Swiss PV Circle

Work package 1 - Database

Operating model of the database/platform for second-hand photovoltaic modules

Work package number	AP1
Work package title	Database
Work package lead	Bern University of Applied Sciences
Deliverable number	AP1.1
Deliverable name	Operating model of the database/platform for second-hand photovoltaic modules
Status	Final report
Author	Ässia Boukhatmi
Distribution level	Public
Publication date	16.06.2025

Contents

Mit Unterstützung von energieschweiz

Executive Summary

The rapid expansion of photovoltaics (PV) to support climate change is expected to lead to a significant increase in end-of-life modules. In order to manage the growing waste streams and promote resource efficiency, the circular economy is an economic model that aims to create circular material flows. Digital technologies, including Digital Product Passports (DPP), are a much-discussed driver of the circular economy as they provide stakeholders in the solar industry with important information on installed PV systems to make better decisions on reuse practices. Even though the DPP has become well known in recent years, depending on the industry, it is often overlooked that it is based on a database that collects and updates the relevant data on the product life cycle, as well as a digital platform that enables data exchange between relevant actors and incentivises them economically with the help of 'value added services'. For this reason, the basis for the future implementation of a digital product passport for PV modules was created as part of work package 1 in the Swiss PV Circle project. This endeavour includes several sub-aspects, including the collection and preparation of data from various public and non-public data sources within Switzerland, as well as the development of a database based on the OpenAPI standard to enable later adaptations and additions. In addition, an initial concept for the operationalisation of the platform and a prototype for the visualisation of the data in the form of a DPP were developed. The concept also includes a possible business model for the platform, which was developed in consultation with the project partners and other stakeholders in the solar industry. Due to compliance with data protection guidelines, the data used will not be made available to the public.

Mit Unterstützung von energieschweiz

1. Introduction

Digital technologies play a crucial role in the transformation towards a circular economy by improving the flow of information along value chains and enabling data-driven decisions. Key technologies include digital platforms that act as intermediaries between different players and promote transactions and the shared use of resources. These platforms support circular business models by creating transparency, facilitating the exchange of products and materials and promoting reuse. In addition, databases provide a powerful infrastructure for the structured collection and management of product, process and life cycle data. By combining various digital technologies such as digital product passports with analysis techniques, comprehensive information about products and their condition can be collected, which in turn supports the development of efficient strategies for effective reuse, refurbishment and recycling.[1]

Databases are structured systems for storing, managing and retrieving large amounts of information. They make it possible to store data in an organised form and process it efficiently. A relational database, one of the most commonly used models, organises data into tables with rows and columns that can be linked together. This structure allows complex queries, the merging of information from different tables and the consistent management of data.[2]

Digital product passports (DPPs) comprise and centralise standardised data on products throughout their entire life cycle. They contain information on material composition, origin, use, repair options and end-of-life options such as reuse or recycling.[3] The aim of digital product passports is to increase transparency in the value chain and promote circular strategies through improved traceability and data-based decisions

Digital platforms play a central role in the implementation of the digital circular economy by networking various digital technologies (e.g. databases, DPPs and data analysis techniques) and promoting collaboration and innovation between different stakeholders.[4] A key success factor for platforms is the network effect, which states that the value of a platform increases with the number of its users. Digital platforms can be found in various contexts, whether within a company, between companies or across sectors in value chains and ecosystems.[5] While market-mediated platforms primarily enable the exchange of products and services in multi-sided markets, platform ecosystems offer more comprehensive opportunities for value creation thanks to their openness and innovative strength.[6] In order to make platforms economically viable and encourage their user groups to share and exchange data in the sense of the circular economy, a good service portfolio ('value added services') is of key relevance. Platform services refer to the central activities and functions that

[1] Boukhatmi, Nyffenegger, and Grösser, "Designing a Digital Platform to Foster Data-Enhanced Circular Practices in the European Solar Industry"; Pagoropoulos, Pigosso, and McAloone, "The Emergent Role of Digital Technologies in the Circular Economy"; Kristoffersen et al, "The Smart Circular Economy"; Bressanelli et al, "Exploring How Usage-Focused Business Models Enable Circular Economy through Digital Technologies"; Chauhan, Parida, and Dhir, "Linking Circular Economy and Digitalisation Technologies."

[2] Elmasri and Navathe, *Fundamentals of Database Systems*.

[3] Boukhatmi, Nyffenegger, and Grösser, "Designing a Digital Platform to Foster Data-Enhanced Circular Practices in the European Solar Industry"; Walden, Steinbrecher, and Marinkovic, "Digital Product Passports as Enabler of the Circular Economy"; Honic, Kovacic, and Rechberger, "Concept for a BIM-Based Material Passport for Buildings."

[4] Autio, "Orchestrating Ecosystems"; Bonina et al, "Digital Platforms for Development."

[5] Thomas, Autio, and Gann, "Architectural Leverage."

[6] Parker, Alstyne, and Choudary, *Platform Revolution*; Tiwana, *Platform Ecosystems*.

connect the platform architecture with its users and thus enable joint value creation in the platform ecosystem.[7]

The results achieved in the project with regard to the use of databases, DPPs and digital platforms are presented below.

2. Data basis

2.1 Data sources

The data used for this study came from four main sources. Firstly, we used a public dataset from the Opendata.Swiss portal, which is regularly published by the Swiss Federal Office of Energy (SFOE). The dataset contains the electricity production plants registered in the Swiss Guarantee of Origin system with location, installation date, installed capacity and PV plant type. By the end of the year, this dataset comprised around 225,000 PV systems between 0 and 35 years old.[8]

The second, non-public data source, which was provided by the SFOE together with Pronovo as part of the Swiss PV Circle project, comprises fifteen time series data sets that show the monthly energy production of each PV system between 2009 and 2023. Further data sets from the SFOE, which were taken into account for the development of the database, include information on the orientation, tilt angle and system extensions of each production unit. Furthermore, a dataset with the module types digitally tracked since 2021 was taken into account, allowing an additional, relevant data type to be included for the development of the database. Also included in the SFOE data was a dataset that enables the translation of pronovo identification numbers (KEV/EIV/MKF/HKN number) to public geo-portal IDs. This is relevant for linking internal, non-public plant data with public data (e.g. from the guarantee of origin system).

Another non-public source, provided by the Swiss recycling system SENS eRecycling and partner of the Swiss PV Circle project, includes all collection orders from 2017 to June 2024 that were requested by companies or collection centres for the collection and recycling of end-of-life PV modules.[9] The dataset contains the collection address, date, quantity (kg), PV module type, module condition and end-of-life reason of each collection order.

In addition, two data sets with the Reuse testing data from the pilot studies carried out in the project were integrated into the development of the database. These data sets mainly contain all the test data, such as the measured residual power of the modules, open-circuit voltage, short-circuit current, fill factor and the test parameters used for the measurement (irradiance, air temperature, etc.).

These data sets provide the basis for covering as many phases of the PV module value chain as possible with currently available data. While existing DPP-driven data models define the 'best-case scenario',[10] the approach chosen here is aligned with reality, but nevertheless endeavours to derive the greatest possible information content from the available data.

---

[7] Aarikka-Stenroos, Ritala, and Thomas, "Circular Economy Ecosystems"; Adner, "Ecosystem as Structure."

[8] Opendata.Swiss, "Electricity Production Plants - Opendata.Swiss."

[9] SENS eRecycling, "Recycling system for photovoltaics in Switzerland."

[10] Boukhatmi, Nyffenegger, and Grösser, "Designing a Digital Platform to Foster Data-Enhanced Circular Practices in the European Solar Industry."

2.2 Data preparation

Data preparation was a key step in ensuring the data quality and consistency of the various data sets used to create the database. As the data came from different public and non-public sources, it was first analysed and the individual data types interpreted. This included the correction of missing values, the elimination of duplicates and the harmonisation of the names of PV systems, module types and identification numbers across all sources. More detailed explanations for future adjustments to the data and information systems are documented in detail (see Deliverable 1.2).

Another important part of the data preparation was linking the Pronovo identification numbers with the public geo-portal IDs in order to combine internal, non-public data with publicly accessible information. In addition, the time series data of monthly energy production and collection orders for end-of-life PV modules were aggregated in such a way that they could be compared and analysed across all years.

For the test data of the Reuse pilot cases, attention was paid to the conversion of the measurement parameters to ensure that important information such as the residual power, the open-circuit voltage, the short-circuit current and the fill factor of the PV modules from the existing data sources could be correctly interpreted and mapped in the database. Finally, all data records were checked for inconsistencies that could have been caused by manual input and, if necessary, suggestions for adjustments were documented (see Deliverable 1.2).

For further analyses, all previously digitally tracked PV module types were also evaluated, as the manufacturer type designation is entered via a free text field. The analysis covers around 93,000 systems, of which around 80,000 could be analysed. Figure1 shows an overview of the analysed PV module types. It is important to note that there may be deviations in these results due to the large number of systems with module types that cannot be referenced. It should also be noted that the majority of PV installations are covered by attached rooftop systems.

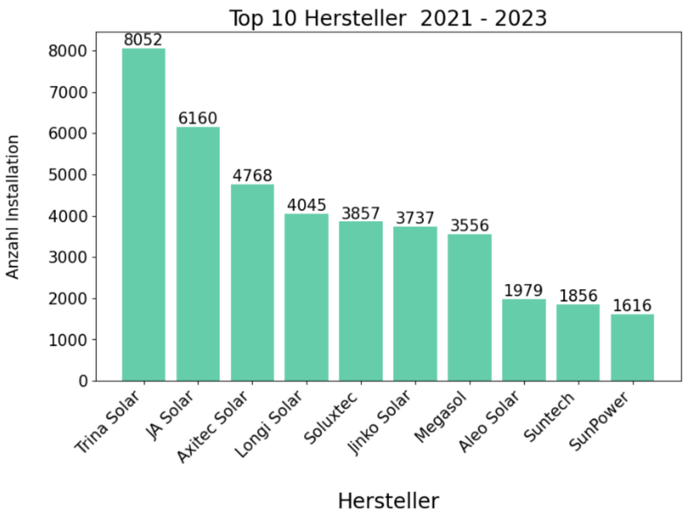

Figure1 : Top 10 installed module manufacturers 2021 - 2023, which were specified in the free text field via the Pronovo portal when registering the system.

Mit Unterstützung von energieschweiz

3. Database development

The development of a robust and scalable database forms the foundation for the subsequent implementation of a digital product passport (DPP) for PV modules. In order to promote circular value chains in the solar industry, a comprehensive and consistent database is required that covers all relevant information over the entire life cycle of PV systems - from installation and operation through to decommissioning and possible reuse.

The design of the database, which integrates the data collected from the sources mentioned, is described below. The use of frameworks to improve the interoperability of different information systems (such as the OpenAPI standard), which facilitates the development and subsequent expansion of the database, is discussed. It also explains how various data sets, for example on energy production, end-of-life PV modules and reuse tests, were prepared and linked in order to ensure broad coverage of the value chain.

This database not only serves as a central information system for the DPP, but its flexible structure also offers the possibility of integrating additional data sources in the future and developing further 'value added services' to support circular practices.

3.1 OpenAPI standard

The OpenAPI standard is a widely used framework for the specification of RESTful APIs (Representational State Transfer Application Programming Interfaces), which makes it possible to define web service interfaces in a structured and standardised way. It supports developers in the creation and documentation of APIs by providing a machine- and human-readable description. By using the OpenAPI standard, client SDKs, mock servers and comprehensive API documentation can be generated automatically, which considerably simplifies the development, expansion and maintenance of database-supported platforms. This is particularly relevant in the context of the DPP, as requires a flexible and scalable database architecture in order to continuously record and update product information and make it accessible to various stakeholders.[11]

As part of work package 1 within Swiss PV Circle, comprehensive OpenAPI documentation was created that describes the database schema for managing information on PV systems. The specification follows the OpenAPI standard in version 3.0.3 and defines in detail the available endpoints and the associated data schemas. The recorded data includes technical parameters such as serial numbers, power values and module types as well as logistical information such as the system address. The documentation contains corresponding meta information to clearly identify the relevance of the recorded attributes for the database. In addition, the schema has been designed in such a way that subsequent extensions and customisations are possible without any problems. The OpenAPI documentation thus represents an important building block for the future implementation of a DPP that facilitates data exchange between solar industry players and supports a sustainable circular economy.

3.2 Database structure

SQLite, a lightweight, serverless database engine that is particularly suitable for embedded applications, was used to build the database. SQLite was used because it is an uncomplicated and resource-saving solution

[11] OpenAPI Initiative, "OpenAPI Specification - Version 3.1.0 | Swagger."

Mit Unterstützung von energieschweiz

that does not require any additional server configuration. This makes it ideal for projects that prioritise flexibility and rapid prototyping. Secondly, SQLite offers full SQL support, making it easy to integrate and query complex data sets. Thirdly, SQLite is characterised by its high reliability and widespread acceptance, which makes it possible to migrate to other database systems at a later date. This potential migration is supported by the Open API standard, which simplifies switching to other database systems.

The database was structured in such a way that it contains several interlinked tables that map the different phases of PV value creation (seeFigure *2* , with data types to be expanded in the future marked in green). The central tables (not exhaustive) include

- **Production units:** This table stores basic information on the registered PV systems such as location, installation date and installed output at initial commissioning, including extensions. For the development of reuse business models, this information is relevant for determining the age of the system and the installation location. Based on the results of work package 3 "Forecasting", data analysis techniques could also be used to enrich this information with further statements on reuse potential. Furthermore, the addition of the minimum operating period (based on the type of subsidy) would be an important building block in order to allow conclusions to be drawn as to when deinstallation would be legally possible. It would also be helpful in terms of improved data management to add the 'reason for extension' in order to better understand possible module changes (e.g. in the event of premature damage or repowering) (see Deliverable 1.2).
- **Energy fed into the grid:** The monthly time series data on the energy production of the individual plants between 2009 and 2023 is recorded here, including the proportion of self-utilised and energy fed into the grid. Anomalies in energy production and changes in the plant's yield can provide information on possible module changes and possible decommissioning, which is an important key to expanding the end-of-life database (see work package 3 "Forecasting").
- **Collection order**: This table contains the data on the collection orders for end-of-life modules, including quantity, collection address, PV module type, condition of the modules and reason for disposal. This information is also important for expanding the current database on end-of-life systems, but also for the development of decision-making tools to enable improved triage between recycling and reuse (see work package 2 "Business model" and work package 3 "Forecasting").
- **Test reuse:** These tables contain the test data from the two reuse pilot projects carried out, including the serial numbers of individual modules and measured test parameters such as test date, residual power, open-circuit voltage, short-circuit current and fill factor. This data is essential for assessing the reusability of PV modules and for the possible future creation of a 'reuse certificate', which guarantees the reuse of the modules (see work package 2 "Business model").
- **Orientation:** This table contains further information on the orientation of the system, including the angle of inclination and type of extensions. This data is not primarily relevant for reuse, but can further enrich the information content of each installation.
- **PV modules (type):** This table contains the registered module type and the number of modules per system part for systems installed from 2021. This information is particularly relevant for reuse, as the module type allows conclusions to be drawn about the data sheet, which means that important physical and electrical properties of the modules (Wp performance, weight, mass) and potential

degradation based on the installation time can already be derived for the dismantling/testing of the modules (see work package 2 "Business model").

- **GEO Portal ID:** This table is used to link internal identification numbers (KEV/EIV/MKF/HKN) with the public geo-portal IDs to enable seamless integration of public and non-public datasets.
- **ElectricityProductionPlant:** This table contains all information from the public dataset "Electricity production plants", which is regularly updated and published via Opendata.Swiss. The data is largely redundant with that from the 'Production units' table. What is relevant here, however, is that this data is publicly available and therefore harbours potential for a project-independent implementation of circular business models. Adding the module type would be a relevant addition to this data set (see work package 3 "Forecasting").

The structure of the database was designed in such a way that it enables clear and comprehensible data organisation. Relationships between the tables allow the data records to be linked via primary and foreign keys, which were recorded as part of the OpenAPI documentation. In addition, the use of SQLite facilitates the subsequent expansion of the database with further tables and attributes, for example to integrate new data records or additional information on PV systems. Overall, the structure chosen for enables efficient storage, querying and processing of the data, which means that both existing and future requirements for the DPP can be covered.

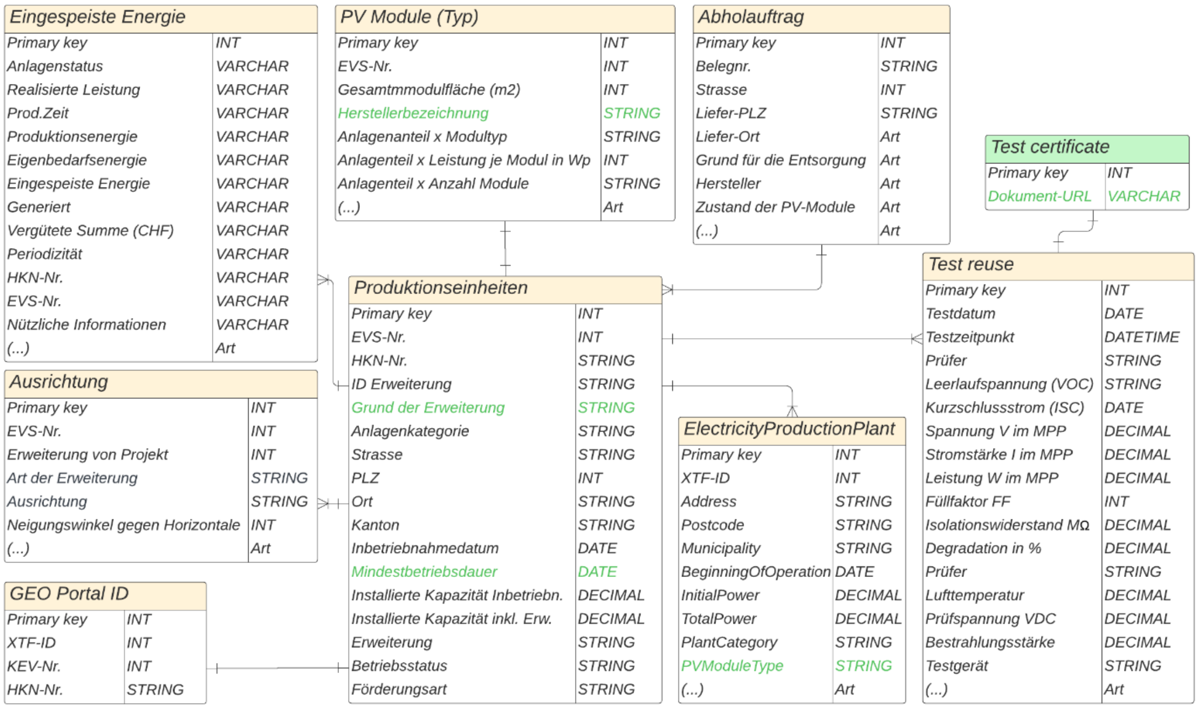

Figure 2 : ER schema of the database, taking into account the most important entities and data types. Future recommendations for further data types are highlighted in green. The data provides the basis for the development of the DPP.

Figure3 shows the individual tables and attributes of the database schema in SQLite. The names of the tables were taken as far as possible from the original names of the individual data records in order to facilitate future assignment.

Name	Type	Schema
Tables (10)		
20240218_EINGESPEISTE-ENERGIE_(y...		CREATE TABLE "20240218_EINGESPEISTE-ENERGIE_(year)" ("Name der Produktionsanlage" TEXT, "Anlagenstat
2024_04_30_RC_202405231547		CREATE TABLE "2024_04_30_RC_202405231547" ("Serial number" TEXT, "DateTime Started" TEXT, "PV-module
Ausrichtung		CREATE TABLE "Ausrichtung" ("EVS-Nr." INTEGER, "Erweiterung von Projekt" TEXT, "Anlagen-ID" INTEGER, "Su
ElectricityProductionPlant		CREATE TABLE "ElectricityProductionPlant" ("xtf_id" INTEGER, "Address" TEXT, "PostCode" INTEGER, "Municipali
GEO-Portal-ID		CREATE TABLE "GEO-Portal-ID" ("Bezeichnung" TEXT, "ID" INTEGER, "Laufnummer" TEXT, "EVS-Nr." TEXT)
KEV-EIV-Anlagen		CREATE TABLE "KEV-EIV-Anlagen" ("EVS-Nr." TEXT, "Erweiterung von Projekt" TEXT, "Technologie" TEXT, "Kate
Messprotokolle n PV-Module		CREATE TABLE "Messprotokolle n PV-Module" ("Seriennummer" TEXT, "Sichtkontrolle. Stecker, Backsheet, Glas...
PV Module		CREATE TABLE "PV Module" ("EVS-Nr." INTEGER, "Gesamtmodulfläche (m2)" INTEGER, "Anlagenteil 1 Modultyp
Produktionseinheiten		CREATE TABLE "Produktionseinheiten" ("EVS-Nr." TEXT, "HKN-Nr" TEXT, "Erweiterung von Projekt" TEXT, "Stras
year_Auszug_SENS-Abholaufträge		CREATE TABLE "year_Auszug_SENS-Abholaufträge" ("Belegnr." TEXT, "Kundenr." TEXT, "Artikelnr." INTEGER, "N

Figure3 : Screenshot of the SQLite database. The tables '2024_04_30_RC_202405231547' and 'Measurement logs n PV modules' contain the test data from the two pilot projects that were carried out as part of WP2.

4. Operationalisation

In the previous chapters, the focus was mainly on the collection and preparation of data and the development of the database. In the future, these sub-processes described should enable the automated embedding of further inputs using the OpenAPI standard and predefined rules, including both different file formats and data sources. The processing and standardisation of all data inputs enables the continuous expansion and further development of the database, which represents the output of this data flow process, as summarised in

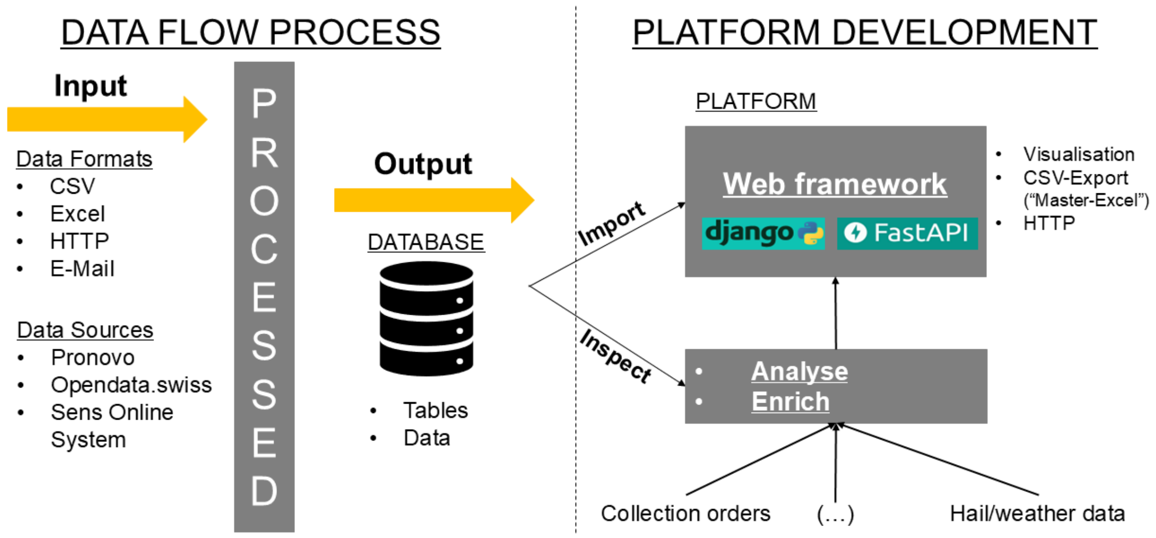

Figure4 on the left-hand side . On the right-hand side, on the other hand, the future platform development is described, which should enable data access and exchange for players in the Swiss solar industry. The platform interface, which is built using a web framework (Django or FastAPI in this example), can be used to map the relevant data for each PV system in the form of the DPP. Other new data can also be fed in via the interface by users or via an API (e.g. weather data or collection orders) and added to the database. Furthermore, data analysis techniques (see work package 3 "Forecasting") in the platform could enable improved statements on the recyclability of individual systems and be tracked as additional information in the DPP. CSV exports of the data could also simplify access and further processing of the data, for example for companies in the reuse or recycling sector.

Mit Unterstützung von energieschweiz

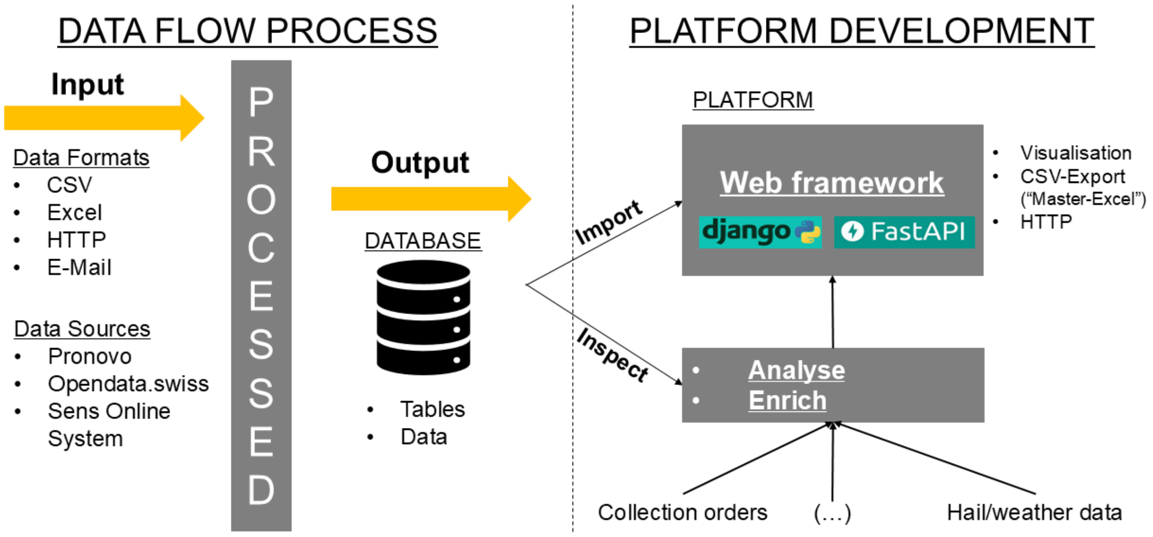

Figure4 : Diagram of the platform operationalisation. The left-hand side shows the data flow processes that ensure the continuous updating of the database. The right-hand side shows the platform development by means of a web framework and the enrichment of additional data sources (by users and APIs) and the application of data analysis techniques.

4.1 Platform prototype

At the end of the project, an initial prototype of the platform was developed that visualises the desired vision of the digital product passport in a simplified form. When accessing the website, a map view of Switzerland with three markers appears first. Two of these markers (the regions of Arlesheim and Geneva) represent the pilot locations of the project. Not only were reuse tests carried out for these, but all relevant life cycle data was also collected, consolidated and clearly visualised.

Clicking on the markers opens detailed information on the systems, including the identification numbers, the (anonymised) location, the commissioning date, the product type, the system category, the current status, the type of subsidy and the installed capacity. Production data from various years can also be viewed and downloaded via the "Show diagram" tab.

A central element of the prototype is the test results, in which different procedures were used for the two pilot systems. These are listed under the menu item "Test procedure". At "Show module table", the test data can be individually selected on a serial number basis and displayed in tabular form. In the future, the corresponding test certificate could also be available here to ensure quality-assured reuse, for example by a publicly recognised body such as Swissolar. There are also plans to make tested PV modules available directly via an online marketplace in future by clicking on the "Buy modules" button.

A third use case shows a PV system that is still installed in the Landquart region. The static system data and the associated production table can also be viewed here. In contrast to the pilot systems, however, no test results appear. Instead, there is a "Release modules for reuse" button, which will be used to enable forwarding to the SENS collection system in future.

The prototype is available at the following website:

https://swiss-pv.onrender.com/

Mit Unterstützung von energieschweiz

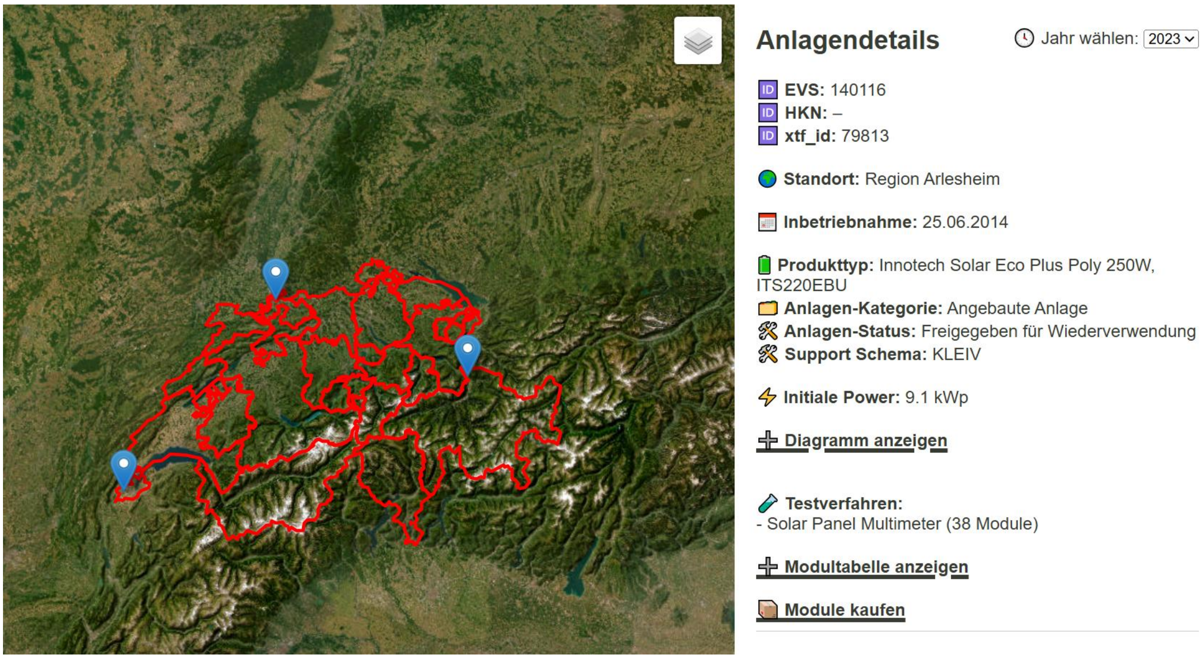

Figure5 : Screenshot of the platform prototype.

4.2 Future development

The knowledge gained in the project should enable and drive the future development of the platform. As has been clearly demonstrated in all work packages of the Swiss PV Circle project, data is an important driver for the application of business models in the area of reuse, as it enables early decisions to be made about the reuse potential of PV systems. An online marketplace is also a suitable intermediary for efficiently organising the future resale of tested PV modules and securing it with a test certificate. The basis for this is the digital product passport (see*Figure*), which centralises all relevant data on PV systems from various sources and makes it accessible to all players in the industry via the platform. Additional value-added services, such as the calculation of the CO_2footprint of a reuse system or a reporting tool for regulatory compliance, could ensure the economic viability of the platform and the industry's increasing demand for efficiently documented sustainability .[12] A software-as-a-service (Saas) solution (e.g. licence subscription) is envisaged for the use of the platform services, while the reuse marketplace should be freely accessible in order to increase the potential user base and thus enable the generation of network effects.[13]

---

[12] Boukhatmi and Groesser, *Investigating the Current State of Circular Economy Software Platforms*.

[13] Parker, Alstyne, and Choudary, *Platform Revolution*.

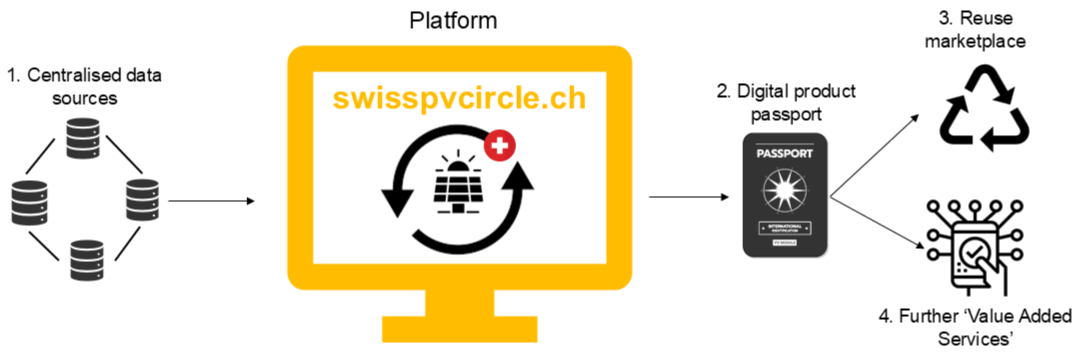

Figure 6: Sketch of the most important components of the future platform (exemplary designation as 'swisspvcircle.ch').

The question of data sovereignty and ownership of the platform is still unresolved. Discussions with all project partners revealed that hosting via SENS eRecycling or Swissolar is a possible option, as these organisations have the necessary neutrality to create trust in the solar industry. In addition, a neutral and recognised player from the solar industry could make a better contribution to motivating companies to make their data available on the platform. Furthermore, the inclusion of fixed partners for the testing and recertification of old modules with reuse potential is an important building block in order to be able to regularly feed the marketplace with new offers within Switzerland. The development of these partnerships and the further development of value-added services based on current market requirements will be an important part of future initiatives.

5. Conclusion

This report summarised the most important content on database development and the initial concepts for future platform development within work package 1 of the Swiss PV Circle project. In particular, the collection and preparation of data in Switzerland made it clear that the development of a digital product passport for PV modules requires a centralised database that enables the standardisation and embedding of data sets from different sources. Extensions to the existing data for a more efficient development of circular business models, especially in the area of reuse, were also described as part of the database development. Further adjustments for improved data management in the future were addressed in deliverable 1.2. The project provides a promising glimpse into the future with regard to the digitalisation of the circular economy. As the prototype presented demonstrates, the development of a DPP for PV systems in Switzerland can be made possible without any problems, but there are still open questions regarding data provision and sovereignty, which will be further investigated in follow-up projects. Nevertheless, as shown, a first DPP can be established by means of additions, which will contribute to the development of further business models in the future, for example for more efficient recycling.

Mit Unterstützung von energieschweiz

Literature

Aarikka-Stenroos, Leena, Paavo Ritala, and Llewellyn D. W. Thomas. "Circular Economy Ecosystems: A Typology, Definitions, and Implications." In *Research Handbook of Sustainability Agency*, 260-76. Edward Elgar Publishing, 2021. https://www.elgaronline.com/display/edcoll/9781789906028/9781789906028.00024.xml.

Adner, Ron. "Ecosystem as Structure: An Actionable Construct for Strategy." *Journal of Management* 43, no. 1 (January 1, 2017): 39–58. https://doi.org/10.1177/0149206316678451.

Autio, Erkko. "Orchestrating Ecosystems: A Multi-Layered Framework." *Innovation* 24, no. 1 (January 2, 2022): 96-109. https://doi.org/10.1080/14479338.2021.1919120.

Bonina, Carla, Kari Koskinen, Ben Eaton, and Annabelle Gawer. "Digital Platforms for Development: Foundations and Research Agenda." *Information Systems Journal* 31, no. 6 (2021): 869-902. https://doi.org/10.1111/isj.12326.

Boukhatmi, Ässia, and Stefan Groesser. *Investigating the Current State of Circular Economy Software Platforms*, 2023.

Boukhatmi, Ässia, Roger Nyffenegger, and Stefan N. Grösser. "Designing a Digital Platform to Foster Data-Enhanced Circular Practices in the European Solar Industry." *Journal of Cleaner Production* 418 (September 15, 2023): 137992. https://doi.org/10.1016/j.jclepro.2023.137992.

Bressanelli, Gianmarco, Federico Adrodegari, Marco Perona, and Nicola Saccani. "Exploring How Usage-Focused Business Models Enable Circular Economy through Digital Technologies." *Sustainability* 10, no. 3 (March 2018): 639. https://doi.org/10.3390/su10030639.

Chauhan, Chetna, Vinit Parida, and Amandeep Dhir. "Linking Circular Economy and Digitalisation Technologies: A Systematic Literature Review of Past Achievements and Future Promises." *Technological Forecasting and Social Change* 177 (April 1, 2022): 121508. https://doi.org/10.1016/j.techfore.2022.121508.

Elmasri, Ramez, and Sham Navathe. *Fundamentals of Database Systems*. Seventh edition. Boston Munich: Pearson, 2016.

Honic, M, I Kovacic, and H Rechberger. "Concept for a BIM-Based Material Passport for Buildings." *IOP Conference Series: Earth and Environmental Science* 225 (February 24, 2019): 012073. https://doi.org/10.1088/1755-1315/225/1/012073.

Kristoffersen, Eivind, Fenna Blomsma, Patrick Mikalef, and Jingyue Li. "The Smart Circular Economy: A Digital-Enabled Circular Strategies Framework for Manufacturing Companies." *Journal of Business Research* 120 (November 1, 2020): 241-61. https://doi.org/10.1016/j.jbusres.2020.07.044.

OpenAPI Initiative. "OpenAPI Specification - Version 3.1.0 | Swagger," 2025. https://swagger.io/specification/.

Opendata.Swiss. "Electricity Production Plants - Opendata.Swiss," 2024. https://opendata.swiss/en/dataset/elektrizitatsproduktionsanlagen.

Pagoropoulos, Aris, Daniela C. A. Pigosso, and Tim C. McAloone. "The Emergent Role of Digital Technologies in the Circular Economy: A Review." *Procedia CIRP*, 9th CIRP IPSS Conference: Circular Perspectives on PSS, 64 (January 1, 2017): 19–24. https://doi.org/10.1016/j.procir.2017.02.047.

Mit Unterstützung von energieschweiz

Parker, Geoffrey, Marshall W. Van Alstyne, and Sangeet Paul Choudary. *Platform Revolution: How Networked Markets Are Transforming the Economy and How to Make Them Work for You*. W. W. Norton & Company, 2016.

SENS eRecycling. "Recycling system for photovoltaics in Switzerland." SENS eRecycling, 2024. https://www.erecycling.ch/wissenswertes/wissensblog/fach-94.html.

Thomas, Llewellyn, Erkko Autio, and David Gann. "Architectural Leverage: Putting Platforms in Context." *Academy of Management Executive* 28 (June 2, 2014): 198-219. https://doi.org/10.5465/amp.2011.0105.

Tiwana, Amrit. *Platform Ecosystems: Aligning Architecture, Governance, and Strategy*. Newnes, 2013.

Walden, Joerg, Angelika Steinbrecher, and Maroye Marinkovic. "Digital Product Passports as Enabler of the Circular Economy." *Chemistry Engineering Technology* 93, no. 11 (2021): 1717-27. https://doi.org/10.1002/cite.202100121.