV-control		X	
6.10	Advanced grid operation and control of PV systems based on PV forecast		X	X
6.11	Integration of V2G & G2V into self-consumption optimisation software			
6.12	Further integration of virtual batteries into self-consumption optimisation software			
6.13	Predictive control-based EMS for PV storage self-consumption optimisation			
6.14	Operation and planning of PV for the provision of ancillary services to the grid operators			
6.15	Operation of PV ensuring active power reserve available to provide ancillary services			

6.1 Energy performance index

The EPI is a ratio between the final energy yield (Y_f), described earlier, and the expected energy yield (Y_E). The Y_E reflects the energy that should have been produced by a PV system over a certain period according to field setup and measurements that are fed into a simulation model. Hence, it is affected by the accuracy of the model used. The EPI can be used to compare plants if the same model is used for the calculation of Y_E, or to detect flaws in a plant operation if the EPI is much lower than 1. Equation (9) shows how the EPI is calculated.

$$EPI = \frac{Y_f}{Y_E} \tag{9}$$

Where:

$$Y_E = \frac{PR_{exp}}{Y_r} \tag{10}$$

Such that:

- PR_{exp}: expected performance ratio according to plant characteristics and climatic conditions
- Y_r: reference yield [kWh/kW_p]

6.1.1 Impact of WP2 innovations on EPI

Modelling of bifacial PV systems (2.1) is expected to influence the EPI, according to partners 2A, 2B, and 2D. Partner 2D clarified that improvements in the calculation of Y_E leads to a more accurate EPI. Hence, the EPI can go up or down depending on whether the Y_E was overestimated or underestimated beforehand. The magnitude of the impact can reach a few percentage points depending on how much the Y_E changes, particularly if the model previously used was of poor quality. Partner 2A also agrees that any improvement in simulation models would lead to a more accurate EPI. However, partner 2A expects only a positive impact such that the EPI gets closer to 1 as the Y_E approaches the Y_f. Partner 2B believes that improved modelling from innovation 2.1 would assist in rapid failure detection which can, in turn, significantly improve the performance or EPI. The magnitude of the improvement depends on the actual failure rate of the PV plant in question. Other project partners, like 2H and 2F, also predict an increase in the EPI due to the more accurate modelling offered by this innovation. Partner 2F stated that the increase can be significant, reaching a maximum of 5%. Nevertheless, one of the innovation owners, partner 2C, does not foresee any impact on the EPI. The aforementioned owners and partners expect a similar impact as that described for innovation 2.1 from the modelling of floating PV systems (2.2). This time, partner 2D highlighted that the impact may not be that significant as the impact of water temperature on system performance is limited.

As for the modelling of small and BAPV systems (2.3), partners 2G and 2A foresee an impact on the EPI while partner 2C does not. Partner 2G stated that, together with improvements in forecasting (WP5), innovation 2.3 can significantly improve the EPI. Partner 2A clarified that the aim of developing such models is to have valid results regardless of the system size, so impacts on large-scale systems should be transferable to smaller ones. Hence, partner 2A anticipates that innovation 2.3 would decrease the uncertainty in PV plants analysis and evaluation metrics, including the EPI, by a few percentage points. Other project partners, like 2B and 2H, anticipate similar impacts as those stated earlier for innovation 2.1. Partners 2A and 2C, owners of modelling of BIPV systems of different sizes (2.4), as well as other project partners, like 2B and 2H, expect similar impacts on the EPI as those stated for innovation 2.3.

Partner 2D, one of the owners of modelling of soiling (2.5), expects the innovation to influence the EPI as an improved calculation of the Y_E considering soiling losses leads to a more accurate EPI. The EPI can increase or decrease, as explained for innovation 2.1, but the magnitude of change may not be that significant as the soiling impact is limited. Partner 2A expects a similar impact on the EPI as that stated earlier for innovation 2.1 while partner 2G expects a similar impact as that outlined for innovation 2.3. Other project partners, like 2H and 2F, expect a similar impact in nature as stated for innovation 2.1. However, partner 2F mentioned a lower magnitude of improvement (2-3%) this time.

Partner 2G, one of the owners of modelling of snow (2.6), predicts the same impact as that described earlier for innovation 2.3. Partner 2D, another owner, said that improved Y_E calculations that consider snow loss can lead to a more accurate EPI. The direction of change depends on whether the Y_E was previously overestimated or underestimated. Partner 2D stated that the impact can be significant, reaching a few percentage points, depending on the location and timescale used for the calculation. A higher impact can be expected in northern countries and for daily/weekly calculations relative to annual ones. Partner 2A, another owner, clarified that innovation 2.6 will help in shifting from using rough guesses to using local data available in weather databases. A global coverage with yearly and monthly averages is the aim of the development. As such, the Y_E will be more accurately estimated bringing the EPI closer to 1.

Partner 2D, one of the owners, considers the modelling of degradation (2.7) to be influential when it comes to the EPI. Again, an improved calculation of the Y_E considering degradation losses can lead to a more accurate EPI. The EPI can go up or down depending on previous estimations of the Y_E, and the change can be significant if the initial model was of poor quality and/or in locations with increased degradation rates. Partner 2A, another owner, highlighted that the aim of this innovation is not to directly estimate degradation losses but to develop maps showing the regions with a higher probability of PV plant components degradation. This can be then used to support the decision-making process but is not expected to have a direct impact on the EPI. Partner 2F expects a slight improvement in the EPI (<1%) due to more accurate modelling while partner 2B foresees no impact.

6.1.2 Impact of WP3 innovations on EPI

Specific data analytics for bifacial PV systems (3.1) are deemed to be non-influential by some of the innovation owners, partners 3A and 3D. Other owners, like partners 3B and 3C, expect some influence on the EPI. Partner 3B stated that innovation 3.1 would be influential if noticeable underperformance has been detected. In that case, it can result in a change in the EPI of more than 20% per year depending on regional characteristics, irradiation levels, and system topography, among other factors. Partner 3C expects a much smaller impact, at 2-5% decrease in uncertainty, due to improved understanding of bifacial systems performance as well as improved algorithms that lead to a better estimation of the Y_E. Partners 3F and 3E expect an indirect improvement in the EPI via the impact on modelling (WP2). The opinions of partners 3A, 3C, 3D, 3E, and 3F also apply to specific data analytics for floating PV systems (3.2). Partner 3B expects a similar impact in nature from innovation 3.2 as that mentioned for innovation 3.1, but the magnitude of the change is smaller at more than 10% per year.

The owners of specific data analytics for small and BAPV systems (3.3) have the following opinions regarding its impact on the EPI: partner 3B expects a similar impact to that of innovation 3.2 and partner 3D foresees no impacts. Partners 3F and 3E anticipate a similar impact to that stated for innovation 3.1. Partner 3D deems the specific data analytics for BIPV systems of different sizes (3.4) non-influential when it comes to the EPI. Partner 3B, another owner, stated that a change of a few percentage points in the EPI can be expected as the impact on utility-scale PV plants should be transferable to other systems of different sizes. The opinions of partners 3F and 3E regarding innovation 3.1 are applicable to innovation 3.4 as well.

Partners 3A and 3D, owners, deem specific data analytics for soiling (3.5) as non-influential. Partner 3C, an owner, expects the same impact on the EPI as that stated for innovation 3.1 and partner 3B, another owner, expects the same as for innovation 3.2. The opinions of partners 3F and 3E remain the same, expecting indirect improvement in the EPI via the impact on modelling. Partners 3A, 3B and 3D, innovation owners, anticipate a similar impact from specific data analytics for snow (3.6) and degradation (3.7) as that from soiling (3.5). Again, the views of partners 3F and 3E remain the same.

The owner of IV curve data analytics (3.8), partner 3A, foresees no impact from the innovation on the EPI. Partners 3E and 3F expect an indirect improvement via the impact on modelling (WP2). Partner 3L believes that improved analytics can lead to rapid failure detection which can increase the performance and the EPI significantly. The same opinions apply to IR imaging data analytics (3.9). The owners, partners 3A and 3C, expect no impact. Partners 3E, 3F and 3L anticipate some positive impact as explained for innovation 3.8.

Failure detection and diagnosis methods (3.10) are deemed as non-influential, according to its owners 3A, 3C and 3D. Nevertheless, another owner, partner 3B, anticipates an influence on the EPI similar in nature and magnitude to the one described for innovation 3.2. Partner 3F anticipates an improvement in the EPI due to better modelling of the state-of-health of the PV system in question. The magnitude of improvement depends on the quality of monitoring data as well as its temporal and spatial resolutions. Partner 3L also anticipates a positive impact for the same reasons described earlier for innovation 3.8.

Partner 3G, the owner of the fault detection/diagnosis toolbox for small PV (3.11), expect the innovation to significantly improve the EPI when combined with improvements in forecasting (WP5). Partners 3F and 3L, expect a similar impact to that outlined for innovation 3.8. Project partners 3E, 3F and 3L anticipate an indirect improvement of EPI due to PV inverter efficiency characterisation (3.12) via the impact on modelling similar to that mentioned for innovation 3.8. Partner 3L anticipates that innovation 3.12 would improve analytics that assist in rapid failure detection. This can significantly improve the system performance, thereby improving the EPI. Partner 3L stated that the magnitude of improvement would depend on the failure rate of the system in question. Partner 3F stated that this innovation would lead to better modelling of inverter efficiency via monitoring data which would improve the EPI. Partner 3E envisions an indirect impact via the impact on modelling. In other words, the improved data analytics would enhance modelling and increase the EPI.

The PV inverter digital twin (3.13) is expected to improve the EPI, according to its owner 3F. The innovation would improve the modelling of the internal temperature and the conversion efficiency of PV inverters via the available monitoring data. The magnitude of improvement is still unknown as stated by partner 3F. Partner 3E also expects an improvement in the EPI (<1%) as a result of modelling improvements. Partner 3G expects a significant improvement in the EPI due to this innovation as well as improvements in forecasting (WP5).

Partner 3F is also the owner of the battery digital twin (3.14). Innovation 3.14 is expected to lead to better modelling of the state-of-health, the state-of-charge, and the remaining useful life of batteries via monitoring data. This should improve the EPI, but the significance on the impact is still unknown. Partner 3J, the other owner, stated that this innovation can have a moderate influence on the EPI, but the mechanism of the impact was not clarified. Partner 3G expects a similar impact to that stated earlier for innovation 3.13.

A higher EPI is expected from the utilisation of a BIPV digital twin, according to its owner partner 3F, as a result of the better modelling of the system via the monitoring data provided. Partner 3H, the other owner, did not state any potential impacts. Partners 3E and 3L expect a similar positive impact as that outlined earlier for innovations 3.12 and 3.13, respectively.

6.1.3 Impact of WP4 innovations on EPI

The owner of specific procedures for bifacial PV systems (4.1), partner 4A, anticipates no impact from the innovation on the EPI. Nevertheless, partner 4H envisions that innovation 4.1 can lead to rapid failure detection onsite which would significantly increase the EPI. The magnitude of the impact depends on the actual failure rate of the PV plant in question. Partner 4B expects an indirect impact via the impact on modelling. The owners of specific procedures for floating PV systems (4.2), partners 4A and 4C, also foresee no impact on the EPI. The opinions of partners 4B and 4H regarding the impact of innovation 4.1 extend to this innovation as well. The same applies to new procedures for PV inverters field testing (4.3), whereas partners 4A and 4D, the owners, deem the innovation as non-influential while partners 4B and 4H envision similar impacts as those stated for innovation 4.1. Partner 4F, one of the owners of new procedures for batteries field testing (4.4), stated that the innovation can have a high influence of great importance on the EPI but did not clarify the mechanism of that impact. Partner 4H expects a similar impact on the EPI as that stated earlier for innovation 4.1 while partner 4D foresees no impact.

Partner 4G, the owner of quality control procedures for solar radiation and meteorological measurements (4.5), expects the innovation to significantly impact the EPI. This is because these measurements are essential inputs to PV simulation models and, if not quality checked beforehand, can lead to significant errors in the whole simulation chain. Solar radiation has a direct impact on the Y_E. Overestimation of solar radiation leads to overestimation of the Y_E and underestimation of the EPI, and vice versa. Errors in solar radiation estimation can lead to errors in Y_E estimation of up to 10% per year, with a more pronounced effect on monthly calculations. The magnitude of the error depends on the PV technology under investigation as well as its operating environment. Nevertheless, partners 4B and 4D foresee no impact on the EPI.

Partner 4C, one of the owners of the soiling measurement kit (4.6), believes the innovation has no impact on the EPI. Partner 4H stated that soiling detection will define the cleaning interval which can, in turn, significantly improve the EPI. The magnitude of improvement depends on the actual soiling rate. Partner 4B foresees an indirect impact via the impact on modelling. Partner 4H stated that the capacitive I-V tracer (4.7) can help in failure detection via the resulting IV curves which, when addressed, can significantly improve the EPI depending on the actual failure rate. Partner 4B expects a similar impact as that stated for innovation 4.6.

6.1.4 Impact of WP5-6 innovations on EPI

Partner 5H predicts that short-term PV power forecasting (5.1), together with modelling improvements (WP2), can significantly improve the EPI. Partner 5F foresees no impact on the EPI. The opinions of partners 5H and 5F also apply to PV power nowcasting (5.2).

Partner 5C, one of the owners, deems improved power forecasting in extreme events (5.3) as non-influential when it comes to the EPI. Partner 5H anticipates a similar impact from innovation 5.3 as that stated for innovation 5.1.

Partner 5C, the owner, foresees no impact from forecasting applied to bifacial (5.4) and floating (5.5) PV systems on the EPI. Partner 5H maintains the same view outlined earlier for innovation 5.1.

Partners 5F and 5H maintain the same views on forecasting applied to residential PV systems (5.6) as they had regarding innovation 5.1. The views of partners 5F and 5H regarding innovation 5.1 also apply to forecasting for spatial averaging and PV aggregation (5.7).

Regarding WP6 innovations, only one of them is deemed as influential by its owner. Partner 6A, owner of curtailment of PV system and delivery of evidence of performed curtailments (6.3), stated that curtailments can impact the Y_E. Partner 6Aclarified that, on one hand, if no power limit is considered in the calculation at all, a reduction in the EPI can be expected. That is because the Y_E would be overestimated if clipping due to reaching maximum inverter capacity or curtailment during low demand periods are not taken into consideration. On the other hand, when the actual feed-in power is smaller than the power limit, a slight increase in the EPI can be expected. The impact and its significance depend on how power limit proofs are technically documented as well as on their timely communication.

6.2 Data availability

Simply put, data availability is the fraction of time for which monitoring data is available relative to the total monitoring time of a system. The lower the number of missing values is, the better the KPI is. For an individual sensor, the data recorded is logged separately. Then, to calculate the data availability for the entire system, the availability of one sensor is multiplied by the availability of the measurement in question from all the sensors used.

6.2.1 Impact of WP2 innovations on DA

Modelling of bifacial (2.1) and floating (2.2) PV systems is not expected to affect data availability according to some of the owners, like partners 2C and 2D. Partner 2A, another owner, expects these innovations to provide high quality simulation data for monitoring systems as error detection algorithms are deployed and errors are corrected. Partner 2B, another owner, believes that these innovations will provide more measurement points but that may increase data gaps if the measurement system quality is not high. Thus, it may reduce data availability. Partner 2G anticipates a somewhat significant improvement in data availability due to innovations 2.1 and 2.2 although the mechanism of the impact was not clarified.

Similarly to innovations 2.1 and 2.2, partner 2C does not deem the modelling of small and BAPV systems (2.3) as influential. Partner 2G, another owner, mentioned that this innovation should lead to some improvement but did not clarify how that is realised. Partner 2A clarified that the aim of these developments is to have models that are valid irrespective of the system size, so improvements in utility-scale PV systems (2.1 and 2.2) should be transferable to this innovation for smaller systems. As for the modelling of BIPV systems (2.4), partner 2C does not expect any impact on data availability. Partner 2A mentioned that this innovation can improve the modelling of such systems as well as the estimation of reference/simulated performance metrics. Partner 2G again expects some improvement, but no clarification was given regarding the mechanism of the impact.

Partner 2D, one of the owners of modelling of soiling (2.5), does not anticipate an impact from the innovation on data availability. Partners 2A and 2G, other owners, expect a similar impact as that outlined for innovations 2.1 and 2.2. The opinions of partners 2D and 2G regarding this innovation are also applicable to the modelling of snow (2.6). Partner 2A, another owner, clarified that innovation 2.6 will help in shifting from rough guesses to estimates based on local data available from weather databases. The aim is to have yearly and monthly averages with a global coverage, thereby data availability is expected to increase especially during winter months in sites with snowfall.

Finally, partner 2D does not anticipate an impact from degradation modelling (2.7) on data availability. Partner 2A, the other owner, clarified that the aim of this innovation is not to directly estimate degradation. The aim is, rather, to develop maps showing the regions with a higher probability of increased degradation of PV components in order to support the decision-making process. Partner 2G expects a similar impact as that outlined earlier for innovations 2.1 and 2.2.

6.2.2 Impact of WP3 innovations on DA

Specific data analytics for bifacial PV systems (3.1) are deemed to be non-influential when it comes to data availability by most of the innovation owners, like partners 3A, 3C and 3D. Nevertheless, partner 3B expects an improvement of more than 20% per year if noticeable underperformance is detected. Partner 3G expects a somewhat significant improvement in data availability as the use of specific analytics should make more data available. Partner 3E mentioned that data analytics can lead to a better understanding of unavailability periods and adaptation of data collection procedures accordingly. This should increase data availability by a few percentage points. Partner 3K stated that this innovation is valuable for assessing the relevance of data availability. In other words, it can add valuable insights such as detecting existing communication issues that affect data availability. The opinions of partners 3A, 3C, 3D, 3E, 3G and 3K regarding this innovation also apply to specific data analytics for floating (3.2) and small and BAPV (3.3) systems. Partner 3B also expects a similar impact as that mentioned for innovation 3.1, but the magnitude of the impact is lower; more than 10% per year.

The aforementioned opinions from different innovation owners and project partners regarding innovation 3.1 extend to specific data analytics for BIPV systems of different sizes (3.4). Except for partner 3B, who clarified that the developed models should be applicable to systems of different sizes, so improvements in large-scale systems should be transferable to smaller ones. An impact reaching a few percentage points is expected. The expectations of different owners and partners that were outlined earlier for innovation 3.2 are applicable to specific data analytics for soiling (3.5), snow (3.6), and degradation (3.7) as well.

Partner 3A, the owner of IV curve data analytics (3.8), does not expect an impact from the innovation on data availability. Other project partners, like 3E and 3G, expect a positive impact similar to that stated for innovation 3.1. IR imaging data analytics (3.9) are also expected to be non-influential by its owners, partners 3A and 3C, while partners 3G and 3E expect a similar impact as that from innovation 3.1.

Partners 3A, 3C and 3D, owners of failure detection and diagnosis methods (3.10), envision no impact on data availability from this innovation. Partner 3B, another owner, and partner 3G expect a similar impact as that mentioned earlier for innovation 3.2. Partner 3G is the owner of fault detection/diagnosis toolbox for small PV (3.11) and, again, expects a positive impact from this innovation as the one stated for innovation 3.1. Partner 3E also expects a positive impact similar to that of innovation 3.1. Partner 3L expects a negative impact due to more data gaps if the increased measurement points offered by the innovation are not of adequate quality. Partner 3K expects no impact on data availability.

Partners 3A and 3F foresee no impact of PV inverter efficiency characterisation (3.12) on data availability while partner 3G expects a somewhat positive impact. Partner 3G anticipates a somewhat positive impact of PV inverter digital twin (3.13) on data availability although the mechanism was not clarified. Partner 3L expects a negative impact as explained earlier for innovation 3.11.

Partner 3J, an owner, expects the PV battery digital twin (3.14) to have a moderate influence on data availability although no details were provided regarding the mechanism of this influence. Partners 3G and 3L have a similar expectation as that mentioned earlier for innovation 3.13. The opinions of partners 3G and 3L on the impact of the BIPV digital twin (3.15) are the same as that stated for innovation 3.13.

6.2.3 Impact of WP4 innovations on DA

Specific procedures for bifacial PV systems (4.1) are not deemed influential by its owner, partner 4A, when it comes to data availability. Nevertheless, partner 4B believes that better procedures can lead to higher data availability. Specific procedures for floating PV systems (4.2) are owned by partners 4A and 4C. Similarly to innovation 4.1, no impact is expected on data availability. Partner 4B, however, expects a similar impact as that stated for innovation 4.1.

As for new procedures for PV inverters field testing (4.3), partner 4A expects it to be non-influential as well. Again, partner 4B expects a similar impact to that stated for innovation 4.1. Partner 4F, one of the owners of new procedures for batteries field testing (4.4), mentioned that the innovation can have a high influence of great importance on data availability, but did not clarify the mechanism of this impact. Partner 4B stated the same impact as that for innovation 4.1.

Partner 4G, the owner of quality control procedures for solar radiation and meteorological measurements (4.5), insisted on the importance of such measurements as inputs to simulation models. Partner 4G stated that any error in these measurements can affect the whole PV simulation chain and that quality control procedures would help in avoiding such significant errors. This statement can be interpreted more as an improvement in data quality rather than availability.

One of the owners of the soiling measurement kit (4.6), partner 4C, highlighted that the kit is autonomous and that decouples the availability of data from the availability of energy supply. In other words, innovation 4.6 is expected to increase data availability by a few percentage points depending on the quality of the local electrical grid. Project partners, like 4B and 4I, anticipate no impact of using a capacitive I-V tracer (4.7) while partner 4J expects the innovation to fairly improve data availability.

6.2.4 Impact of WP5-6 innovations on DA

None of the owners of the innovations from WP5 expect these innovations to be influential when it comes to data availability. The same applies to the rest of the project partners.

The characterisation of PV inverters using a generic IEC 61850 data model as a fundamental element for telecommunication and control of PV systems (6.1) is expected to usually have a positive impact on data availability from distribution system operators (DSO), according to partner 6A. Partner 6A clarified that having an appropriate model size can improve the data availability. Having a data model that is too large would otherwise cause more communication failures and worsen data availability. The extent of the impact would depend on the number of integrated management systems (iMsys) and controllable local systems (CLS) in the field. Partner 6A is also the owner of acquisition of PV measurements and status data using smart/advanced-metering-infrastructure with high resolution (6.2). Again, a positive impact is expected with its magnitude depending on the number of iMsys and CLS in the field. This is because this innovation could enable more communication connections to PV systems which increases overall data availability from DSOs.

Partner 6C mentioned that the integration of algorithms for automatic PV data integration in smart grid data systems (6.6) can result in reliable data streams and more reliable management. Partner 6C also mentioned that in this case sparse data unavailability might not be a problem, but longer unavailability periods are undesirable.

Partner 6A, the owner of digital twin of the grid (6.8), expects an improvement in the availability of all operational data. partner 6A clarified that meta data is mainly available via the cooperation with DSOs and that the installation of smart meters would make live data available. The digital twin can then provide an estimation of all grid data, like live voltages and currents. Real-time grid congestion management (6.9) improves the availability of almost all congestion data which is relevant for DSOs, according to partner 6A. This innovation would make possible violations of grid operational limits, like voltage violations and overloading of grid components, available. Partner 6A is also the owner of advanced grid operation and control of PV systems based on forecasts (6.9) and expects the innovation to improve the data availability of almost all operational and congestion data. This is because the integration of forecast data will improve the accuracy of data estimated and offered by the grid digital twin.

6.2.5 Impact from other WPs on DA

Partner 7A highlighted the relevance of one of the innovations of WP7 for data availability. This innovation should be the results of T7.4 with the goal of creating a database of PV components, including modules, inverters, batteries, and trackers. Partner 7A clarified that currently information regarding PV components is fragmented, hard to find, inconsistent, and involves a lot of manual processes. Hence, the aim of T7.4 is to establish a reliable, centralised, and publicly available catalogue of PV components. This will enhance the availability of PV-related parameters and ensure that every consumer has easy access to them from a centralised and collaborative platform. This information can then be used for simulations, comparisons, and decision making. The impact and value of this innovation when it comes to data availability is not measurable per consumer, but for the entire industry.

6.3 Data quality

Data measured by sensors usually passes through a filtering system first to eliminate any outliers or false values. In that sense, data quality could be reflected by the number of measurements discarded by the filtering system with respect to the total number of measurements recorded by the monitoring system. However, this depends on the quality of the filtering system as well. Hence, it can only be used for plant inter-comparison if the same filtering system is employed by all the plants in question.

6.3.1 Impact of WP2 innovations on DQ

Most of the owners of modelling of bifacial (2.1) and floating (2.2) PV systems, like partners 2B, 2C and 2D, expect no impact from these innovations on data quality. Nevertheless, partner 2A expects these innovations to provide high quality simulation data for monitoring systems, where automated and advanced error detection algorithms can then be used.

Partner 2C also expects no impact from modelling of small and BAPV (2.3) and BIPV systems of different sizes (2.4) on data quality. When it comes to innovation 2.3, other owners, like partners 2G and 2A, expect some positive impact on data quality. Partner 2G stated that innovation 2.3 can lead to a better understanding of expected values so the quality of monitoring data can be assessed and enhanced. Partner 2A mentioned that the aim of these developments is to have valid PV models irrespective of the system size, so improvements in large-scale systems (2.1 and 2.2) should also be applicable to smaller ones. As for innovation 2.4, partner 2A expects an improvement in PV yield modelling and reference PV metrics estimation as a result. This should decrease uncertainty in PV plants analysis and evaluation by a few percentage points. Partner 2G anticipates a similar impact as that stated for innovation 2.3.

Partners 2A and 2G, owners of modelling of soiling (2.5), expect a positive impact from the innovation on data quality. Partner 2G's expectations are the same as stated earlier for innovation 2.3. Partner 2A's expectations are the same as outlined earlier for innovations 2.1 and 2.2. Nevertheless, partner 2D foresees no impact on data quality from this innovation. The opinions of partners 2D and 2G regarding innovation 2.4 also apply to the potential impact of snow modelling (2.6). Partner 2A clarified that the goal of this innovation is to switch from rough guesses to more accurate estimates based on available local data from weather databases. Yearly and monthly average coverage values for the entire globe are to be developed as part of this innovation. This would also lead to better estimations of expected electricity yield and other related performance metrics. The higher quality data would be of particular importance during winter months in locations with snowfall.

Partner 2D, an owner, deems the modelling of degradation (2.7) as non-influential when it comes to data quality. Partner 2A, another owner, stated that while their target is not to directly estimate degradation, the resulting maps will show which regions face an increased risk of higher PV components degradation. This data can then be used to support the decision-making process. Partner 2G expects a similar positive impact as that mentioned earlier for innovation 2.3.

6.3.2 Impact of WP3 innovations on DQ

Some of the owners of specific data analytics for bifacial PV systems (3.1), like partners 3A, 3C and 3D, foresee no impact from this innovation on data quality. Partner 3B expects an improvement of over 20% per year if noticeable underperformance was detected beforehand. The significance of the impact depends on regional characteristics, irradiation levels, and system topography. Partner 3G expects a positive and significant impact on data quality due to improvements in data processing, pipelines, and error detection and handling. Partner 3E also expects a positive impact that can reach a few percentage points. This is because specific data analytics can lead to a better understanding of unavailability periods and adaptation of data collection procedures accordingly. Partner 3K believes that innovation 3.1 can be valuable for data quality as it can provide beneficial insights into factors that compromise quality, like sensor failures and frozen values. All the aforementioned views also apply to specific data analytics for floating PV systems (3.2). The only exception is the magnitude of the impact anticipated by partner 3B where, in this case, it is up to 10% per year.

Partner 3D explicitly stated that no impacts of specific data analytics for small and BAPV systems (3.3) on DQ are foreseen. Nevertheless, partner 3B expects a positive impact like that of innovation 3.2. Other project partners, like 3E, 3G and 3K, expect similar impacts as those explained earlier for innovation 3.1. Partner 3D foresees no impact of specific data analytics for BIPV systems of different sizes (3.4) on data quality. Partner 3B highlighted that the goal is to develop models that are valid irrespective of the PV system size. Thus, potential impacts on large-scale systems should be transferable to smaller ones. Partner 3B expects an improvement of a few percentage points in data quality due to innovation 3.4. Partners 3G, 3E and 3K expect similar impacts from this innovation on data quality as those expected from innovation 3.1.

Partners 3A, 3C and 3D foresee no impact on data quality as a result of employing specific data analytics for soiling (3.5). Partner 3B anticipates a positive impact like the one stated earlier for innovation 3.2. Other project partners, 3E, 3G and 3K, envision similar impacts to those mentioned earlier for innovation 3.1. The aforementioned impacts stated by innovation owners and project partners for innovation 3.5 also apply to specific data analytics for snow (3.6) and degradation (3.7).

Partner 3A is the owner of IV curve data analytics (3.8) and believes the innovation has no impact on data quality. However, partners 3E and 3G anticipate a similar positive impact as that of innovation 3.1. The same applies to IR imaging data analytics (3.9), where partners 3A and 3C foresee no impact and partners 3G and 3E predict a positive one.

Partners 3A, 3C and 3D, envision no impact of utilizing failure detection and diagnosis methods (3.10) on data quality. Partner 3B expects a similar impact in nature and magnitude to that from innovation 3.2. Partner 3F mentioned that innovation 3.10 includes new automatic preconditioning tools that would enhance data quality. As for the fault detection/diagnosis toolbox for small PV (3.11), partner 3G expects a similar positive impact as that stated earlier for innovation 3.1. Partner 3E also expects a positive impact similar to that of innovation 3.1 while partner 3K foresees no impact on data quality from this innovation.

Partner 3G predicts a significant positive impact of PV inverter efficiency characterisation (3.12) for the same reasons stated for innovation 3.1. When it comes to the PV inverter digital twin (3.13), partner 3F anticipates an improvement in data quality for the same reason stated for innovation 3.10. Partner 3G expects a positive impact like that due to innovation 3.1 while partners 3E and 3K foresee no impact on data quality.

Partner 3J, as one of the owners of the PV battery digital twin (3.14), mentioned a moderate potential influence on data quality but did not clarify the mechanism of this impact. The views of partners 3E, 3G and 3K regarding innovation 3.13 are also applicable to this one as well as the BIPV digital twin (3.15). Partner 3F, owner of innovation 3.15, envisions a positive impact on data quality for the same reason stated for innovation 3.10.

6.3.3 Impact of WP4 innovations on DQ

Specific procedures for bifacial PV systems (4.1) are deemed to be non-influential when it comes to data quality, according to partner 4A. Other project partners, like 4B and 4J, expect an improvement in data quality due to the use of specific procedures. Partner 4A, along with partner 4C, also expects no impact from the use of specific procedures for floating PV systems (4.2). Nevertheless, other project partners, like 4B and 4J, expect an improvement in data quality due to this innovation.

New procedures for PV inverters field testing (4.3) are also deemed to be non-influential, according to 4A. Other project partners, like 4J and 4B, expect some positive impact on data quality due to the utilisation of better procedures. This is also applicable to new procedures for batteries field testing (4.4). Partner 4F, an owner of innovation 4.4, also expects a high influence of great importance on data quality. However, the mechanism of the impact was not clarified.

Partner 4G believes that the use of quality control procedures for solar radiation and meteorological measurements (4.5) can help in avoiding errors of up to 10% per year in energy yield estimations, among other metrics, due to poor quality measurements. This is because solar radiation and meteorological measurements are essential inputs for PV simulation and any errors in them can lead to significant errors along the whole chain of simulation. In contrast, simulations based on high quality ground measurements show smaller deviations from the actual recorded electricity production and, thus, enable studying PV plants in high detail. Other project partners, like 4J and 4B, also expect an improvement in data quality as a result of this innovation.

Partner 4C, owner of the soiling measurement kit (4.6), stated that measuring the soiling impact on small modules of the same technology as the ones in the PV plant in question can provide more accurate values compared to optical measurements. The more accurate soiling impact can show if any on-site maintenance is needed and enhance knowledge of the actual situation. Partner 4C expects an improvement in data quality due to innovation 4.6 that can reach a few percentage points. Partner 4J expects some positive impact while partner 4B foresees no impact on data quality. Other project partners, like 4B and 4I, foresee no impact from the use of a capacitive I-V tracer (4.7) while partner 4J anticipates a fairly significant positive impact on data quality.

6.3.4 Impact of WP5-6 innovations on DQ

None of the innovation owners or project partners expect forecasting innovations from WP5 to have an impact on data quality.

A few of the innovations from WP6 are expected to influence data quality. Partner 6C stated that the integration of algorithms for automatic PV data integration into smart grid data systems (6.6) can lead to better quality data and more reliable management of the system. Partner 6C clarified that exchanging data between the PV system and a third-party model can enable cross-checking of both sources. That way systematic problems can tackled via machine learning and higher quality data can be fed in the future.

Partner 6A, owner of the digital twin to the grid (6.8), expects the innovation to improve data quality although the magnitude of this improvement is hard to quantify at the moment. Partner 6A clarified that the use of a digital twin, compared to using only smart meters, will cover the whole grid and can correct false or inaccurate data from smart meters. Partner 6A also anticipates a positive impact on data quality from advanced grid operation and control of PV systems based on PV forecasts (6.10). Partner 6A explained that the integration of forecasts can enhance the quality of data obtained from the grid digital twin. The magnitude of this impact is said to be hard to quantify at the moment.

6.3.5 Impact from other WPs on DQ

Partner 7A highlighted the potential impact of the developing a database of PV components as part of T7.4 from WP7 on data quality. Currently, available datasheets and PAN and OND files do not provide a reliable source for PV-related parameters. The aim of T7.4 is to develop a reliable and centralised catalogue for PV components, such as modules, inverters, batteries, and trackers. The data in the catalogue is automatically and manually validated and certified so that every consumer can get the same high-quality data. That way everyone can have access to reliable data for simulations, comparisons, and decision making. The impact and value of this task when it comes to data quality is not measurable per consumer but, rather, for the whole PV industry.

7 Impact of innovations on profitability KPIs

The profitability of a PV system is affected by both the costs incurred and the performance of the system. Thus, using capital and operational expenditures alone to compare PV plants does not capture the whole picture as they do not take into consideration how well the plants perform or for how long. D1.1 [1] selected five KPIs that better reflect the profitability of PV plants while accounting for their operational conditions. These are the levelised cost of electricity (LCoE), the net present value (NPV), and the modified internal rate of return (MIRR). Other metrics like the weighted average cost of capital (WACC), and the profile factor (PF) were also selected. These KPIs are briefly described then the hypothesised impact of SERENDI-PV innovations on them is summarised (see Table 7.1) and discussed. For more details on the KPIs, the **"D1.1 KPIs on state of the art PV reliability, performance, profitability and grid integration"** [1] can be consulted.

Table 7.1: Summary of the impact of SERENDI-PV innovations on profitability KPIs

ID	Innovation	LCoE	PF	WACC	NPV	(M)IRR
2.1	Modelling of bifacial PV systems	X	X	X	X	X
2.2	Modelling of floating PV systems	X	X	X	X	X
2.3	Modelling of small PV systems, including BAPV	X		X	X	X
2.4	Modelling of BIPV systems, any size	X		X	X	X
2.5	Modelling of soiling	X		X	X	X
2.6	Modelling of snow	X			X	
2.7	Modelling of degradation	X		X	X	X
3.1	Specific data analytics for bifacial PV systems	X	X		X	X
3.2	Specific data analytics for floating PV systems	X	X		X	X
3.3	Specific data analytics for small PV systems, including BAPV	X	X		X	X
3.4	Specific data analytics for BIPV systems, any size	X	X		X	X
3.5	Specific data analytics for soiling	X	X		X	X
3.6	Specific data analytics for snow	X	X		X	X
3.7	Specific data analytics for degradation	X	X		X	X
3.8	IV curve data analytics	X	X		X	X
3.9	IR imaging data analytics	X	X		X	X
3.10	Failure detection and diagnosis methods	X		X	X	X
3.11	Fault detection/diagnosis toolbox for small PV	X				
3.12	PV inverter efficiency characterisation	X			X	
3.13	PV inverter digital twin	X		X	X	X
3.14	PV battery digital twin	X		X		
3.15	BIPV digital twin	X		X	X	X
4.1	Specific procedures for bifacial PV systems	X				
4.2	Specific procedures for floating PV systems	X	X		X	X
4.3	New procedures for PV inverters field testing	X				
4.4	New procedures for batteries field testing	X				
4.5	Quality control procedures for solar radiation and meteorological measurements	X				
4.6	Soiling measurement kit	X	X		X	X
4.7	Capacitive I-V tracer at 1,500V	X				

ID	Innovation	LCoE	PF	WACC	NPV	(M)IRR
5.1	Short-term PV power forecasting based on integrating satellite data and NWP models with PV power production data	X			X	X
5.2	PV power nowcasting by merging satellite data with sky-camera data and methods for PV power output aggregation	X			X	X
5.3	Improved power forecasting in presence of snow, dust, fog, and other extreme events	X			X	X
5.4	Forecasting applied to bifacial PV systems	X			X	X
5.5	Forecasting applied to floating PV systems	X			X	X
5.6	Forecasting applied to residential PV systems	X			X	X
5.7	Forecasting for spatial averaging and PV aggregation	X			X	X
6.1	Characterisation of PV inverters as a fundamental element for telecommunication and control of PV systems	X			X	X
6.2	Acquisition of PV measurements using Smart/Advanced-Metering-Infrastructure with high resolution in DSO SCADA	X			X	X
6.3	Curtailment of PV system from DSO SCADA via secured CLS-channel and delivery of evidence for performed curtailments	X			X	X
6.4	Algorithms for automatic PV data integration in DSO SCADA	X			X	X
6.5	Algorithms for automatic PV data integration in PV meta-data registry	X			X	X
6.6	Integration of algorithms for automatic PV data integration in smart grid data systems of participating project partners	X			X	X
6.7	Service system for aggregating anonymous data for the monitoring and management of distributed generation systems	X			X	X
6.8	Digital twin of the grid, real-time state estimation based on load and PV-measurements	X			X	X
6.9	Real-time congestion management of the grid based on the Digital twin of the grid and different algorithms for PV-control	X			X	X
6.10	Advanced grid operation and control of PV systems based on PV forecast	X			X	X
6.11	Integration of V2G & G2V into self-consumption optimisation software	X	X		X	X
6.12	Further integration of virtual batteries into self-consumption optimisation software	X	X		X	X
6.13	Predictive control-based EMS for PV storage self-consumption optimisation	X	X		X	X
6.14	Operation and planning of PV for the provision of ancillary services to the grid operators					
6.15	Operation of PV ensuring active power reserve available to provide ancillary services					

7.1 Levelised cost of electricity

The LCoE distributes the lifecycle costs of a solar PV system over the generated electricity during its anticipated useful lifetime. It is expressed in terms of €/kWh, where the cost is discounted to the initial year of investment to obtain a single value in terms of the currency of the base year. There are different formulae with varying complexity used to calculate the LCoE. However, a relatively simple one has been chosen in D1.1 [1] to calculate it for all types and sizes of solar PV systems in the SERENDI-PV project. This formula is as shown below:

$$LCoE_N = \frac{CAPEX_0 + \sum_{i=1}^{N} \frac{OPEX_i + T_i}{(1+d)^i}}{\sum_{i=1}^{N} \frac{E_i}{(1+d)^i}} \tag{11}$$

Where:

- $LCoE_N$: the calculated LCoE for a system with a theoretical lifetime of N years [$€_{\text{base year}}$/kWh]
- $CAPEX_0$: capital expenditures for year 0 [€]
- $OPEX_i$: operational expenditures for year i [€]
- T_i: taxes and other related payments for year i [€]
- E_i: electricity produced during year i [kWh]
- d: discount rate [%]
- N: theoretical system lifetime [years]

Many SERENDI-PV innovations are deemed to have an impact on the LCoE of solar PV systems. A sensitivity analysis looking into the main parameters influencing LCoE showed that besides location (local solar resource available), the second most significant parameter influencing the LCoE is the WACC (the after-tax discount rate mentioned in the previous formula); with a sensitivity almost as high as the solar resource available [5] The Table 7.1 summarised expert opinions on the matter. The influential factors are further discussed below.

7.1.1 Impact of WP2 innovations on LCoE

Modelling of bifacial PV systems (2.1) is expected to have a positive impact on the LCoE. According to partners 2B, 2C, and 2E, better modelling will decrease the uncertainty in yield assessment for potential projects. It will also lead to better optimisation of the proposed system. Better assessment of project potential and lower uncertainty will potentially lead to a lower WACC and lower CAPEX (as highlighted by partners 2C and 2E) while better optimisation of the design will lead to higher electricity yield (based on partner 2E) and reduction of the system cost (CAPEX and OPEX) due to better project adaptation to local conditions (as highlighted by partner 2F). Both will lead to lower LCoE of the project. The magnitude of this effect is said to be hard to quantify. Such an impact can be considered indirect. One of the owners, partner 2D, expects no direct impact on the LCoE.

Modelling of floating PV systems (2.2) is expected to have a similar impact to innovation 2.1 according to partners 2B and 2C. Again, partner 2D deems this innovation as non-influential due to lack of direct impact. The impact is expected to be indirect, via decreased uncertainty and potentially lower WACC for financing the project.

Modelling of small BAPV systems (2.3), and modelling of BIPV systems (2.4) are expected to influence the system's LCoE as per the responses of partners 2B, 2E, and 2G. The mechanism of the impact is expected to be indirect via decreased uncertainty and potentially lower WACC for financing the project. Partner 2E also expects an opportunity to increase the yield due to better optimisation of the project. Partner 2C envisions no direct impact.

Modelling of soiling (2.5) is said to have a positive and fairly significant impact on LCoE via the more accurate simulation of system losses over time according to partner 2G, one of the innovation owners. Partner 2F envisions the same positive impact through the optimisation of cleaning schedules. This can lead to the optimisation of yield and operational expenditures resulting in a lower LCoE. Partner 2D, another one of the innovation owners, expects no impact from this innovation on the LCoE. Partners 2G and 2D, owners of innovation 2.6, maintain the same opinions about the impact of modelling soiling on the LCoE for the impact of modelling snow. Partner 2B highlights an overall positive impact of the improved modelling in case of soiling (2.5) and snow (2.6) as it reduces uncertainty and potentially allows to lower the WACC for financing the project which leads to overall LCoE reduction.

Modelling of degradation (2.7) is expected to have no impact on the LCoE, according to partner 2D. Other project partners, like 2F, envision a small impact. However, the direction of change is uncertain. According to partner 2F, this innovation can have a positive impact on the LCoE if it leads to better optimisation of the system at hand. But it can also have a negative impact if this optimisation entails installing a bigger system to counteract degradation losses, resulting in an increase in CAPEX. Partner 2B highlights an overall positive impact of the improved modelling as it reduces uncertainty and potentially allows to lower the WACC for financing the project which leads to overall LCoE reduction.

7.1.2 Impact of WP3 innovations on LCoE

Specific data analytics for bifacial PV systems (3.1) are expected to have a minor positive impact on the LCoE, according to partners 3A and 3C. According to partner 3A, it can lead to better and more regular and timely maintenance of the PV system increasing the yield and, ultimately, decreasing the LCoE. Partner 3C also envisions a positive impact on the LCoE via the decrease in uncertainty about the reliability and performance of the PV system. Partner 3D, however, expects this innovation to be non-influential. Partner 3L sees an indirect impact via the validation/falsification of the models and, consequently, the reduction of uncertainty in the project planning stage.

The views of partners 3A and 3D about specific data analytics for floating PV systems (3.2) are the same as those for innovation 3.1. The same applies to specific data analytics for small BAPV systems (3.3) and specific data analytics for BIPV systems (3.4). Partner 3G additionally envisions a positive and fairly significant impact on the LCoE via the ability to detect and correct problems in the system. This leads to short- and long-term improvements in the system performance as well as cost savings resulting in a lower LCoE. For innovations 3.3 and 3.4, the impact can vary from minor to moderate significance, according to partner 3A, depending on the extent of degradation and other factors that can affect the system performance.

Innovations 3.5 through 3.7 are about the development of specific data analytics for soiling (3.5), snow (3.6), and degradation (3.7), respectively. Partner 3A, one of the innovations’ owners, expects a positive impact on the LCoE from these innovations via the improved maintenance and performance of the system. The significance of these impacts varies from minor to moderate depending on the location of the project which, in turn, implies the frequency and severity of soiling, snow events, and degradation. The higher that is the more the system stands to benefit from the development of specific data analytics for these factors. Partner 3G additionally envisions a positive and fairly significant impact on the LCoE via the ability to detect and correct problems in the system. This leads to short- and long-term improvements in the system performance as well as cost savings resulting in a lower LCoE. Partner 3D, however, deems these innovations as non-influential.

As for IV curve and IR imaging data analytics (3.8 and 3.9), partner 3A expects a minor to moderate positive impact on the LCoE depending on the location and system type, among other factors. Again, this is because of the improved maintenance and performance of the system. The impact is expected to be at the string level for innovation 3.8 while it is at the string and/or module level for innovation 3.9.

Failure detection and diagnosis methods (3.10) are expected to have a positive impact on LCoE, according to partners 3C and 3F. This is due to improvements in the electricity yield and possible OPEX reduction, ultimately decreasing the LCoE. Partner 3D, however, deems this innovation as non-influential. Innovation 3.11 is similar to 3.10 but in the form of a toolbox for small PV systems. Its owner, partner 3G, expects a positive and fairly significant impact on LCoE as a result of detecting and correcting faults leading to short- and long-term improvements in system performance as well as cost savings. PV inverter efficiency characterisation (3.12) is expected to have no impact on the LCoE according to partner 3H, its owner. Nevertheless, partner 3G anticipates a positive and somewhat significant impact as the analysis and testing of installations would lead to the detection and correction of problems. This, in turn, would improve the system performance and save money, resulting in a lower LCoE.

When it comes to the PV inverter digital twin (3.13), an improvement in the LCoE is expected by partners 3F and 3I as a result of the performance improvements. Partner 3I expects the magnitude of reduction in the LCoE to be similar to that of the increase in reliability and performance of the system. The battery digital twin (3.14) is expected to have a great influence on the LCoE by one of its owners, partner 3J. However, the mechanism and direction of that influence were not clarified. Partner 3E envisions the influence to be positive as better modelling can lead to the identification of faults which increases the yield and decreases the LCoE. Finally, the BIPV digital twin (3.15) is expected to reduce operational expenditures and potentially improve the electricity yield according to partner 3F. This would lead to a decrease in the LCoE whose magnitude depends on the preventative on-field inspections applied. Partner 3H, however, expects no such impact.

7.1.3 Impact of WP4 innovations on LCoE

Specific procedures for bifacial PV systems (4.1) are expected by partner 4A to reduce the uncertainty in the expected performance and the reliability of the PV system, thereby decreasing the LCoE. Similarly for specific procedures for floating PV systems (4.2), procedures like the selection of appropriate PV modules that are resistant to the harsh operating environment can guarantee a good level of performance and LCoE, according to partner 4C. While it is not expected that the LCoE would decrease, it is expected that an increase can be avoided due to the mitigated additional degradation that would occur otherwise. This is especially important for floating systems over salt water.

New procedures for inverters and batteries field testing (4.3 and 4.4) are expected to have a positive impact on the LCoE, according to partner 4A. This is due to the potential improvements in the system's performance and reliability. Partner 4G did not state any envisioned impact for quality control procedures for solar radiation and meteorological measurements (4.5) on the LCoE. However, partner 4J anticipates a positive and somewhat significant impact if these procedures are more efficient.

A soiling measurement kit (4.6) is expected by partner 4C to have a positive impact whose magnitude depends on the location, system type, and soiling type. This is via having an appropriate cleaning strategy, both regularly and for specific events, that enables the mitigation and reduction of the soiling impact and benefits electricity production. A capacitive I-V tracer (4.7) is expected to have a similar impact on the LCoE for similar reasons as stated for specific procedures for bifacial PV systems (4.1).

7.1.4 Impact of WP5 innovations on LCoE

None of the owners involved in WP5 envisions an impact from its innovations on the LCoE. However, other project partners, like 5F and 5H, expect some impacts but with different views on the nature of the impact. On the one hand, partner 5H expects a positive and significant impact on the LCoE due to better optimisation of electricity consumption based on better knowledge of energy availability offered by these forecasting innovations, potentially resulting in lower curtailment rates. Partner 5F, on the other hand, anticipates a negative impact as the innovations' implementation would increase operational expenditures if considered as part of the PV electricity generation system.

7.1.5 Impact of WP6 innovations on LCoE

Several innovations from WP6 are expected to have an impact on the LCoE. Partner 6B anticipates that innovations 6.1-6.13 would increase the LCoE if they are considered as part of the PV electricity generation system. Partner 6A does not expect innovations 6.8-6.10 to impact the profitability of PV systems, but they may lead to less curtailment which is reimbursed by distribution system operators (DSO). Innovation 6.8, digital twin of the grid, can also lead to less grid reinforcement which improves the profitability of DSOs. The same is envisioned for innovation 6.9, which is the real-time congestion management of the grid.

7.2 Profile factor

The PF describes how the hour-to-hour solar PV production profile compares to the price profile of the wholesale electricity market. In this case, the wholesale electricity market price is the same as that in the merchant power purchase agreement (PPA). The PF is calculated as the ratio of the average wholesale electricity price weighted by the produced electricity from PV in each time step to the average wholesale electricity price. Only actual power production data, not forecasted ones, are used in the calculation while the day-ahead wholesale electricity price is usually the one used. This metric is useful for independent power producers, even if their PPA is under a fixed price. That is because they would have to buy the demand not met by solar PV production on the wholesale market. The PF can be complemented by the imbalance factor, which is discussed in detail in **"D1.1 KPIs on state of the art PV reliability, performance, profitability and grid integration"** [1]. It is usually calculated on a yearly basis to account for seasonal fluctuations in production and prices. Equation (12) shows how the PF is calculated.

$$PF = \frac{\sum_n Q_n \cdot P_n}{\sum_n Q_n} / \frac{\sum_n P_n}{N} \tag{12}$$

Where:

- PF: profile factor [-]
- n: hour n of a year, varying between 1 and N
- N: total number of hours in a year, i.e. 8760
- Q_n: volume of produced PV electricity in hour n [kWh]
- P_n: wholesale electricity market price in hour n [€/kWh]

A few of the SERENDI-PV project innovations have a potential impact on the PF according to expert opinion. These were outlined in the table above. A more detailed explanation of these impacts follows below.

7.2.1 Impact of WP2 innovations on PF

Partner 2D, and other owners of innovations, envision these innovations to be non-influential in case of the PF. Only partner 2F suggests that the design can be adapted to maximise the PF, probably via maximisation of yield during some peak demand hours. The rest of the innovations from this WP are expected to have no impact on the PF.

7.2.2 Impact of WP3 innovations on PF

For innovations 3.1-3.4, partner 3A expects a minor impact on the PF for utility-scale bifacial and floating PV systems (3.1 and 3.2). This impact can be of a higher significance for BAPV and BIPV systems (3.3 and 3.4) depending on degradation and other events that affect system performance. The impact is due to improved electricity production as a result of better maintenance based on the specific analytics. The direction and value of change in the PF would depend on the price profile. Partner 3D anticipates no impact from these innovations on the PF.

Partner 3A expects an impact from specific analytics for soiling (3.5) on the PF for the same reason stated for innovations 3.1-3.4. The significance of the impact would in this case depend on soiling events frequency and severity, and may reach few percentage points depending on the location. The same applies to innovation 3.6, regarding snow, where the PF is expected to increase as costs go higher in winter. Again, the significance of the impact depends on snow events frequency and severity, which is tied to the location, and may reach several percentage points. A similar logic applies to innovation 3.7, regarding degradation, according to partner 3A. Nevertheless, partner 3D envisions no impact from these innovations on the PF.

IV curve and IR imaging data analytics (3.8 and 3.9) can also lead to better maintenance and improved electricity production, according to partner 3A. The impact of the former is at the string level and is expected to be of minor to moderate significance depending on location, system type, degradation, and other events affecting performance. The impact of the latter is at the string and/or module level and is, again, of minor to moderate significance depending on the same factors. The remaining innovations from this WP are expected to have no impact on the PF.

7.2.3 Impact of WP4 innovations on PF

Specific procedures for floating PV systems (4.2) would lead to selecting resilient PV modules suitable for the harsh operating environment, according to partner 4C. This guarantees a good level of electricity production, but the direction and magnitude of the impact on the PF would depend on the price profile. As for innovation 4.6, partner 4C expects more timely and appropriate cleaning of the PV modules based on the information provided by the soiling measurement kit. Again, this guarantees a good level of electricity production with the direction and magnitude of the impact depending on the price profile. Other innovations from this WP are not anticipated to be influential for the PF.

7.2.4 Impact of WP5 innovations on PF

None of the owners and project partners expects any of the forecasting innovations from this working package to have an impact on the profile factor.

7.2.5 Impact of WP6 innovations on PF

Innovations from this WP are not expected to impact the PF, except for innovations 6.11-6.13. Partner 6B expects innovations 6.11 and 6.12, integration of V2G & G2V and further integration of virtual batteries into self-consumption optimisation software, to lead to a higher PF. Partner 6B also expects innovation 6.13, predictive control-based energy management system for PV storage, to cause a higher PF depending on the market as the algorithms take into account the time-of-use tariff.

7.3 Weighted average cost of capital

The discount rate, mentioned earlier, is the after-tax weighted average cost of capital. The WACC reflects the level of risk associated with investing in a certain project at the time of investment and is usually assumed to remain constant over the lifetime of the project for simplification reasons. Several factors can affect the WACC, of which some are endogenous to the project type and some are exogenous depending on where the investment is made. Endogenous factors include the maturity level and track record of the technology used and the system components. Exogenous factors include market risks, regulatory risks, and resource risks. There is a nominal WACC and a real WACC, which are calculated as shown below:

$$WACC_{nom} = \frac{D}{D+E}(1-T_c)\cdot r_D + \frac{E}{D+E}\cdot r_E \tag{13}$$

$$WACC_{real} = \frac{1+WACC_{nom}}{1+Inflation} - 1 \tag{14}$$

Where:

- $WACC_{nom}$: nominal weighted average cost of capital [- or %]
- D: the used amount of debt [€]
- E: the used amount of equity [€]

- r_D: cost of debt, i.e. effective interest rate paid on debts [-]
- r_E: levered cost of equity, i.e. return rate required for an investment [-]
- T_c: average corporate tax rate [-]
- $WACC_{real}$: real weighted average cost of capital [- or %]
- Inflation: estimated average annual inflation [-]

According to expert opinion, several of the innovations of SERENDI-PV have a potential impact on the WACC. From the proposal phase of the SERENDI-PV project, the working theory is that a reduction of the WACC could be conveyed to the financial sector from the PV industry by providing better energy yield assessments, better quality control as well as better component and system reliability. Table 7.1 summarised both influential and non-influential innovations. The influential ones are discussed more below.

7.3.1 Impact of WP2 innovations on WACC

Innovation 2.1 results in more accurate modelling of bifacial PV systems which would lower the risks for financers, according to partner 2E. This decreases the WACC, but the magnitude of this impact is hard to quantify. Partner 2C envisions the same for innovations 2.1 and 2.2 as less uncertainties with energy yield assessments would bring down the risks associated with bifacial and floating PV projects. Partner 2D, however, anticipates no impact from these innovations on the WACC.

When it comes to innovations 2.3 and 2.4, concerning BAPV and BIPV systems, partner 2E maintains the same opinion regarding the mechanism and direction of the impact of these innovations as for innovation 2.1. Nevertheless, partner 2C does not anticipate these innovations to be influential.

The remaining innovations from this WP are deemed non-influential by their owners. Modelling of soiling (2.5) and degradation (2.7) are envisioned to have an impact on the WACC by partner 2F. In the case of innovation 2.5, partner 2F expects the WACC to decrease as the yield increases or as the uncertainty about the yield decreases. As for innovation 2.7, partner 2F also expects a decrease in the WACC because of yield optimisation or adaptation of the project lifetime and module replacement which would decrease the associated risks.

For all modelling innovations, partner 2B foresees a positive impact on the WACC due to reduced uncertainty and, thus, lower project risks.

7.3.2 Impact of WP3 innovations on WACC

Only innovations 3.13-3.15 are deemed influential by at least one of their owners when it comes to the WACC. Partner 3F anticipates that the digital twins of inverters (3.13), batteries (3.14), and BIPV systems (3.15) would provide better knowledge about these technologies and their field performance. This could potentially reduce the WACC. Partner 3F envisions the same effect and impact for the failure detection and diagnosis methods (3.10) as well. Partners 3M and 3N suggest that all the WP3 innovation have potential to directly or indirectly reduce the uncertainty and lower project risks, and thus allow lower WACC for the projects.

7.3.3 Impact of WP4-6 innovations on WACC

None of the innovations developed under working packages 4, 5, and 6 are expected by any of the owners and project partners to be influential when it comes to the WACC.

7.4 Net present value

An annual income and loss statement includes all acquired positive and incurred negative cash flows during the year in question. These are then summarised to calculate a net profit or net loss for that year. This is also called the annual free cash flow. All the annual free cash flows over the lifetime of a project can then be discounted to a base year and summed up to calculate the net present value of the project. The annual free cash flow for NPV, and subsequently (M)IRR excludes cost of capital and in particular cost for interests and financing costs, as this is captured in the discount rate [6]. The NPV of a project is highly dependent on its size and financing circumstances. It is not sufficient on its own to reflect the profitability of a project or to compare it with other projects. Thus, it is complemented by the modified internal rate of return, described in the following sub-section, or normalised with respect to the nominal installed DC capacity of a solar PV project. The formula used to calculate the NPV is shown below:

$$NPV = \sum_{i=0}^{N} \frac{Free\ Cash\ Flow_i}{(1+d)^i} = -I + \sum_{i=1}^{N} \frac{Free\ Cash\ Flow_i}{(1+d)^i} \tag{15}$$

Where:

- NPV: net present value for a theoretical system lifetime of N years [€]
- N: theoretical system lifetime [years]
- Free Cash Flow$_i$: free cash flow in year i [€]
- d: discount rate [%]
- I: initial investment in year 0 [€]

The table above summarised partners' opinions on which SERENDI-PV innovations have a potential impact on the NPV, and which do not. The impactful ones are also discussed in more detail below.

7.4.1 Impact of WP2 innovations on NPV

The impact of modelling of bifacial (2.1), floating (2.2), BAPV (2.3) and BIPV (2.4) systems, on the NPV follows a similar logic as the impact on the LCoE, according to partner 2E. Better modelling leads to better optimisation of the system design and higher yields. It also leads to a lower WACC which, all in all, would improve the NPV. Nevertheless, partner 2D anticipates no impact from innovations 2.1 and 2.2 on the NPV while partner 2C anticipates no impact from innovations 2.3 and 2.4.

Modelling of soiling (2.5), snow (2.6), and degradation (2.7) are not expected to be influential by their owners. However, other project partners envision some impact. For instance, partner 2F anticipates that innovation 2.5 can lead to an increase in yield or to a design adaptation that adds value to the project, thereby the NPV may increase to a significant extent. Partner 2F anticipates the same type of impact when it comes to innovation 2.7. This time it is due to yield optimisation and adjustment of module replacement strategy such that the uncertainty regarding the system lifetime is reduced. As for innovation 2.6, partner 2B expects that it would decrease uncertainty and increase the NPV. However, the magnitude of the impact is said to be hard to quantify.

7.4.2 Impact of WP3 innovations on NPV

Partner 3A expects innovations 3.1-3.4 to positively impact the NPV for the same reasons and in the same manner stated for the LCoE. In other words, specific data analytics for bifacial (3.1), floating (3.2), BAPV (3.3), and BIPV (3.4) systems can lead to higher maintenance which improves electricity production and income. Thus, the NPV would increase. The impact is expected to be minor for utility-scale bifacial and floating system but may reach a few percentage points for BAPV and BIPV systems. Partner 3D, however, envisions no impact at all from these innovations on the NPV.

Partner 3A's expectations for the impact of specific analytics for soiling (3.5), snow (3.6) and degradation (3.7) on the NPV are also a likely improvement with minor to moderate significance for the same reasons stated for 3.1-3.4. For innovation 3.5, the significance of the impact would depend on the frequency and severity of soiling events. The same applies to innovation 3.6, but with respect to snow. For innovation 3.7, it would depend on the degree of degradation, faults, and ageing of the system. In other words, the degree of improvement in NPV as a result of innovations 3.5-3.7 depends on the location.

For IV curve data analytics (3.8), partner 3A anticipates a positive impact on the NPV at the string level for the same reasons stated above. The significance of the impact depends on the location and system type, among other things. The same applies to IR imaging data analytics (3.9), but at the string and/or module level.

Partner 3F expects failure detection and diagnosis methods (3.10) to reduce operational expenditure and improve the energy yield. This, in turn, leads to a higher NPV. The magnitude of the impact would depend on preventative on-field inspection. Partner 3F expects a similar impact from innovations 3.13 and 3.15, digital twins of PV inverter and BIPV.

According to partner 3L, PV inverter efficiency characterisation (3.12) can lead to the validation or falsification of modelling efforts. However, the direction and magnitude of the impact is said to be hard to quantify. Innovation 3.11, failure detection/diagnosis toolbox for small PV, is not expected to be influential by its owner or any of the other project partners. The same applies to innovation 3.14, PV battery digital twin.

7.4.3 Impact of WP4 innovations on NPV

Partner 4C expects the same impacts with the same reasoning from innovations 4.2 and 4.6 on the NPV as explained earlier for the LCoE. In other words, specific procedures for floating PV systems (4.2) can lead to selecting more resilient PV modules that are suited for harsh operating conditions. This guarantees that electricity production and the income generated from it are not negatively affected. In that sense, innovation 4.2 would mitigate a decrease in the NPV to a minor extent. The use of a soiling measurement kit (4.6) can ensure appropriate cleaning which improves electricity production and increases the income generated from it. This would increase the NPV with minor to moderate significance depending on the frequency and severity of soiling events or, simply put, the location. The remaining innovations from the WP are not expected to impact the NPV by any of the owners and project partners.

7.4.4 Impact of WP5 innovations on NPV

The owners and project partners do not expect the innovations from WP5 to impact the NPV. This is because the NPV is not based on forecasted data. The only exception would be if the implementation costs of such innovations are considered as part of the PV electricity generation system, according to partner 5F. In this case, the operation expenditures would increase which lowers the NPV.

7.4.5 Impact of WP6 innovations on NPV

Partner 6B expects innovations 6.1-6.10 to lower the NPV if the implementation costs of the innovations are considered as part of the PV system costs. As for innovations 6.11-6.13, partner 6B anticipates that they would lead to a higher NPV although no explanation of the impact mechanism was given. Partner 3M anticipates innovations 6.14 and 6.15 regarding ancillary services to affect the NPV and the profitability of PV power plants. The direction of change is still unclear.

7.5 (Modified) Internal rate of return

The IRR is the discount rate at which the NPV would be exactly equal to zero. The MIRR is a variation in which financing and reinvestment rates are differentiated to better mirror reality. The MIRR also has different versions depending on the calculation used. One is the project MIRR, which is calculated for the solar PV asset and disregards the financing conditions. Another is the equity or levered MIRR, where the financing conditions are considered, which is important for equity investors. Both values are usually calculated as they provide important information for different types of stakeholders. In all cases, the (M)IRR should be at least equal to the WACC of the project in question. The free cash flow considered for NPV and (M)IRR calculations excludes cost of capital and in particular cost for interests and financing costs, as this is captured in the discount rate [6].

Based on partners' opinion, several SERENDI-PV innovations can potentially impact the (M)IRR. The impact potential of all the innovations was summarised in Table 7.1. The impactful ones are discussed in the sub-sections below.

7.5.1 Impact of WP2 innovations on (M)IRR

Similar to LCoE, better modelling of bifacial, floating, BAPV, and BIPV (2.1-2.4) leads to a better optimisation of those systems and higher yields. This effect can improve the (M)IRR, according to partners 2E and 2F for innovations 2.1, 2.2, 2.3, and 2.4.

For the modelling of soiling and degradation (2.5 and 2.7), partner 2F anticipates a significant positive impact on the (M)IRR. In case of soiling, that is due to the increase in yield or the decrease in the yield uncertainty. In case of degradation, that is due to the optimisation of yield or module replacement strategy which can enhance the project lifetime. The modelling of snow (2.6) is not expected to be influential by any of the parties involved.

7.5.2 Impact of WP3 innovations on (M)IRR

Partner 3A expects an indirect impact on the (M)IRR as a result of the impact on the NPV from innovations 3.1-3.9. These include specific data analytics for bifacial, floating, BAPV and BIPV systems, soiling, snow, degradation, IV curve, and IR imaging. In general, as these innovations cause an increase in the NPV, the (M)IRR would decrease. The significance and nature of the impact per innovation mimics that described above for the NPV.

Partner 3F anticipates a reduction in operational expenditure and a potential improvement in yield as a result of the implementation of failure detection and diagnosis methods (3.10). This would, in turn, lead to a higher (M)IRR. The same applies to PV inverter digital twin (3.13) and BIPV digital twin (3.15). The remaining innovations from this WP are not expected to have an impact on the (M)IRR.

7.5.3 Impact of WP4 innovations on (M)IRR

Partner 4C expects an indirect impact on the (M)IRR stemming from the impact on the NPV from innovations 4.2 and 4.6. As the specific procedures for floating PV systems (4.2) mitigate a decrease in the NPV or, in other words, stabilise the NPV, the (M)IRR is expected to stabilize as well. The increase in the NPV due to the utilisation of a soiling measurement kit (4.6) would cause the (M)IRR to decrease. The impact is expected to be of minor significance for both innovations.

7.5.4 Impact of WP5 innovations on (M)IRR

While none of the innovations' owners from WP5 expect them to influence the (M)IRR, partner 5F envisions some impact. According to partner 5F, if the implementation costs of these forecasting innovations are considered as part of the PV system costs, the operational expenditures would increase. That would, in turn, lead to a reduction in the (M)IRR.

7.5.5 Impact of WP6 innovations on (M)IRR

Partner 6B expects the (M)IRR to decrease if the implementation costs of innovations 6.1-6.10 are treated as part of the system costs. For innovations 6.11-6.13, partner 6B anticipates a higher (M)IRR although no justification was given.

8 Conclusions

This report summarised the innovations developed under the SERENDI-PV project and briefly explained the key performance indicators introduced in task 1.1 of working package 1 of the project and publicly shared in D1.1 [1]. The purpose of the report was to outline and discuss the potential impact of the SERENDI-PV innovations on the selected key performance indicators according to expert (partners) opinion as a midterm follow-up. To that end, a survey was conducted to gather partner opinion regarding the mechanism of any potential impacts, whether they are positive or negative, and how significant they could be. Out of all the project partners, 14 sent back their responses. The responses were then collected, sorted, and analysed to arrive at the integral view of the respondents regarding the impact of every innovation on each of the key performance indicators. These hypothesised impacts are yet to be validated against the results from demonstration projects as a final follow-up at the end of the SERENDI-PV project.

There are 16 key performance indicators concerned with different aspects of solar PV plants, which are performance, reliability, power modelling and forecasting, monitoring, and profitability. Performance indicators include the performance ratio, the temperature-corrected performance ratio, and the soiling ratio. Only one indicator has been selected to measure reliability, which is the performance loss rate. Four indicators have been selected to gauge the accuracy of solar PV power modelling and forecasting. These are the root mean square error, the mean absolute error, the mean bias error, and the forecasting skill score. Monitoring indicators include the energy performance index, data availability, and data quality. Finally, five indicators have been selected to assess and compare the profitability of solar PV plants. These are the levelised cost of electricity, the profile factor, the weighted average cost of capital, the net present value, and the (modified) internal rate of return.

The innovations whose impact has been analysed in this report span working packages 2 to 6, and they are to be demonstrated at different test sites as part of working package 8. The innovations from working package 2 focus on the modelling of different new solar PV technologies (bifacial, floating and BIPV) and system sizes as well as the modelling of factors like soiling, snow, and degradation. Working package 3 innovations are concerned with specific data analytics that help in failure detection and diagnosis for different new solar PV technologies (bifacial, floating and BIPV) and system sizes. As for working package 4, the innovations developed tackle specific and new procedures to be used with different technologies for quality control and performance and reliability enhancement. Working package 5 has to do with developments in PV power forecasting, again for different technologies and system sizes. Lastly, the innovations from working package 6 tackle grid operation and management under high shares of solar PV integration. Exceptionally, one innovation from working package 7 has been deemed by one of the participating project partners to be influential when it comes to monitoring indicators. Thus, it was highlighted and discussed.

The key performance indicator that is affected the most by SERENDI-PV innovations is the levelised cost of electricity, where 49 out of 51 innovations are expected to influence it directly or indirectly. This is followed by the performance loss rate and the net present value (see Figure 8.1:). In contrast, only 10 innovations from working packages 2 and 3 are anticipated by owners to influence the weighted average cost of capital, even though partners 3M and 3N suggest that such innovations can reduce uncertainty and thus indirectly help to reduce projects' WACC. On average, reliability is affected by the highest number of innovations, followed by monitoring and performance, while power modelling and forecasting is the least affected.

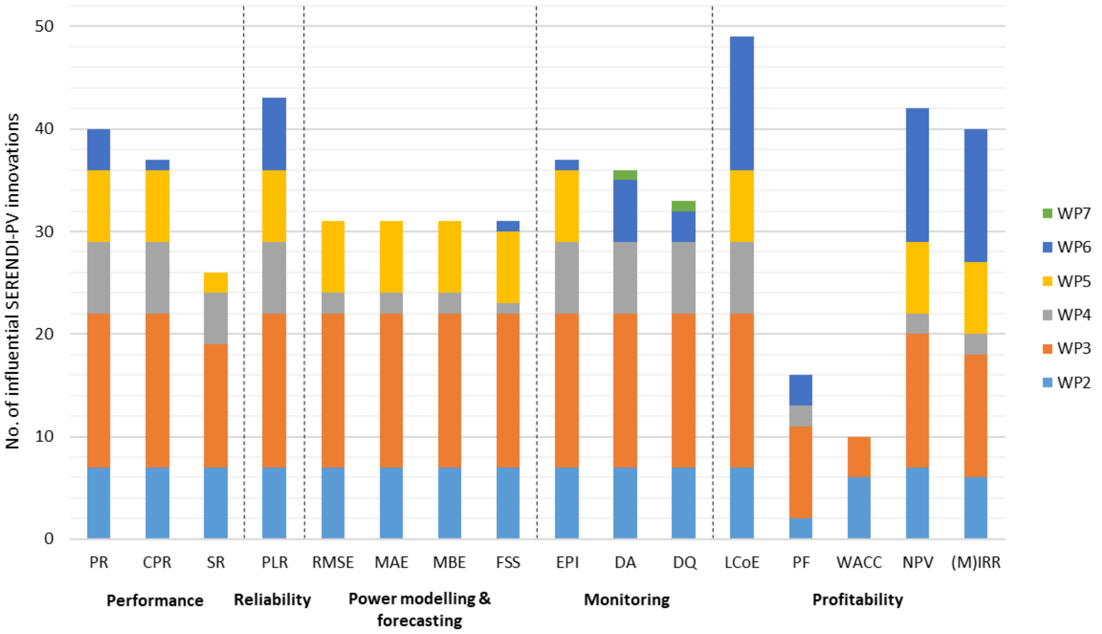

Figure 8.1: Number of potentially influential SERENDI-PV innovations per key performance indicator

The modelling of bifacial and floating PV systems, innovations 2.1 and 2.2, are expected to influence all the key performance indicators selected for the SERENDI-PV project. In contrast, the operation of solar PV ensuring active power reserve available for ancillary services (6.15) is predicted to affect only two indicators, which are the performance loss rate and the net present value. Many innovations from working packages 2 and 3 are deemed influential for at least 80% of the selected key performance indicators. On average, working package 2 impacts the most key performance indicators, followed by working packages 3 and 5. The innovations from working package 6 affect the least number of key performance indicators on average.

In summary, the innovations developed as part of working packages 2 and 3 are deemed the most influential on the selected key performance indicators as per expert (partners) opinion. Conversely, the innovations from working package 6 are seen as the least influential. The levelised cost of electricity, the performance loss rate, the net present value, the performance ratio, and the (modified) internal rate of return should witness the most change as a result of the SERENDI-PV innovations. These key performance indicators span performance, reliability, and profitability. Overall, 14 out of 16 key performance indicators are affected by at least 50% of the developed innovations suggesting a potential high impact from the SERENDI-PV project on the performance of future PV systems.

The results outlined here represent the current expectations of the innovations owners and partners from these developed innovations. However, the impact will be assessed, quantified, and validated at the end of the project on the basis of actual measurements acquired from the Demonstration WP8. This will be presented in the final follow-up on KPIs progress on PV reliability, performance and profitability, and grid integration.

9 Appendix

ID	Innovation	Performance			Reliability	Power modelling & forecasting				Monitoring			Profitability				
		PR	CPR	SR	PLR	RMSE	MAE	MBE	FSS	EPI	DA	DQ	LCoE	PF	WACC	NPV	(M)IRR
2.1	Modelling of bifacial PV systems	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
2.2	Modelling of floating PV systems	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
2.3	Modelling of small PV systems, including BAPV	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X
2.4	Modelling of BIPV systems, any size	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X
2.5	Modelling of soiling	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X
2.6	Modelling of snow	X	X	X	X	X	X	X	X	X	X	X	X			X	
2.7	Modelling of degradation	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X
3.1	Specific data analytics for bifacial PV systems	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X
3.2	Specific data analytics for floating PV systems	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X
3.3	Specific data analytics for small PV systems, including BAPV	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X
3.4	Specific data analytics for BIPV systems, any size	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X
3.5	Specific data analytics for soiling	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X
3.6	Specific data analytics for snow	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X
3.7	Specific data analytics for degradation	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X
3.8	IV curve data analytics	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X
3.9	IR imaging data analytics	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X
3.10	Failure detection and diagnosis methods	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X
3.11	Fault detection/diagnosis toolbox for small PV	X	X		X	X	X	X	X	X	X	X	X				
3.12	PV inverter efficiency characterisation	X	X		X	X	X	X	X	X	X	X	X			X	
3.13	PV inverter digital twin	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X
3.14	PV battery digital twin	X	X	X	X	X	X	X	X	X	X	X	X		X		
3.15	BIPV digital twin	X	X		X	X	X	X	X	X	X	X	X		X	X	X
4.1	Specific procedures for bifacial PV systems	X	X	X	X					X	X	X	X				
4.2	Specific procedures for floating PV systems	X	X	X	X					X	X	X	X	X		X	X
4.3	New procedures for PV inverters field testing	X	X		X					X	X	X	X				

ID	Innovation	Performance			Reliability	Power modelling & forecasting				Monitoring			Profitability				
		PR	CPR	SR	PLR	RMSE	MAE	MBE	FSS	EPI	DA	DQ	LCoE	PF	WACC	NPV	(M)IRR
4.4	New procedures for batteries field testing	X	X	X	X	X	X	X	X	X	X	X	X				
4.5	Quality control procedures for solar radiation and meteorological measurements	X	X	X	X	X	X	X		X	X	X	X				
4.6	Soiling measurement kit	X	X	X	X					X	X	X	X	X		X	X
4.7	Capacitive I-V tracer at 1,500V	X	X		X					X	X	X	X				
5.1	Short-term PV power forecasting based on integrating satellite data and NWP models with PV power production data	X	X		X	X	X	X	X	X			X			X	X
5.2	PV power nowcasting by merging satellite data with sky-camera data and methods for PV power output aggregation	X	X		X	X	X	X	X	X			X			X	X
5.3	Improved power forecasting in presence of snow, dust, fog, and other extreme events	X	X	X	X	X	X	X	X	X			X			X	X
5.4	Forecasting applied to bifacial PV systems	X	X	X	X	X	X	X	X	X			X			X	X
5.5	Forecasting applied to floating PV systems	X	X		X	X	X	X	X	X			X			X	X
5.6	Forecasting applied to residential PV systems	X	X		X	X	X	X	X	X			X			X	X
5.7	Forecasting for spatial averaging and PV aggregation	X	X		X	X	X	X	X	X			X			X	X
6.1	Characterisation of PV inverters as a fundamental element for telecommunication and control of PV systems										X		X			X	X
6.2	Acquisition of PV measurements using Smart/Advanced-Metering-Infrastructure with high resolution in DSO SCADA										X		X			X	X
6.3	Curtailment of PV system from DSO SCADA via secured CLS-channel and delivery of evidence for performed curtailments									X			X			X	X
6.4	Algorithms for automatic PV data integration in DSO SCADA												X			X	X
6.5	Algorithms for automatic PV data integration in PV meta-data registry												X			X	X

ID	Innovation	Performance			Reliability	Power modelling & forecasting				Monitoring			Profitability				
		PR	CPR	SR	PLR	RMSE	MAE	MBE	FSS	EPI	DA	DQ	LCoE	PF	WACC	NPV	(M)IRR
6.6	Integration of algorithms for automatic PV data integration in smart grid data systems of participating project partners				X				X		X	X	X			X	X
6.7	Service system for aggregating anonymous data for the monitoring and management of distributed generation systems												X			X	X
6.8	Digital twin of the grid, real-time state estimation based on load and PV-measurements	X			X						X	X	X			X	X
6.9	Real-time congestion management of the grid based on the Digital twin of the grid and different algorithms for PV-control	X			X						X		X			X	X
6.10	Advanced grid operation and control of PV systems based on PV forecast	X			X						X	X	X			X	X
6.11	Integration of V2G & G2V into self-consumption optimisation software												X	X		X	X
6.12	Further integration of virtual batteries into self-consumption optimisation software				X								X	X		X	X
6.13	Predictive control-based EMS for PV storage self-consumption optimisation				X								X	X		X	X
6.14	Operation and planning of PV for the provision of ancillary services to the grid operators	X	X														
6.15	Operation of PV ensuring active power reserve available to provide ancillary services				X												

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