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PROJECT FINAL REPORT

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Project acronym: Performance Plus

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4.1 Final publishable summary report

Executive Summary

The Performance Plus project was structured in two main phases. In the first phase, a series of devices, models, methods and tools to assess and optimize the performance and lifetime of photovoltaic (PV) installations have been developed. In the second phase, the results have been validated and demonstrated thanks to a User Group composed of large portfolio owners and strong EPC and O&M contractors that gave access to 25 PV systems across Europe making a total of more than 50 MW of installed capacity. In a nutshell, the final results of the project are:

Tools and methods to help reducing the risk during design phase

A method to combine satellite derived irradiation and ground measured data called **Smart Irradiation Service** has been developed. Up to 30% improvement in accuracy has been achieved by applying this method. Moreover, an innovative multi-directional irradiance sensor called **ESA**, that measures both the direct and indirect solar radiation was designed and built within the project. ESA's smaller size, easier installation and operation and up to 85% of cost reduction compared with an equivalent solar irradiation station are amongst the advantages of this innovative sensor.

The **new indoor PV module and inverter test procedures** developed by the consortium help to characterize better the PV system components for real operating conditions and to discover quality issues before installation. In addition, thanks to the fine-grained temporal and spatial models that are able to take into account very complex environmental conditions, the overall uncertainty during design phase is reduced.

Tools and methods to increase the performance during operation phase

The consortium has developed a method to detect and diagnose faults and degradation remotely using monitoring data. The application of this method called **PV Health Scan** can increase the performance up to 10% thanks to the early detection of issues. Furthermore, the new **toolbox for on-site testing of PV modules and inverters** developed by the consortium allows to check the components directly on-site without the need of sending them to a laboratory for testing.

Tools and methods to allow a better integration of PV into the power grid

The consortium developed new methods to forecast imminent irradiance changes thanks to a **sky imager** that extracts the cloud distribution and their motion as well as the resulting surface shadow and solar irradiance fields. In combination with the fine-grain simulation models developed within the project, the accuracy of PV energy yield nowcasting methods is significantly improved. Moreover, the application of a **Model Predictive Control (MPC)** framework that allows harnessing flexibility from any controllable load enables a better integration of PV plants into the power grid. As demonstrated by the consortium, the application of this method can save up to 30% on heating energy costs during winter in Belgium.

The Performance Plus consortium presented the final results of this three years project to an audience of industry and researchers during a closing event, held in Brussels on the 6th of October 2015. The presentations given during this closing event and all public results are available on the project website: www.perfplus.eu

Project Context and Objectives

Beyond Improving Components: System Level Optimization

The PV industry is today at an interesting point in its history. To ensure a continuous decrease of the costs linked to electricity from PV, the prices of modules, inverters and balance of system (BOS) components have to be further decreased. This has to be accomplished, while performance, functionality, reliability and lifetime on the component and system level need to be increased. Needless to say, the industry has made large technological progress with PV cells, modules and inverters in terms of costs and reliability. However, from an integrated perspective, PV system performance emerges from, but is not limited to, the performance of the components. Therefore, in order to improve the performance of PV systems, we need to look at how we can improve the system as a whole.

Limitations during Design Phase: Predicted vs Real Performance

There are several PV performance modelling software packages available on the market, specially developed to predict the amount of energy that a PV system can produce. The predicted performance from these models can differ significantly between each other and from actual performance from real systems. One of the main goals of this work was to better understand these discrepancies between predicted and actual performance of PV systems.

The large amount of input parameters like irradiance, temperature, array orientation, module and inverter performance, user-defined values for additional losses such as soiling, mismatching, cabling, etc. have inherent uncertainties. These uncertainties have to be properly taken into account, as their correct quantification is essential for evaluating the financial risk of PV investments.

Improving Operation & Maintenance: Early and Reliable Detection of Operational Performance Issues

For PV professionals, the early detection and diagnosis of faults is of the utmost importance to obtain and maintain high energy yield of PV systems. Moreover, the timely remediation of faults not only restores the production promptly but also avoids the occurrence of additional component failures and leads to reduction of costs for operation and maintenance (O&M). However, this early and reliable detection of issues requires accurate models of the expected behaviour of the well-performing PV plant. In practice, tools are required to help PV plant owners and operators reducing the occurrence of component failures and thus reducing O&M costs. Ideally, such models and tools can provide insight in the root causes of performance losses.

Overall Objectives

The main goal of the Performance Plus project was to develop and demonstrate models and tools to monitor, control and test PV systems. These models and tools would then be used to optimize and enhance the performance, reliability and lifetime of commercial PV systems. Furthermore, the work focused on improved integration of PV-generated electricity into the power system through methods for short-term forecasting, testing and diagnostics, integrated energy management and storage control of thermal systems and PV system monitoring and control. The goal is to improve the competitiveness of PV on the system level.

The resulting collection of tools will be applicable to the decisive phases in the life cycle of a PV plant, namely, design, operation and maintenance. All results and models are validated with empirical data and the resulting tools are demonstrated in a relevant environment.

The project also tackled the question of energy storage. PV is increasingly becoming integrated with on-site storage and energy management systems. This is done in order to increase the sales value of the PV electricity for the owner or an aggregator acting as intermediary. Of course, it is essential for these systems to have a good control system. Suboptimal control may cause unnecessary over-sizing of storage devices or a significant drop of the overall energy conversion efficiency of the PV-energy management-storage system. Here, model-predictive control (MPC) is recommended for optimally controlling these systems.

The Performance Plus project

The Performance Plus project focused on reliable, cost-effective and highly performing photovoltaic systems. The overall objective of Performance Plus was to develop and demonstrate models and tools for monitoring, control and testing of PV systems. Means for a better integration of PV-generated electricity into the power system were provided by methods for short-term forecasting, PV system monitoring and integrated energy management and storage control.

The Performance Plus consortium looked at how to improve the PV system as a whole rather than on component level. Therefore, the PV modules and inverters were studied with focus on their operation within a system. Moreover, the Performance Plus project also studied the discrepancies between predicted and actual performance of PV systems. The consortium analyzed the way the uncertainties of all input parameters propagate throughout the PV modelling chain and affect the predicted performance. The developed models, methods and tools, aiming at reducing these uncertainties, focus on the early and reliable detection of operational performance issues by providing insight on the root causes of performance losses. This knowledge will help PV plant owners and operators to reduce the occurrence of component failures, and thus reduce their O&M costs.

The developed models, methods and tools were validated and demonstrated within the project. The Performance Plus consortium had access to a total of 25 PV systems across Europe. Where needed, the monitoring data from these plants were integrated into 3E's monitoring and reporting platform SynaptiQ, so the developed methods and tools could be applied. Furthermore, a new type of irradiance sensor was developed within the project and prototypes were installed at five different sites across Europe for validation.

The main objective of the validation and demonstration phase was to bring the developed devices, methods and tools into practice and to ensure the quality of the results. The results of the long-term assessment of monitoring and control in view of sensing, fault detection, performance analysis, communication and effectiveness of the algorithms for energy management and storage control are presented in the public technical reports D6.2 *Demonstration and validation report for sensor and monitoring system* and D6.3 *Demonstration and validation report for tools for field testing*, both available at the project website. The results of the validation and demonstration phase serve for transforming the project results into recommendations and applicable solutions for the industry.

Available PV Plants for Validation and Demonstration

For the validation and demonstration of the models, methods and tools developed within the project, the Performance Plus consortium used monitoring data from a total of 25 PV systems across Europe. One of the installations has been in operation for more than 27 years; others have recently been installed with new PV technology. The available plants cover a wide range of installation capacity, from small residential-scale systems to large utility-scale PV plants, and are distributed over Europe as shown in Figure 1.

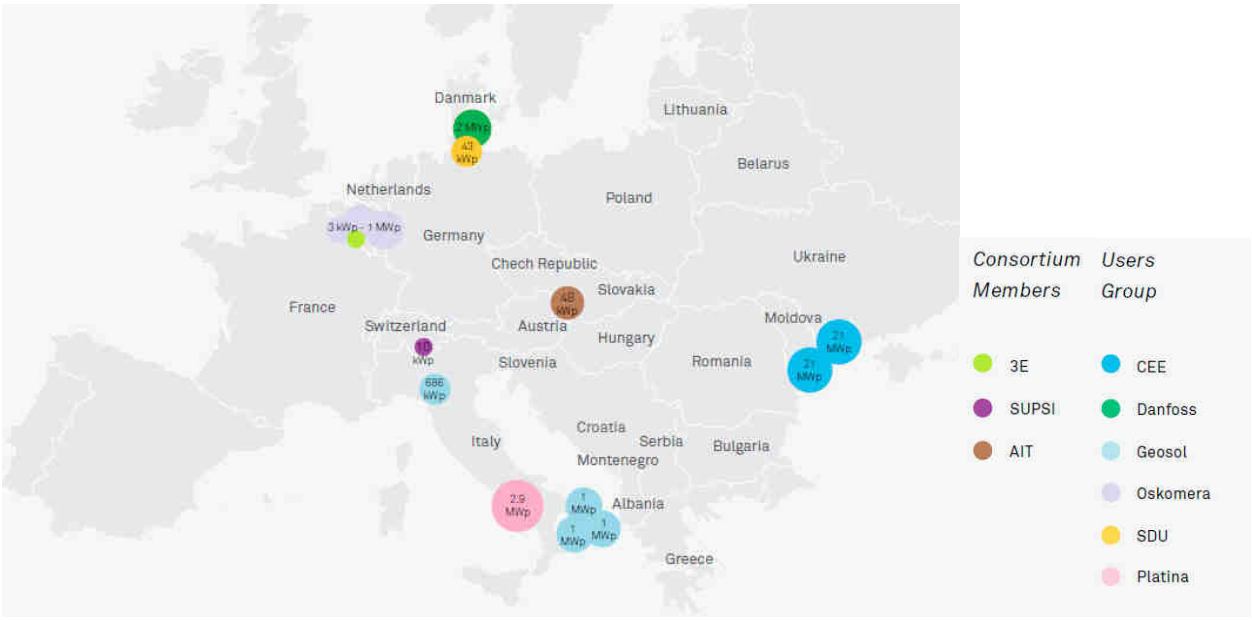


Figure 1: Geographical distribution and size overview of the PV plants used for demonstration and validation activities

Main S&T Results/Foregrounds

Tools and methods to help reducing the risk during design phase

The performance Plus consortium studied the effect of the uncertainties in the underlying PV modelling steps. **Best practice guidelines on uncertainty in PV modelling and monitoring** have been published by the project team. These guidelines will help developers and investors to evaluate more carefully the financial risks during the design phase of a PV plant. The assessment of the solar resource has been identified as the most important element in the contribution to the total uncertainty. Therefore, if appropriate, the consortium recommends combining ground measurements and satellite estimates in order to reduce the uncertainty of the solar resource assessment. The developed method called **Smart Irradiation Service** that combines satellite estimates and ground measured data through a kriging-of-difference methodology has been validated with data collected over 204 sites across Belgium, the Netherlands and France. The validation results show that in average, around 30% of improvement in accuracy can be achieved by this methodology (Figure 2).

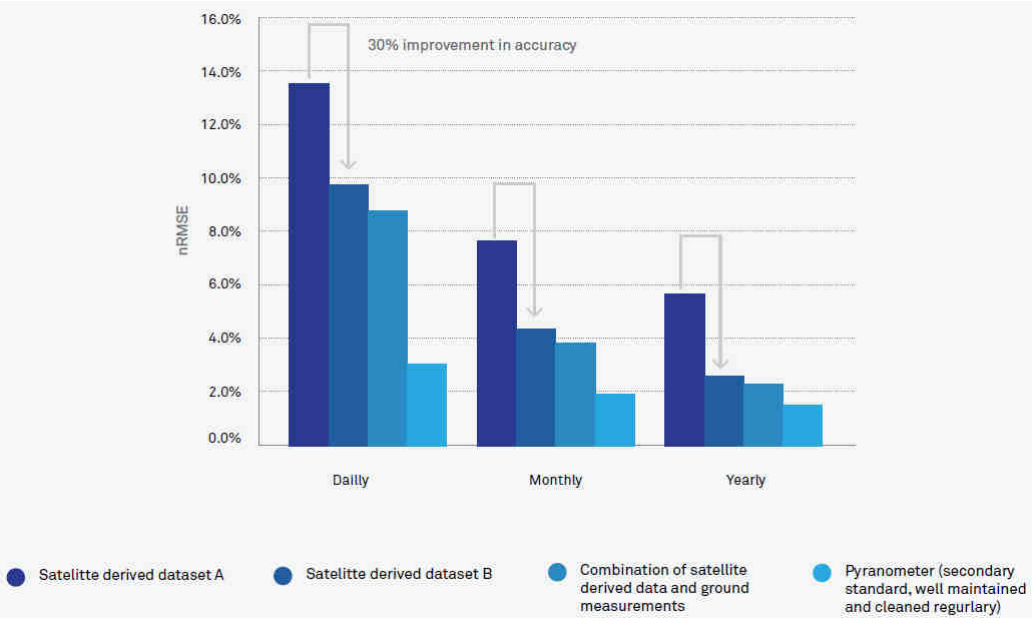


Figure 2: Normalized Root mean square error (nRMSE) of various satellite references compared with ground data from 204 weather stations in Belgium, The Netherlands and France and standard RMSE on pyranometer data

For situations where a high accuracy of the modelled output power is required, the project team has developed **thermo-electric models to account for the effect of non-uniform and fast changing ambient conditions**. Validation results of the developed model show that the daily estimates for average days across a period with both sunny, uniform cloudy and variable cloudy conditions, have been improved from 4% in PVSYST and 3.5% in the Sandia model to 2.5% in our new physics-based fine-grain electro-optical-thermal model. Therefore, the scientific and technical objectives for this task as described in the previous section according to the Annex I of the grant agreement where a reduction from the currently 4% to approximately 3% have been successfully reached. Moreover, results have shown that today's models fully ignore the non-uniformity across a PV module, assuming all cells to behave in an identical way. Results show that non-uniformities of up to 4-6 °C are present which means an error of 2-3% compared to the nominal average temperature values. Finally, a **system scenario approach to speed-up the calculation** has been introduced by the consortium. Results show that the speed up is potentially very large reducing the electrical-optical-thermal (E-O-T) model simulation from 1 day for 1 year of data down to 3 minutes (about factor 500 speedup). At the same time the daily energy yield root mean squared error (RMSE) compared to the accurate E-O-T model increases from 2.5% to 3.75% only, which is a very acceptable and interesting trade-off. When compared to PVSYST, the RMSE is even very similar (4.02 %) so no accuracy is lost then, and the speedup is still significant.

Furthermore, an innovative **multi-directional irradiance sensor called ESA**, that measures both the direct and indirect solar radiation was designed and built within the project. ESA’s smaller size, easier installation and operation and up to 85% of cost reduction compared with an equivalent solar irradiation station are amongst the advantages of this innovative sensor (Figure 3).

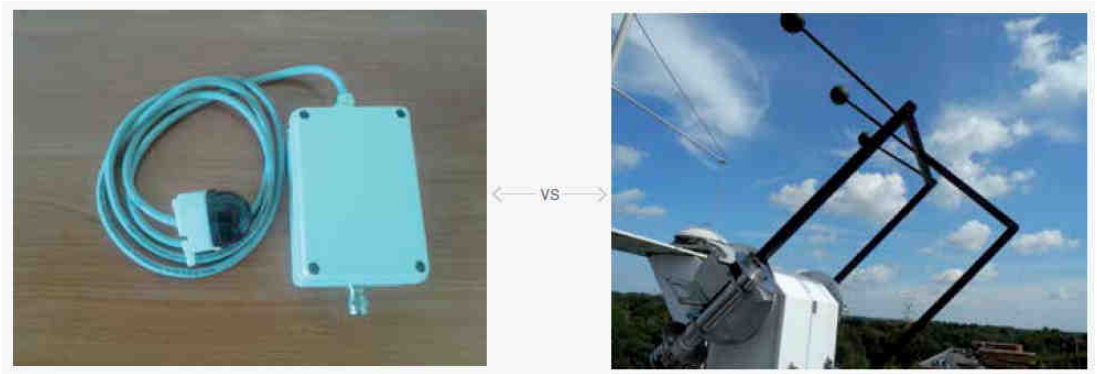


Figure 3: Comparison of the ESA sensor with its junction box (left – source: Alitec Srl) and an equivalent solar irradiance measurement station equipped with a suntracker with shaded pyranometer and pyrheliometer that measure diffuse and direct normal irradiance (right – source: University of Oldenburg)

The proper functioning of the multi-directional irradiance sensor (ESA) has been successfully demonstrated in four sites across Europe (Figure 4).

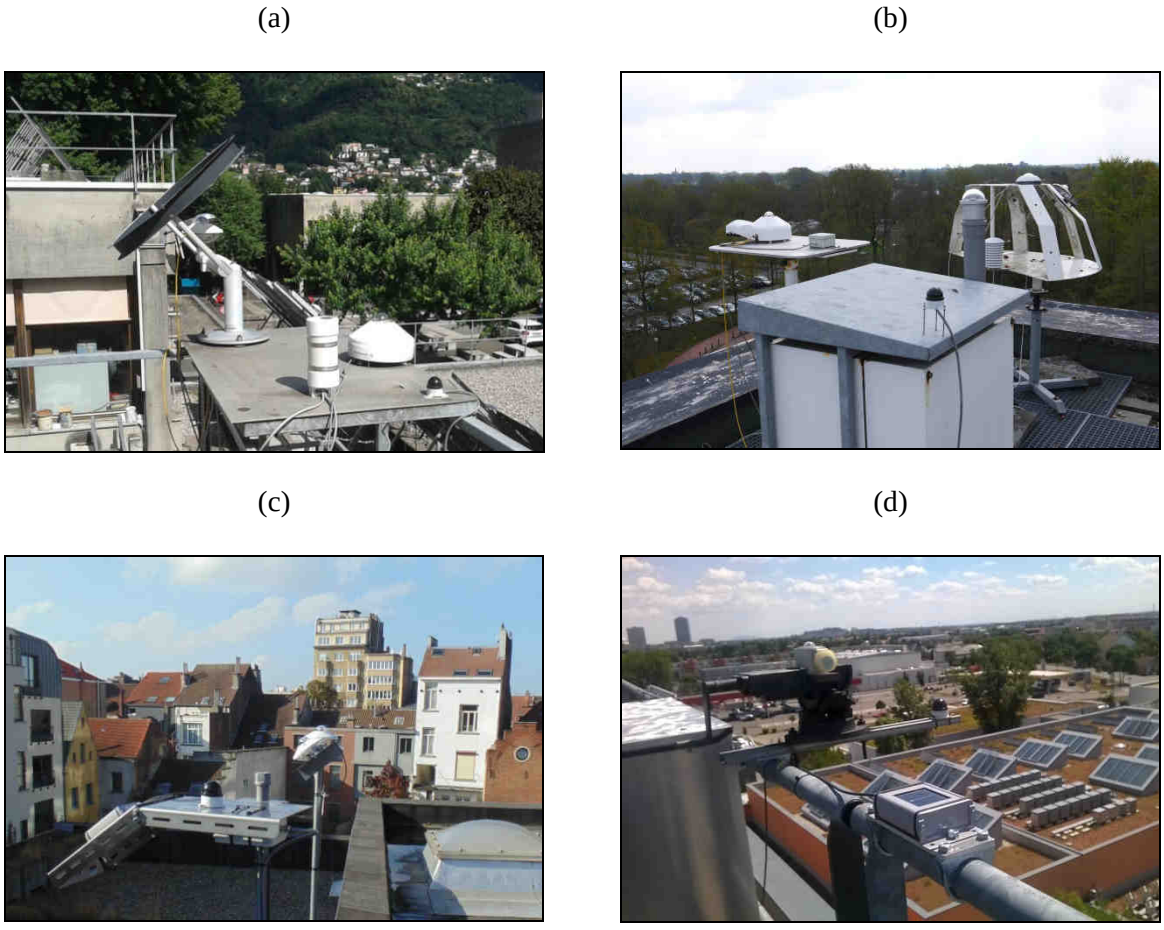


Figure 4: Measurement setup of the ESA irradiance sensor and the reference measurement devices in (a) Lugano, (b) Oldenburg, (c) Brussels and (d) Vienna

The validation results show that the accuracy of the ESA irradiance sensor is good and comparable with second class pyranometers found in the market. Moreover, the validation results of the separate irradiation components demonstrated the ability of the ESA irradiance sensor to measure the diffuse and direct normal components of the irradiation with remarkable accuracy considering the size and price of the ESA sensor.

The ESA sensor's innovative features result in reduced monitoring costs and maintenance efforts, thus allowing not only for small PV plants to perform solar irradiance monitoring, but also for medium to large PV plants to perform distributed rather than single-point solar irradiance monitoring. Moreover, in the field of energy management and optimal control of thermal systems, it enables the active optimization and fine-tuning of heating and/or cooling related energy use.

Moreover, the consortium developed **new indoor PV module and inverter test procedures** that help to characterize better the PV system components for real operating conditions and to discover quality issues before installation. In addition, thanks to the fine-grained temporal and spatial models that are able to take into account very complex environmental conditions, the overall uncertainty during design phase is reduced. Additional accelerated stress reliability tests have been developed to qualify PV inverters for real world applications under different climate conditions. Moreover, for a better understanding and estimating the long-term energy performance of PV modules, new indoor test procedures for degradation mechanisms have been introduced. The procedures will allow for determining the tendency of performance degradation mechanisms caused by potential induced degradation (PID) and dynamic load stress during the PV module's lifetime. These new procedures continue under development within the respective working groups of the International Electrotechnical Commission (IEC).

Tools and methods to increase the performance during operation phase

The consortium has developed a methodology able to characterize the PV array through physical parameters estimated from operational data and to provide insight in the root causes of performance losses. This methodology has been called the **PV Health Scan** and is used to detect and diagnose faults and degradation remotely using monitoring data. The PV Health Scan methodology is illustrated in Figure 5. The method starts from closed-form relationships between regression parameters and underlying physical parameters.

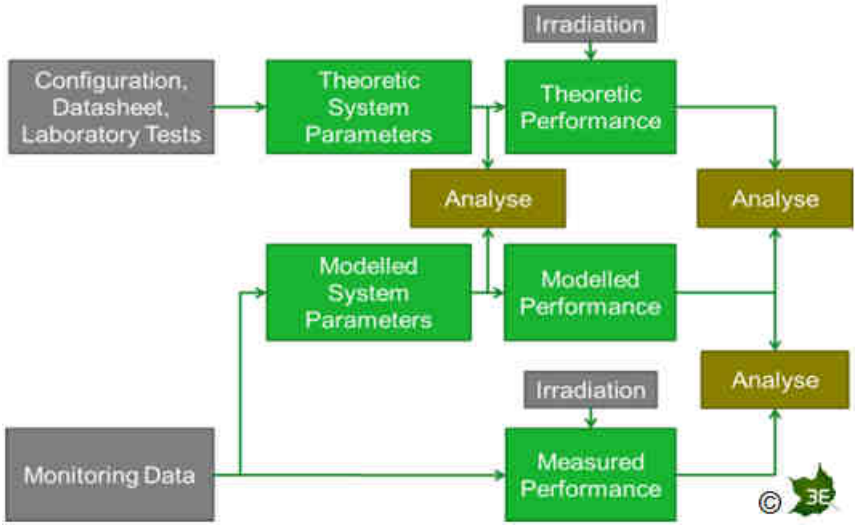


Figure 5: PV Health Scan methodology

A screenshot of some of the features of the PV Health Scan is shown in Figure 6.

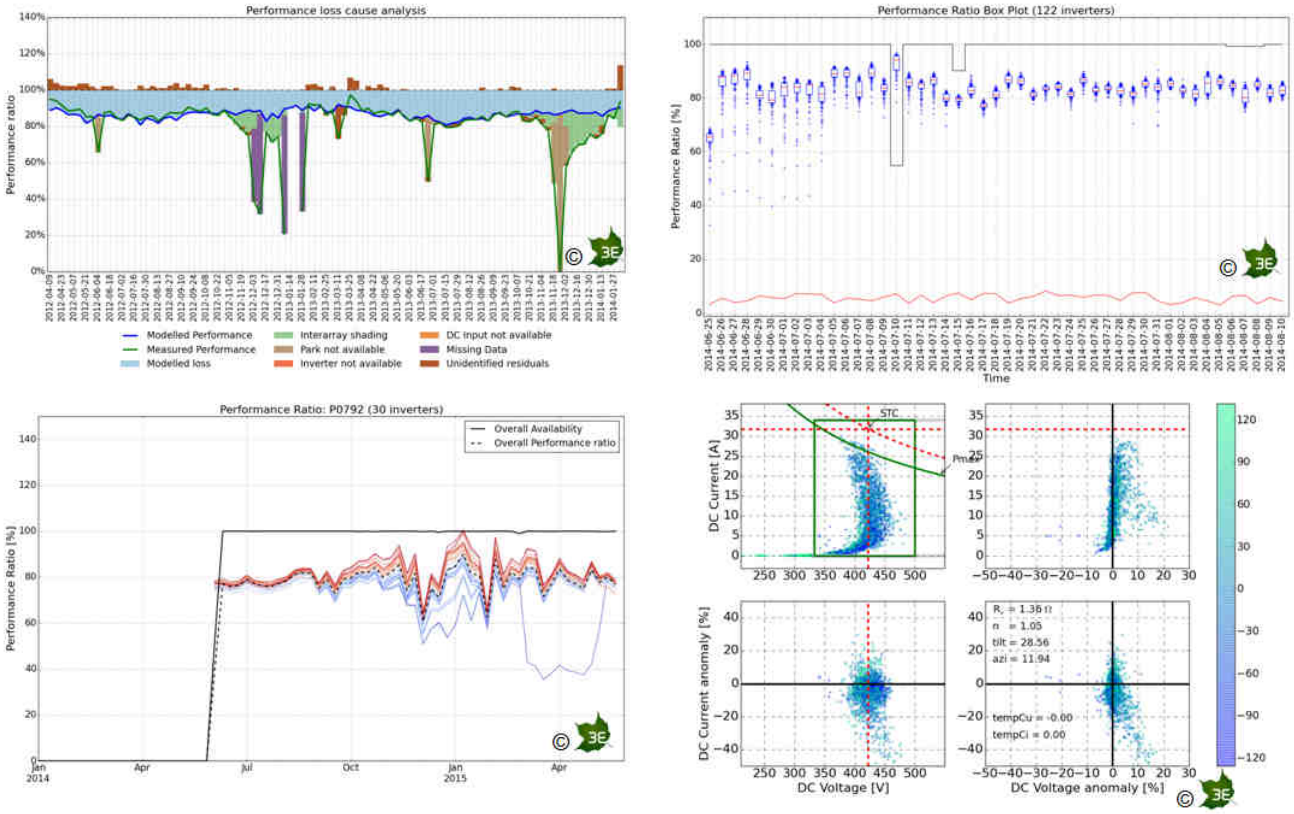
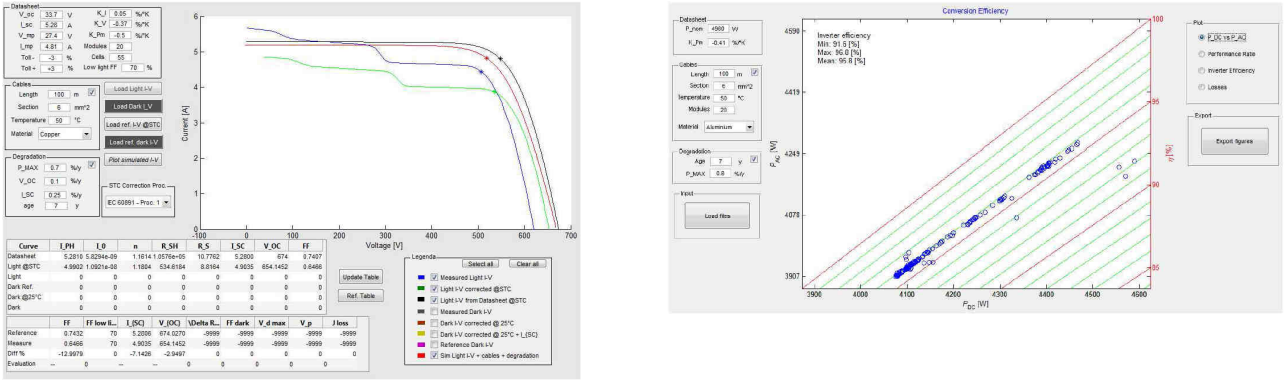


Figure 6: Screenshot of some features of the PV Health Scan

Results of the validation and demonstration phase show that the application of this method can increase the performance up to 10% thanks to the early detection of issues. Moreover, the PV Health Scan allows the systematic analysis of operational data in an efficient way, identifying how design choices and operation and maintenance (O&M) practices lead to inferior or, on the contrary, superior performance in the field. The results show how the toolbox not only detects various performance issues, but it also facilitates the root cause analysis by identifying probable root causes. Among the detected issues were string failures, inter-row shading, vegetation growth, bypass diode failures, potential induced degradation, maximum power point tracking errors, losses due to wrong inverter settings and configuration errors.

Furthermore, the project team developed a new **toolbox for on-site testing of PV modules and inverters**. This toolbox allows checking the components directly in the field without the need of sending them to a laboratory for testing. A screenshot of some of the features of the toolbox is shown in Figure 7.



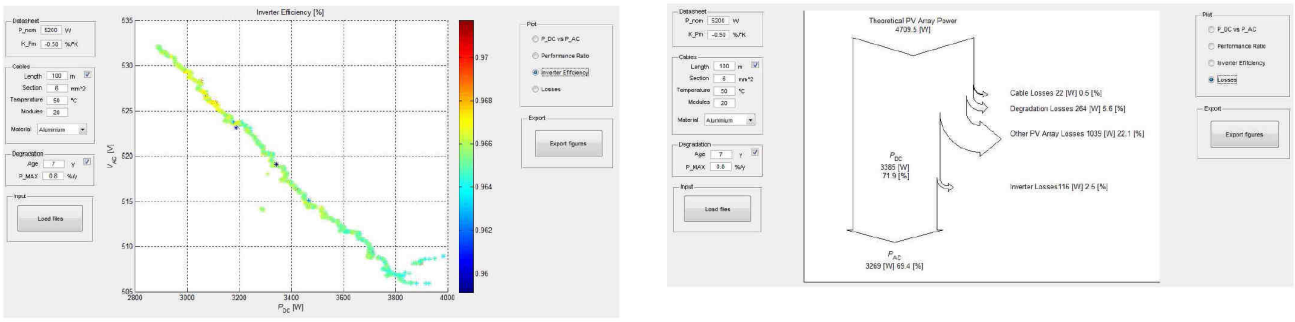


Figure 7: Screenshot of some features of the toolbox for on-site testing of PV modules and inverters

The toolbox for on-site testing of PV modules and inverters has been successfully demonstrated and validated in real PV plants; one of them being a very old PV plant (>30 years under operation). Results of the validation and demonstration phase show that the toolbox allows to analyse PV installations of different ages and types and to investigate the root causes behind the under-performance and energy losses.

Tools and methods to allow a better integration of PV into the power grid

The consortium developed new methods to forecast imminent irradiance changes with a **sky imager** that extracts the cloud distribution and their motion as well as the resulting surface shadow and solar irradiance fields. A screenshot of the short-term forecasting is shown in Figure 8.

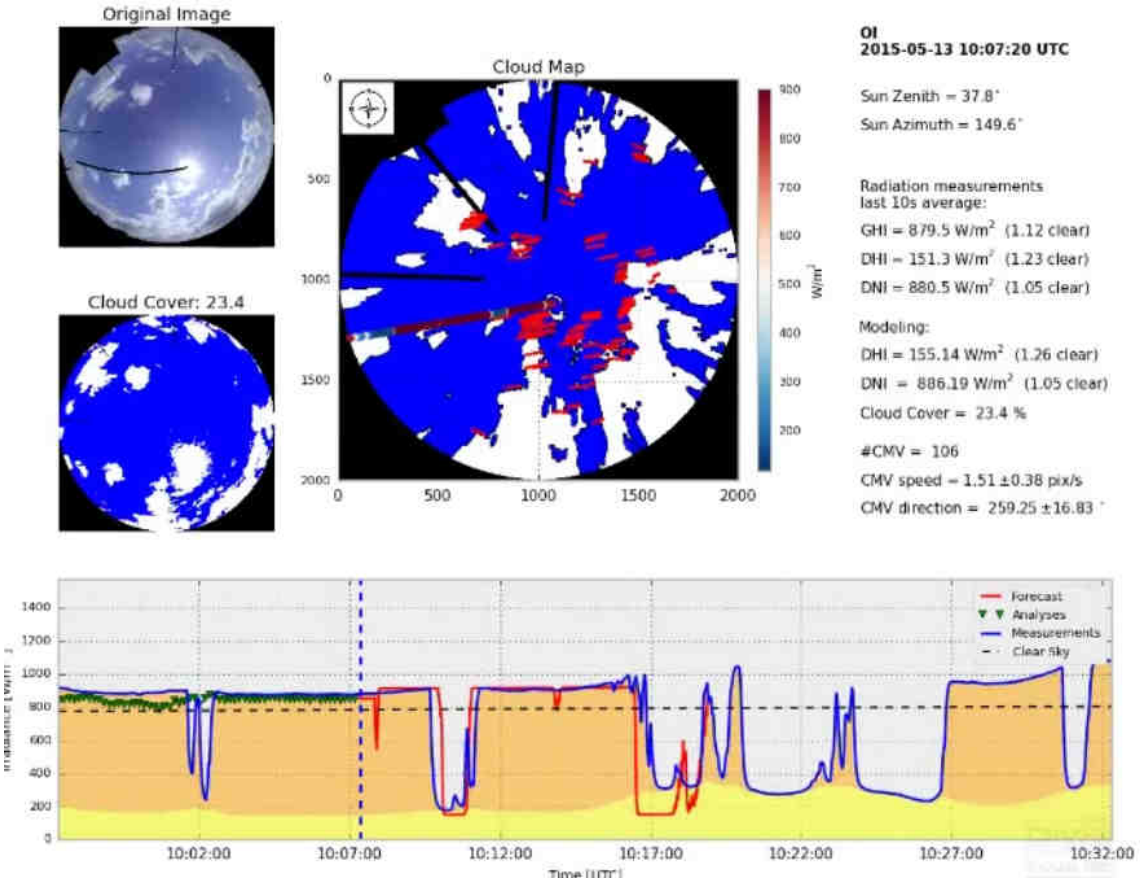


Figure 8: Screenshot of the short-term irradiance forecasting application to Oldenburg data using sky imaging techniques

Results of the validation show that the global horizontal irradiance (GHI) retrieved on the basis of sky images and a machine learning approach, outperforms Meteosat Second Generation (MSG)

satellite derived data for the measurement site of the University of Oldenburg. RMSE values of the developed sky imager irradiance retrieval are 25% lower than for state of the art satellite models for hourly irradiance values. The developed sky imager based forecast model can provide forecasts with a temporal resolution of 1s and a spatial resolution of a few meters. Moreover, as no expensive radiometric measurement devices are required, the proposed approach reduces significantly the initial investment and operational costs.

Furthermore, in combination with the simulation models developed within the project, the accuracy of **PV energy yield nowcasting methods** has been improved. The validation results show that for a horizon of five minutes, the developed PV energy yield nowcasting method combining sky imaging with simulation models outperforms the persistence model. Moreover, the accuracy of the proposed model is in line with state-of-the-art energy yield forecasts, but with the added value that the irradiation-to-energy error is already included. Additionally, promising results have been obtained from the validation of the modelling of coupled cell-inverter thermal behaviour.

Furthermore, the project team focussed on minimizing the operational costs of installations by means of optimal controllers. The consortium has developed a **Model Predictive Control (MPC)** framework that allows harnessing flexibility from any controllable load and enables a better integration of PV plants into the power grid. In the MPC framework, the system is controlled using control inputs that are found by optimizing the model-predicted future behaviour of the system as shown in Figure 9.

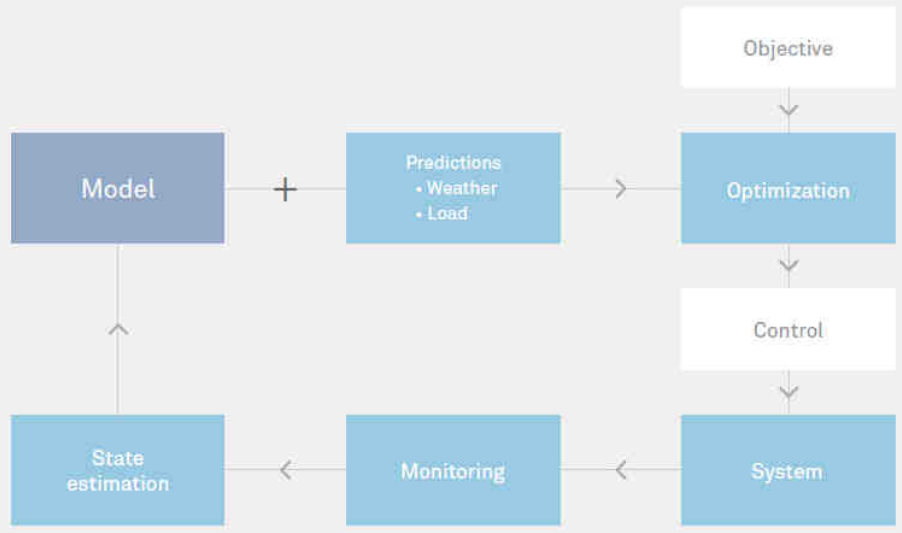


Figure 9: Overview of the Model Predictive Control (MPC) framework

The developed method for **energy management and storage control** has been demonstrated through three use cases comprising PV, controllable thermal energy resources and energy storage. For the heating case, results show that the self-consumption rate can be increased from 54% to 74% by minimizing the system's operational cost for building energy use and PV production compared to the building energy use only. This is a 36% increase in self-consumption. At the same time, the self-production is increased with 29%. These results from the implementation of the MCP in an office building in Brussels show that the use of model predictive controllers (MPC) during the winter in Belgium allows saving up to 30% of the heating energy costs compared to the initially used rule based controller. For the cooling case, the simulation results show that self-consumption rate can be increased from 77% (set point tracking reference) or 54% (optimal energy use controller) to 100%. This is a 29% or 85% increase respectively. Moreover, while improving the self-consumption, also the self-production was increased and also the total operational cost was reduced with 30%.

Potential Impact, Dissemination Activities and Exploitation of Results

Potential Impact

The Performance Plus project has developed models, methods and tools to optimize and enhance the performance, reliability and lifetime of commercial PV systems beyond the state-of-the-art. The results were validated and demonstrated with more than 50 MW of empirical data from a total of 25 PV systems across Europe. The results of the validation and demonstration phase are publicly available on the project website and have been presented in both scientific conferences and in public workshops organized by the consortium. Novel methods have been introduced and validated for advanced PV module modelling, short-term forecasting, testing and diagnostics, advanced PV system monitoring techniques, and integrated energy management and storage control. Some of these project results are already being transformed into practically applicable solutions and proven marketable products.

The following models, methods and tools to assess and optimize the performance of PV systems have been developed by the Performance Plus consortium:

Tools and methods to reduce the risk during design phase

- Smart Irradiation Service (SIS)
- Multi-directional irradiance sensor (ESA sensor)
- Fine-grained models
- Indoor PV module and inverter test procedures

Tools and methods to increase performance during operation phase by detecting and diagnosing failures

- PV Health Scan and Solar Sensor Check
- Toolbox for on-site testing of PV modules and inverters

Tools and methods to integrate PV into power system by optimally managing and controlling the energy

- Sky imager
- PV energy yield nowcasting combining sky imaging with simulation models
- Model Predictive Control (MPC) for optimal energy management and storage control

The pursued impacts grouped by target group are listed below.

Policy makers

- Cost Reduction: Investment costs, inverter lifetime, module power over time, system performance ratio
- System Integration: Private self-consumption, energy management/storage control & communication for grid support, short-term production forecast.

Utility sector (Grid operators, energy suppliers, energy service companies)
Improved economics of integrated PV with storage and energy management systems. Smart grid and power system integration.

PV system integrators, plant operators, energy aggregators, financing institutions

Reduced investment risk, PV forecast quality, gains from energy management & storage control, improved PV system performance and reliability, reduced occurrence of false alarms & reliable detection of real faults.

PV module, inverter and other component manufacturers
Improved PV system & component performance and reliability, compatible communication interfaces.

Engineering, design, monitoring and forecasting service providers
Models improving existing design & monitoring tools, higher confidence in energy yield predictions, PV forecast quality, reduced occurrence of false alarms & reliable detection of real faults.

Research & higher education
Progress beyond the state of the art in the core technologies: PV system & component modelling, forecasting, energy modelling & optimisation, MPC sensing, pattern recognition, data mining, inverter control and diagnostic testing.

Media, civil society, interested public
Foster dialogue and debate on strategic impacts: LCOE reduction and system integration/ grids, progress towards KPIs of the SEII.

Dissemination Activities

Over the project duration, the consortium partners wrote 30 scientific papers of which 7 were published in peer-reviewed journals. All the papers were presented at various scientific conferences through Europe. Besides the scientific publications, the consortium members were invited to present the project results in different occasions (see section 4.2 tables A1 and A2).

Furthermore, two project workshops were organized by the consortium to disseminate the project findings, lessons learned and recommendations.
The first project workshop took place on Wednesday 19th of November 2014 in Brussels, Belgium and was attended by over 30 participants (Figure 10). The workshop was focused on exploring how the new models and tools that were being developed in the project can improve the performance of PV systems and counted with the participation of the User's Group members.

Figure 10: First Performance Plus workshop

The second project workshop was held together with another FP7 project (PVCROPS) and took place on Tuesday 6th of October 2015 in Brussels, Belgium and was attended by over 60 participants (Figure 11). This closing event was focused on the dissemination of the final results of the demonstration and validation phase of the developed devices, methods and tools.

Figure 11: Performance Plus closing event

All presentations of both events are publically available at the project website under http://perfplus.eu/news. Furthermore, the consortium prepared an infographic (Figure 12) for the closing event on October 2015. The infographic summarizes the project outcomes and presents quantitative results.

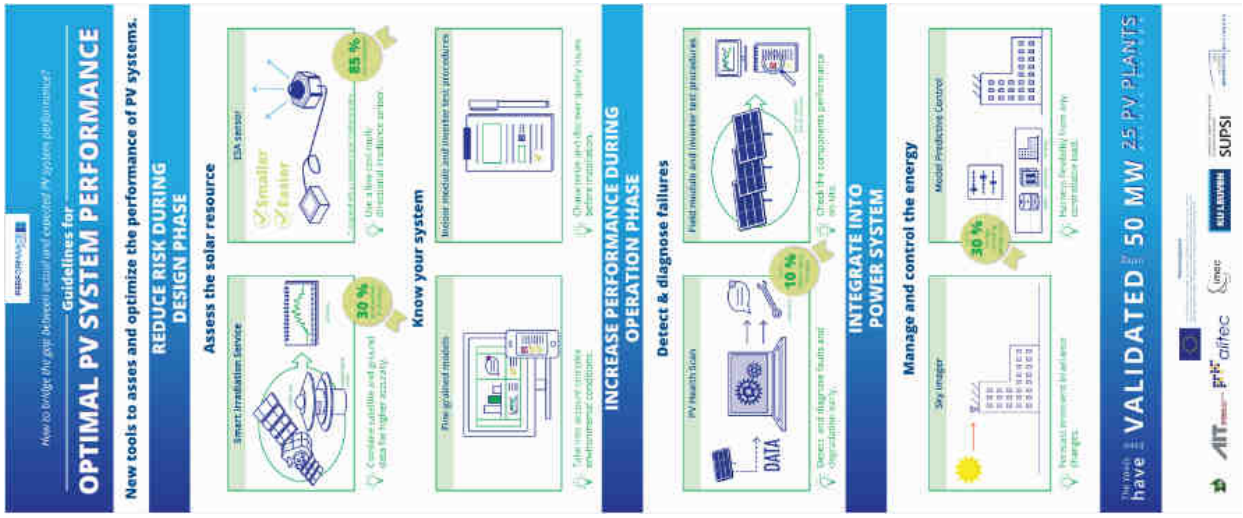


Figure 12: Performance Plus project infographic

Furthermore, three press releases targeted to the civil society were launched during the duration of the project. All the press releases were disseminated through different communication channels e.g. Figure 13 shows one of the press releases, leading to an article in the Sun & Wind Energy magazine for renewable energies in March 2014. Moreover, all press releases were also disseminated through the project website (http://perfplus.eu/news).

Figure 13: Performance Plus press release published in Sun & Wind Energy magazine

Exploitation of Results

The project partners are able to exploit the project results in the following ways:

3E

- *PV Health Scan:* 3E is planning to exploit the PV health scan method in a first stage as a service linked to 3E's monitoring portal SynaptiQ. In the longer term, this can also be offered as a consultancy service.

- *Smart Irradiation Service (SIS):* 3E is already applying this method for consultancy services as a reference irradiation for projects with no existing or low quality irradiation measurements.

- *Model Predictive Control (MPC) for optimal energy management and control:* 3E plans further collaboration with KU Leuven towards offering commercial MPC services.

Alitec

- Multi-directional irradiance sensor (ESA sensor): Alitec will offer the ESA sensor and provide technical assistance to EPC and O&M contractors.

IMEC

- *Tools for detailed thermal optical electrical energy yield modelling of PV modules:* IMEC will continue with the improvement of these models. Moreover, the following customer segments are targeted for their further application:

    - PV rooftop or plant installers/aggregators and solar car or transport providers: training and transfer of methodologies and tools in prototype form;

- PV energy yield model providers: in depth transfer of methodologies and tools in "white-box" mode. They will provide similar services as IMEC to customer segments described above, but in a fully commercial model. 3E is considered as a prime partner to start with.

- *PV energy yield nowcasting combining sky imaging with simulation models:* this is a joint result shared with the University of Oldenburg. It has been agreed by both partners that this result can be used in the future by both sides without accounting so they provide a cross-license towards each other for this information and the usage in demonstrations. Both partners plan to extend this cooperation beyond the project to further build on the obtained results.

- *Thermal model for mutual impact of the local DC-AC convertor and PV module in a PV string setup:* this is a joint result shared with AIT. It has been agreed by both partners that both the instantiated model and the experimental results obtained are considered as public knowledge (a joint journal paper is foreseen). This knowledge can be used in the future by both sides without accounting. However, both parties will only use this while always mutually citing each other's contribution.

KU Leuven

- *Model Predictive Control (MPC) for optimal energy management and control:* KU Leuven will continue the development of MPC. Moreover, negotiations for future cooperation have started between KU Leuven and 3E. Both partners plan to extend their cooperation beyond the project to further build on the obtained results.

SUPSI

- *Sampling and evaluation procedures for indoor PV module testing:* SUPSI will use these new procedures for indoor testing of batch of PV modules. The new procedures include methods for the selection of the number and the sample of modules to test inside a large batch and the definition of the qualitative KPIs to evaluate the results.

- *Toolbox for on-site testing of PV modules and inverters:* SUPSI and AIT have collaborated into the development of new procedures and tools for field testing on PV plants. Both the instantiated model and the experimental results will be used in the future by both sides without accounting. However, both parties will only use this while always mutually citing each other's contribution.

UOL

- *Sky imager:* The University of Oldenburg will continue research to improve solar irradiation forecasting based on Sky imaging.

- *PV energy yield nowcasting combining sky imaging with simulation models:* This is a joint result shared with IMEC. It has been agreed by both partners that this results can be used in the future by both sides without accounting so they provide a cross-license towards each

other for this information and the usage in demonstrations. Both partners plan to extend this cooperation beyond the project to further build on the obtained results.

AIT

- *Switch based PV inverter models:* AIT is planning to offer this as a consultancy service for inverter manufacturers.

- *PV inverter average models:* AIT will use these accurate PV inverter average models to predict possible revenue of PV plants in a design stage based on site related mission profiles. Furthermore, the models can also be used to calculate the possible revenue from running PV plants and help to identify and analyse deviations from this maximum value. AIT will target PV power plant owners as well as consultants to analyse PV plants using this model. Furthermore, due to the low computing resources needed, private users would also be able to analyse their expected revenue based on a best-case calculation.

- *PV inverter reliability and robustness tests:* AIT will offer these tests as a consultancy service for inverter manufacturers.

- *PV inverter lifetime estimation:* AIT will target with this service mainly PV inverter manufacturers. Furthermore, PV site planners could also use this service for non-standard fields of application to evaluate the risk of failure during the time of use.

- *PV "Golden Inverter" tool:* AIT will target PV site owners/consultants/service providers to help to monitor PV inverter performance using either internal inverter readings or measurement devices.

- *Toolbox for on-site testing of PV modules and inverters:* AIT and SUPSI have collaborated into the development of new procedures and tools for field testing on PV plants. Both the instantiated model and the experimental results will be used in the future by both sides without accounting. However, both parties will only use this while always mutually citing each other's contribution.

- *Thermal model for mutual impact of the local DC-AC convertor and PV module in a PV string setup:* this is a joint result shared with IMEC. It has been agreed by both partners that both the instantiated model and the experimental results obtained are considered as public knowledge (a joint journal paper is foreseen). This knowledge can be used in the future by both sides without accounting. However, both parties will only use this while always mutually citing each other's contribution.

Project Public Website

www.perfplus.eu

4.2 Use and dissemination of foreground

Section A (public)

TEMPLATE A1: LIST OF SCIENTIFIC PUBLICATIONS, STARTING WITH THE MOST IMPORTANT ONES											
NO.	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers[2] (if available)	Is/Will open access[3] provided to this publication?	Type
1	*Practical implementation and evaluation of model predictive control for an office building in Brussels*	*Roel De Coninck , Lieve Helsen*	*Energy and Buildings*	*Vol. 111*	*Elsevier BV*	*The Netherlands*	*01/01/2016*	*290-298*	*10.1016/j.enbuild.2015.11.014*	*Yes (LIRIAS database KU Leuven)*	*Peer reviewed publication*
2	*Evaluating the spatio-temporal performance of sky imager based solar irradiance analysis and forecasts*	*T. Schmidt , J. Kalisch , E. Lorenz , D. Heinemann*	*Atmospheric Chemistry and Physics Discussions*	*Vol. 15/Issue 19*	*European Geosciences Union*	*Germany*	*01/01/2015*	*26997-27039*	*10.5194/acpd-15-26997-2015*	*Yes*	*Peer reviewed publication*
3	*Spatial and temporal analysis of wind effects on PV module temperature and performance*	*H. Goverde*	*Sustainable Energy Technologies and Assessments*	*Volume 11 (2015)*	*Elsevier BV*	*Amsterdam, The Netherlands*	*2015*	*36 - 41*	*10.1016/j.seta.2015.05.003*		*Peer reviewed publication*
4	*IEC 61850/61499 Control of Distributed Energy Resources: Concept, Guidelines, and Implementation*	*Filip Andren , Roland Brundlinger , Thomas Strasser*	*IEEE Transactions on Energy Conversion*	*Vol. 29/Issue 4*	*Institute of Electrical and Electronics Engineers Inc.*	*United States*	*01/12/2014*	*1008-1017*	*10.1109/TEC.2014.2352338*		*Peer reviewed publication*

[2] A permanent identifier should be a persistent link to the published version full text if open access or abstract if article is pay per view) or to the final manuscript accepted for publication (link to article in repository).

[3] Open Access is defined as free of charge access for anyone via Internet. Please answer "yes" if the open access to the publication is already established and also if the embargo period for open access is not yet over but you intend to establish open access afterwards.

5	Toolbox for development and validation of grey-box building models for forecasting and control	Roel De Coninck , Fredrik Magnusson , Johan Åkesson , Lieve Helsen	Journal of Building Performance Simulation	Vol. 8	Taylor and Francis Ltd.	United Kingdom	15/06/2015	1-16	10.1080/19401493.2015.1046933	Yes (LIRIAS database KU Leuven)	Peer reviewed publication
6	Quantification of flexibility in buildings by cost curves – Methodology and application	Roel De Coninck , Lieve Helsen	Applied Energy	Vol. 162	Elsevier BV	Netherlands	01/01/2016	653-665	10.1016/j.apenergy.2015.10.114	Yes (LIRIAS database KU Leuven)	Peer reviewed publication
7	Rule-based demand-side management of domestic hot water production with heat pumps in zero energy neighbourhoods	R. De Coninck , R. Baetens , D. Saelens , A. Woyte , L. Helsen	Journal of Building Performance Simulation	Vol. 7/Issue 4	Taylor and Francis Ltd.	United Kingdom	04/07/2014	271-288	10.1080/19401493.2013.801518	Yes (LIRIAS database KU Leuven)	Peer reviewed publication
8	Optical-Thermal-Electrical Model for a Single Cell PV Module in Non-Steady-State and Non-Uniform Conditions Build in SPICE	H. Goverde, J. Govaerts, K. Baert, F. Catthoor, J. Driesen, J. Poortmans	28th European Photovoltaic Solar Energy Conference and Exhibition		EU PVSEC	Germany	04/10/2013	3291 - 3295			Paper in Proceedings of a Conference/ Workshop
9	Experimental Validation of Solar Resource Assessment Methodologies	M. Richter, T. Gonzalez, C. Morilla	28th European Photovoltaic Solar Energy Conference and Exhibition		EU PVSEC	Germany	04/10/2013	3909 - 3914			Paper in Proceedings of a Conference/ Workshop
10	A tool chain for model predictive control of buildings based on grey-box models	R. De Coninck, F. Magnusson, J. Åkesson, L. Helsen	Intelligent Building Operations Workshop		IBPSA-USA		22/06/2013				Paper in Proceedings of a Conference/ Workshop
11	Bottom-up quantification of the flexibility potential of buildings	R. De Coninck, L. Helsen	13th International Conference of the International Building Performance Simulation Association		IBPSA		28/08/2013				Paper in Proceedings of a Conference/ Workshop
12	Grey-Box Building Models for Model	R. De Coninck, F. Magnusson, J.	Proceedings of the 10th		MODELICA		12/03/2014				Paper in Proceedings of

	Order Reduction and Control	*Åkesson, and L. Helsen*	*International ModelicaConference March 10-12*								*a Conference/ Workshop*
13	*Setting up a framework for model predictive control with moving horizon state estimation using JModelica*	*M. Vande Cavey, R. De Coninck, and L. Helsen*	*Proceedings of the 10th International ModelicaConference March 10-12*		*MODELICA*		*12/03/2014*				*Paper in Proceedings of a Conference/ Workshop*
14	*PV Array Characterisation from Operational Data*	*K. De Brabandere, F. Assiandi, M. Richter, O. Gammoh, and A. Woyte*	*29th European Photovoltaic Solar Energy Conference and Exhibition*		*EU PVSEC*	*Germany*	*26/09/2014*				*Paper in Proceedings of a Conference/ Workshop*
15	*System Cost Optimization of SmartPV Technology Under Non-Uniform Conditions*	*M. Richter, K. De Brabandere, C. Tjengdrawira, K. Baert, H. Goverde, A. Masolin, G. Mulder, and P. Van Tichelen*	*29th European Photovoltaic Solar Energy Conference and Exhibition*		*EU PVSEC*	*Germany*	*26/09/2014*				*Paper in Proceedings of a Conference/ Workshop*
16	*Modeling and Simulation of a Residential Neighborhood with Photovoltaic Systems Coupled to Energy Storage Systems*	*Baggi, Shalako and Rivola, Davide and Medici, Vasco and Corbellini, Gianluca and Strepparava, Davide and Rudel, Roman*	*29th European Photovoltaic Solar Energy Conference and Exhibition*		*EU PVSEC*	*Germany*	*26/09/2014*				*Paper in Proceedings of a Conference/ Workshop*
17	*Presentation of a Verilog-AMS Model for Detailed Transient Electro-Thermal Simulations of PV Modules and Systems*	*D. Anagnostos, H. Goverde, F. Catthoor, D. Soudris*	*29th European Photovoltaic Solar Energy Conference and Exhibition*		*EU PVSEC*	*Germany*	*26/09/2014*				*Paper in Proceedings of a Conference/ Workshop*
18	*Demonstration and validation of an energy yield prediction model suitable for non-steady state non-uniform conditions*	*D.Anagnostos, H.Goverde, B.Herteleer, F.Catthoor, D.Soudris, J.Driesen and J.Poortmans*	*6th World Conference on Photovoltaic Energy Conversion (WCPEC)*		*WCPEC*		*27/11/2014*				*Paper in Proceedings of a Conference/ Workshop*

19	*A Clustering Approach for PV Module Sampling*	*G. Corbellini, S. Dittmann*	*30th European Photovoltaic Solar Energy Conference and Exhibition*		*EU PVSEC*	*Germany*	*18/09/2015*				*Paper in Proceedings of a Conference/ Workshop*
20	*Uncertainties in PV Modelling and Monitoring*	*M. Richter, K. De Brabandere, A. Woyte, J. Kalisch, T. Schmidt, and E. Lorenz*	*30th European Photovoltaic Solar Energy Conference and Exhibition*		*EU PVSEC*	*Germany*	*18/09/2015*				*Paper in Proceedings of a Conference/ Workshop*
21	*PV Energy Yield Nowcasting Combining Sky Imaging with Simulation Models*	*Anagnostos, D. G., Schmidt, T., Goverde, H., Kalisch, J., Catthoor, F., Soudris, D.*	*30th European Photovoltaic Solar Energy Conference and Exhibition*		*EU PVSEC*	*Germany*	*18/09/2015*				*Paper in Proceedings of a Conference /Workshop*
22	*Model Requirements for Accurate Short Term Energy Yield Predictions during Fast-Varying Weather Conditions*	*H.Goverde, D.Anagnostos, G.Van den Broeck, K.Baert, F.Catthoor, J.Driesen, J.Poortmans, B.Herteleer*	*30th European Photovoltaic Solar Energy Conference and Exhibition*		*EU PVSEC*	*Germany*	*18/09/2015*				*Paper in Proceedings of a Conference /Workshop*

TEMPLATE A2: LIST OF DISSEMINATION ACTIVITIES								
NO.	Type of activities[4]	Main leader	Title	Date / Period	Place	Type of audience[5]	Size of audience	Countries addressed
1	*Web sites/Applications*	*3E N.V.*	*Project website: www.perfplus.eu*	*01/01/2013*	*Brussels, Belgium*	*Scientific community (higher education, Research) - Industry - Civil society - Policy makers - Medias*		*International*
2	*Oral presentation to a scientific event*	*KATHOLIEKE UNIVERSITEIT LEUVEN*	*A tool chain for model predictive control of buildings based on grey-box models, Intelligent Building Operations Workshop*	*22/06/2013*	*Boulder, CO, USA*	*Scientific community (higher education, Research)*		*International*
3	*Oral presentation to a scientific event*	*KATHOLIEKE UNIVERSITEIT LEUVEN*	*Bottom-up quantification of the flexibility potential of buildings*	*28/08/2013*	*Le Bourget Du Lac, France*	*Scientific community (higher education, Research)*		*EU*
3	*Oral presentation to a scientific event*	*3E N.V.*	*Performance Plus - Tools for Enhanced Photovoltaic System Performance. Progress in Photovoltaics and Nanotechnology: from FP7 to Horizon 2020 – The EU PV Clusters 2nd Workshop and General Assembly (26th – 28th November 2013)*	*28/11/2013*	*Barcelona, Spain*	*Scientific community (higher education, Research)*		*EU*
4	*Oral presentation to a scientific event*	*INTERUNIVERSITAIR MICRO-ELECTRONICA CENTRUM VZW*	*Optical-Thermal-Electrical Model for a Single Cell PV Module in Non-Steady-State and Non-Uniform Conditions Build in SPICE*	*04/10/2013*	*Franckfurt, Germany*	*Scientific community (higher education, Research) - Industry*		*EU*
5	*Posters*	*3E N.V.*	*Experimental Validation of Solar Resource Assessment Methodologies*	*04/10/2013*	*Franckfurt, Germany*	*Scientific community (higher education, Research) - Industry*		*EU*

[4] A drop down list allows choosing the dissemination activity: publications, conferences, workshops, web, press releases, flyers, articles published in the popular press, videos, media briefings, presentations, exhibitions, thesis, interviews, films, TV clips, posters, Other.

[5] A drop down list allows choosing the type of public: Scientific Community (higher education, Research), Industry, Civil Society, Policy makers, Medias, Other ('multiple choices' is possible).

6	*Oral presentation to a scientific event*	*3E N.V.*	*Performance Plus - Tools for Enhanced Photovoltaic System Performance. Progress in Photovoltaics and Nanotechnology : from FP7 to Horizon 2020 – The EU PV Clusters 2nd Workshop and General Assembly (26th – 28th November 2013)*	*28/11/2013*	*Barcelona, Spain*	*Scientific community (higher education, Research)*		*EU*
7	*Press releases*	*3E N.V.*	*Launch of the European Research Project Performance Plus a new System-Level Approach to Future Decrease LCOE from PV*	*04/03/2014*	*Brussels, Belgium*	*Industry - Civil society - Medias*		*EU*
8	*Oral presentation to a scientific event*	*KATHOLIEKE UNIVERSITEIT LEUVEN*	*Grey-Box Building Models for Model Order Reduction and Control*	*12/03/2014*	*Lund, Sweden*	*Scientific community (higher education, Research)*		*EU*
9	*Oral presentation to a scientific event*	*KATHOLIEKE UNIVERSITEIT LEUVEN*	*Setting up a framework for model predictive control with moving horizon state estimation using Modelica*	*12/03/2014*	*Lund, Sweden*	*Scientific community (higher education, Research)*		*EU*
10	*Oral presentation to a scientific event*	*3E N.V.*	*PV System Health Characterization and Loss Analysis using Operation Data. EPRI-Sandia PV Systems Symposium ? PV Reliability and O&M Workshop*	*07/05/2014*	*EPRI Headquarters, 3420 Hillview Avenue, Palo Alto, CA. USA.*	*Scientific community (higher education, Research) - Industry*		*USA and EU*
11	*Oral presentation to a scientific event*	*CARL VON OSSIETZKY UNIVERSITAET OLDENBURG*	*Small-Scale Cloud Mapping by Means of Sky Images for Predictions of Solar Fluctuations*	*26/09/2014*	*Amsterdam, The Netherlands*	*Scientific community (higher education, Research) - Industry*		*EU*
12	*Posters*	*3E N.V.*	*PV Array Characterisation from Operational Data*	*26/09/2014*	*Amsterdam, The Netherlands*	*Scientific community (higher education, Research) - Industry*		*EU*
13	*Posters*	*3E N.V.*	*System Cost Optimization of Smart PV Technology Under Non-Uniform Conditions*	*26/09/2014*	*Amsterdam, The Netherlands*	*Scientific community (higher education, Research) - Industry*		*EU*

14	*Posters*	*SCUOLA UNIVERSITARIA PROFESSIONALE DELLA SVIZZERA ITALIANA (SUPSI)*	*Modeling and Simulation of a Residential Neighborhood with Photovoltaic Systems Coupled to Energy Storage Systems*	*26/09/2014*	*Amsterdam, The Netherlands*	*Scientific community (higher education, Research) - Industry*		*EU*
15	*Posters*	*INTERUNIVERSITAIR MICRO-ELECTRONICA CENTRUM VZW*	*Presentation of a Verilog-AMS Model for Detailed Transient Electro-Thermal Simulations of PV Modules and Systems*	*26/09/2014*	*Amsterdam, The Netherlands*	*Scientific community (higher education, Research) - Industry*		*EU*
16	*Oral presentation to a scientific event*	*CARL VON OSSIETZKY UNIVERSITAET OLDENBURG*	*Small-scale solar irradiance nowcasting with sky imager pictures*	*10/10/2014*	*Prague, Czech Republic*	*Scientific community (higher education, Research) - Industry*		*EU*
17	*Organisation of Workshops*	*3E N.V.*	*First Performance Plus Project Workshop*	*19/11/2014*	*Brussels, Belgium*	*Scientific community (higher education, Research) - Industry - Policy makers - Medias*	*45*	*EU*
18	*Oral presentation to a scientific event*	*INTERUNIVERSITAIR MICRO-ELECTRONICA CENTRUM VZW*	*Demonstration and validation of an energy yield prediction model suitable for non-steady state non-uniform conditions, 6th World Conference on Photovoltaic Energy Conversion (WCPEC)*	*27/11/2014*	*Kyoto, Japan*	*Scientific community (higher education, Research) - Industry*		*International*
19	*Press releases*	*3E N.V.*	*Performance Plus Entering Demonstration and Validation Phase*	*18/03/2015*	*Brussels, Belgium*	*Industry - Civil society - Medias*		*EU*
20	*Oral presentation to a scientific event*	*CARL VON OSSIETZKY UNIVERSITAET OLDENBURG*	*Retrieval of direct and diffuse irradiance with the use of hemispheric sky images, International Conference Energy & Meteorology ICEM*	*26/06/2015*	*Boulder, CO, USA*	*Scientific community (higher education, Research) - Industry*		*International*
21	*Posters*	*SCUOLA UNIVERSITARIA PROFESSIONALE DELLA SVIZZERA ITALIANA*	*A Clustering Approach for PV Module Sampling*	*18/09/2015*	*Hamburg, Germany*	*Scientific community (higher education, Research) - Industry*		*EU*

		(SUPSI)						
22	*Oral presentation to a scientific event*	*3E N.V.*	*Uncertainties in PV Modelling and Monitoring*	*18/09/2015*	*Hamburg, Germany*	*Scientific community (higher education, Research) - Industry*		*EU*
23	*Oral presentation to a scientific event*	*INTERUNIVERSITAIR MICRO-ELECTRONICA CENTRUM VZW*	*PV Energy Yield Nowcasting Combining Sky Imaging with Simulation Models*	*18/09/2015*	*Hamburg, Germany*	*Scientific community (higher education, Research) - Industry*		*EU*
24	*Oral presentation to a scientific event*	*NTERUNIVERSITAIR MICRO-ELECTRONICA CENTRUM VZW*	*Model Requirements for Accurate Short Term Energy Yield Predictions during Fast-Varying Weather Conditions*	*18/09/2015*	*Hamburg, Germany*	*Scientific community (higher education, Research) - Industry*		*EU*
25	*Organisation of Workshops*	*3E N.V.*	*Performance Plus closing event*	*06/10/2015*	*Brussels, Belgium*	*Scientific community (higher education, Research) - Industry - Policy makers - Medias*	*80*	*EU*
26	*Posters*	*3E N.V.*	*Performance Plus Infographic*	*06/10/2015*	*Brussels, Belgium*	*Scientific community (higher education, Research) - Industry - Civil society - Policy makers - Medias*		*EU*
27	*Oral presentation to a scientific event*	*3E N.V.*	*Evaluation of Satellite Irradiation Data at 200 Sites in Western Europe, Results of the Performance Plus project presented at the 4th PV Performance Modelling and Monitoring Workshop*	*22/10/2015*	*Cologne, Germany*	*Scientific community (higher education, Research) - Industry*		*EU and USA*

Section B (Confidential[6] or public: confidential information to be marked clearly)
Part B1

TEMPLATE B1: LIST OF APPLICATIONS FOR PATENTS, TRADEMARKS, REGISTERED DESIGNS, ETC.					
Type of IP Rights[7]:	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Application reference(s) (e.g. EP123456)	Subject or title of application	Applicant (s) (as on the application)
Patents	*YES*	-	*Submission reference no: 102015000060893*	*Polyhedral Solar Sensor*	*Alitec S.r.l.*
Patents	*YES*	*01/10/17*	*EPO Submission reference number: 3002958* *EPO Application number: EP14184926*	*Optical, Thermal and Electrical Modelling of Photovoltaic Modules*	*IMEC VZW*

[6] Note to be confused with the "EU CONFIDENTIAL" classification for some security research projects.

[7] A drop down list allows choosing the type of IP rights: Patents, Trademarks, Registered designs, Utility models, Others.

Part B2

Type of Exploitable Foreground[8]	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application[9]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
General advancement of knowledge	*Data sets of solar irradiance and temperature as meteorological input sets, complemented with PV module measurements and satellite data (D2.1, D2.2).*	*NO*		*Monitoring data archive from Oldenburg*	*D35.1.1 - Production of electricity*	-	-	*CARL VON OSSIETZKY UNIVERSITAET OLDENBURG*
Commercial exploitation of R&D results	*Multi-directional solar irradiance sensor (D4.1).*	*YES*	-	*Multi-directional irradiance sensor (ESA)*	*D35.1.1 - Production of electricity* *C26.5.1 - Manufacture of instruments and appliances for measuring, testing and navigation* *C27.5.1 - Manufacture of electric domestic appliances* *C28.2.5 - Manufacture of non-domestic cooling and ventilation equipment*	-	*Patent application. Reff no. 102015000060893*	*Alitec S.R.L.*

[19] A drop down list allows choosing the type of foreground: General advancement of knowledge, Commercial exploitation of R&D results, Exploitation of R&D results via standards, exploitation of results through EU policies, exploitation of results through (social) innovation.

[9] A drop down list allows choosing the type sector (NACE nomenclature) : http://ec.europa.eu/competition/mergers/cases/index/nace_all.html

General advancement of knowledge	*Sky imager systems for monitoring and local short term forecasts of irradiance (D2.1, D2.2).*	*YES*	*-*	*Sky imager systems for monitoring and forecasting*	*D35.1.1 - Production of electricity*	*-*	*-*	*CARL VON OSSIETZKY UNIVERSITAET OLDENBURG*
Commercial exploitation of R&D results	*Methodology, techniques, algorithms and code for detection, identification and root cause analysis of faults and performance degradation based on monitoring data (D4.2).*	*YES*	*-*	*PV Health Scan*	*D35.1.1 - Production of electricity*	*2016*	*-*	*3E N.V.*
Commercial exploitation of R&D results	*Methodology and implementation for combination of satellite and ground stations by use of kriging-of-differences (D2.3)*	*YES*	*-*	*Smart Irradiation Service (SIS)*	*D35.1.1 - Production of electricity*	*2015*	*-*	*3E N.V.*
General advancement of knowledge	*Sky imager systems for monitoring and local short term forecasts of irradiance (D2.1, D2.2) and tools for detailed thermal optical electrical energy yield modelling of PV modules (D1.2, D1.3).*	*YES*	*-*	*PV energy yield nowcasting combining sky imaging with simulation models*	*D35.1.1 - Production of electricity*	*-*	*-*	*INTERUNIVERSITAIR MICRO-ELECTRONICA CENTRUM VZW & CARL VON OSSIETZKY UNIVERSITAET OLDENBURG*
General advancement of knowledge	*Model Predictive Control framework for optimal energy management and storage control (D3.4, D3.5).*	*YES*	*-*	*Model Predictive Control (MPC) toolchain*	*F41.1.0 - Development of building projects*	*-*	*-*	*KATHOLIEKE UNIVERSITEIT LEUVEN & 3E N.V.*
General advancement of knowledge	*Optical-thermal-electrical model of a PV module suitable to analyse non-steady state and non-uniform ambient conditions (D1.2).*	*YES*	*-*	*Optical, Thermal and Electrical Modelling of Photovoltaic Modules*	*D35.1.1 - Production of electricity*	*-*	*Patent application. Reff no. EP14184926*	*INTERUNIVERSITAIR MICRO-ELECTRONICA CENTRUM VZW*
General advancement of knowledge	*Fine-grained temporal and spatial modelling of the optical, thermal and electrical aspects of a PV module (D1.2) and models for generic thermal modelling of DC-AC convertors.*	*YES*	*-*	*Thermal model for mutual impact of the local DC-AC convertor and PV module in a PV string setup*	*D35.1.1 - Production of electricity*	*-*	*-*	*INTERUNIVERSITAIR MICRO-ELECTRONICA CENTRUM VZW & AIT AUSTRIAN INSTITUTE OF TECHNOLOGY GMBH*

General advancement of knowledge	*Methodology, techniques and code for laboratory and field testing of PV modules and inverters (D5.5, D5.6).*	*YES*	*-*	*Toolbox for on-site testing of PV modules and inverters for root cause analysis*	*D35.1.1 - Production of electricity*	*-*	*-*	*SCUOLA UNIVERSITARIA PROFESSIONALE DELLA SVIZZERA ITALIANA (SUPSI) & AIT AUSTRIAN INSTITUTE OF TECHNOLOGY GMBH*
Commercial exploitation of R&D results	*Methodology, techniques and code for the evaluation of the performance of PV inverters as part of a PV system (D5.3, D5.4, D5.5, D5.6).*	*YES*	*-*	*- Switch based PV inverter models - PV inverter average models - PV inverter reliability and robustness tests - PV inverter lifetime estimation - PV "Golden Inverter" tool*	*D35.1.1 - Production of electricity*	*-*	*-*	*AIT AUSTRIAN INSTITUTE OF TECHNOLOGY GMBH*

Explanation of the Exploitable Foreground

Monitoring data archive from Oldenburg

The dataset contains meteorological measurements (solar irradiance, temperature, wind speed and wind direction) and PV module measurements with 1 Hz resolution The data set allows for evaluation of PV performance with respect to meteorological parameters, evaluation of PV modelling, and characterization of fluctuating irradiance and its impact on the energy production, grid operation and power trading.
The University of Oldenburg has made the meteorological data set publically available on http://doi.pangaea.de/10.1594/PANGAEA.847830 (doi:10.1594/PANGAEA.847830). Additionally, PV module measurements are available on request.

Multi-directional irradiance sensor (ESA) sensor

The ESA sensor is a fix detector of global, diffuse and direct solar irradiation capable of performing real-time measurements and of providing information about the sun position. The ESA sensor innovative features result in reduced monitoring costs and maintenance efforts, thus allowing not only for small PV plants to perform solar irradiance monitoring, but also for medium to large PV plants to perform distributed rather than single-point monitoring. Moreover, in the field of energy management and optimal control of thermal systems, it enables the active optimization

and fine-tuning of heating and/or cooling related energy use. Alitec is planning to sell the ESA sensor and to provide technical assistance to EPC and O&M contractors. Alitec has already applied for a patent for this sensor.

Sky imager systems for monitoring and local short-term forecasts of irradiance

Webcam-based security cameras are inexpensive, widely available and usable as sky imagers. Archiving and post-processing scripts for operational applications have been developed. The sky images and videos are used on websites to monitor the weather condition real time, which is of research, touristic and agricultural interest. Post-processed data for cloud cover, cloud type, cloud movement and surface solar irradiance distribution can be provided. Additionally, the archived images and post processed meta data could be valuable for a posterior validation of solar power plant performance. Sky images can be used to generate cloud maps. In combination with derived cloud motion local short-term forecasting of irradiance can be done. Even the calculation of the radiative components (direct and diffuse) is possible. The developed system provides an inexpensive forecasting technique for local use, and may be for example applied for optimization of PV-Diesel-plant operation saves fuel. The University of Oldenburg will use the developed system as a basis for further development in new projects with the aim of improving the algorithms as well as developing licensable software (potentially open source), products and services.

PV Health Scan

3E's PV Health Scan is the generation and delivery of technical and business intelligence for a PV plant or portfolio of PV plants by analysing and mining measured data. The PV Health Scan is targeted to asset managers of PV plant portfolios and to operations and maintenance (O&M) contractors. The PV Health Scan will provide the root-cause intelligence the customer needs for increasing performance and availability at minimal costs. 3E is planning to exploit the PV health scan method in a first stage as a one-time service linked to 3E's monitoring portal SynaptiQ. In the longer term, this can also be exploited as a one-time consultancy service and as an automated service on top of a standard subscription for PV plant monitoring.

Smart Irradiation Service (SIS)

The Smart Irradiation Service is a service that provides reference irradiation data. The method combines satellite estimates and ground measured data reducing the overall uncertainty. 3E is already using this method for consultancy services as a reference irradiation for projects with no existing or low quality irradiation measurements.

PV energy yield nowcasting combining sky imaging with simulation models

The University of Oldenburg and IMEC have cooperated on an energy yield forecasting model based on cloud analysis from sky imager data. It has been agreed by both partners that this results can be used in the future by both sides without accounting so they provide a cross-license towards each other for this information and the usage in demonstrations. Both partners plan to extend this cooperation beyond the project to further build on the obtained results.

Model Predictive Control (MPC) for optimal energy management and control
The MPC framework allows harnessing flexibility from controllable loads and enables a better integration of PV plants into the power grid by improving the self-consumption, increasing self-production and reducing operational costs. KU Leuven will continue the development of MPC. Moreover, as 3E has also cooperated on the development, implementation and demonstration, negotiations for future cooperation have started between KU Leuven and 3E. Both partners plan to extend their cooperation beyond the project to further build on the obtained results.

Tools for detailed thermal optical electrical energy yield modelling of PV modules
This flexible and fully parameterized optical-electrical-thermal model can be used for accurate short-term energy yield predictions and to evaluate energy yield of novel module concepts. IMEC is planning to offer this both to their PV programme partners as a potential activity for them to participate and transfer and they will use this as basis for future funded project proposals to continue their research pipeline.

The following customer segments are targeted for their further application:

- PV rooftop or plant installers/aggregators and solar car or transport providers: training and transfer of methodologies and tools in prototype form;

- PV energy yield model providers: in depth transfer of methodologies and tools in “white-box” mode. They will provide similar services as IMEC to customer segments described above, but in a fully commercial model. 3E is considered as a prime partner to start with.

Thermal model for mutual impact of the local DC-AC convertor and PV module in a PV string setup
AIT and IMEC have cooperated on a thermal model for the mutual impact of the (local) DC-AC convertor and the PV module in a PV string setup. It has been agreed by both partners that both the instantiated model and the experimental results obtained are considered as public knowledge (a joint journal paper is foreseen). This knowledge can be used in the future by both sides without accounting. However, both parties will only use this while always mutually citing each other’s contribution.

Toolbox for on-site testing of PV modules and inverters
SUPSI and AIT have collaborated into the development of new procedures and tools for field testing on PV plants; these activities contributed to develop two software tools for analysing the performance of PV components and whole systems and in the future could be integrated into devices to be installed in existing or new PV plants. The purpose of this software/device would be to analyse periodically the performance and so detect under performance and relative root causes. It has been agreed by both partners that both the instantiated model and the experimental results will be used in the future by both sides without accounting. However, both parties will only use this while always mutually citing each other’s contribution.

Switch based PV inverter models
Switch-based inverter models are mainly used in an early development phase of power electronics. With AIT's switch-based PV inverter models the switches are thermally described to properly assess the junction temperature of the semiconductors as well as the (floating) heat sink temperature within a case. An adequate power loss model can be set up for changing temperatures as an input for various mission profiles. AIT is planning to offer this as a consultancy service for inverter manufacturers.

PV inverter average models
AIT procedures for inverter characterization can help to provide a more accurate way of yield prediction and verification for PV-power plants as a high accuracy model of an inverter can be developed using AIT laboratory infrastructure including thermal chambers to introduce temperature dependency for higher performance. AIT will use these accurate PV inverter average models to predict possible revenue of PV plants in a design stage based on site related mission profiles. Furthermore, the models can also be used to calculate the possible revenue from running PV plants and help to identify and analyse deviations from this maximum value. AIT will target PV power plant owners as well as consultants to analyse PV plants using this model. Furthermore, due to the low computing resources needed, private users would also be able to analyse their expected revenue based on a best-case calculation.

PV inverter reliability and robustness tests
AIT PV inverter reliability and robustness tests are based on laboratory tests in climate chambers using specified test procedures to characterize the inverter behaviour as well as identify design errors causing early failure. AIT will offer these tests as a consultancy service for inverter manufacturers.

PV inverter lifetime estimation
AIT PV inverter lifetime estimation is based on either laboratory tests in climate chambers using specified test procedures or thermal inverter simulation to characterize the inverter behaviour. Using this information together with device information a reliability model can be set up to evaluate the application lifetime for different (site specific) mission profiles. AIT will target with this service mainly PV inverter manufacturers. Furthermore, PV site planners could also use this service for non-standard fields of application to evaluate the risk of failure during the time of use.

PV "Golden Inverter" tool
The idea of the "Golden Inverter" model is to extract a best performing average model from the individual inverters in a power plant. This model can later be used to identify low performing inverters in the field by calculating the expected inverter performance and comparison with actual data. AIT will target PV site owners/consultants/service providers to help to monitor PV inverter performance using either internal inverter readings or measurement devices.

4.3 Report on societal implications

Replies to the following questions will assist the Commission to obtain statistics and indicators on societal and socio-economic issues addressed by projects. The questions are arranged in a number of key themes. As well as producing certain statistics, the replies will also help identify those projects that have shown a real engagement with wider societal issues, and thereby identify interesting approaches to these issues and best practices. The replies for individual projects will not be made public.

A General Information *(completed automatically when **Grant Agreement number** is entered.*	
Grant Agreement Number:	308991
Title of Project:	Tools for Enhanced Photovoltaic System Performance
Name and Title of Coordinator:	Mr. Mauricio Richter 3E N.V.

B Ethics	
1. Did your project undergo an Ethics Review (and/or Screening)? • If Yes: have you described the progress of compliance with the relevant Ethics Review/Screening Requirements in the frame of the periodic/final project reports? Special Reminder: the progress of compliance with the Ethics Review/Screening Requirements should be described in the Period/Final Project Reports under the Section 3.2.2 *'Work Progress and Achievements'*	***No***
2. Please indicate whether your project involved any of the following issues (tick box) :	
RESEARCH ON HUMANS	
• Did the project involve children?	No
• Did the project involve patients?	No
• Did the project involve persons not able to give consent?	No
• Did the project involve adult healthy volunteers?	No
• Did the project involve Human genetic material?	No
• Did the project involve Human biological samples?	No
• Did the project involve Human data collection?	No
RESEARCH ON HUMAN EMBRYO/FOETUS	
• Did the project involve Human Embryos?	No
• Did the project involve Human Foetal Tissue / Cells?	No
• Did the project involve Human Embryonic Stem Cells (hESCs)?	No
• Did the project on human Embryonic Stem Cells involve cells in culture?	No
• Did the project on human Embryonic Stem Cells involve the derivation of cells from Embryos?	No
PRIVACY	
• Did the project involve processing of genetic information or personal data (eg. health, sexual lifestyle, ethnicity, political opinion, religious or philosophical conviction)?	No
• Did the project involve tracking the location or observation of people?	No
RESEARCH ON ANIMALS	
• Did the project involve research on animals?	No
• Were those animals transgenic small laboratory animals?	No
• Were those animals transgenic farm animals?	No

• Were those animals cloned farm animals?	No
• Were those animals non-human primates?	No
RESEARCH INVOLVING DEVELOPING COUNTRIES	
• Did the project involve the use of local resources (genetic, animal, plant etc)?	No
• Was the project of benefit to local community (capacity building, access to healthcare, education etc)?	No
DUAL USE	
• Research having direct military use	No
• Research having the potential for terrorist abuse	No

C Workforce Statistics

3. Workforce statistics for the project: Please indicate in the table below the number of people who worked on the project (on a headcount basis).

Type of Position	Number of Women	Number of Men
Scientific Coordinator	2	6
Work package leaders	2	6
Experienced researchers (i.e. PhD holders)	7	22
PhD Students	0	9
Other	7	15

4. How many additional researchers (in companies and universities) were recruited specifically for this project?	**4**
Of which, indicate the number of men:	4

D Gender Aspects

5. Did you carry out specific Gender Equality Actions under the project?

○ Yes
⊙ No

6. Which of the following actions did you carry out and how effective were they?

	Not at all effective				Very effective
❑ Design and implement an equal opportunity policy	○	○	○	○	○
❑ Set targets to achieve a gender balance in the workforce	○	○	○	○	○
❑ Organise conferences and workshops on gender	○	○	○	○	○
❑ Actions to improve work-life balance	○	○	○	○	○

○ Other:

7. Was there a gender dimension associated with the research content – i.e. wherever people were the focus of the research as, for example, consumers, users, patients or in trials, was the issue of gender considered and addressed?

○ Yes- please specify

⊙ No

E Synergies with Science Education

8. Did your project involve working with students and/or school pupils (e.g. open days, participation in science festivals and events, prizes/competitions or joint projects)?

⊙ Yes- please specify: Master theses and PhD Theses

○ No

9. Did the project generate any science education material (e.g. kits, websites, explanatory booklets, DVDs)?

○ Yes- please specify

⊙ No

F Interdisciplinarity

10. Which disciplines (see list below) are involved in your project?

⊙ Main discipline[10]: 2.2 Electrical engineering, electronics

⊙ Associated discipline[10]: 1.1 Mathematics and computer sciences

○ Associated discipline[10]: Earth and related environmental sciences

G Engaging with Civil society and policy makers

11a Did your project engage with societal actors beyond the research community? *(if 'No', go to Question 14)*

⊙ Yes
○ No

11b If yes, did you engage with citizens (citizens' panels / juries) or organised civil society (NGOs, patients' groups etc.)?

○ No

○ Yes- in determining what research should be performed

⊙ Yes - in implementing the research

○ Yes, in communicating /disseminating / using the results of the project

[10] Insert number from list below (Frascati Manual).

11c In doing so, did your project involve actors whose role is mainly to organise the dialogue with citizens and organised civil society (e.g. professional mediator; communication company, science museums)?	○ ⊙	Yes No

12. Did you engage with government / public bodies or policy makers (including international organisations)

- ⊙ No
- ○ Yes- in framing the research agenda
- ○ Yes - in implementing the research agenda
- ○ Yes, in communicating /disseminating / using the results of the project

13a Will the project generate outputs (expertise or scientific advice) which could be used by policy makers?

- ○ Yes – as a **primary** objective (please indicate areas below- multiple answers possible)
- ⊙ Yes – as a **secondary** objective (please indicate areas below - multiple answer possible)
- ○ No

13b If Yes, in which fields?

Agriculture	⊙	Energy		Human rights	
Audiovisual and Media		Enlargement		Information Society	
Budget		Enterprise		Institutional affairs	
Competition		Environment		Internal Market	
Consumers		External Relations		Justice, freedom and security	
Culture		External Trade		Public Health	
Customs		Fisheries and Maritime Affairs		Regional Policy	
Development Economic and Monetary Affairs		Food Safety		Research and Innovation	
		Foreign and Security Policy		Space	
Education, Training, Youth		Fraud		Taxation	
Employment and Social Affairs		Humanitarian aid		Transport	

13c If Yes, at which level?

- ○ Local / regional levels
- ○ National level
- ◉ European level
- ○ International level

H Use and dissemination

14. How many Articles were published/accepted for publication in peer-reviewed journals?	**7**
To how many of these is open access[11] provided?	**5**
How many of these are published in open access journals?	**1**
How many of these are published in open repositories?	**4**
To how many of these is open access not provided?	**0**
Please check all applicable reasons for not providing open access:	
☒ publisher's licensing agreement would not permit publishing in a repository ❑ no suitable repository available ❑ no suitable open access journal available ☒ no funds available to publish in an open access journal ❑ lack of time and resources ❑ lack of information on open access ❑ other[12]: Internal Policies	

15. How many new patent applications ('priority filings') have been made? *("Technologically unique": multiple applications for the same invention in different jurisdictions should be counted as just one application of grant).*		**2**
16. Indicate how many of the following Intellectual Property Rights were applied for (give number in each box).	Trademark	**0**
	Registered design	**0**
	Other	**0**
17. How many spin-off companies were created / are planned as a direct result of the project?		**0**
Indicate the approximate number of additional jobs in these companies:		**0**

18. Please indicate whether your project has a potential impact on employment, in comparison with the situation before your project:

☒	Increase in employment, or	☒	In small & medium-sized enterprises
❑	Safeguard employment, or	❑	In large companies
❑	Decrease in employment,	❑	None of the above / not relevant to the project
❑	Difficult to estimate / not possible to quantify		

19. For your project partnership please estimate the employment effect resulting directly from your participation in Full Time Equivalent (*FTE = one person working fulltime for a year*) jobs:	*Indicate figure:*

[11] Open Access is defined as free of charge access for anyone via Internet.
[12] For instance: classification for security project.

Difficult to estimate / not possible to quantify	☒

I Media and Communication to the general public

20. As part of the project, were any of the beneficiaries professionals in communication or media relations?

○ Yes ⊙ No

21. As part of the project, have any beneficiaries received professional media / communication training / advice to improve communication with the general public?

○ Yes ⊙ No

22 Which of the following have been used to communicate information about your project to the general public, or have resulted from your project?

☒	Press Release	☒	Coverage in specialist press
❑	Media briefing	❑	Coverage in general (non-specialist) press
❑	TV coverage / report	❑	Coverage in national press
❑	Radio coverage / report	❑	Coverage in international press
☒	Brochures /posters / flyers	☒	Website for the general public / internet
❑	DVD /Film /Multimedia	☒	Event targeting general public (festival, conference, exhibition, science café)

23 In which languages are the information products for the general public produced?

❑	Language of the coordinator	☒	English
❑	Other language(s)		

***Question F-10*:** Classification of Scientific Disciplines according to the Frascati Manual 2002 (Proposed Standard Practice for Surveys on Research and Experimental Development, OECD 2002):

FIELDS OF SCIENCE AND TECHNOLOGY

1. NATURAL SCIENCES

1.1 Mathematics and computer sciences [mathematics and other allied fields: computer sciences and other allied subjects (software development only; hardware development should be classified in the engineering fields)]

1.2 Physical sciences (astronomy and space sciences, physics and other allied subjects)

1.3 Chemical sciences (chemistry, other allied subjects)

1.4 Earth and related environmental sciences (geology, geophysics, mineralogy, physical geography and other geosciences, meteorology and other atmospheric sciences including climatic research, oceanography, vulcanology, palaeoecology, other allied sciences)

1.5 Biological sciences (biology, botany, bacteriology, microbiology, zoology, entomology, genetics, biochemistry, biophysics, other allied sciences, excluding clinical and veterinary sciences)

2 ENGINEERING AND TECHNOLOGY

2.1 Civil engineering (architecture engineering, building science and engineering, construction engineering, municipal and structural engineering and other allied subjects)

2.2 Electrical engineering, electronics [electrical engineering, electronics, communication engineering and systems, computer engineering (hardware only) and other allied subjects]

2.3. Other engineering sciences (such as chemical, aeronautical and space, mechanical, metallurgical and materials engineering, and their specialised subdivisions; forest products; applied sciences such as

geodesy, industrial chemistry, etc.; the science and technology of food production; specialised technologies of interdisciplinary fields, e.g. systems analysis, metallurgy, mining, textile technology and other applied subjects)

3. MEDICAL SCIENCES

3.1 Basic medicine (anatomy, cytology, physiology, genetics, pharmacy, pharmacology, toxicology, immunology and immunohaematology, clinical chemistry, clinical microbiology, pathology)

3.2 Clinical medicine (anaesthesiology, paediatrics, obstetrics and gynaecology, internal medicine, surgery, dentistry, neurology, psychiatry, radiology, therapeutics, otorhinolaryngology, ophthalmology)

3.3 Health sciences (public health services, social medicine, hygiene, nursing, epidemiology)

4. AGRICULTURAL SCIENCES

4.1 Agriculture, forestry, fisheries and allied sciences (agronomy, animal husbandry, fisheries, forestry, horticulture, other allied subjects)

4.2 Veterinary medicine

5. SOCIAL SCIENCES

5.1 Psychology

5.2 Economics

5.3 Educational sciences (education and training and other allied subjects)

5.4 Other social sciences [anthropology (social and cultural) and ethnology, demography, geography (human, economic and social), town and country planning, management, law, linguistics, political sciences, sociology, organisation and methods, miscellaneous social sciences and interdisciplinary , methodological and historical S1T activities relating to subjects in this group. Physical anthropology, physical geography and psychophysiology should normally be classified with the natural sciences].

6. HUMANITIES

6.1 History (history, prehistory and history, together with auxiliary historical disciplines such as archaeology, numismatics, palaeography, genealogy, etc.)

6.2 Languages and literature (ancient and modern)

6.3 Other humanities [philosophy (including the history of science and technology) arts, history of art, art criticism, painting, sculpture, musicology, dramatic art excluding artistic "research" of any kind, religion, theology, other fields and subjects pertaining to the humanities, methodological, historical and other S1T activities relating to the subjects in this group]

2. FINAL REPORT ON THE DISTRIBUTION OF THE EUROPEAN UNION FINANCIAL CONTRIBUTION

This report shall be submitted to the Commission within 30 days after receipt of the final payment of the European Union financial contribution.

Report on the distribution of the European Union financial contribution between beneficiaries

Name of beneficiary	Final amount of EU contribution per beneficiary in Euros
1.	
2.	
n	
Total	