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D7.4 Public databases for solar resource, PV components & PV systems and grid integration

T7.4 Public databases for solar resource, PV components & PV systems and grid integration

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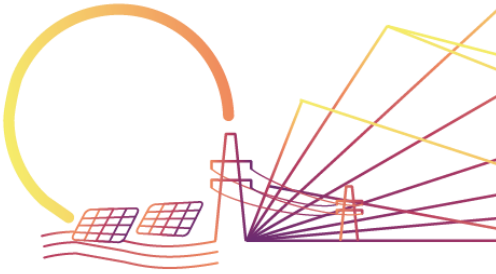

Summary

Public platforms and databases for: a) ground measured solar resource, meteorological and atmospheric data; b) PV components; c) PV system metadata and performance worldwide

This deliverable is an output of task T7.4

Document Information

Title	Public databases for solar resource, PV components & PV systems and grid integration
Lead Beneficiary	Solargis
Contributors	TEC, FHG, QPV, LUC, CEG, ENF, ING, BI, MLS
Distribution	PU - Public
Report Name	Public databases for solar resource, PV components & PV systems and grid integration

Document History

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30/10/2024	V1.0	Ricardo Alonso	TEC	Javier del Pozo (TEC)	Final contributions and final review and submission of deliverable

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Contents

Tables

Figures

1 EXECUTIVE SUMMARY

1.1 Description of the deliverable content and purpose

This document describes the innovations developed within the Task 7.4 of the SERENDI-PV project. The task was organized in 3 subtasks, each of which focused on different kinds of databases. Their common theme is the improvement of access to data and resources relevant to the research and development in the photovoltaic (PV) industry. All subtasks developed open, publicly available data stores, aimed mostly at PV professionals to enable them to research and develop new solutions for the industry on the basis of validated, high-quality data. It is the ambition of the partners to continue operating these solutions after the end of the SERENDI-PV project.

At the start, a general view of the databases developed within the scope of the SERENDI-PV project is given, detailing how the SERENDI-PV-database link and fit into the “European Framework for sharing data to support innovative energy services”, thus supporting the “EU Action Plan for Digitalising the Energy System”. Interoperability is crucial to support this initiative, and data that adhere to the FAIR principle of scientific data leverage the use and re-use of these data in innovative business cases.

The first subtask 7.4.1 is focused on developing and implementing a database of solar resource and weather data. The database provides access to public measurements of solar resource and meteorological parameters. The measurements are distributed worldwide. Some of the locations are enhanced with Solargis Quality Assessment reports, and Solargis satellite model data to provide context to the measured data.

The second subtask 7.4.2 is focused on developing a database and online application providing access to verified specifications of PV components. The specifications follow major international standards and formats, and are verified before publishing, ensuring high quality of data. The application aims to become the single source of PV component specifications, particularly for users of PV yield simulation software.

The third subtask 7.4.3 is focused on building databases of real-world PV systems metadata and performance data. The databases centralize already publicly available data, which used to be difficult to find, and enhances it with new resources. Industry users are therefore given access to valuable insights into the operation of real-world PV powerplants and can use the data in development of solutions for the industry. The subtask also investigates general topics related to collection, sorting and sharing of data relevant to solar industry.

1.2 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 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
All	The current deliverable feeds from all project activities and work packages.

1.3 Abbreviation list

The table below summarizes the abbreviations used in this report.

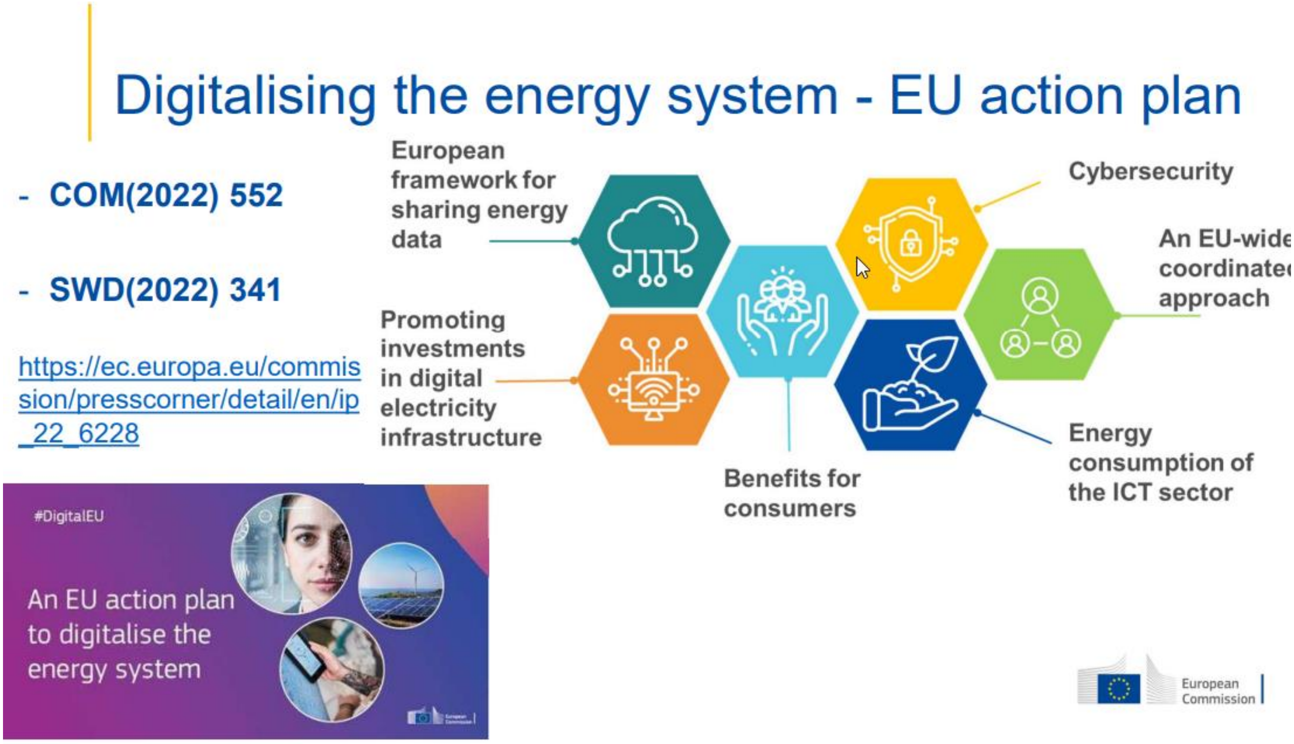
Table 1.2: List of used abbreviations

Abbreviation	Meaning
API	Application Programmable Interface
BDPV	Base de Données Photovoltaïque
CSER	climate-specific energy ratings
EL	Electroluminescence
FAIR	Findable, Accessible, Interoperable, and Reusable
FDD	Fault Detection & Diagnosis
FF	Fill Factor
GHI	Global Horizontal Irradiance
GTI	Global Tilted Irradiance
IDS	International Data Spaces
Imp	Current of a PV module at the maximum power point
Isc	Short-circuit current of a PV module
IV	Current-Voltage
MPP	Maximum Power Point
NREL	National Renewable Energy Laboratory
PV	Photovoltaic
PVCC	Photovoltaic Components Catalog
Rp	Shunt (or parallel) resistance
Rs	Series resistance
SAM	System Advisor Model
SSER	site-specific energy ratings
STC	standard test conditions
UI	User Interface
URL	Uniform Resource Locator
Vmp	Voltage of a PV module at the maximum power point
Voc	Open-circuit voltage of a PV module

2 DATABASES IN WP7 FROM THE VIEWPOINT OF INTERNATIONAL DATA SPACES

2.1 Motivation

In this chapter we look into international initiatives of data sharing and data spaces, thus highlighting the role that the European “framework for sharing data to support innovative energy services” will incur on the future energy marketplace and also on the scientific community, and how the databases developed and maintained within WP7 of SERENDI-PV can be seen and integrated within this framework. The EU has laid out an Action Plan to digitalize the Energy System [1] that is outlined in the following paragraphs:



Digitalising the energy system - EU action plan

- COM(2022) 552
- SWD(2022) 341

https://ec.europa.eu/commission/presscorner/detail/en/ip_22_6228

Figure 2.1: EU Action Plan “Digitalising the Energy System” [2]

The EU Action Plan for Digitalising the Energy System represents a pivotal step toward transforming Europe’s energy landscape, aiming to reduce dependence on fossil fuels, address the climate crisis, and ensure affordable energy access for all citizens. Based on the ambitious goals set by the European Green Deal and REPowerEU, the plan includes specific targets, such as installing PV systems on all commercial and public buildings by 2027 and ensuring that at least 45% of energy comes from renewable sources by 2030. The transition to a more sustainable energy system is not just a necessity but a strategic goal for Europe's energy independence and environmental commitments.

To achieve these targets, a deep digital and sustainable transformation of the energy system is required. Digitalization will play a crucial role in enabling energy efficiency, promoting electrification, facilitating sector integration, and decentralizing the energy system.

Central to this initiative is the establishment of a common European energy data space, which aims to facilitate secure and seamless data sharing among trusted parties. This framework is essential for enabling innovative energy services and enhancing flexibility within the energy market. By sharing data across the energy value chain and integrating it with weather models, mobility patterns, and geographic systems, the EU can foster new levels of precision and efficiency.

Key Legislative Frameworks

The success of the Action Plan is underpinned by several key legislative initiatives:

- **Data act**: This legislation is designed to ensure that users can access and share data generated in the EU across various sectors. It clarifies the rights of users to freely access and utilize data generated by their products, including the right to share this data with third parties. By promoting fair data use and interoperability, the Data Act aims to broaden the participation of various stakeholders in the energy market, thereby enhancing competitiveness and innovation.
- **Data governance act**: This act aims to strengthen data sharing mechanisms and foster trust in data intermediaries by improving the availability and quality of data. It establishes a framework for secure data exchange, ensuring that personal data and sensitive information are adequately protected while facilitating the sharing of high-value datasets. This is particularly vital for sectors like energy, where data can enhance operational efficiency and consumer engagement.
- **Electricity directive**: Integral to the EU's energy strategy, the Electricity Directive includes provisions for interoperability requirements and non-discriminatory access to metering and consumption data. This is essential for enabling demand response mechanisms, where consumers can adjust their energy usage based on real-time pricing and availability. By promoting transparency and consumer choice, the directive supports a more dynamic and responsive energy market.
- **Fit-for-55 package**: This comprehensive legislative package sets out the EU's commitment to reducing greenhouse gas emissions by at least 55% by 2030. Included within this framework are specific provisions for data exchanges and digital solutions that enhance the efficiency and sustainability of the energy system.
- **Digital decade policy programme**: This programme aligns digitalization efforts with the EU's green goals, emphasizing the importance of digital infrastructure in achieving climate targets. It aims to ensure that digital technologies are effectively integrated into energy systems, promoting data-driven decision-making and enhancing overall system resilience.

As Europe accelerates its digital and green transitions, the synergy between energy and digital policies will be crucial in achieving a sustainable, efficient, and resilient energy system. The EU Action Plan for Digitalising the Energy System, supported by robust legislative frameworks, will enable the sharing of energy-related data and foster innovative solutions that empower consumers while enhancing market flexibility.

By prioritizing these initiatives, the EU aims to create a strong, interconnected energy ecosystem that leverages data-driven insights to optimize energy use, promote renewable resources, and ultimately create a greener, more resilient future for all citizens.

2.2 International initiatives of data spaces and data sharing in the energy domain

In addition to these legislative efforts, initiatives like GAIA-X aim to create an international data space that promotes collaboration among EU member states and global partners. GAIA-X focuses on establishing a European cloud ecosystem that prioritizes data sovereignty, cybersecurity, and interoperability. By fostering international cooperation, the EU seeks to avoid incompatible standards and ensure that the benefits of digitalization are realized across borders.

[3] introduces International Data Spaces (IDS) as follows:

International Data Spaces (IDS) facilitate the sovereign and self-determined exchange of data across organizational boundaries by providing a standardized connection. The IDS initiative addresses the main points in data usage, such as interoperability, transparency, trust, security, and scalability. To achieve this, IDS develops a standardized architecture continuously updated in the IDSA Reference Architecture Model (RAM).

The core concept of IDS revolves around linking data with usage conditions, ensuring both organizational and technical processes are managed effectively. This approach emphasizes a federated structure, allowing raw data to be exchanged directly between participants without requiring a central data store or third-party involvement. This design promotes data sovereignty, enabling data owners to retain control over their data while defining usage restrictions that data consumers must accept.

Trust is fundamental for data sharing within the IDS ecosystem. Each participant and software component must undergo a certification process to ensure they meet defined security and operational standards. Security is tightly integrated with trust; all systems in the IDS must adhere to state-of-the-art security measures, which are also part of the certification criteria.

Data sovereignty allows data owners to define usage restrictions before sharing their data, ensuring that data consumers comply with these policies. The IDS ecosystem encourages the development of new business models that leverage shared data, as no single entity typically possesses all the data required to deliver innovative services. For effective data exchange, standardized interoperability is essential, enabling different data ecosystems to communicate seamlessly.

The IDS Reference Architecture Model comprises several technological components, with the International Data Spaces Connector being a key element. The Connector ensures that data sovereignty is maintained while facilitating secure communication and the enforcement of usage policies. It acts as an interface between internal systems and the broader IDS ecosystem.

Additional key components include the Identity Provider, which manages participant identities; the Metadata Broker, which mediates data requests; and the Clearing House, which oversees financial and data exchange transactions. These components work together to create a robust framework for data sharing while ensuring compliance with established policies.

In summary, the International Data Spaces initiative aims to create a secure, interoperable, and sovereign data exchange environment. By focusing on trust, security, and standardized interoperability, IDS enables innovative data-sharing solutions that empower data owners while fostering collaboration across industries.

2.3 The European framework for sharing data to support innovative energy services

The European framework for sharing energy data aims to prioritize the use of European data for European companies. This includes a robust legislative foundation comprising the Data Act, Data Governance Act, and Digital Market Act, alongside complementary regulations like the AI Act. It has been announced on several workshops to the topic [4]

A central component of this framework is the establishment of common European data spaces. These spaces are designed to integrate both public and private initiatives, ensuring interoperability and a governance structure that facilitates cross-sectoral data exchange (see chapter 2.2). The goal is to create an environment where sensitive data can be shared securely while respecting individual privacy and fostering trust among stakeholders.

The digital transformation of the energy sector is also a priority, aligning digital strategies with the European Green Deal. This includes integrating renewable energy sources and promoting sustainability. The framework emphasizes the importance of fairness in data value distribution, ensuring that all participants benefit equitably from shared data. Additionally, it aims to guarantee the safety and rights of individuals and businesses involved in data transactions. To support these objectives, a robust technical infrastructure is required. This includes interoperable data spaces, cloud-edge services, and secure data exchange APIs that facilitate efficient data access and usage.

To effectively implement this framework, several best practices should be adopted:

- **Data sharing policy**: Organizations should establish clear policies governing data sharing. These policies must prioritize user privacy and data security, outlining specific conditions under which data can be shared.
- **Interoperability standards**: Adopting common standards is crucial for enhancing compatibility across different data systems. This will facilitate easier data exchange and utilization, promoting a more integrated energy market.
- **Stakeholder engagement**: Engaging a diverse range of stakeholders, including businesses, consumers, and regulatory bodies, is essential for the successful development of data spaces. Their involvement ensures that the data-sharing ecosystem meets the needs and expectations of all parties.
- **Trust mechanisms**: Building trust is critical for successful data sharing. Implementing transparent agreements regarding data usage and establishing secure governance frameworks can enhance confidence among data holders.
- **Public awareness**: Educating both businesses and consumers about the benefits of data sharing is vital. Awareness campaigns can highlight how data sharing can lead to improved energy systems and cost savings.
- **Technical infrastructure**: Investment in robust technical infrastructures, such as data marketplaces and cloud-edge services, is necessary to provide the necessary tools for efficient data access and sharing.

By adhering to these practices, Europe can successfully foster a collaborative environment for sharing energy data, driving innovation and sustainability in the energy sector.

2.4 FAIR data in the Photovoltaic domain

The famous FAIR principles - Findable, Accessible, Interoperable, and Reusable, and first described in the well-known publication by [5] - provide a framework for effective data management that is also relevant in the context of the energy sector. Adhering to these principles ensures that data is organized and shared in a way that maximizes its utility. For instance, data should be easily discoverable through metadata and identifiers, allowing stakeholders to locate relevant information quickly. Moreover, it should be accessible to authorized users, with clearly defined access protocols and permissions. Interoperability is crucial, as data must be structured in a way that allows different systems to exchange and interpret it without compatibility issues. Finally, data should be documented sufficiently to enable its reuse for various applications, ensuring long-term value.

In summary, the FAIR principle adapted to the PV domain consists of the following:

- **Findable**: PV data (simulation and Monitoring), related metadata with persistent identifiers/DOIs/FDOs, findable and citable (e.g. via Catalogue Service Web)
- **Accessible**: No Data Silos. PV simulation data and associated services openly accessible, clear instructions on how to access and utilize them.
- **Interoperable**: well-documented metadata that describes the PV simulation data, simulation methodology, input parameters, assumptions. Standardized data formats, information models and/or ontologies specific to the Photovoltaic domain to enhance interoperability.
- **Reusable**: proper data licensing and usage terms to enable reuse and collaboration among researchers and practitioners in the PV field (even beyond the original purpose)

2.5 Information models in the PV domain

Information models serve as frameworks that define how data is structured, organized, and exchanged within the energy sector. These models enable different systems—including energy management software, grid operators, and consumer applications—to communicate effectively. By standardizing data formats, protocols, and terminologies, information models streamline processes such as digital twinning of (PV) systems, energy monitoring, demand response, and peer-to-peer energy trading.

In the photovoltaic domain, information models should include clear definitions of data elements related to solar energy production, consumption, and performance metrics, ensuring compatibility across systems. They should also outline data flow structures, providing guidelines on how data moves between stakeholders and detailing input and output requirements for various applications. Additionally, including use case scenarios—such as real-time monitoring of PV system generation or integration with battery storage systems—will enhance the practical applicability of these models.

To pave the way for trust federations in the photovoltaic domain, several key steps can be taken. First, it is essential to establish standardized information models tailored to the photovoltaic sector. This involves collaborating with stakeholders—including manufacturers, installers, grid operators, and researchers—to create standardized data formats and protocols that adhere to the FAIR principles. Such collaborative efforts will ensure a common understanding of data elements and their uses.

Next, implementing trust frameworks is crucial. These frameworks should outline governance structures for data sharing, establishing legal and operational guidelines that define roles, responsibilities, and rights regarding data usage. By fostering a secure environment for data sharing, stakeholders can confidently exchange and access information.

Enhancing data interoperability is another critical step. This can be achieved by investing in tools and technologies that promote interoperability, such as developing Application Programming Interfaces (APIs) that facilitate data exchange between different systems. Ensuring that systems can easily communicate without compatibility issues is vital for the efficiency of the energy ecosystem. Encouraging the adoption of widely accepted data standards across the photovoltaic sector will further support these efforts.

Additionally, **fostering collaborative platforms that enable stakeholders to share data, insights, and best practices is essential**. These platforms should prioritize user privacy and data security while including features that allow for real-time **data sharing and analytics**. By creating a central hub for information exchange, stakeholders can collaborate more effectively and drive innovation.

Consumer engagement plays a significant role in this transformation as well. It is important to educate consumers about the benefits of data sharing in the photovoltaic domain. Developing user-friendly tools and applications can empower consumers to monitor their energy usage and generation actively. Encouraging participation in programs that reward consumers for sharing their data will further increase engagement in the energy market.

Moreover, continuous monitoring of the effectiveness of established trust federations and information models is necessary. Gathering feedback from stakeholders will help identify challenges and opportunities for improvement. This adaptive approach will allow for refinements based on technological advancements and evolving industry needs.

By following this comprehensive path, the photovoltaic domain can create a robust ecosystem that maximizes the potential of data sharing, enhances trust among stakeholders, and accelerates the transition to sustainable energy sources. This collaborative approach will not only improve operational efficiency but also drive innovation in the renewable energy sector, ultimately contributing to a greener and more resilient energy future.

2.6 The role of SERENDI-PV databases and outlook

The SERENDI-PV project has developed several databases that are described in this deliverable, namely the **Public Database of Solar Resource and Weather Data** and the **Public Database of PV Components**, both of which are designed to comply with the FAIR principles—Findable, Accessible, Interoperable, and Reusable. The **Public Database of Solar Resource and Weather Data** aims to improve public access to high-quality solar resource measurements, integrating publicly available ground-measured data with advanced Solargis satellite model data. This integration allows users to cross-compare ground measurements with state-of-the-art satellite modelling, fostering a deeper understanding of both data types' uses and limitations. The database features a user-friendly interface built with Google Maps, which ensures that the data is Findable and Accessible. It includes links to source data and comprehensive validation reports that outline quality control measures, providing critical transparency that empowers users—such as students and industry practitioners—to identify potential data quality issues.

In parallel, the **Public Database of PV Components** serves as a centralized platform for manufacturers to input verified technical specifications of PV components, including modules, inverters, and energy storage systems. This platform addresses the common challenges of outdated and unverified information prevalent in existing databases. By implementing an automated verification process, the database ensures that all entries are accurate and reliable, which is vital for fostering trust among its users. The API access allows software developers to seamlessly integrate this high-quality data into their energy simulation tools, enhancing the Reusability of the information.

Both databases are instrumental in contributing to the International Data Spaces (IDS) ecosystem, by facilitating the sovereign exchange of data across organizational boundaries. This approach effectively breaks down data silos, enabling stakeholders—from manufacturers to researchers—to access and leverage a comprehensive array of datasets. For example, a PV system designer could utilize the Public Database of PV Components to obtain verified specifications for PV modules while simultaneously consulting the Public Database of Solar Resource and Weather Data to analyse site-specific solar conditions. Such an integrated approach empowers designers to optimize PV system performance based on reliable data, ultimately leading to more efficient energy solutions and innovative business cases in the end.

Additionally, these databases align with the European Framework for sharing data to support innovative energy services by providing a robust foundation for developing new business models and services based on accurate and reliable data. By facilitating access to high-quality datasets, the SERENDI-PV databases drive collaboration and innovation within the renewable energy sector, significantly contributing to the broader goal of transitioning to a sustainable energy future in Europe. Through these initiatives, SERENDI-PV not only promotes transparency and quality in data sharing but also sets a precedent for future data ecosystems designed to enhance energy efficiency and sustainability.

These databases may also play a role – as data services - in a future PV Federation of Trust. Figure 2.2 from [3] summarizes the three main pillars of a Federation of Trust, pivotal of course Trust, but also Interoperability, leading to enhanced data value by supporting market place services for the energy sector.

Figure 2.2: Building blocks of a Federation of Trust,

The vision of a Federation of Trust is crucial for establishing a robust framework for data sharing and collaboration. Identity provision could be implemented by services such as Eduroam, Internet2, or GEANT. This federation emphasizes the importance of authentication and security, allowing participants to trust the systems and data they engage with. By leveraging Digital Twins and offering “Simulation as a Service,” the federation enables applications across various domains (e.g. including agriculture domain to support AgriPV applications, but also such as PV systems with storage capabilities). The concept of *PV Digital Twinning as a Service* further enhances this framework by promoting standardized access to information from adjacent domains—such as geospatial data, weather forecasts, or crop models—through APIs. This interconnected approach could also support federated learning within data spaces, fostering innovation while ensuring compliance with European GDPR regulations. Ultimately, this would lead to eradication of data silos, enabling seamless data exchange and collaboration across sectors, thereby enhancing the efficiency and effectiveness of data-driven decision-making.

3 PUBLIC DATABASE OF SOLAR RESOURCE AND WEATHER DATA

3.1 Motivation

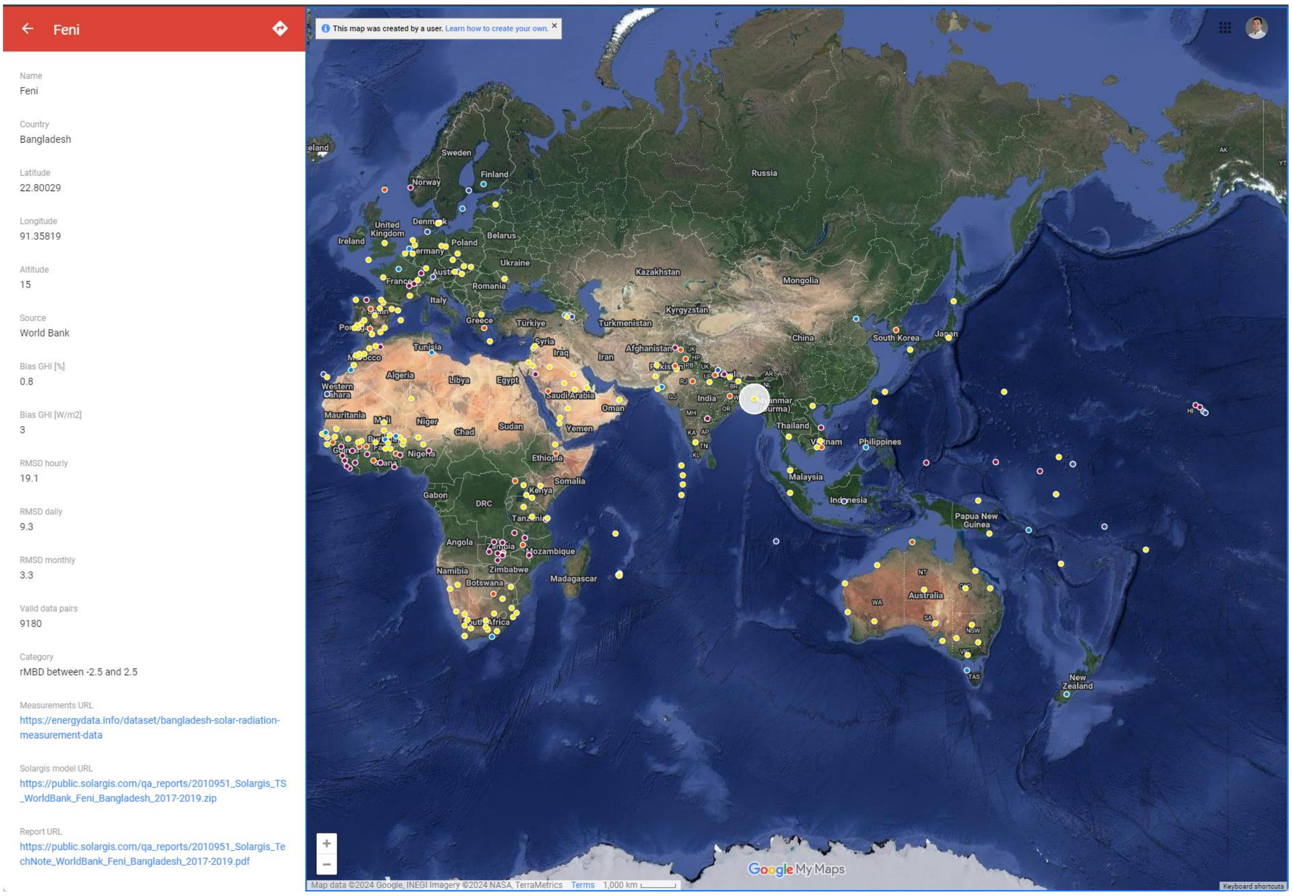
Although there exist publicly available ground measurements of solar resource and meteorological data, this data is often not easy to find. Moreover, even if a student or a practitioner in the industry do find ground-measured data, it can be often of a questionable quality and reliability. To improve the public access to high-quality data and to support the careful study of it, a public database of solar resource and weather data was prepared within the scope of the SERENDI-PV project.

The ground-measured data is supplemented by Solargis satellite model data to provide a view of the state-of-the-art modelling of solar resource and enable the visitors to cross-compare the measured data with the model data. This enables better understanding of the use and limitations of satellite-based solar resource models, and a more efficient use of the satellite-model based data in the industry.

3.2 The database

The database is integrated with the Solargis methodology section on validation and uncertainty of solar resource data, published on the Solargis website. Link to the website is also posted in an article on the COPLASIMON platform. The user interface, shown in Figure 3.1, is built using Google My Maps, which has several advantages:

- No development costs for a custom map display utility
- Easy and quick update of underlying data through spreadsheets
- Intuitive interface of Google Maps, which most users are familiar with



This map was created by a user. Learn how to create your own.

Name
Feni

Country
Bangladesh

Latitude
22.80029

Longitude
91.35819

Altitude
15

Source
World Bank

Bias GHI [%]
0.8

Bias GHI [W/m2]
3

RMSD hourly
19.1

RMSD daily
9.3

RMSD monthly
3.3

Valid data pairs
9180

Category
rMBD between -2.5 and 2.5

Measurements URL
https://energydata.info/dataset/bangladesh-solar-radiation-measurement-data

Solargis model URL
https://public.solargis.com/qa_reports/2010951_Solargis_TS_WorldBank_Feni_Bangladesh_2017-2019.zip

Report URL
https://public.solargis.com/qa_reports/2010951_Solargis_TechNote_WorldBank_Feni_Bangladesh_2017-2019.pdf

Figure 3.1: User interface of the database of solar resource and weather data

The interface displays sites around the world, at which Solargis has performed a validation of its satellite-based solar resource data with publicly available ground-measured data. This ground-measured data is now being published via links to the source data. Alongside it, the Solargis satellite model data is being published, as well as reports outlining the quality control of the ground measurements and the validation statistics at the site. This allows the user a detailed analysis of the two datasets provided, and understanding of their relative advantages and disadvantages.

The quality assessment and validation reports are an important part of the database. As mentioned above, poor quality of the ground measured data is a frequent issue. However, for a student or a practitioner with limited experience with solar resource data, the issues are typically not obvious. These users are then in danger of using incorrect data to support their research and learning, which has ramifications for any conclusions they draw. By making the outputs of the quality assessment public, all readers are given the chance to study the typical issues and the methods used for identifying them. Moreover, the validation statistics are performed by comparing with the quality-assessed data, resulting in consistent and robust results. In the broader view, the database therefore promotes the use of high-quality data in studies and analyses, and transparency of methods and inputs used in the industry.

The sites for which the data and the reports were published at the end of August 2024 is shown in Table 3.1 below. The list is being expanded to include more validated sites. To do this, legal conditions of publishing must be analysed, and the appropriate publishing consents gained from the data owners. The quality assessment of the measured data must be performed, and a report outlining the assessment and the validation statistics prepared.

Table 3.1: Sites for which the measured data, Solargis data, and report are provided in the database at the end of August 2024

Site name	Country	Latitude	Longitude	Measured data owner	Climatic zone
Alice springs	Australia	-23.79510	133.88900	BoM	Arid
Carpentras	France	44.08300	5.05900	BRSN	Temperate
Dédougou	Burkina Faso	12.46620	-3.47294	World Bank	Tropical
Feni	Bangladesh	22.80029	91.35819	World Bank	Tropical
Lindenberg	Germany	52.21670	14.11670	BSRN	Cold
Pretoria	South Africa	-25.75308	28.22859	SAURAN	Temperate
Sao Martinho da Serra	Brazil	-29.44278	-53.82305	BRSN	Temperate
SRRL BMS	USA	39.74200	-105.18000	NREL	Arid
Tateno	Japan	36.05810	140.12580	BSRN	Cold

The database will be expanded and promoted beyond the scope of the SERENDI-PV project. Collaborations with other data providers are being planned and actively explored. Ultimately, the database aims to become a platform for publishing solar resource data with transparent sources, processing, quality assessments and where relevant comparisons are provided. The users will be thus able to browse several different sources of data, understand their respective differences, and choose the one most appropriate for their use case.

4 PUBLIC DATABASE OF PV COMPONENTS

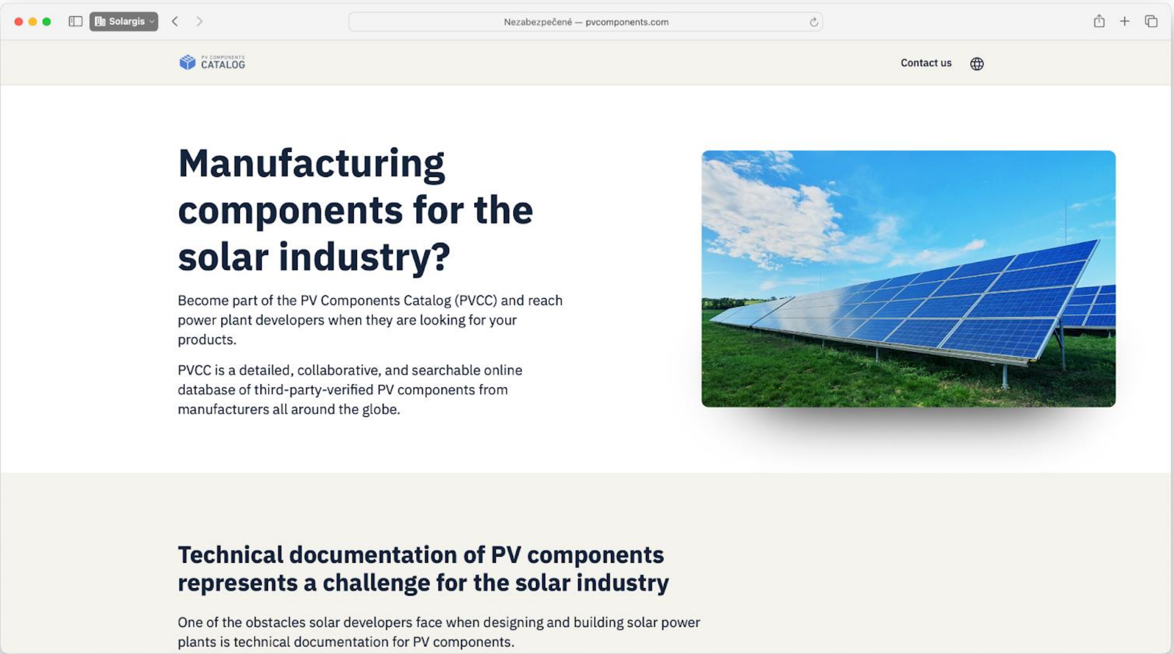
4.1 Motivation

Access to accurate and verified technical specifications of PV components (PV modules, inverters, trackers, energy storage, …) is important for a range of industry users. Even though some initiatives to provide this data exist, their weak points are occurrence of outdated and unverified information, insufficient transparency and outdated interface. Within the SERENDI-PV project, we have developed a platform, located under a separate web domain, that serves the following needs:

1. It can be used as one single entry point for manufacturers to insert technical specifications of their products
2. Information inputs from manufacturers are automatically verified, reviewed by domain experts, and categorized to confidence classes for the quality and trustworthiness of the information
3. PV software developers can use information from this platform as a source of technical input into their energy simulation and analysis algorithms
4. Professionals and general public have access to the technical information stored in the platform and review process results for inquiries and research about PV components
5. Technically, the access to the platform is offered via an interactive web–based interface as well as via API (for automated communication with other software tools). The general exploration of the information is possible with unrestricted access and without any previous user registration. Access to specific data and services and to a working area is restricted to registered users.

4.2 The database

The platform is available at https://www.pvcomponents.com where all basic information about the project is available for interested parties.



Manufacturing components for the solar industry?

Become part of the PV Components Catalog (PVCC) and reach power plant developers when they are looking for your products.

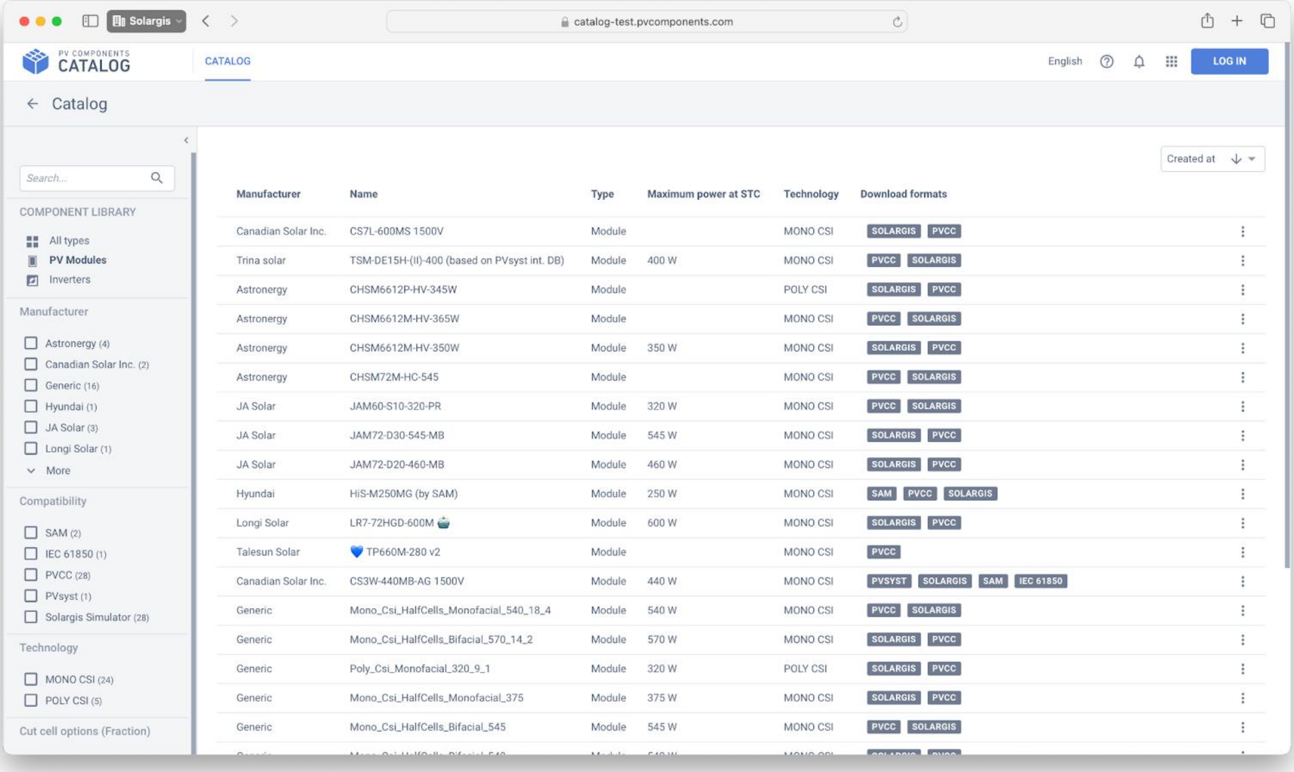
PVCC is a detailed, collaborative, and searchable online database of third-party-verified PV components from manufacturers all around the globe.

Technical documentation of PV components represents a challenge for the solar industry

One of the obstacles solar developers face when designing and building solar power plants is technical documentation for PV components.

Figure 4.1: Landing page of the PV Components Catalogue

The catalogue itself is at the second level URL https://catalog.pvcomponents.com where without logging in, users can explore basic information about PV components.

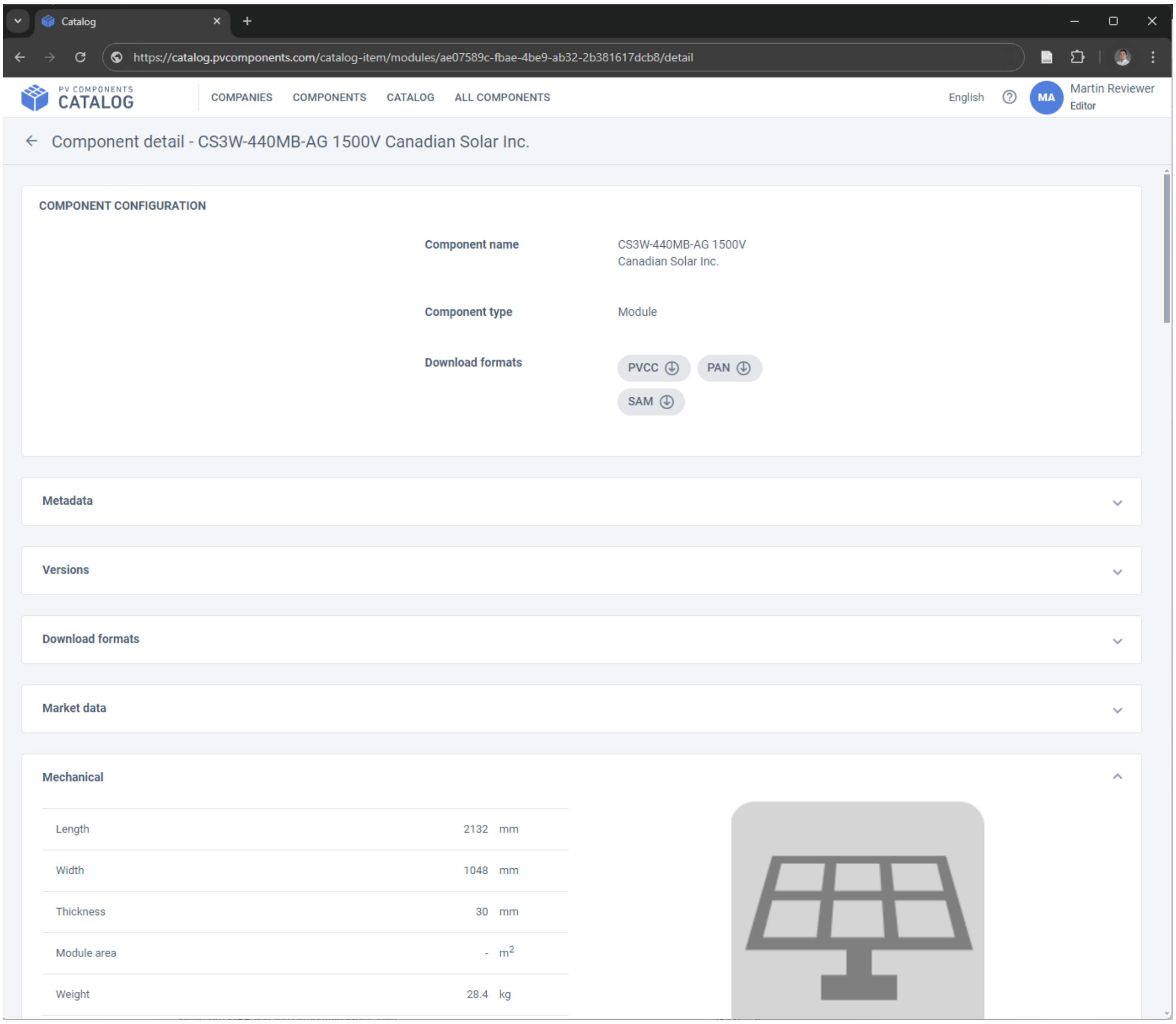


Manufacturer	Name	Type	Maximum power at STC	Technology	Download formats
Canadian Solar Inc.	CS7L-600MS 1500V	Module		MONO CSI	SOLARGIS PVCC
Trina solar	TSM-DE15H-(II)-400 (based on PVsyst int. DB)	Module	400 W	MONO CSI	PVCC SOLARGIS
Astronergy	CHSM6612P-HV-345W	Module		POLY CSI	SOLARGIS PVCC
Astronergy	CHSM6612M-HV-365W	Module		MONO CSI	PVCC SOLARGIS
Astronergy	CHSM6612M-HV-350W	Module	350 W	MONO CSI	SOLARGIS PVCC
Astronergy	CHSM72M-HC-545	Module		MONO CSI	PVCC SOLARGIS
JA Solar	JAM60-S10-320-PR	Module	320 W	MONO CSI	PVCC SOLARGIS
JA Solar	JAM72-D30-545-MB	Module	545 W	MONO CSI	SOLARGIS PVCC
JA Solar	JAM72-D20-460-MB	Module	460 W	MONO CSI	SOLARGIS PVCC
Hyundai	HiS-M250MG (by SAM)	Module	250 W	MONO CSI	SAM PVCC SOLARGIS
Longi Solar	LR7-72HGD-600M 🤖	Module	600 W	MONO CSI	SOLARGIS PVCC
Talesun Solar	💙 TP660M-280 v2	Module		MONO CSI	PVCC
Canadian Solar Inc.	CS3W-440MB-AG 1500V	Module	440 W	MONO CSI	PVSYST SOLARGIS SAM IEC 61850
Generic	Mono_Csi_HalfCells_Monofacial_540_18_4	Module	540 W	MONO CSI	PVCC SOLARGIS
Generic	Mono_Csi_HalfCells_Bifacial_570_14_2	Module	570 W	MONO CSI	SOLARGIS PVCC
Generic	Poly_Csi_Monofacial_320_9_1	Module	320 W	POLY CSI	SOLARGIS PVCC
Generic	Mono_Csi_HalfCells_Monofacial_375	Module	375 W	MONO CSI	SOLARGIS PVCC
Generic	Mono_Csi_HalfCells_Bifacial_545	Module	545 W	MONO CSI	PVCC SOLARGIS

Figure 4.2: The main interface of the PV Components Catalogue

To fully use the PVCC, users have to register for a free account. This enables a closer control of the PVCC use, both in terms of uploading and downloading data. Only with this control the quality of the provided information can be ensured.

Within the database, the registered and logged-in user can browse the details of the PV component specifications. Currently, PVCC supports the specifications of PV modules and inverters, which are the two most important components of PV power plants. The user can use filters (left side of the interface in Figure 4.2) to search for a component with particular properties. By clicking on a component, the user can display its details, and view all specified parameters (Figure 4.3).



Component detail - CS3W-440MB-AG 1500V Canadian Solar Inc.

COMPONENT CONFIGURATION

Component name	CS3W-440MB-AG 1500V Canadian Solar Inc.
Component type	Module
Download formats	PVCC PAN SAM

Metadata

Versions

Download formats

Market data

Mechanical

Length	2132	mm
Width	1048	mm
Thickness	30	mm
Module area	-	m^2
Weight	28.4	kg

Figure 4.3: Detail of a PV module specification in the PVCC. Notice the available downloads, based on the three specification formats

The component specifications in the PVCC are based on specifications in 3 major simulation tools, and an international standard:

- Solargis PV simulator
- PVSyst simulator
- NREL System Model Advisor (SAM) simulator
- IEC 61850 standard

The superset of the required parameters of the 4 systems listed above is relatively large and contains parameters which are difficult to obtain. The PVCC therefore requires the user to enter a much smaller set of parameters for the component to be saved in the database. However, if all parameters required by any of the above systems are entered, the PVCC can export a component specification compliant with that system.

4.3 PVCC quality assurance

The basic workflow of the PVCC is shown in the diagram in Figure 4.4 below.

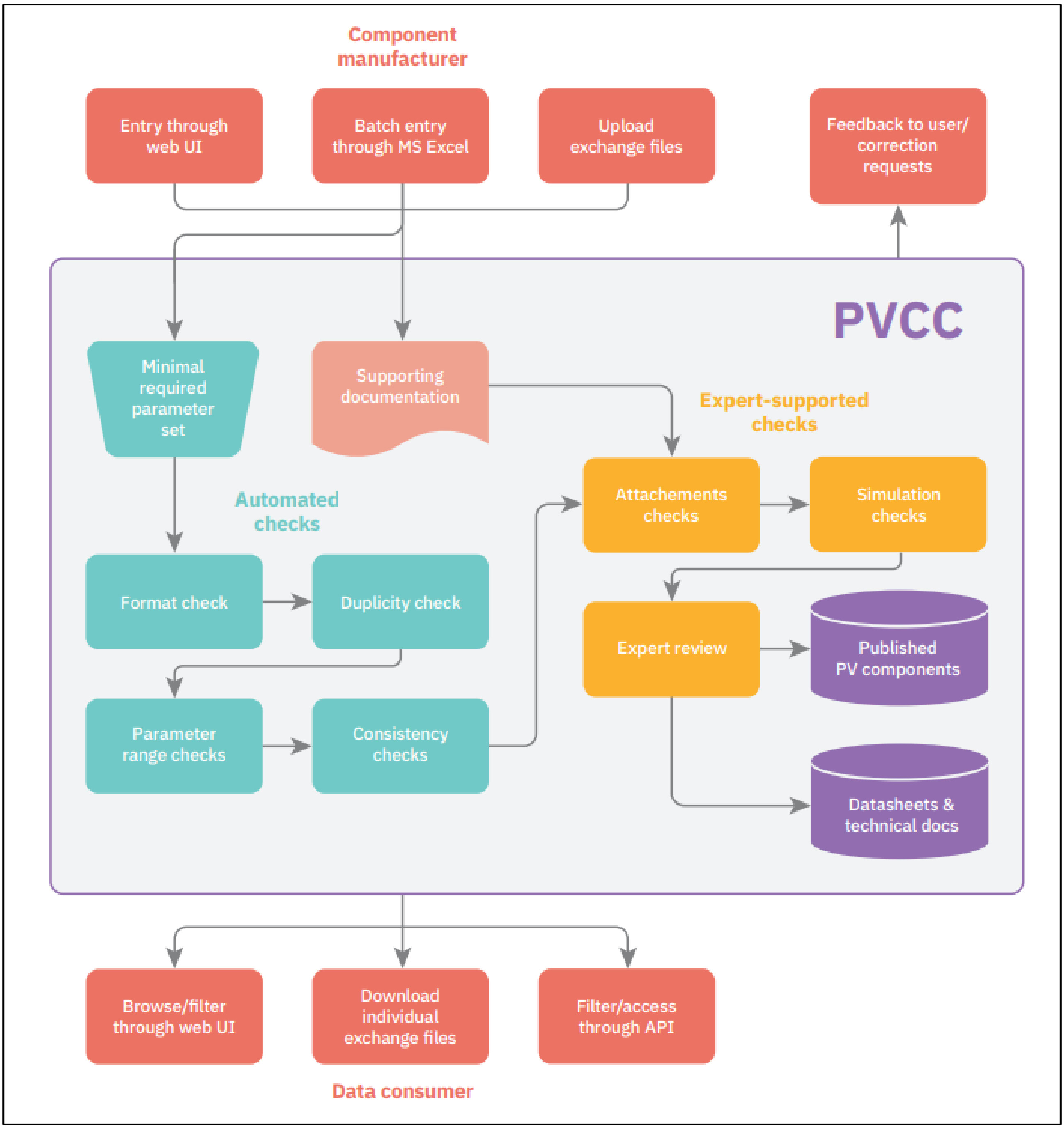
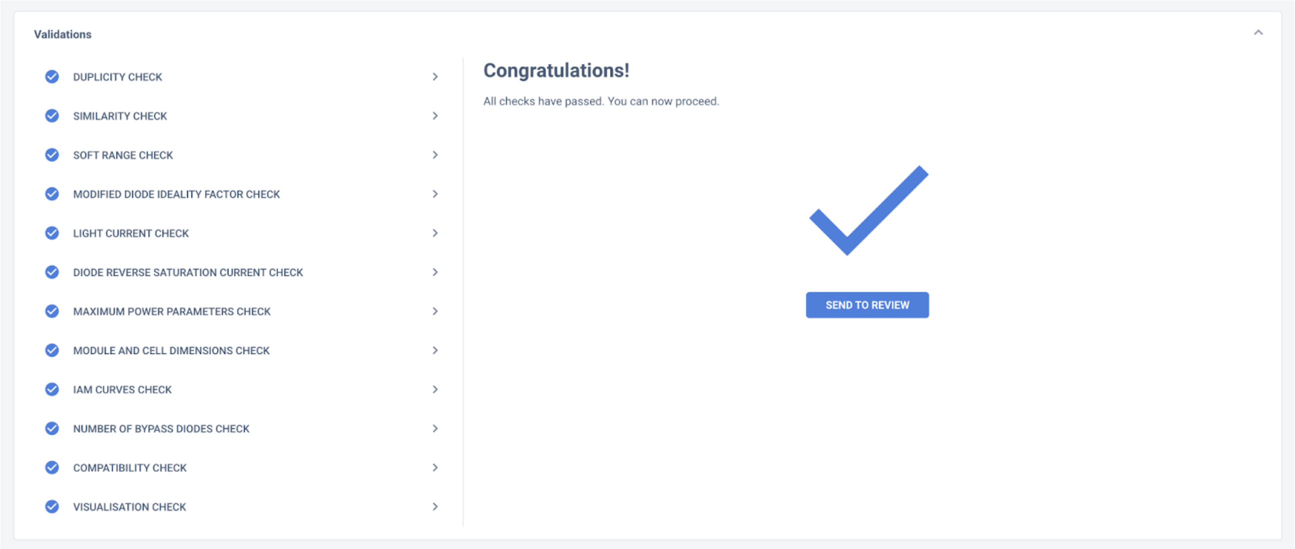


Figure 4.4: Basic workflow of the PVCC

Registered users can establish a company account (associated with a known legal entity) and add PV components associated with selected manufacturers. The list of manufacturers is controlled by back-office operators to ensure integrity of the database. The component specifications can be added manually one by one through the web interface, or by bulk upload through an Excel template. The user is also asked to provide supporting documentation such as datasheets and testing certificates, these are, however, not mandatory.

Once a component specification is entered and supporting documentation uploaded, the user can request the specification to be verified. The verification is the key element of the PVCC, distinguishing it from similar solutions, and an answer to one of the main pain points of the industry – inaccurate specifications. The verification comprises two stages – automatic and manual checks.

The automatic checks verify the parameters of the component specification based on physical rules and relationships between the individual parameters. These checks have been specified by the domain experts and serve to filter out gross errors and inaccuracies in the specifications. If a component fails any of the checks, the user is notified and guided to correct the error. Once all mandatory parameters are specified, and all automatic checks are passing, the user can submit the component specification for an expert verification.



Validations

- ✓ DUPLICITY CHECK
- ✓ SIMILARITY CHECK
- ✓ SOFT RANGE CHECK
- ✓ MODIFIED DIODE IDEALITY FACTOR CHECK
- ✓ LIGHT CURRENT CHECK
- ✓ DIODE REVERSE SATURATION CURRENT CHECK
- ✓ MAXIMUM POWER PARAMETERS CHECK
- ✓ MODULE AND CELL DIMENSIONS CHECK
- ✓ IAM CURVES CHECK
- ✓ NUMBER OF BYPASS DIODES CHECK
- ✓ COMPATIBILITY CHECK
- ✓ VISUALISATION CHECK

Congratulations!

All checks have passed. You can now proceed.

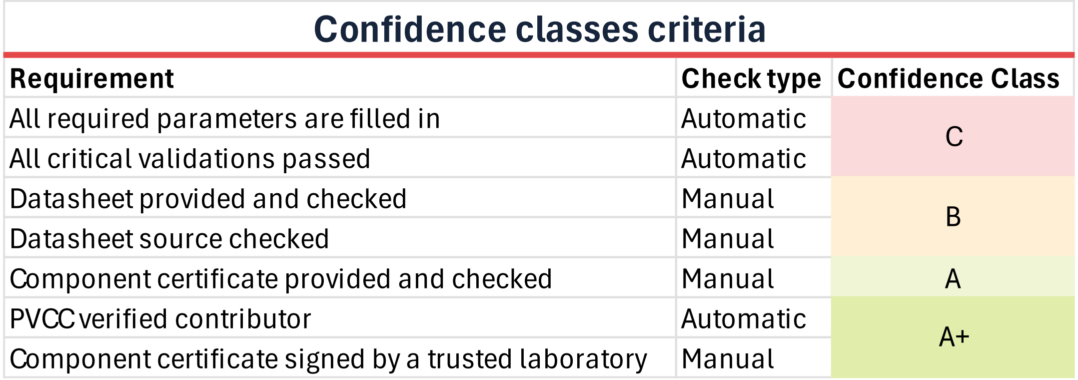
Figure 4.5: User interface of a component specification which successfully passed automated checks (listed on the left)

The expert check is the second step of the verification process. It includes checks which require domain knowledge and human assessment that is difficult to algorithmize and automate. The expert review is supported by a PV simulation in the Solargis simulator using the component specification, to obtain its performance characteristics. The supporting documentation is also checked at this stage. If there are any issues observed during the expert review, the user is notified and asked to rectify the issues. Once the expert verification is completed, the component specification can be published in the PVCC.

The PVCC also enables the user to store the component specification in a private area of the PVCC such that the specification is not visible to the other users of PVCC. This is a feature designed based on interviews with potential users, who stated that the specifications they have and use for PV yield simulations are privately shared by component manufacturers and must not be made public.

The workflow of adding the component specifications for inverters was trialled by Ingeteam, who entered and submitted specifications of several of their inverters. Based on this experience, a collaborative feedback session between Ingeteam and Solargis engineers was organized, in which the user experience was analysed, and several proposals for refinement were created. Thanks to this approach within the SERENDI-PV project, the PVCC is designed and built with consideration for real user experience.

Based on the number of the parameters entered, the quality of the supporting documentation, and the trustworthiness of the user entering the specification, the component specifications are sorted into confidence classes. These classes express the quality and trustworthiness of the specification based on objective measures and can guide the user aiming to perform a PV yield simulation with the specification. The higher the confidence class, the higher the assurance to the user that the PV yield simulation with the component specification will produce accurate results. The criteria for assigning the confidence classes to the specifications is shown in Figure 4.6 below. All specified criteria for a certain class must be met for the component to be awarded the confidence class.



Confidence classes criteria

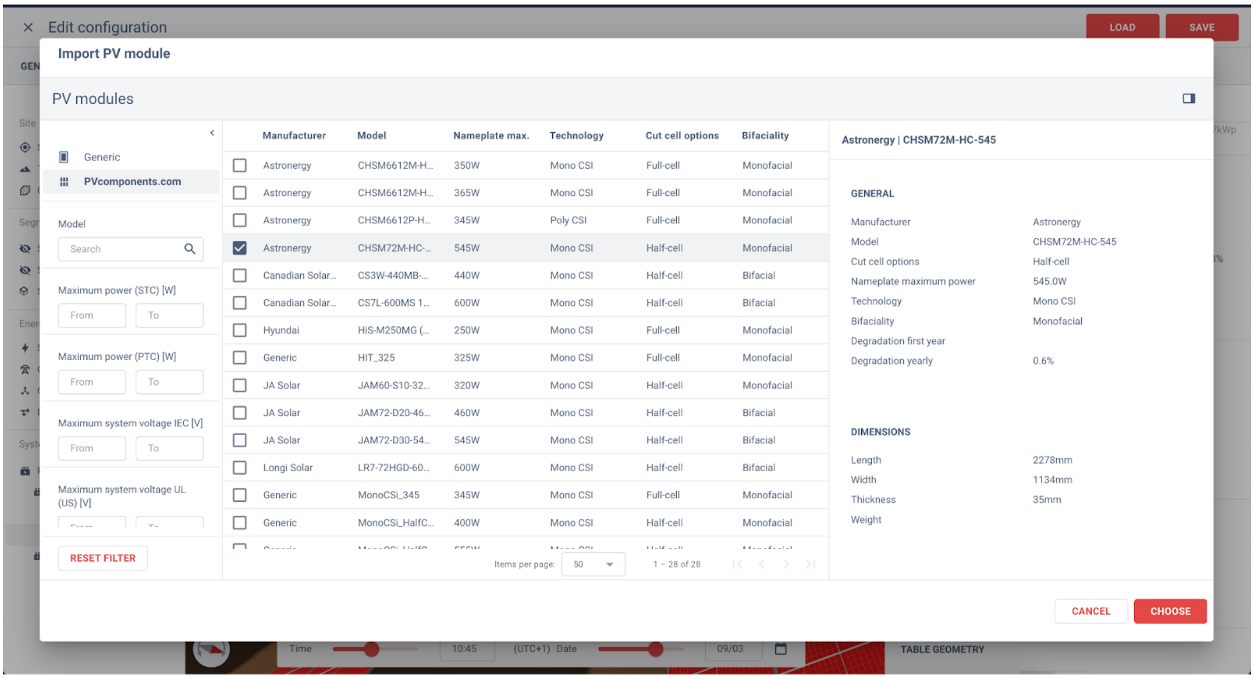
Requirement	Check type	Confidence Class
All required parameters are filled in	Automatic	C
All critical validations passed	Automatic	
Datasheet provided and checked	Manual	B
Datasheet source checked	Manual	
Component certificate provided and checked	Manual	A
PVCC verified contributor	Automatic	A+
Component certificate signed by a trusted laboratory	Manual	

Figure 4.6: Confidence class criteria for component specifications in PVCC

4.4 PVCC integration

The access to the component specifications in PVCC is provided through a web interface and an API. In the web application, any user can search the database, and download individual specification files following one of the available component specification standards (as detailed in a section above). The API access is provided only to company users. They can generate an API key from the web application, which is then used to access the PVCC at the published API web link. The company users can therefore integrate PVCC with their applications that require high-quality specifications of PV components.

The API access was tested by integrating PVCC with the Solargis Evaluate application. Through the integration, the users of Solargis Evaluate can access components specifications published in PVCC (Figure 4.7).



	Manufacturer	Model	Nameplate max.	Technology	Cut cell options	Bifaciality
☐	Astronergy	CHSM6612M-H...	350W	Mono CSI	Full-cell	Monofacial
☐	Astronergy	CHSM6612M-H...	365W	Mono CSI	Full-cell	Monofacial
☐	Astronergy	CHSM6612P-H...	345W	Poly CSI	Full-cell	Monofacial
☑	Astronergy	CHSM72M-HC-...	545W	Mono CSI	Half-cell	Monofacial
☐	Canadian Solar...	CS3W-440MB-...	440W	Mono CSI	Half-cell	Bifacial
☐	Canadian Solar...	CS7L-600MS 1...	600W	Mono CSI	Half-cell	Bifacial
☐	Hyundai	HiS-M250MG (...	250W	Mono CSI	Full-cell	Monofacial
☐	Generic	HIT_325	325W	Mono CSI	Full-cell	Monofacial
☐	JA Solar	JAM60-S10-32...	320W	Mono CSI	Half-cell	Monofacial
☐	JA Solar	JAM72-D20-46...	460W	Mono CSI	Half-cell	Bifacial
☐	JA Solar	JAM72-D30-54...	545W	Mono CSI	Half-cell	Bifacial
☐	Longi Solar	LR7-72HGD-60...	600W	Mono CSI	Half-cell	Bifacial
☐	Generic	MonoCSi_345	345W	Mono CSI	Full-cell	Monofacial
☐	Generic	MonoCSi_HalfC...	400W	Mono CSI	Half-cell	Monofacial

Astronergy | CHSM72M-HC-545

GENERAL

Manufacturer	Astronergy
Model	CHSM72M-HC-545
Cut cell options	Half-cell
Nameplate maximum power	545.0W
Technology	Mono CSI
Bifaciality	Monofacial
Degradation first year	
Degradation yearly	0.6%

DIMENSIONS

Length	2278mm
Width	1134mm
Thickness	35mm
Weight	

Figure 4.7: Interface from Solargis Evaluate allowing users to access component specifications published in PVCC

PVCC also provides "private" or "company" APIs. Every company account can generate its own API token with a key and access its own unpublished components. This allows users to use their own confidential specifications in their preferred PV yield simulation tool.

5 PUBLIC DATABASE FOR PV SYSTEM METADATA AND PERFORMANCE WORLDWIDE

In the framework of subtask 7.4.3 a public repository for PV system metadata has been put in place using two main resources:

- A CKAN database, available at https://ckan.coplasimon.eu/ in which the COPLASIMON users can upload and download the publicly available data provided to the database by external users and by SERENDI-PV partners.
- A mapping of available data and resources, which has been built in a blog embedded in COPLASIMON with an architecture of tags in order to map the existing initiatives and available datasets. The blog is available at https://coplasimon.eu/index.php/2024/09/21/annuary-of-collaborations/ and includes contributions from external stakeholders to the project and SERENDI-PV partners.

This chapter describes some of the datasets uploaded on the database and in the resource mapping.

5.1 Performance monitoring of non-degraded and degraded PV modules

5.1.1 General description of the database (parameters of the dataset)

A public dataset for benchmarking of Fault Detection and Diagnosis (FDD) tools at PV module level has been generated. This dataset has been generated for a period of 6 months (from April to September 2024).

During this period, several PV modules have been monitored, collecting their operating conditions (solar radiation and module temperature), their output voltage and current while connected to a microinverter and their continuous electrical characterization through IV curve measurements. Some of these PV modules present degraded conditions and others non-degraded to allow FDD tool developers to test their solutions, evaluating if their tools can detect and diagnose degradation modes from the PV module operating voltages and currents.

The dataset includes the following parameters of 7 PV modules connected to maximum power point (MPP) trackers:

1. Weather conditions monitoring (synchronized with modules electrical measurements):
    a. global tilted irradiance (GTI)
    b. global horizontal irradiance (GHI)
    c. module temperature
    d. relative humidity
    e. ambient temperature and
    f. wind speed.
2. Periodic measurements of modules working conditions:
    a. Operating current and voltage connected to maximum power point (MPP) trackers, with a frequency of 1 minute
    b. IV curves of the PV modules are measured every 5 minutes, starting 15 minutes before sunrise and ending 15 minutes after sunset. The most important characteristics parameters are automatically extracted from the IV curve measurement and stored in the database:
        i. short-circuit current (Isc),
        ii. open-circuit voltage (Voc),
        iii. maximum power point current (Imp),

iv. maximum power point voltage (Vmp),
v. Fill Factor (FF),
vi. series resistance (Rs) and
vii. shunt resistance (Rp)

These datasets are made available through COPLASIMON in the following link:

https://coplasimon.eu/index.php/2024/10/28/public-database-for-pv-module-performance-monitoring/

Next sections describe the implemented testbench, monitoring equipment, degradation modes and specification of the public dataset.

5.1.2 Description of testbench

The implemented testbench consists of a monitoring platform for a set of seven PV modules in TECNALIA facilities. The specific location is 43°17´46.45´´N, 2°52´14.23´´ W. Figure 5.1 shows the location of implemented monitoring platform in TECNALIA facilities (Derio, Spain)

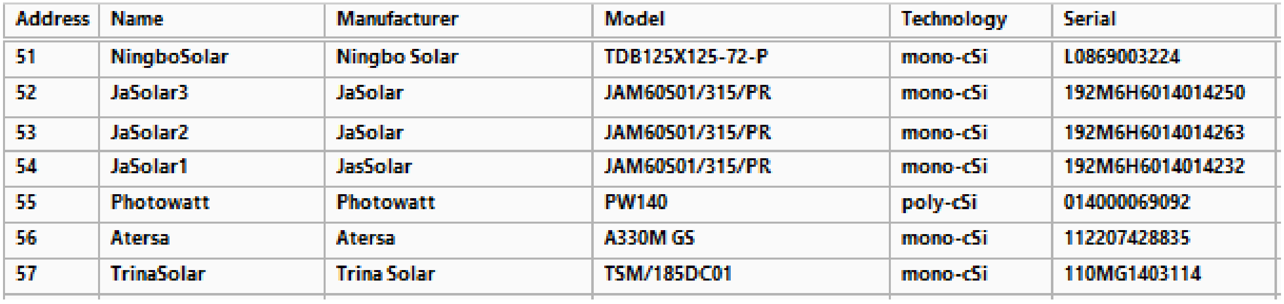
Figure 5.1: Location of implemented monitoring platform in TECNALIA facilities (Derio, Spain)

The monitoring platform is composed by an aluminon metallic structure with an adjustable azimuth and tilt. For the generation of this dataset, the platform was oriented to South, with a fixed azimuth of 180º, while the tilted was fixed to 36º, as shown in Figure 5.2 and Figure 5.3.

Figure 5.2: Monitoring platform oriented to the South

Figure 5.3: Measure of tilt angle of monitoring platform

Figure 5.4 shows the list of the seven PV modules installed in the monitoring platform since April, the 5th, 2024. For each of them, PV module manufacturer, model, technology and reference number is indicated. In Figure 5.5 the specific location of each PV module in the monitoring platform is displayed.



Address	Name	Manufacturer	Model	Technology	Serial
51	NingboSolar	Ningbo Solar	TDB125X125-72-P	mono-cSi	L0869003224
52	JaSolar3	JaSolar	JAM60S01/315/PR	mono-cSi	192M6H6014014250
53	JaSolar2	JaSolar	JAM60S01/315/PR	mono-cSi	192M6H6014014263
54	JaSolar1	JasSolar	JAM60S01/315/PR	mono-cSi	192M6H6014014232
55	Photowatt	Photowatt	PW140	poly-cSi	014000069092
56	Atersa	Atersa	A330M GS	mono-cSi	112207428835
57	TrinaSolar	Trina Solar	TSM/185DC01	mono-cSi	110MG1403114

Figure 5.4: List of monitored PV modules

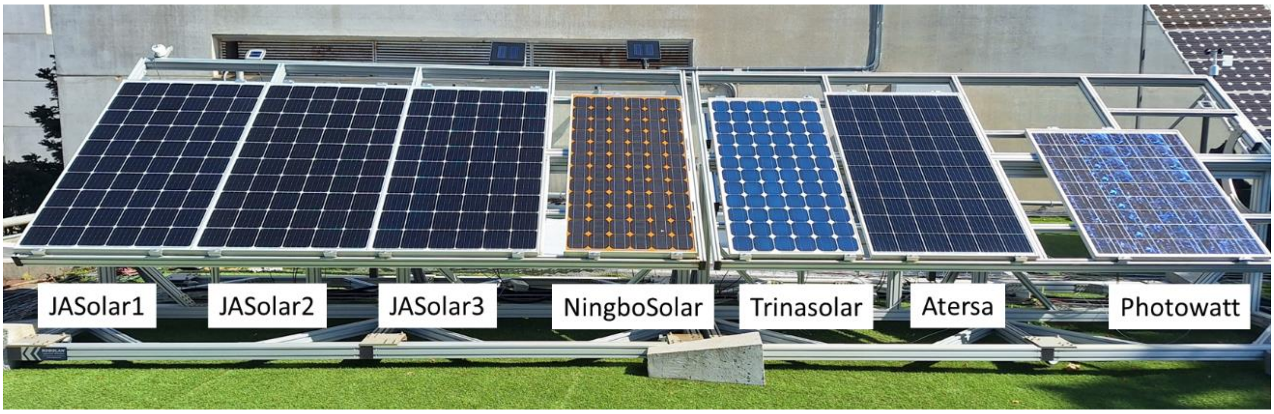


Figure 5.5: Disposition of PV modules in the monitoring platform

There are two clearly differentiated subgroups. On the one hand, a subset of 3x JA solar PV modules for inferring artificial failure modes. These PV modules corresponded to as-fabricated PV modules, in some of which degradation modes have been inferred without damaging the PV module. More specifically, in two of them external devices to increase their series resistance have been introduced.

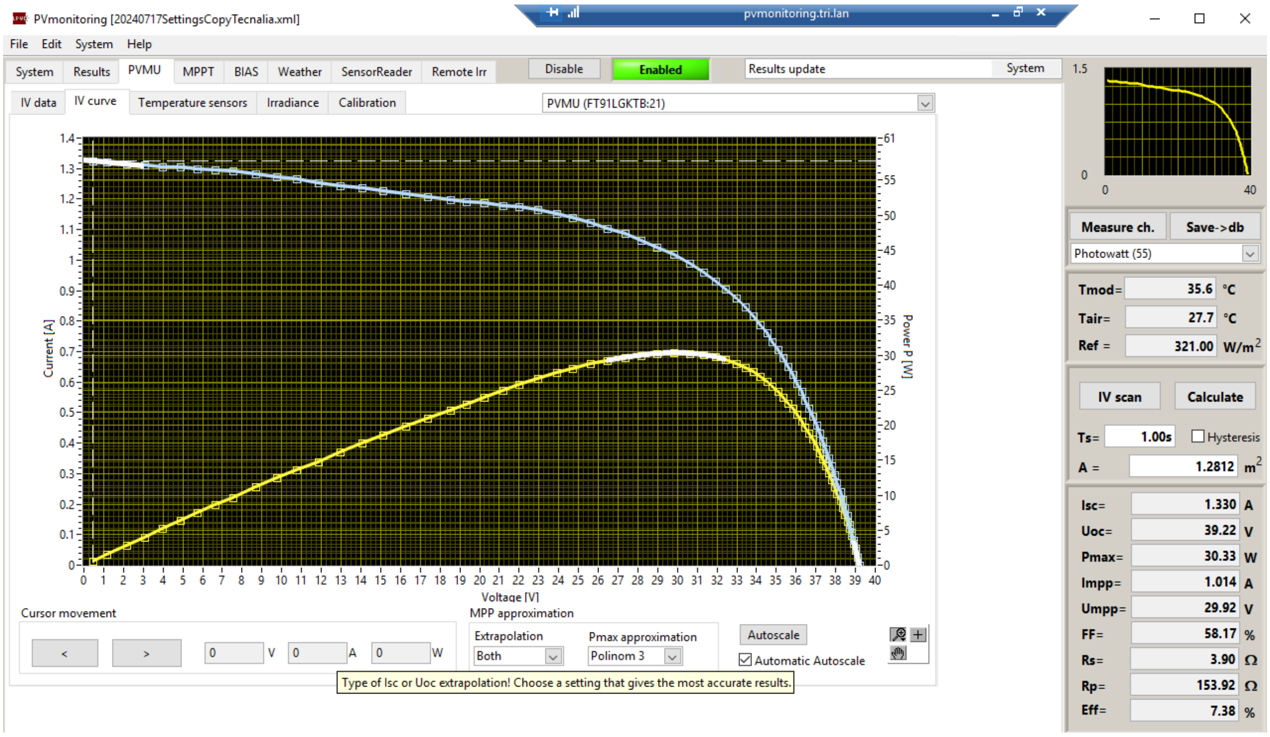
On the other hand, a set of 4x naturally degraded PV modules from different PV facilities. These PV modules have been exposed to harsh environmental conditions and as consequence they show different degradation level due to different degradation modes.

5.1.3 Description of monitoring equipment

The monitoring system for the electrical performance of PV modules is based on a LPV-MS1X16 developed by the University of Ljubljana. This device is presented in Figure 5.6. The electrical characterization combines an IV tracer unit called PVMU with a series of MPP trackers.

This way, IV curves are periodically measured (every 5 minutes) for each PV module. The most important characteristics parameters short-circuit current (Isc), open-circuit voltage (Voc), maximum power point current (Imp), maximum power point voltage (Vmp), Fill Factor (FF), series resistance (Rs) and shunt resistance (Rp) are automatically extracted from the IV curve measurement and stored in the database. A screenshot of the software for IV curve analysis can be observed in Figure 5.7.

Figure 5.6: LPV-MS1X16 monitoring system



Results update
System
PVMU (FT91LGKTB:21)
0 V 0 A 0 W
Extrapolation: Both
Pmax approximation: Polinom 3
☑ Automatic Autoscale
Type of Isc or Uoc extrapolation! Choose a setting that gives the most accurate results.
Photowatt (55)
Tmod= 35.6 °C
Tair= 27.7 °C
Ref = 321.00 W/m^2
Ts= 1.00s
☐ Hysteresis
A = 1.2812 m^2
Isc= 1.330 A
Uoc= 39.22 V
Pmax= 30.33 W
Impp= 1.014 A
Umpp= 29.92 V
FF= 58.17 %
Rs= 3.90 Ω
Rp= 153.92 Ω
Eff= 7.38 %

Figure 5.7: Software for the analysis of measured IV curves

Meanwhile, each PV module is connected to a specific MPP tracker, which monitors the maximum power point current (Imp) and voltage (Vmp) every 60 seconds. The set of MPP trackers are shown in Figure 5.8.

Figure 5.8: MPP trackers in charge of monitoring of Imp and Vmp every 60s

Regarding irradiance sensors, the platform was equipped with a set of 4 MODBUS irradiance sensors of different technologies and purposes.

The global tilted irradiance (GTI) is monitored by a combination of 1x pyranometer HukseFlux SR30-M2-D1 in the plane of the array (POA) and 2x calibrated solar cell MET Atersa 3002095. The pyranometer installed in the POA can be seen in Figure 5.9.

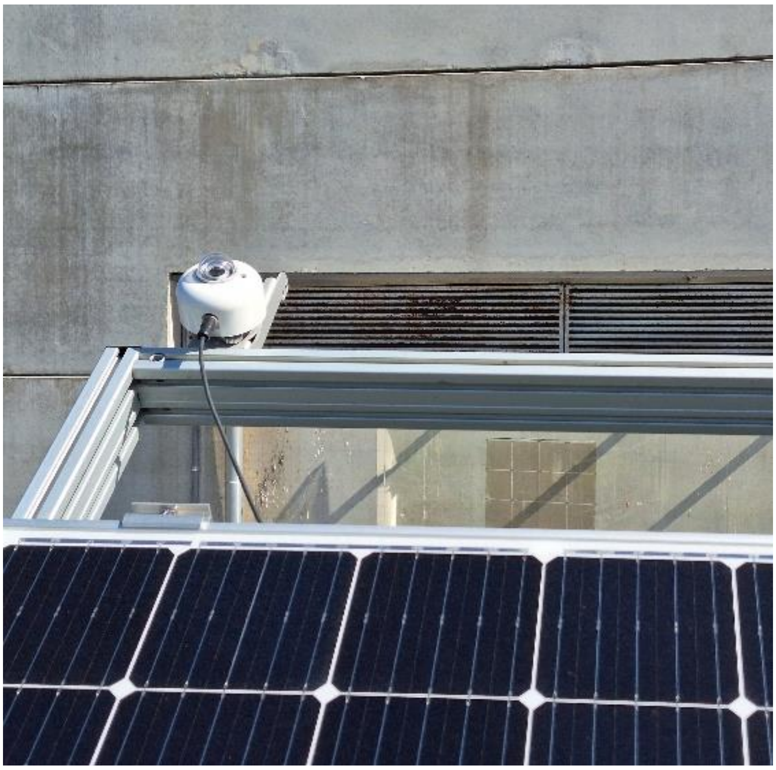


Figure 5.9: HukseFlux SR30-M2-D1 pyranometer installed in the plane of PV array to measure GTI

For the Atersa solar cells, one of them was installed to monitor the irradiance level in the POA and the second one use a special structure that allows to artificially introduce an azimuth or tilt mismatch with the plane of array and emulate some issues in the input data quality. Both are shown in Figure 5.10.

Figure 5.10: MET Atersa 3002095 calibrated cells installed in the plane of PV array with the possibility to introduce slight variations in one of them to emulate input data quality issues

The global horizontal irradiance (GHI) was monitored by means of a pyranometer HukseFlux SR30-M2-D1, as shown in Figure 5.11.

Figure 5.11: HukseFlux SR30-M2-D1 pyranometer horizontally installed to measure GHI

Regarding module temperature, 2x Maxim DS18B20 sensors were located in the middle and lower corner of each PV module. These temperature sensors are displayed in Figure 5.12.

Figure 5.12: Module temperature sensors installed in the middle and lower corner of each PV module

Finally, there is also a meteorological station to measure relative humidity, ambient temperature and wind speed. This meteorological station (left) and the anemometer (right) are presented in Figure 5.13.

Figure 5.13: Meteorological station and anemometer

5.1.4 Description of degradation modes

There are different degradation modes that have been characterized and could be detected by FDD tools:

1. Artificial increase of series resistance.
2. Artificial misalignment of GTI measurements and POA.
3. Natural degradation.

5.1.4.1 Artificial increase of series resistance

A common degradation mode in PV modules is the corrosion of internal interconnections leading to an increase of internal series resistance. With the aim of evaluating detection sensitivity of FDD tools in presence of this failure mode, external resistances with different values have been connected in series to two PV modules from July, the 15th on. More specifically, these have been added to 192M6H60114014263 and 192M6H60114014250 JA Solar Modules, with values of 200mohm and 400mohm, respectively. Figure 5.14 shows internal (top left) and external (top right) appearance of added external series resistance, as well as its electrical connection to the PV module (below).

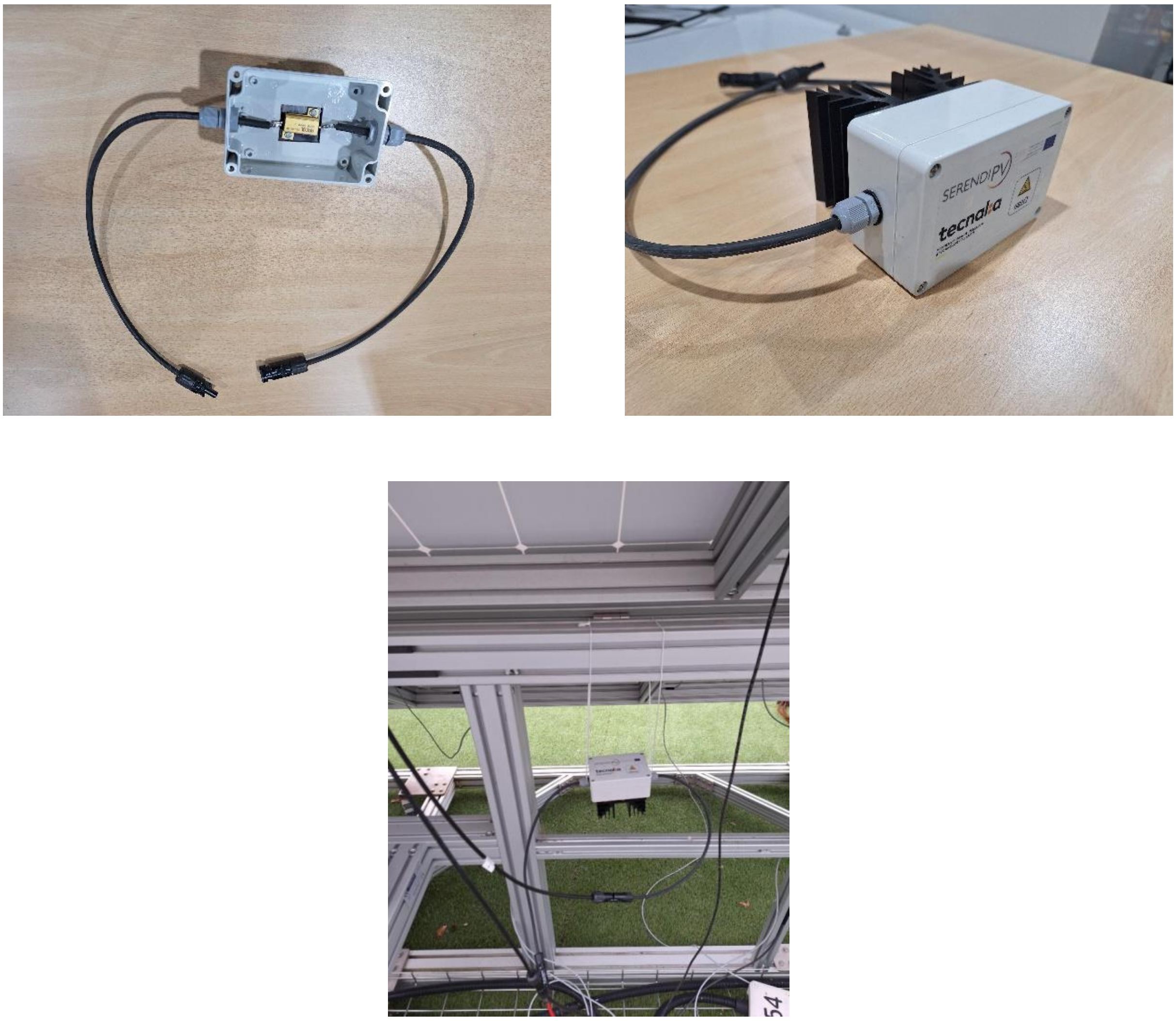


Figure 5.14: External series resistance installed in series with some PV modules to emulate internal corrosion

As a consequence of this series resistance, IV curve of PV module is expected to be modified as shown in the following picture, obtained by simulation for 200mohm case. As it can be computed, maximum power point voltage will be reduced in 6% and maximum power in 7%. Figure 5.15, on the left, displays simulated IV curve of the PV module with and without the series resistance in red and blue lines, respectively. On the right, relative degradation at standard conditions of the different IV curve parameters are presented.

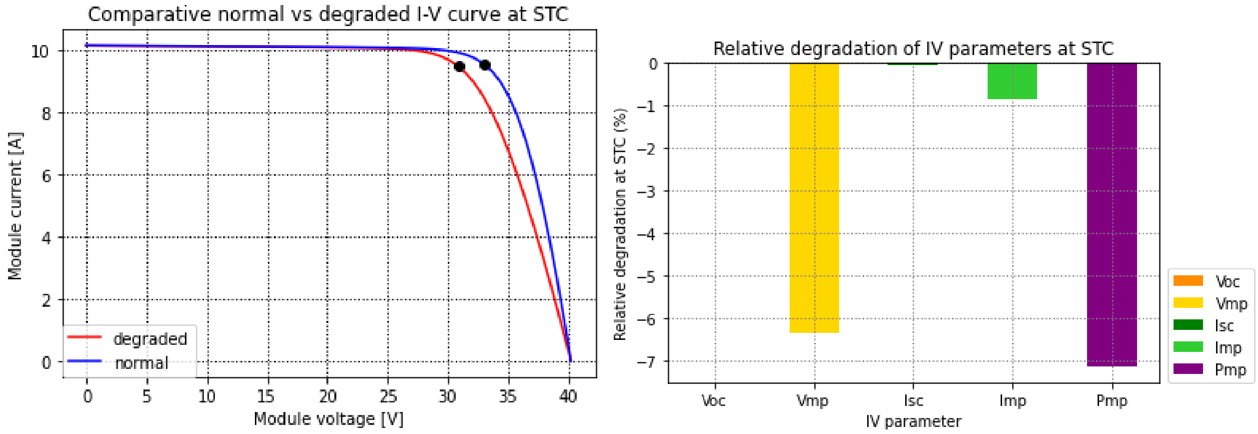


Figure 5.15: Simulated impact on IV curve of PV module when adding a series resistance of 200mohm

5.1.4.2 Artificial misalignment of GTI measurements and POA

As already explained, one of the MET Atersa 3002095 calibrated cells have been installed to emulate a potential issue in the measurement of GTI. More specifically, a common problem in the quality of irradiance measurements is the misalignment between the irradiance sensor and the actual plane of array. This can lead FDD tools to error. To evaluate this impact, one of the calibrated cells have been tilted 30º (instead of 36º) and oriented 3º East (instead of South), as shown in Figure 5.16.

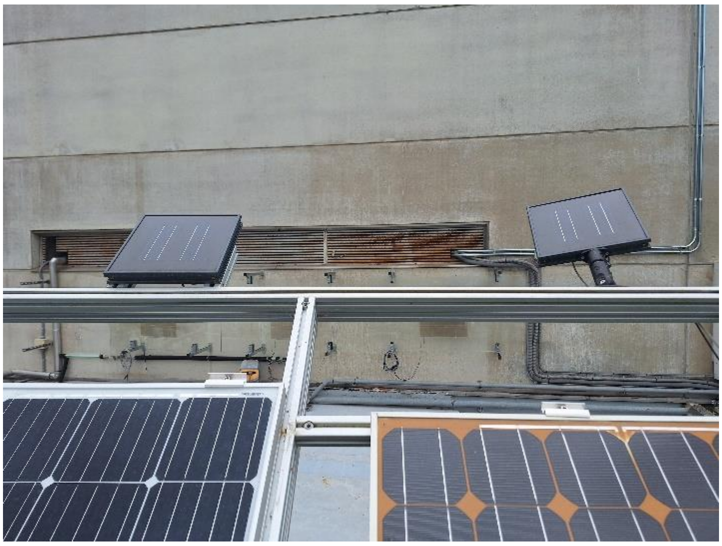


Figure 5.16: Artificial misalignment of one of the calibrated cells measuring GTI

5.1.4.3 Natural degradation

Four of the seven PV modules were removed from different PV sites, mostly after a long period in operation, and they present different natural degradation modes. These PV modules have been characterized in depth to check if FDD tools are able to provide the right diagnosis in qualitative and quantitative terms.

Analysis of the PV module Ningbo Solar TDB125X125-72-P L0869003224

The characteristic parameters of the IV curve provided by the manufacturer of this PV module are shown in Figure 5.17, as well as images of the front and rear side of this PV module.

Sun-Earth
Ningbo Solar
Electric Power Co.,Ltd
Mode: TDB125X125-72-P
Pmax: 175Wp
Vmp: 35.2V Imp: 4.96A
Voc: 44.0V Isc: 5.48A
Max.system voltage: 750V
Specifications at
AM1.5 1000W/m^2 25℃
Date of Manufacture: 15-03-2008
CE IEC

Figure 5.17: Electrical characteristics of Ningbo Solar PV module

Figure 5.18: Pictures of front and rear side of Ningbo Solar PV module

As it can be noticed in the Figure 5.18, the main issue in this PV module is the presence of yellowing and short-circuited protection diodes. As regards the first of the failure modes, a noticeable yellowing can be observed between the PV cells. However, no yellowing is observed on the cells themselves, which rather suggests a degradation of the backsheet. In Figure 5.19 yellowing effect can be analysed more in detail.

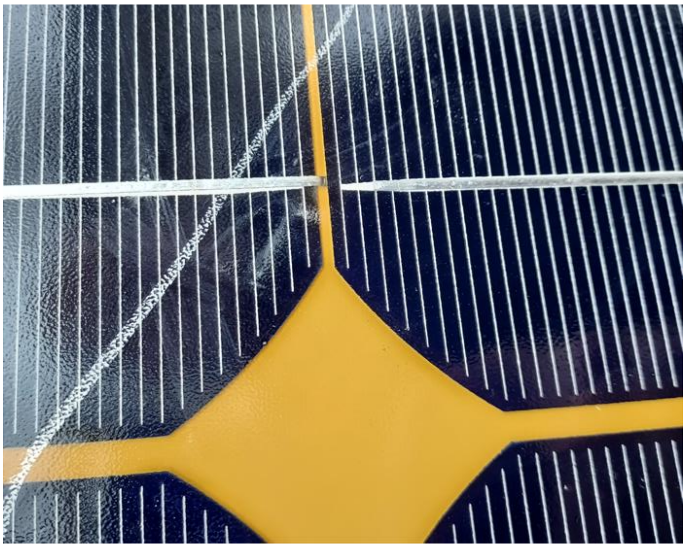


Figure 5.19: Yellowing of the backsheet of Ningbo Solar PV module

In relation to protection diodes, analysis of the junction box reveals very significant damage in most of them. Furthermore, the connection box shows clear symptoms of oxidation problems, as shown in Figure 5.20.

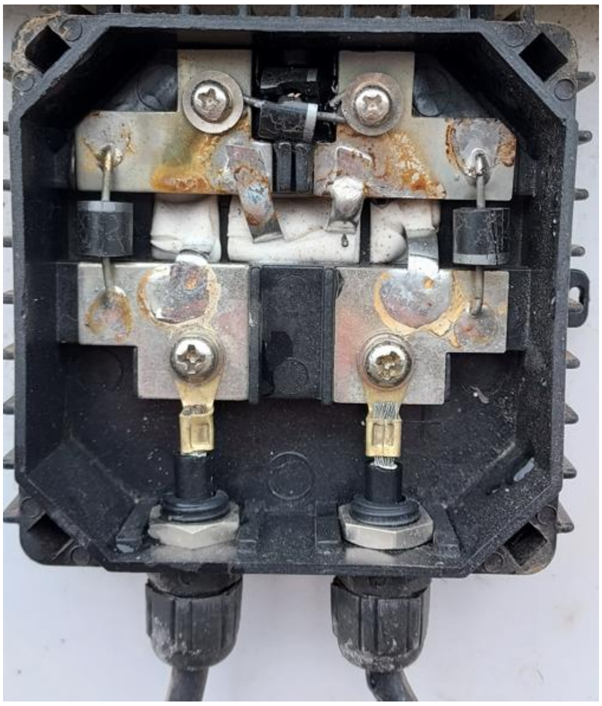


Figure 5.20: Junction box of Ningbo Solar PV module

As expected after the yellowing phenomena detected during visual inspection, a loss of performance associated with a loss of short-circuit current of the order of 5% is noticed during IV curve measurement. Furthermore, as it can be seen in Figure 5.21, the measured IV curve (black line) clearly shows the existence of certain mismatches in current generation within the cell strings leading to an apparent worsening of the parallel resistance of the PV module.

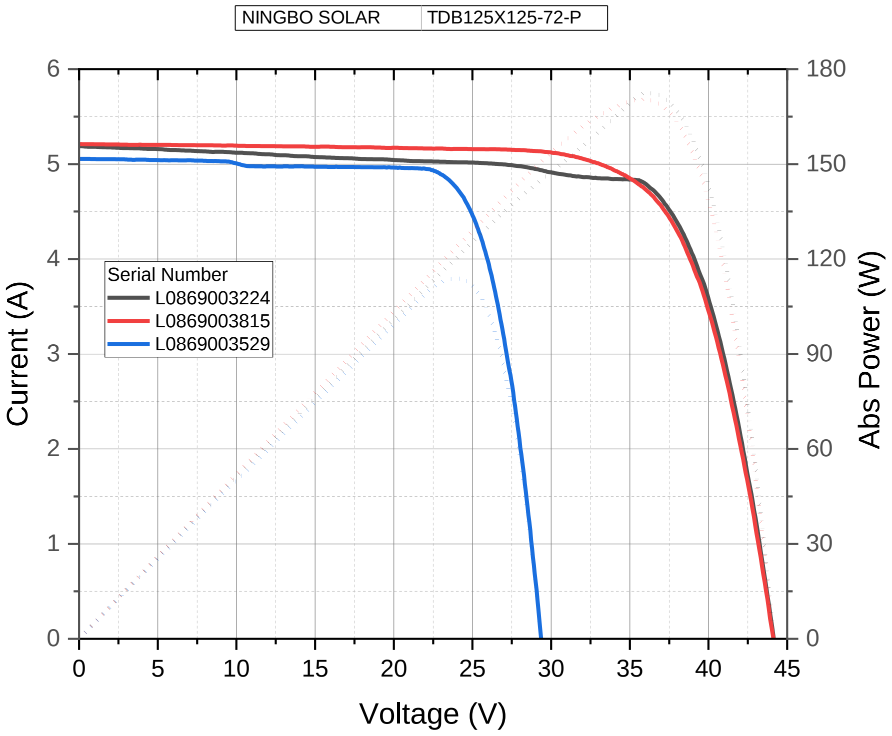
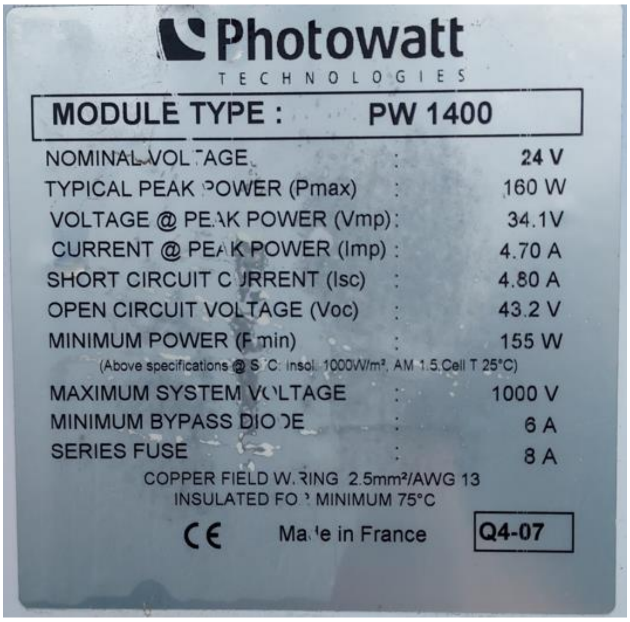


Figure 5.21: Measured IV curve (black line) of selected Ningbo Solar PV module

Analysis of the PV module Photowatt PW140 014000069092

The characteristic parameters of the IV curve provided by the manufacturer of this PV module are shown in Figure 5.22, as well as images of the front and rear side of this PV module in Figure 5.23.


Photowatt
TECHNOLOGIES

MODULE TYPE : PW 1400

NOMINAL VOLTAGE	:	24 V
TYPICAL PEAK POWER (Pmax)	:	160 W
VOLTAGE @ PEAK POWER (Vmp)	:	34.1V
CURRENT @ PEAK POWER (Imp)	:	4.70 A
SHORT CIRCUIT CURRENT (Isc)	:	4.80 A
OPEN CIRCUIT VOLTAGE (Voc)	:	43.2 V
MINIMUM POWER (Pmin)	:	155 W

(Above specifications @ STC: insol. 1000W/m², AM 1.5,Cell T 25°C)

MAXIMUM SYSTEM VOLTAGE	:	1000 V
MINIMUM BYPASS DIODE	:	6 A
SERIES FUSE	:	8 A

COPPER FIELD WIRING 2.5mm²/AWG 13
INSULATED FOR MINIMUM 75°C

CE Made in France Q4-07

Figure 5.22: Electrical characteristics of Photowatt PV module

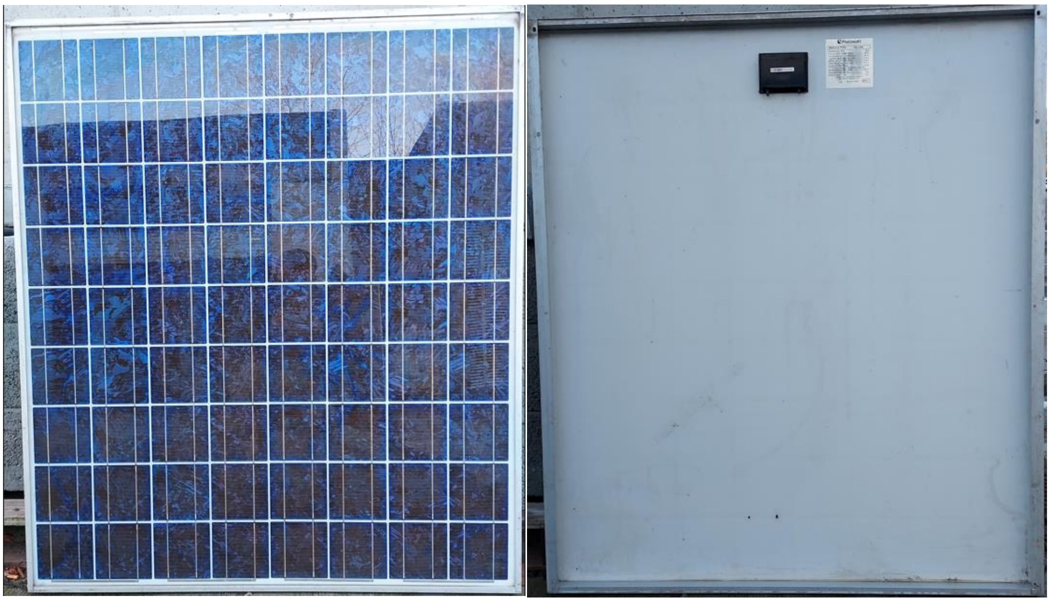


Figure 5.23: Pictures of front (left) and rear side (rigth) of Photowatt PV module

The main defect in this PV module is the existence of hot spots. Visual inspection of the back side reveals that some hot spots have indeed caused local burning of the backsheet, as shown in Figure 5.24.

Figure 5.24: Hot spots visible in the backsheet of Photowatt PV module

This phenomenon seems to be linked to the overheating of the welds between the interconnection strips between cells, which in some cases appear to show symptoms of oxidation. This effect can be observed in Figure 5.25.

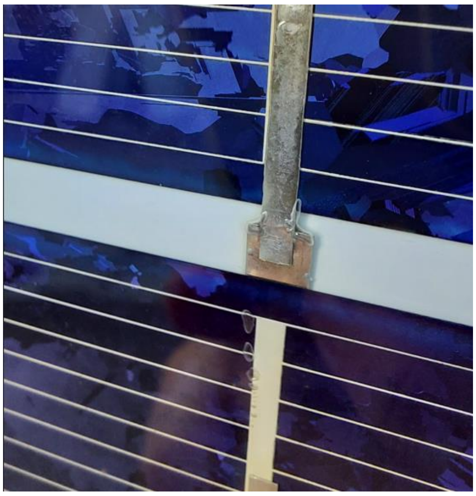


Figure 5.25: Oxidated welds in the interconnection strips of Photowatt PV module

Finally, visual inspection also reveals the existence of degradation of the encapsulant, resulting in a change of its colour, with a darker appearance. In some cases, this change in colour is not homogeneous throughout the cell area. A more detailed visual inspection of these cases determines that there are cells with multiple cracks/breaks that affect their physical integrity. Both issues can be appreciated in Figure 5.26.

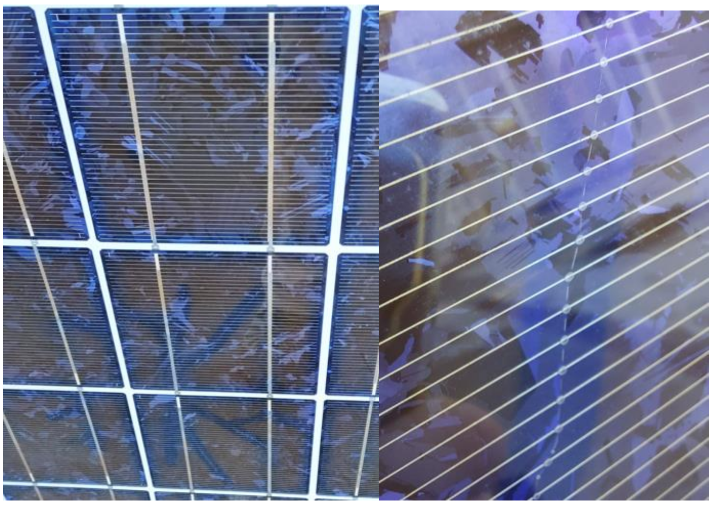


Figure 5.26: Observed decoloured PV cells and some cracks in Photowatt PV module

Consequently, measured IV curve for this PV module presents a significant reduction in the maximum power point voltage of 8%, despite its open circuit voltage does not seem to be affected. This phenomenon is compatible with an increase in the series resistance of the module linked to the failure modes described above, the existence of breaks in the PV cells and the failure of interconnection strips. Furthermore, the analysis of the degradation of the characteristic parameters of the I-V curve also shows a loss of around 15% in the short-circuit current level and 30% for the Imp. This significant reduction in the current level is compatible with the identification of multiple breaks/cracks in the solar cells during visual inspection.

In Figure 5.27 below, IV curve of monitored PV module (red line) shows an apparent reduction in parallel resistance compatible with the mismatch in current generation between cells with different types of breakages. The loss corresponding to the increase of series resistance mentioned above is also very evident.

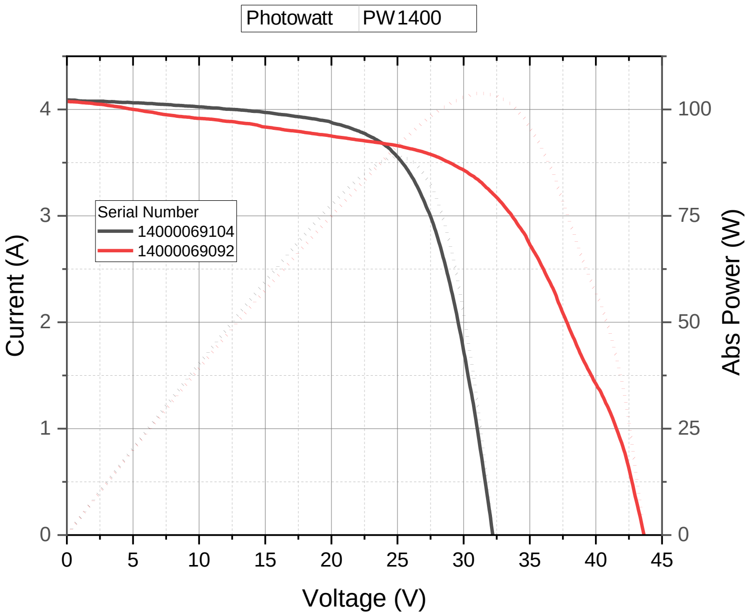


Figure 5.27: Measured IV curve (red line) of the selected Photowatt PV module

Analysis of the PV module Atersa A330M GS 112207428835

This PV module exhibits normal behaviour under visual inspection and IV curve measurement. However, electroluminescence (EL) inspection reveals different defects that could mean underperformance along the time. Some of these issues are microcracks, damages in some fingers and poor efficiency PV cells, as shown in Figure 5.28.

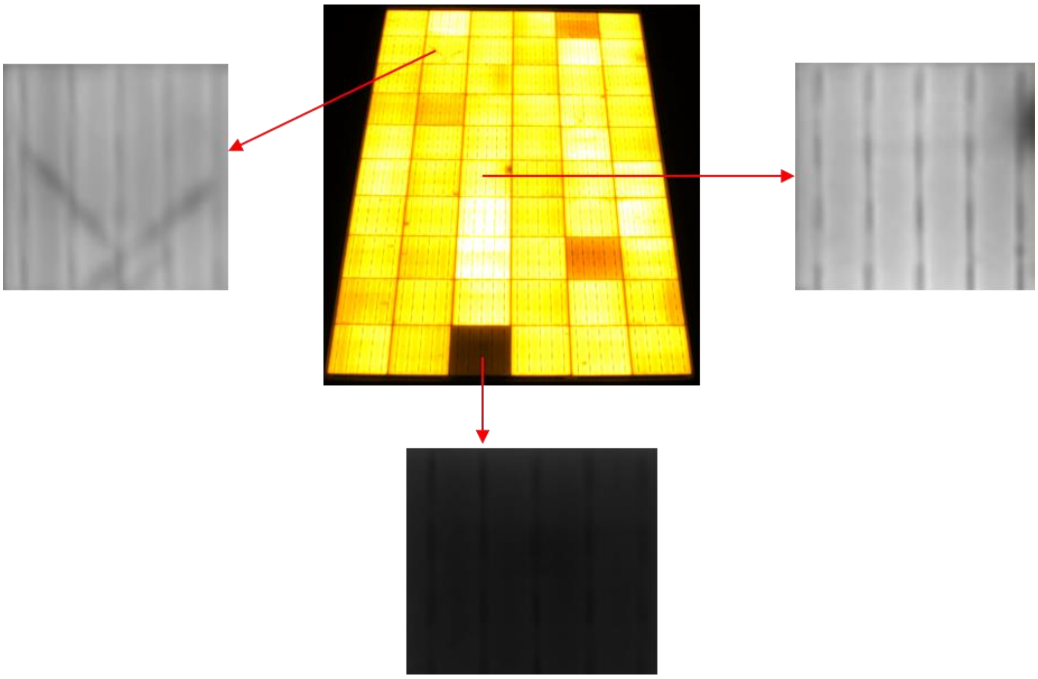
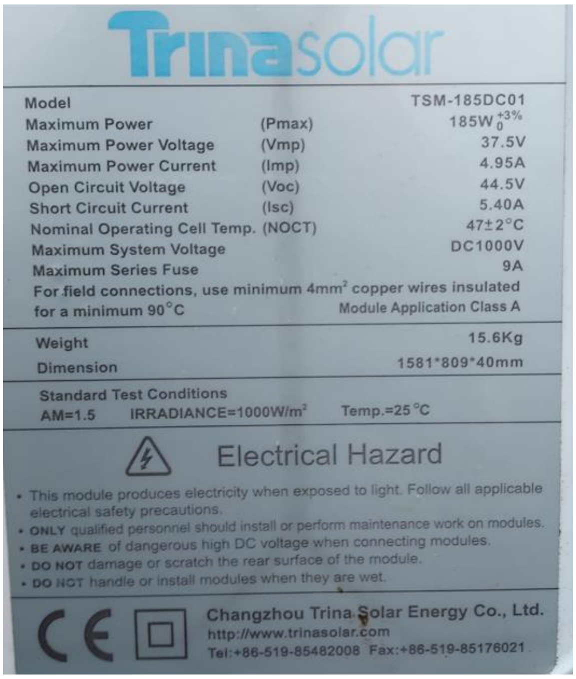


Figure 5.28: Electroluminescence of Atersa PV module with different noticeable defects: microcracks (left), damages in fingers (right) and poor efficiency PV cells (below)

Analysis of the PV module Trina Solar TSM/185DC01 110MG1403114

The characteristic parameters of the IV curve provided by the manufacturer of this PV module are shown in Figure 5.29, as well as images of the front and rear side of this PV module in Figure 5.30.



Trinasolar

Model		TSM-185DC01
Maximum Power	(Pmax)	185W $^{+3\%}_{0}$
Maximum Power Voltage	(Vmp)	37.5V
Maximum Power Current	(Imp)	4.95A
Open Circuit Voltage	(Voc)	44.5V
Short Circuit Current	(Isc)	5.40A
Nominal Operating Cell Temp.	(NOCT)	47±2°C
Maximum System Voltage		DC1000V
Maximum Series Fuse		9A

For field connections, use minimum 4mm² copper wires insulated for a minimum 90°C

Module Application Class A

Weight	15.6Kg
Dimension	1581*809*40mm

Standard Test Conditions
AM=1.5 IRRADIANCE=1000W/m² Temp.=25°C

Electrical Hazard

- This module produces electricity when exposed to light. Follow all applicable electrical safety precautions.
- ONLY qualified personnel should install or perform maintenance work on modules.
- BE AWARE of dangerous high DC voltage when connecting modules.
- DO NOT damage or scratch the rear surface of the module.
- DO NOT handle or install modules when they are wet.

Changzhou Trina Solar Energy Co., Ltd.
http://www.trinasolar.com
Tel:+86-519-85482008 Fax:+86-519-85176021

Figure 5.29: Electrical characteristics of Trina Solar PV module

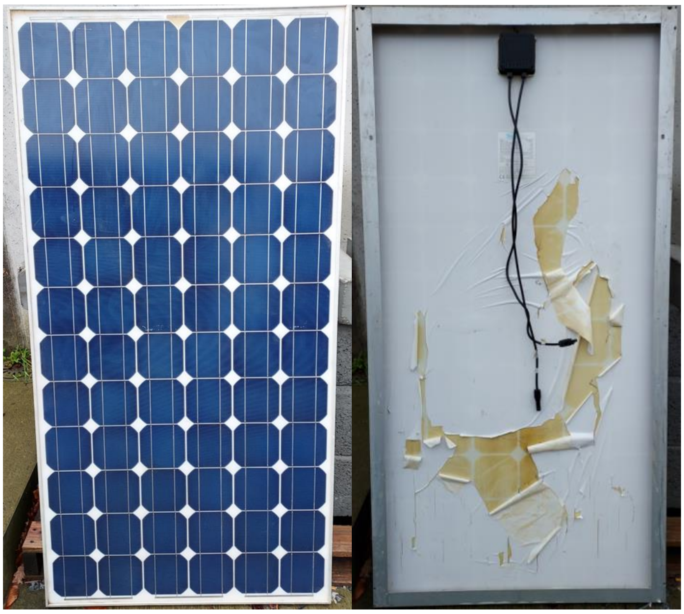


Figure 5.30: Pictures of front (left) and rear side (right) of Trina Solar PV module

In this case the main issue is the degradation of the backsheet. Visual inspection of the rear side reveals significant delamination of the outermost layer of the backsheet. However, the inner layer appears to still protect the encapsulant and the solar cells. This innermost layer shows significant degradation in the form of a change in coloration in the cell area.

As a result, measured IV curve, displayed in Figure 5.31, shows open-circuit voltage and short-circuit current values very close to the nominal values, but both Imp and Vmp show a significant reduction with typical values between 13% and 17%, which combined produce power losses greater than 25%.

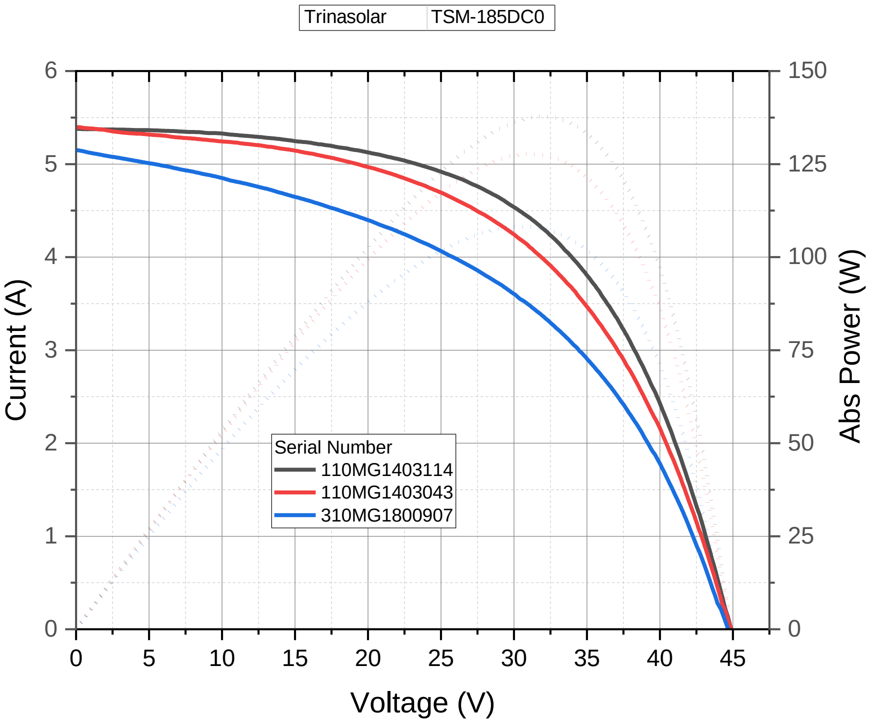
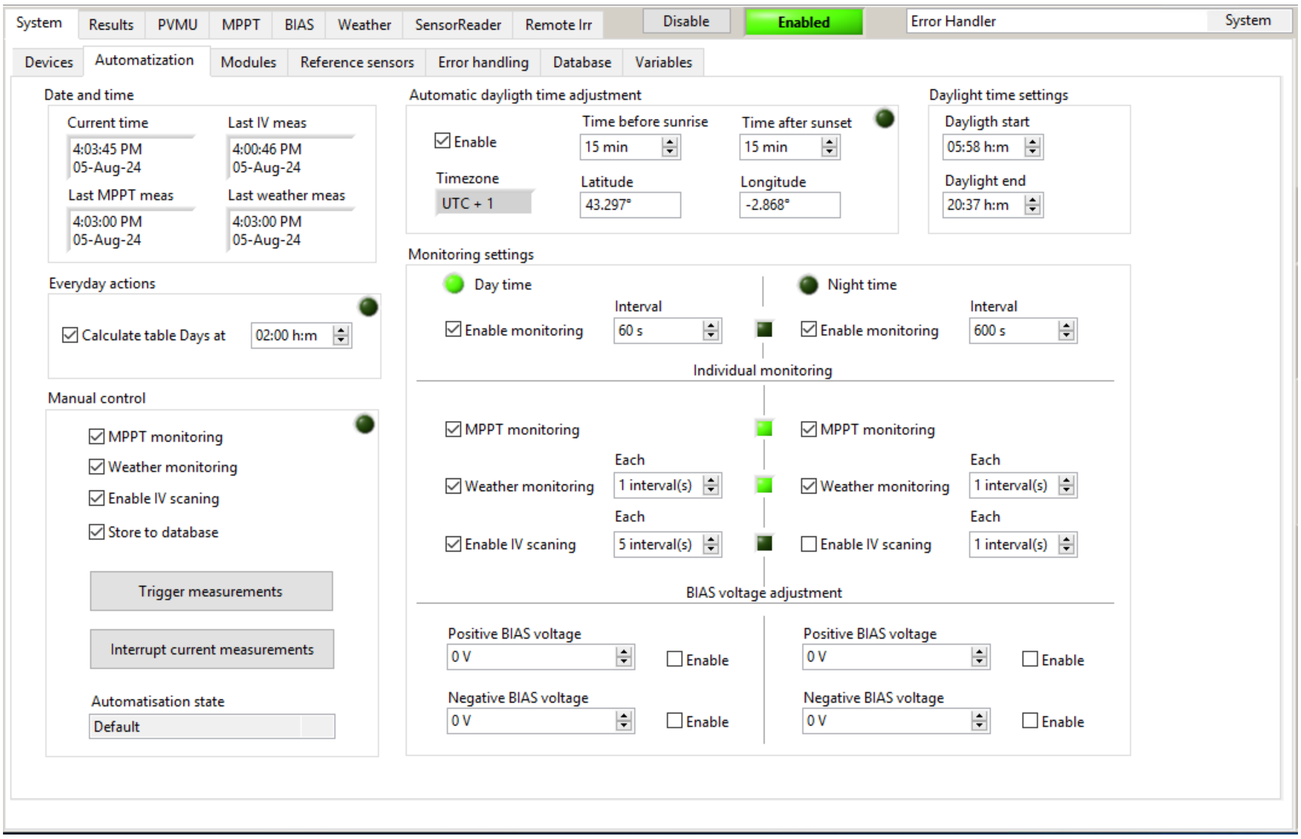


Figure 5.31: Measured IV curve (black) of selected Trina Solar PV module

5.1.5 Configuration of monitoring system

Figure 5.32 presents the configuration of the monitoring system and Figure 5.33 displays the monitored electrical data for one of the seven PV modules.



Date and time
Current time: 4:03:45 PM 05-Aug-24
Last IV meas: 4:00:46 PM 05-Aug-24
Last MPPT meas: 4:03:00 PM 05-Aug-24
Last weather meas: 4:03:00 PM 05-Aug-24

Everyday actions
☑ Calculate table Days at 02:00 h:m

Manual control
☑ MPPT monitoring
☑ Weather monitoring
☑ Enable IV scaning
☑ Store to database
Automatisation state: Default

Automatic daylight time adjustment
☑ Enable
Time before sunrise: 15 min
Time after sunset: 15 min
Timezone: UTC + 1
Latitude: 43.297°
Longitude: -2.868°

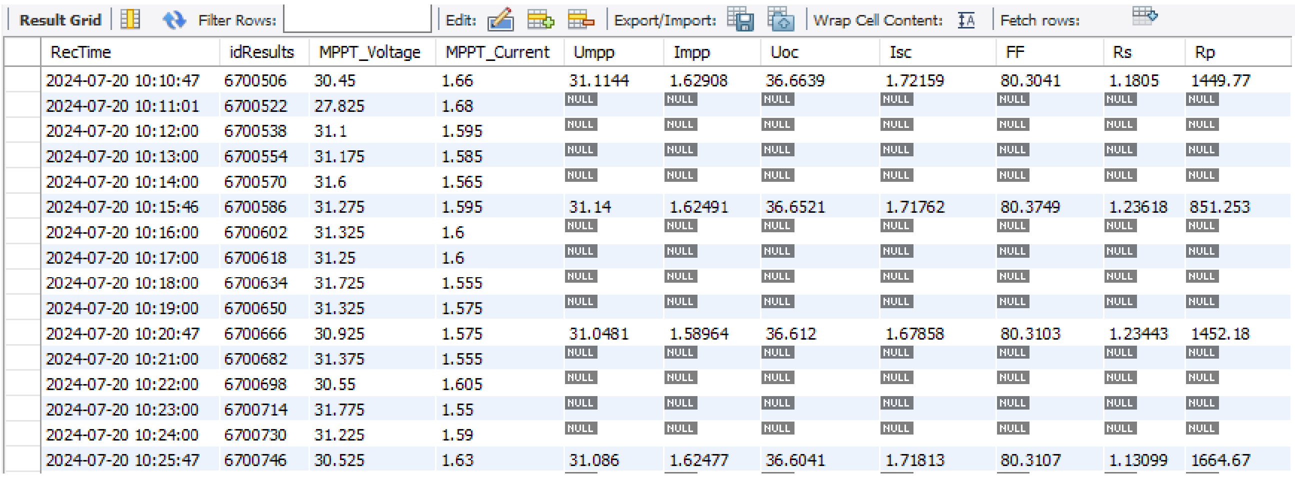
Daylight time settings
Daylight start: 05:58 h:m
Daylight end: 20:37 h:m

Monitoring settings
Day time
☑ Enable monitoring, Interval: 60 s
Night time
☑ Enable monitoring, Interval: 600 s

Individual monitoring
Day time:
☑ MPPT monitoring
☑ Weather monitoring, Each: 1 interval(s)
☑ Enable IV scaning, Each: 5 interval(s)
Night time:
☑ MPPT monitoring
☑ Weather monitoring, Each: 1 interval(s)
☐ Enable IV scaning, Each: 1 interval(s)

BIAS voltage adjustment
Positive BIAS voltage: 0 V ☐ Enable
Negative BIAS voltage: 0 V ☐ Enable
Positive BIAS voltage: 0 V ☐ Enable
Negative BIAS voltage: 0 V ☐ Enable

Figure 5.32: Configuration of monitoring system for data collection



RecTime	idResults	MPPT_Voltage	MPPT_Current	Umpp	Impp	Uoc	Isc	FF	Rs	Rp
2024-07-20 10:10:47	6700506	30.45	1.66	31.1144	1.62908	36.6639	1.72159	80.3041	1.1805	1449.77
2024-07-20 10:11:01	6700522	27.825	1.68	NULL	NULL	NULL	NULL	NULL	NULL	NULL
2024-07-20 10:12:00	6700538	31.1	1.595	NULL	NULL	NULL	NULL	NULL	NULL	NULL
2024-07-20 10:13:00	6700554	31.175	1.585	NULL	NULL	NULL	NULL	NULL	NULL	NULL
2024-07-20 10:14:00	6700570	31.6	1.565	NULL	NULL	NULL	NULL	NULL	NULL	NULL
2024-07-20 10:15:46	6700586	31.275	1.595	31.14	1.62491	36.6521	1.71762	80.3749	1.23618	851.253
2024-07-20 10:16:00	6700602	31.325	1.6	NULL	NULL	NULL	NULL	NULL	NULL	NULL
2024-07-20 10:17:00	6700618	31.25	1.6	NULL	NULL	NULL	NULL	NULL	NULL	NULL
2024-07-20 10:18:00	6700634	31.725	1.555	NULL	NULL	NULL	NULL	NULL	NULL	NULL
2024-07-20 10:19:00	6700650	31.325	1.575	NULL	NULL	NULL	NULL	NULL	NULL	NULL
2024-07-20 10:20:47	6700666	30.925	1.575	31.0481	1.58964	36.612	1.67858	80.3103	1.23443	1452.18
2024-07-20 10:21:00	6700682	31.375	1.555	NULL	NULL	NULL	NULL	NULL	NULL	NULL
2024-07-20 10:22:00	6700698	30.55	1.605	NULL	NULL	NULL	NULL	NULL	NULL	NULL
2024-07-20 10:23:00	6700714	31.775	1.55	NULL	NULL	NULL	NULL	NULL	NULL	NULL
2024-07-20 10:24:00	6700730	31.225	1.59	NULL	NULL	NULL	NULL	NULL	NULL	NULL
2024-07-20 10:25:47	6700746	30.525	1.63	31.086	1.62477	36.6041	1.71813	80.3107	1.13099	1664.67

Figure 5.33: Database with electrical measurements for one of the 7 PV modules

Irradiance parameters correspond to the irradiance measured by the 3x GTI sensors and GHI sensor described above. An averaged module temperature (middle + lower corner) is provided for each PV module. Finally, rest of meteorological parameters: relative humidity, ambient temperature, and wind speed/direction are also provided.

5.1.6 Use of the database (WP7 collaborations)

This database provides a comprehensive electrical performance characterization of seven samples of degraded and non-degraded PV modules working at their maximum power point under Atlantic meteorological conditions for spring and summer.

The main aim of this dataset is to test FDD tools. For this purpose, these FDD tools should be fed with monitored output voltages and currents of every PV module and their monitored working conditions. This way it can be evaluated if these data analytics tools can detect and diagnose the existing degradation modes in some of these samples. The provided characterization of each PV module through periodic IV curve measurements allows to check the test results with high reliability.

5.2 Metadata from 18,000 PV systems available in open database

BDPV (Base de Données Photovoltaïque) is a French database and platform dedicated to the collection, analysis, and sharing of data related to photovoltaic (PV) solar installations in France. BDPV provides insights into the performance of solar PV systems, helping users track and optimize their solar energy production.

The key features of BDPV include:

- **Performance monitoring**: BDPV allows solar PV owners to monitor the performance of their installations by comparing their production data against similar systems in the region. This helps identify underperforming systems and optimize energy yields.
- **Data sharing**: Users can voluntarily share their production data to contribute to a larger dataset that helps track the overall performance of solar PV systems in France.
- **Benchmarking**: BDPV provides benchmarking tools, enabling users to compare their system's performance against the average performance of similar systems, considering factors such as location, size, and technology.
- **Transparency and advocacy**: By aggregating data from thousands of installations, BDPV helps promote transparency in the solar market and supports advocacy for renewable energy by providing reliable data on solar PV performance.
- **Educational resource**: The platform also serves as an educational resource for individuals and companies interested in solar energy, offering insights into system performance, financial returns, and the impact of solar PV on reducing carbon emissions.
- **Community engagement**: BDPV fosters a community of solar enthusiasts, professionals, and researchers who share information, tips, and experiences to improve the performance and adoption of solar PV in France.

BDPV plays a crucial role in the solar PV landscape in France, promoting the use of data to improve system performance, increase transparency, and drive the adoption of solar energy across the country.

The collaboration between LuciSun and BPDV, together with Mines ParisTech and the French TSO RTE, led to the publication of a scientific article [6]. The scientific article "*A crowdsourced dataset of aerial images with annotated solar photovoltaic arrays and installation metadata*" showcases a remarkable collaboration between several prominent institutions.

The article presents a detailed dataset that includes aerial images, segmentation masks, and metadata for over 18,000 solar photovoltaic installations. Created through a large-scale crowdsourcing effort, this dataset is designed to aid in the accurate mapping of PV installations, crucial for energy planning and grid management. The collaboration leveraged diverse expertise in data science, energy systems, and machine learning, resulting in a robust and comprehensive resource.

The metadata are available at https://zenodo.org/records/7358126 and are embedded in the resource mapping put in place on COPLASIMON and as resource in the CKAN platform. For more details, the full article is available at https://www.nature.com/articles/s41597-023-01951-4 .

5.3 MLS feedback on data sharing of over 2000 PV systems

In this section MLS provides its feedback on data sharing for a medium size company (~300 employees – ~50 in R&D) operating 2 systems which have over 15,000 PV systems declared each. MLS data were advertised in the "Residential PV and BIPV collaboration call" described in section 7.3 of deliverable 7.5.

5.3.1 General description of the database (parameters included in the dataset)

The monitoring period is from 2015 to 2021 on 2037 PV systems. The systems are monitored at a 10-minute resolution. The systems are primarily located in Belgium, with the remainder across Europe (see Figure 5.34).

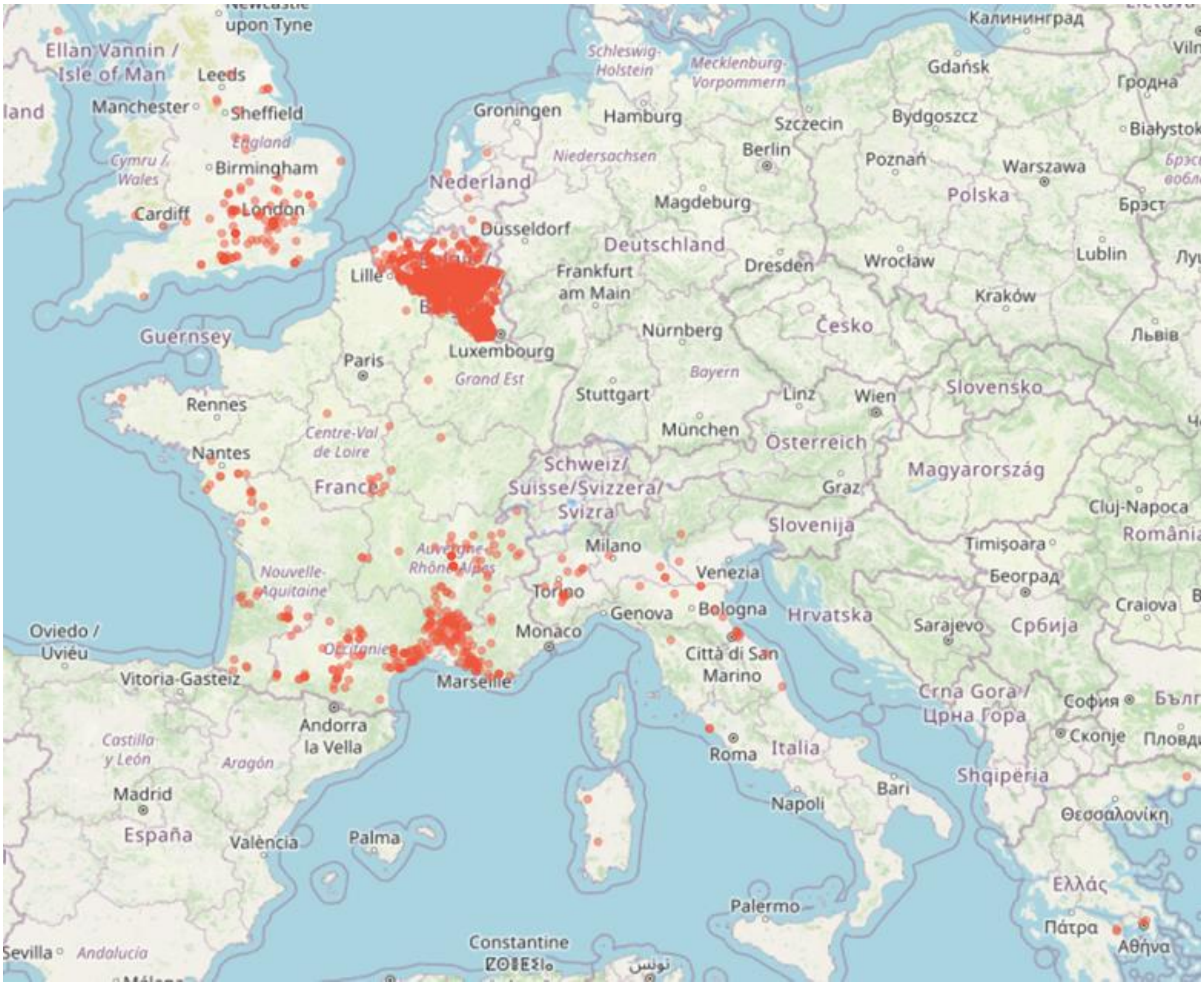


Figure 5.34: Map of the PV systems anonymised data shared by MLS

The majority of these systems have a DC nameplate power below 12 kWp as shown in Figure 5.35

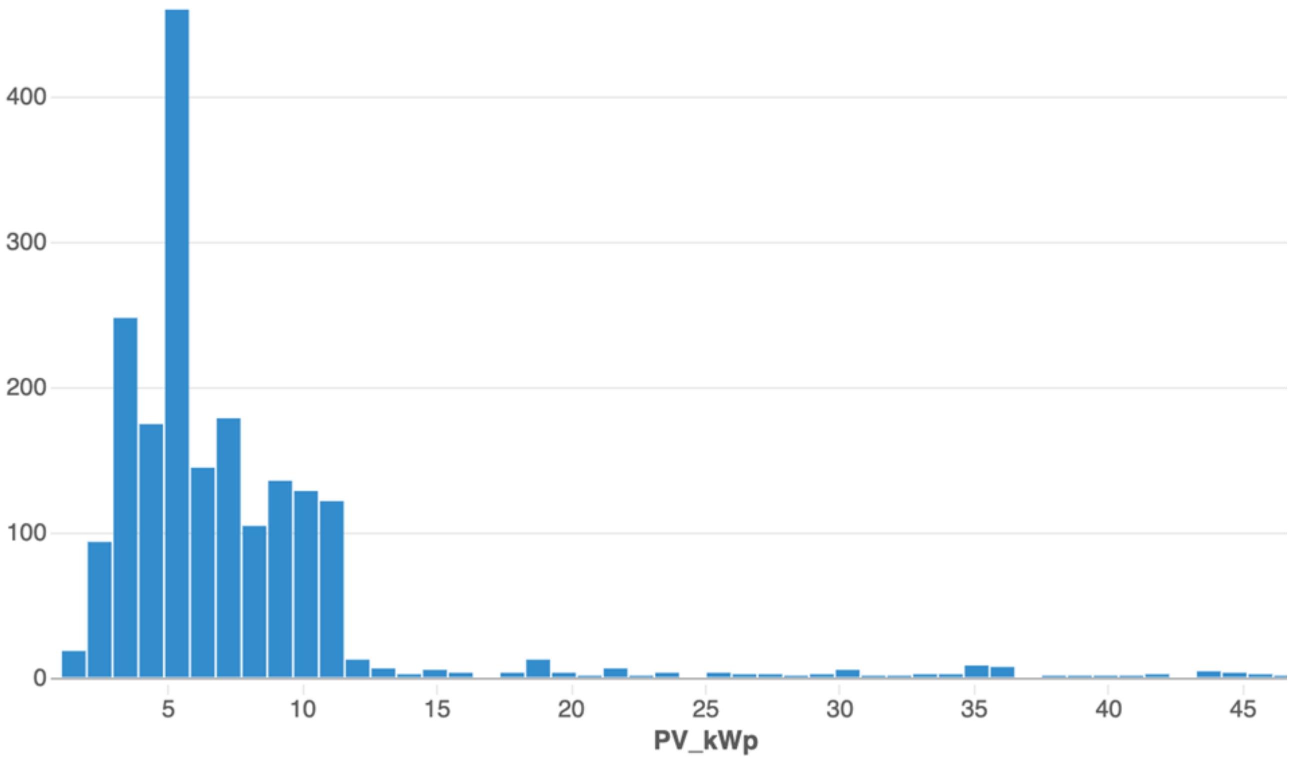


Figure 5.35: kWp distribution of data shared by MLS

The format of the data is:

- Device_id: unique identifier of the PV system
- Timestamp_UTC: time and date in UTC of the measure
- Wh: energy produced during the timestep.

A sample data looks like:

Device_id	Timestamp_UTC	Wh
1978	2011-07-07 11:20:00.000	11670
1978	2011-07-07 11:30:00.000	10190
1978	2011-07-07 11:40:00.000	13410
1978	2011-07-07 11:50:00.000	12180
1978	2011-07-07 12:00:00.000	10410
1978	2011-07-07 12:10:00.000	10790
1978	2011-07-07 12:20:00.000	10020
1978	2011-07-07 12:30:00.000	10090
1978	2011-07-07 12:40:00.000	5580
1978	2011-07-07 12:50:00.000	4180
1978	2011-07-07 11:20:00.000	11670
1978	2011-07-07 11:30:00.000	10190
1978	2011-07-07 11:40:00.000	13410

The metadata includes (many missing values and some inaccurately declared data):

- Latitude (with reduced precision)
- Longitude (with reduced precision)
- Power of the system in kWp

- Panel Surface in m²
- Azimuth in degrees
- Tilt in degrees

5.3.2 Data extraction

5.3.2.1 Source system data extraction

First of all, we will describe the problems we encountered while extracting the data from a running production system. Production systems are usually oriented towards one or many commercial products and their data models are designed towards those use-cases. It usually means that the systems are targeted with workloads that require to access data for one or few users at the same time, and not for massive data extraction.

There are usually two choices to extract massive amounts of data in such settings:

- Request user by user the data at low rate so that the system can continue to operate normally for end-users: it might take days or months to extract the data. Trying to be faster would probably overload and collapse the production system/servers.
- Dump the database into flat files:
  - Most databases have backup/dump options
  - Usually, it has less impact than massively requesting the database, but it is still probably better to do this at night when there are fewer users connected and less activity on the servers
  - In MLS case the administration of this server/database is outsourced, and we needed to plan the request for the dump and its upload to our Azure cloud.

Once this massive amount of data extracted is available, you need to have a system that can read it and process it at scale. In our case the dump was a 100GB MySQL dump file that has to be read sequentially. We tried to restore the dump into a new MySQL instance, but it took hours, and we would need an expensive machine in Azure for that. It would also mean we would have to query the database later and it would be extremely slow to get all the data we wanted to extract. We decided to write a custom MySQL dump reader to read directly the dump file and store the data into a file format efficient for data analysis: Parquet files that we can be processed at scale in Spark/Azure/Databricks.

5.3.2.2 Rebuilding the data model

Once the raw data are extracted, you need to be able to process it. Data and metadata are in many tables, and it is needed to reconstruct the data model, i.e.: links (primary/foreign keys) between those tables. The help of people who developed the application/software might be needed. Having access to the source code to do some reverse engineering might be helpful too. In MLS case we had to rebuild the links between 8 tables to be able to get the metadata associated with the data (location, slope, azimuth, panels surface…) and dig into the source code to understand how units and time zones are stored/processed. Basically, what can be seen in the UI/WebPage and what is stored are sometimes very different. In Figure 5.36, the screenshot shows many PV system characteristics which are not stored with the same unit in the database.

My installation

Peak power: 2.88 kWp

Production (estimate): 2,930.00 kWh/year

Panels: BP Solar BP3160N - 160W 23.00 m²

Orientation: 180° (SOUTH)

Slope: 30°

Inverter: SMA Sunny Boy

My production

▶ 01 Sep 2011 - 22 Sep 2011

Comparison with: 11 Aug 2011 - 01 Sep 2011

Efficiency - within period:

Periods	01/09 - 22/09
kWh	193.80
kWh/kWp	67.29
€	116.28

☐ Search alerts

My production report

My production over the last 12 months

Figure 5.36: Screenshot of RBee solar UI (from public documentation on the website)

5.3.2.3 Data quality checks

MLS did not want to share all those data before checking their quality. Some statistics and data quality checks were performed:

- How many PV systems are there?
- How many years of data do they have?
  - Some customers resigned so only few years of data are available for them
  - Some PV systems might have issues (hardware, communication to the Cloud…)

We did not check the production/irradiation data as they are the core of the products and used by our customers and MLS every day.

We used the following criterion to select the data that MLS proposed to share:

- Operational hours: data is considered only for the hours between 8 am and 7 pm (11 hours of daylight) to avoid excluding systems with nighttime issues.
- Inclusion criteria for shared data:
  - A minimum of 350 days per year with at least one data point.
  - Less than 17% missing data during a year (equating to at least 20,000 data points per year, given that the maximum for 365 days and 11 hours of daylight is 24,090 data points).
- Timespan of many years for enough systems:
  - Data extract done in 2022: 2037 PV systems for 7 years (2015 to 2021)
  - Data extract done in 2024: 467 PV systems for 11 years (2013 to 2023)

5.3.3 Collaboration calls/NDA

MLS could not share publicly those data, for privacy reasons, but MLS has however found an agreement to share them under NDA with more knowledge of the context in which they would be used and how the results would be published. MLS goals are to help research projects and tools within the PV community without putting too much focus on the specificity of the data we shared.

The anonymisation was simple, MLS removed personal data and lower the coordinates resolution to few kilometres as shown in Figure 5.37.

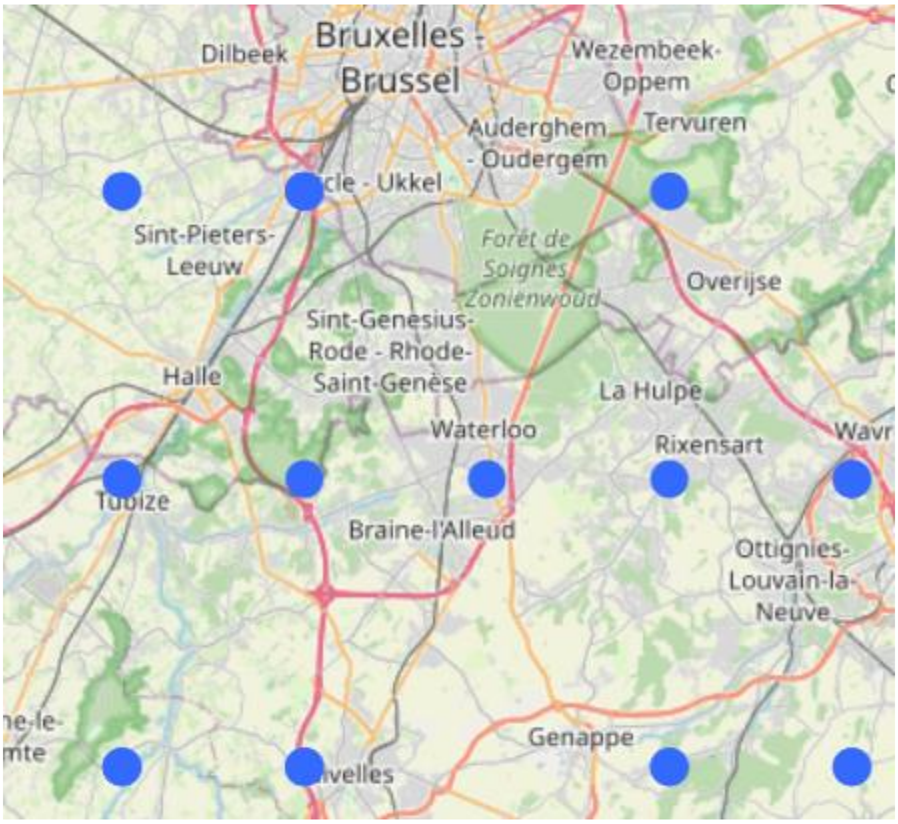


Figure 5.37: Map of coordinates after anonymization

The collaboration calls allowed MLS to have more visibility to people who could be interested in those data. The COPLASIMON platform helped to have a coherent and common public place between multiple actors and business. MLS signed two NDAs in July 2024 and shared the data just after the signature using a key protected Azure blob storage (method described in D7.2).

MLS did not have NDAs related to data sharing before the collaboration calls. We needed to draft new NDAs for this use-case. We particularly paid attention to:

- **What data will be used for**: description of a "project" in the NDA so that partners are cleared on the goals related to the data shared.
- **What will be published**: a formal approval is asked by MLS before anything is published so that we can validate and control how our data were used.
- In case of any dispute, the tribunal in charge will be in France under French law.

A first feedback on the data was gathered at the end of September 2024:

"The PV power production from the long-term dataset (11 years) has been used to build an AI model to predict the global radiation at each site. The peak performance of the sites did not always exactly match the actual power production. Although this suggests that the quality of the metadata could be improved, the first results

from this dataset look promising. Our intermediate results suggest that the PV power production is of high enough quality to perform our analysis."

The feedback is positive and confirmed that some of the metadata were not of good quality.

Even after the end of SERENDI-PV project, MLS will still be opened to discuss sharing some of its PV data under NDA.

5.4 Site Specific Energy Rating Datasets

5.4.1 General description of the dataset and it's parameters.

Measuring photovoltaic (PV) module performance under standard test conditions (STC) has its limitations, highlighting the need for better assessments that reflect real-world conditions. The IEC 61853 standard offers a method to evaluate PV module performance under various climate conditions, factoring in parameters like angle of incidence, solar spectrum variations, module temperature, and irradiance levels.

These datasets allow to evaluate the applicability of these standard climate profiles for two specific locations in Middle (Freiburg, Germany) and South Europe (Canary Islands, Spain). They can be used to comparing climate-specific energy ratings (CSER) with site-specific energy ratings (SSER). This can emphasize the importance of using localized meteorological data for accurate performance assessments.

The datasets have been generated for a period of 12 months to allow for a full seasonal cycle (especially in terms of spectral irradiance distribution.

These datasets are made available and documented in the CKAN section of COPLASIMON, in the following link:

https://ckan.coplasimon.eu/organization/fraunhofer-ise.

The dataset includes the following 40 parameters necessary to conduct a SSER:

- ✓ Weather conditions monitoring (synchronized with modules electrical measurements):
  - Timestamp. The temporal resolution is hourly.
  - Ambient temperature (øC)
  - Wind speed (m/s)
  - RH (%)
  - Sun elevation (ø)
  - Sun incidence angle (ø)
  - Gh (W/m2)
  - Dh (W/m2)
  - G (W/m2)
  - B (W/m2)

- ✓ Inclined global spectral irradiance in 29 bands:
  - 306.8-327.8nm
  - 327.8-362.5nm

  - 362.5-407.5nm
  - 407.5-452.0nm
  - 452.0nm-517.7nm
  - 517.7-540.0nm
  - 540.0-549.5nm
  - 549.5-566.6nm
  - 566.6-605.0nm
  - 605.0-625.0nm
  - 625.0-666.7nm
  - 666.7-684.2nm
  - 684.2-704.4nm
  - 704.4-742.6nm
  - 742.6-791.5nm
  - 791.5-844.5nm
  - 844.5-889.0nm
  - 889.0-974.9nm
  - 974.9-1045.7nm
  - 1045.7-1194.2nm
  - 1194.2-1515.9nm
  - 1515.9-1613.5nm
  - 1613.5-1964.8nm
  - 1964.8-2153.5nm
  - 2153.5-2275.2nm
  - 2275.2-3001.9nm
  - 3001.9-3635.4nm
  - 3635.4-3991.0nm
  - 3991.0-4605.65nm

The parameter set is the same for both SSER datasets

6 CONCLUSION

The innovations developed within Task 7.4 of the SERENDI-PV project are a contribution to the photovoltaic (PV) industry by enhancing access to high-quality, validated data and tools.

In the first subtask, a database of solar resource and weather data was developed and implemented, offering access to high-quality ground-measured data as well as Solargis model data, and comparison of the two.

The second subtask saw development of a database for PV component specifications, which includes rigorous processes for verification and validation of the data entered into the database, and an API connection for the users.

Within the third subtask, a database of performance monitoring of non-degraded and degraded PV modules, and a database of metadata from over 18,000 PV systems were developed, and additionally, operational experience with sharing metadata about a large number of PV system was described.

The three subtasks addressed key aspects of data availability, including solar resource and weather data, PV component specifications, and real-world PV system performance. These databases and tools have been designed with the aim of continuing beyond the project’s completion, offering ongoing support to practitioners in the PV industry in their development of new technologies and solutions.

The alignment of these databases with international standards and the European framework for data sharing highlights their relevance and applicability on a broader scale. By adhering to the FAIR principles (Findable, Accessible, Interoperable, and Reusable), the tools developed in this project will support the broader EU Action Plan for Digitalising the Energy System, promoting collaboration and innovation across the renewable energy sector. These outcomes underscore the project's impact on the digital transformation of the energy industry, fostering advancements in PV technology and sustainable energy solutions.

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