This project has received funding from the European Union's Horizon Europe under grant agreement № 101084259

Deliverable 5.4: Data Specification of Digital Twin

Task 5.4:

WP5: Industry 4.0 Concepts

Lead participant:	ISCK
Delivery date:	30/04/2024
Dissemination level:	Public
Type:	Report

Document History

Date	Version	Prepared by	Organisation	Approved by	Notes
25/03/2024	V01	Swaytha Sasidharan	ISCK		
23/04/2024		Kester Josco	TNO		
30/04/2024	V02	Swaytha Sasidharan	ISCK	Manjunath Prasad	
10/05/2024	V02.1	Daiva Ulbikienė	PROTECH		Final minor editing
10/05/2024				Florian Buchholz	

Acknowledgements

The work described in this publication has received funding from the European Union's Horizon Europe energy research and innovation programme under grant agreement № 101084259.

Disclaimer

This document reflects only the authors' view and not those of the European Community. This work may rely on data from sources external to the members of the IBC4EU project Consortium. Members of the Consortium do not accept liability for loss or damage suffered by any third party as a result of errors or inaccuracies in such data. The information in this document is provided "as is" and no guarantee or warranty is given that the information is fit for any particular purpose. The user thereof uses the information at its sole risk and neither the European Community nor any member of the IBC4EU Consortium is liable for any use that may be made of the information.

Project Partners

Associated Partners

Contents

Figures

Tables

Executive Summary

The document outlines the data specification for Digital Twins for Solar Modules based on the requirements gathered from the EU regulations and the involved project partners. The current standardization activities in this domain have been taken into consideration particularly for circularity and recyclability topics related to photovoltaic modules. The EU regulations that are relevant and included here are Ecodesign, Energy Labelling, WEEE Directive, RoHS Directive, Digital Passport and National Sustainability indicators.

A requirements gathering phase within the IBC4EU group was completed with feedback from module manufacturers, policy experts and reclyling experts were collected. The data specification aims to be complete in terms of the inclusion of all the characterisics of a photovoltaic module. The specification document would serve as the base reference information model to implement digital twins of the photovoltaic modules as per the requirements of the module manufacturer. The specification document is generic and has a modular structure. The attributes and properties are specified along with data types and access rights i.e. what information should be available in the public domain as stipulated by the regulations, those that are shared voluntarily by the module manufacturers and others which are classified as confidential to be used for tracing within the manufacturing line. This allows freedom of information exchange choice for the module manufacturer and the end consumer.

The implementation details is not within the scope of this specification document. This also extends to the development choice in architecture, access management and data/storage of the digital twins. As part of the Task 5.4, a prototype implementation of the Digital Twins will be implemented based on the data specification document. A detailed report on the implementation, architectre, access and data management will be shared with the prototype implementation.

1 Introduction

Photovoltaics plays a crucial role in the transition to renewable energies in the EU region. Global solar capacity is expected to grow to 4.5 terawatts by 2050[1]. To move towards sustainability, the regulations take into account the environmental impact of the photovoltaic modules being installed and at the same time also considers recycling strategies to be considered. The photovoltaic waste is estimated to hit 80 million metric tons by 2050. These photovoltaic modules have a lifespan of 20~25 years. This results in the generation of several thousand tonnes of old modules. The circular economy initiative looks to transform the way that we produce, consume and utilise products and resources – aiming to cut waste to a minimum, and extend resource/product quality and longevity.

A circular economy aims to establish a traceability matrix for the entire lifecycle of the photovoltaics products from manufacturing, sales, installation, recycling and disposal. Since, the solar industry will play a crucial role in addressing the climate crisis challenges and to reach the European Green Deal (EDG) of net zero emissions by 2050, it is very critical to establish a circular economy value chain in photovoltaics. In aiming towards attaining sustainable growth, the EU's transition to a circular economy will reduce pressure on natural resources and will create sustainable growth also paving the way to achieve the EU's climate neutrality target. Regulations such as German Circular Economy Act (and other related country specific regulations) identifies the need for reliability of products, reuse mechanisms in place. The current system faces difficulties in disposal of used PV modules, ensuring resource usage efficiency and optimal disposal mechanisms. One of the biggest challenges is the lack of data and information.

A step forward is to establish a tracing methodology for the entire lifecycle of the product – from design, production and distribution, inventory of materials/resources used, and reduction/recycling of waste. Establishing a digital trace record of the digital twins of the modules would enable to close the information gap. Digital Twins enable the collection of all relevant information and through the adoption of standards, will provide a uniform way to access the stored information. With the current trend in the digitalization and Industry4.0, digital twins are key data enablers for advanced data analytics. This document provides an overview of the minimal and extended data model that would be required to realize a Digital Twin for the modules.

[1] Nat. Energy 2020, DOI: 10.1038/s41560-020-0645-2

2 Standardization Activities

The standardization activities are subdivided into sections as summarized below with individual focus on Photovoltaics and Digital Twin separately.

(i) Photovoltaics – related to circularity, Eco Design, Energy Labelling, Green Passports, etc. Given the expected rise in the scale of transitioning to the renewable energy in the EU region, there is a lot of focus currently on the environmental impact of the sources particularly with the Photovoltaics products – cells, modules and the associated material chain. The initiatives are further divided into regulations for new modules being installed on one hand and alternatively on regulations on the modules to be recycled/discarded.

(ii) Digital Twin: There is still a lack of standards for the terminologies used, the architectural differences and with the diverse application domains, it is difficult to specify a common model between the different fields. We consider the standard under development IEC 63278: Asset Administration Shell for industrial applications as a reference model for the data specification.

This task also looks at incorporating the inputs from the standardization activities for Photovoltaics and into the Digital Twin specifications. The standards landscape consolidates information from entities such as the International Organization for Standardization (ISO), International Electro technical Commission (IEC), International Telecommunication Union (ITU), and Institute of Electrical and Electronics Engineers (IEEE).

2.1 Photovoltaics

The standardization activities considered in this document are shown in Figure 1. The draft versions of the regulations are considered, where it has not yet come into effect. Regulation of PV modules is foreseen to be a combination of mandatory and voluntary policy instruments. A complete review of the regulations is beyond the scope of this document and thereby only provides a brief outline of the same.

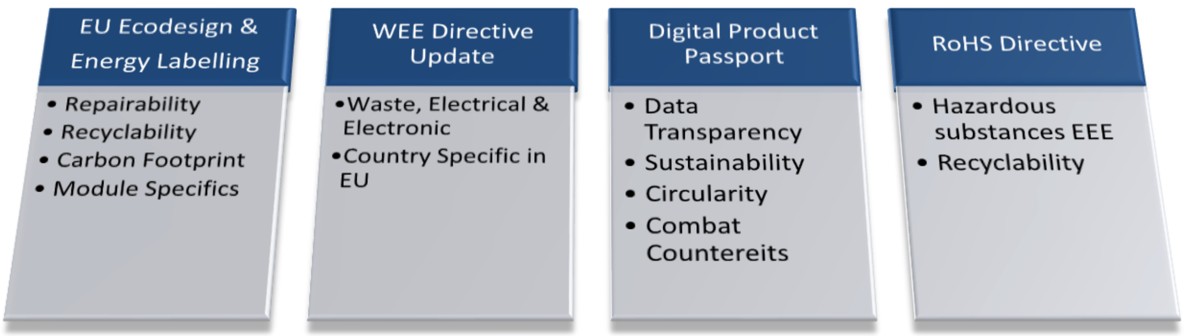


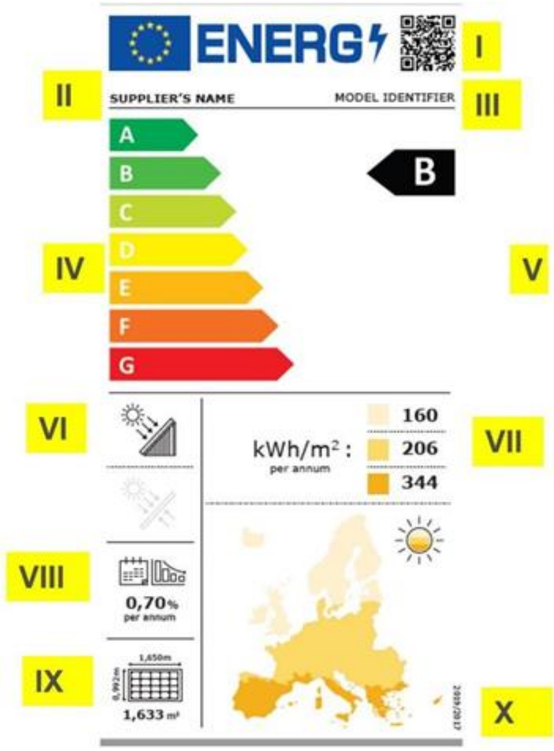
Figure 1: EU Regulations under development

2.1.1 *EU Ecodesign and Energy Labelling*

Photovoltaic products such as cells, modules, inverters and PV systems play an integral role in the decarbonisation plan of the EU's energy ecosystem. Several initiatives are being undertaken to facilitate the transition to sustainable and environment friendly product installations. The European Commission is working on a regulatory proposal encompassing eco-design and energy label requirements to manage the environmental impacts of photovoltaic products. Ecodesign is a measure that sets minimum requirements for all products placed on the market. The regulation is still in the draft version and expected to be adopted as a regulation in the second half of 2024. The ecodesign regulation will address points including:

- Reliability – Test results to indicate the reliability of the photovoltaic modules in different weather conditions such as tropical, coastal or continental should be included.
- Recyclability - QR code or website access on weight of CRMs(Si, Al, etc.), recyclability index , circular requirements
- Carbon footprint - The computation of the Carbon footprint is to be based on the PEFCR methodology using all the relevant parameters which influence the carbon footprint e.g. silicon content, yield, etc.
- Information Requirements - A manual or a free access website must be provided for details regarding replacement, repair and end-of-life operations.

Energy Label is a measure that helps end-consumers understand the energy performance of products. It rates electrical and other products on a range of A to G based on the electricity PV modules produce. A sample energy label as included in the current discussion documents [2] is shown in Figure 2 . Pending adoption of these regulations, the data as specified in the sample energy label are included in the 'EU Energy Label' submodel (Figure 11: EcoDesign SubModel). Some of the requirements stipulated by the regulation includes the disclosure of the supplier's name, energy efficiency class, module characteristics, module specifications and the lifetime performance and degradation rate. The carbon footprint declaration is to be made compulsory from Q2 of 2026 for all multi, mono Si, CdTe modules as part of the energy label. For more detailed information, a reference of the actual regulation is mandatory.



I	QR code
II	Trademark
III	Supplier's model identifier
IV	scale of energy efficiency classes from A to G
V	module energy efficiency class attained by at least two of the three values of EEIM under 'temperate coastal', 'temperate continental' and 'subtropical arid' climate conditions
VI	icon specifying whether the module is monofacial or bifacial
VII	module energy efficiency index value EEIM under 'temperate coastal', 'temperate continental' and 'subtropical arid' climate conditions, calculated according to Annex IV, expressed in kWh/m2 and rounded to the unit
VIII	lifetime performance degradation rate
IX	the photovoltaic module area (AM)
X	number of the Regulation

Figure 2: Sample Energy Label

2.1.2 WEEE Directive:

The Waste Electrical and Electronic Equipment European (WEEE) directive sets out the basic rules that apply to the sale on the market, collection and disposal of electrical and electronic equipment in every country of the European Union [3]. Each country has its own WEEE legislation. When selling directly to other EU countries, manufacturers and retailers may also have to adhere to the local WEEE compliance obligations. The regulation will be available in the last quarter of 2024. Roughly the directive states that the need for 85%/80% (recovery/recycling rate) of waste PV modules by mass to be recycled. Figure 3 shows an overview of the materials used in a solar cell. In the current WEEE legislation there are no specific rules for PV modules. Manufacturers and retailers must adhere to the generic requirements for electrical and electronic equipment. In 2024 the WEEE directive is being evaluated [4]. One of the options being considered is the introduction of specific requirements for recycling of PV modules, including targets for the recovery of critical raw materials. This is in line with the European Critical Raw Materials Act [5], proposed by the European Commission in 2023, that introduces measures to strengthen domestic supply chains for critical raw materials. In preparation for potential targets for the recovery of critical raw materials a submodel "EU Recyclability Materials" is included in the digital twin specification.

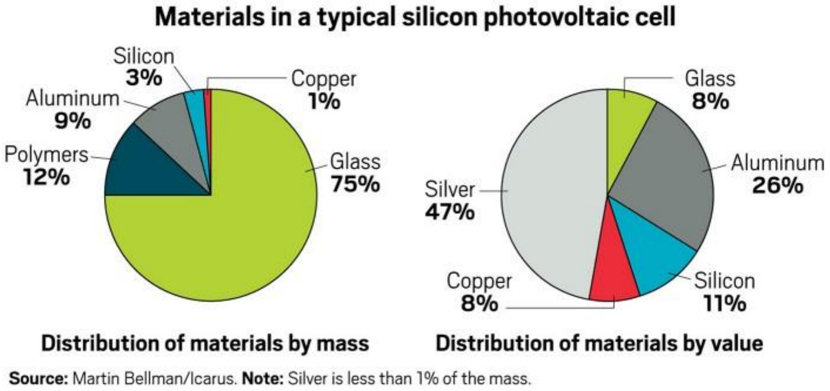


Figure 3: Overview of Materials used in a Solar Cell

2.1.3 RoHS Directive - Restriction of Hazardous Substances in Electrical and Electronic Equipment

Electrical and electronic equipment (EEE) contains hazardous substances. The RoHS Directive [6] aims to prevent the risks posed to human health and the environment related to the management of electronic and electrical waste. It does this by restricting the use of certain hazardous substances in EEE that can be substituted by safer alternatives. These restricted substances include heavy metals, flame retardants or plasticizers. The RoHS Directive currently restricts the use of ten substances: lead, cadmium, mercury, hexavalent chromium, polybrominated biphenyls (PBB) and polybrominated diphenyl ethers (PBDE), bis(2-ethylhexyl) phthalate (DEHP), butyl benzyl phthalate (BBP), dibutyl phthalate (DBP) and diisobutyl phthalate (DIBP). The Directive also promotes the recyclability of EEE, as EEE and its components that have become waste contain fewer hazardous substances. At the same time, it ensures a level playing field for manufacturers and importers of EEE in the European market.

2.1.4 Digital Product Passport

Digital product passports facilitate transparency and the availability of information on the characteristics of products sold in the EU transitioning towards a more resource-efficient single market. The regulation sets up new duties and rights for manufacturers, importers and distributors, dealers, repairers, remanufacturers, recyclers, maintenance professionals, customers, end-users, consumers, national authorities, public interest organisations, the EU Commission, or any organisation acting on their behalf. Currently no harmonized European specification is being developed for Digital Product Passports for PV modules, nor is there any plan to develop such a harmonized specification. Therefore, there is no basis to include this in the digital twin specification.

2.1.5 National sustainability indicators

In addition to the European standards several EU member states have introduced national sustainability indicators for PV modules. Two example sustainability indicators are included in the digital twin specification:

“FR CRE carbon footprint”: Simplified method for carbon evaluation (France) [8]

“NL NMD Dutch Environmental Database”: data for MPG calculation in Dutch environmental database [9].

Other national sustainability indicators can be added if desired.

2.2 Digital Twin

A digital twin is defined as a virtual representation of a physical object/product and is updated with real-time data. There are different types of digital twins e.g. product twin, process twin, system twin, etc. based on the application areas, spanning the entire lifecycle span of the product. A digital twin leads to the creation of information which can be used for several applications ranging from improved R&D, process optimizations and in this case creating an information repository to enable a circular economy tracing possible. This would form the underlying framework for data sharing. A standardized access mechanism removes data ambiguity and hides the underlying technological heterogeneity with regard to the source of the data. The access to the digital twin data is envisioned to be a client-server architecture with REST API interfaces. The end application will access all the digital twin information through a web-server hosted on the premises of the manufacturer or cloud-based solutions. This specification document would be used as the requirements for the choice and design of the implementation and deployment. As mentioned in the proposal, if in agreement with the partners, a demo of the Digital Twin will be implemented with the AAS framework [10]*:* The Asset Administration Shell (AAS) for industrial applications-Part 1: Administration shell structure is the current standard under development related to the topic of virtual entity, it defines a semantic model that describes characteristics of assets, which is the serialization and exchange format between models, submodules.

Some of the additional parameters which are to be handled in the implementation include:

- Implementation Framework – AAS, lean implementation possibilities
- Functional aspects – Decentralized Data Storage, Database Design, Interoperability, Modularity
- Identity and Access Management – Security, Confidentiality, Data Usage Policies, Data Sovereignty
- Digital Twins Repository – Discovery & Registry services based on pre-defined templates

3 Data Specification

A Photovoltaic module can be characterized by several attributes that could largely classified into technical, mechanical, electrical and other relevant properties. The requirement for the digital twins capture all these properties from the entire lifecycle during manufacturing. The specification document is generic which leaves room for architectural design and implementation freedom as required by the manufacturers. The attributes are grouped into categories related properties with units, access rights and requirements from EU regulations. The data access-control and authentication will be provided by the manufacturer along with usage agreement terms.

3.1 PV Module Attributes:

The data or meta-information model for the digital twins of PV modules has been broadly sub-divided into the following categories (i) Identification (ii) Technical Specification (iii) Module Components (iv) EcoDesign (v) Warranty and (vi) Documents. These can be viewed as unique containers that hold hierarchical structures of elements with properties, events, documents, etc. The specifications are represented as generic entity relationship diagrams. Data represents the most important block of the digital twin and is critical for the information exchange and building a repository of digital twins. The different data types and data structures which would be used include:

- Product characteristics: Static characteristics e.g. product serial number, manufacturer name
- Process variables and parameters, telemetry data: dynamic values for a specific instance
- External data sources or files: integration of information stored in external systems

These are then classified into data types string, integer, real, date, image, pdf and Uris. For easy lookup of the sample values, units and confidentiality details are provided below as a table in the glossary. An overview of the module categories is shown in Figure 4

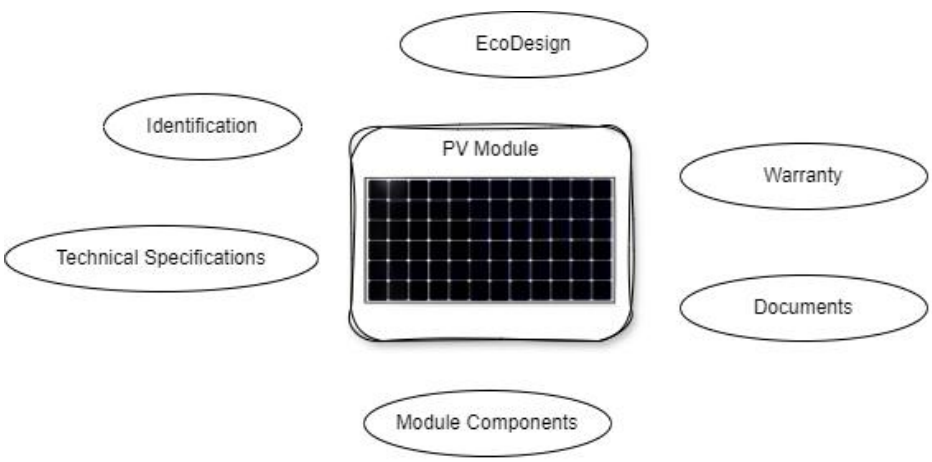


Figure 4: PV Module Twin Attributes Overview

The partners including module manufacturers, regulations experts, module experts and software developers were involved in drafting the requirements for the digital twin of modules. The following section delves into the details of the individual categories defined as SubModels (terminology in reference to the AAS specification). In addition, for standardized identifiers Platform 4.0 and AAS recommend the use of EClass[2], a cross-industry dictionary of standardized semantic identifiers for product descriptions. In this document, the design interpretation is left to the end-user. It is designed such that the manufacturer could pick a data model suitable to their requirements with an overview of the requirements as stipulated by the EU regulations.

3.1.1 Identification SubModel:

The Identification SubModel captures the properties that are related to the identification of the individual module. Each digital twin should have a unique identifier which describes the module. The following entity-relationship diagram reflects the SubModel Elements and corresponding properties. Most of the properties in this SubModel should be made available as open access to adhere to the EU regulations.

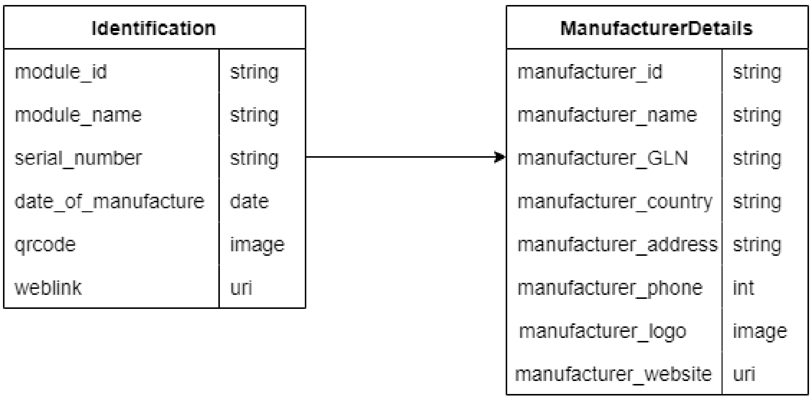


Figure 5: Identification SubModel

Each property in the SubModel is then defined as shown in the sample Figure 6 below. The data structure is to be followed for all the properties in the model.

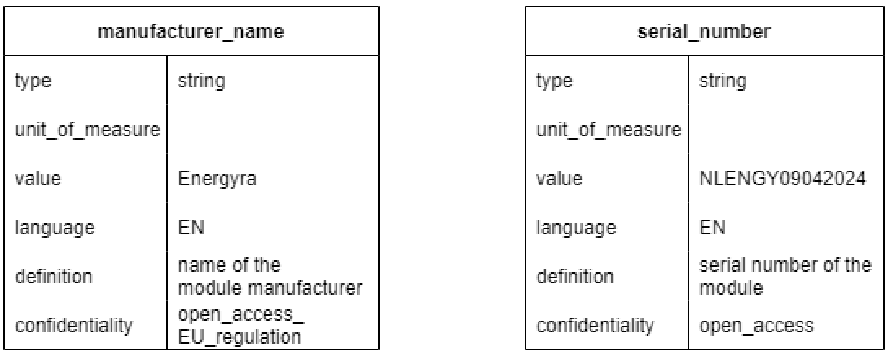


Figure 6: Sample Identification SubModel Properties

[2] https://eclass.eu/

3.1.2 *Technical Specifications SubModel:*

The technical specifications SubModel captures all the technical specifications which is further sub-divided into the following categories: mechanical specifications, electrical specifications, temperature co-efficient, operating conditions and module characterization. Most of the parameters in this model would be available as open access as it refers to the module technical characteristics which are normally available in the form of technical datasheets of the modules.

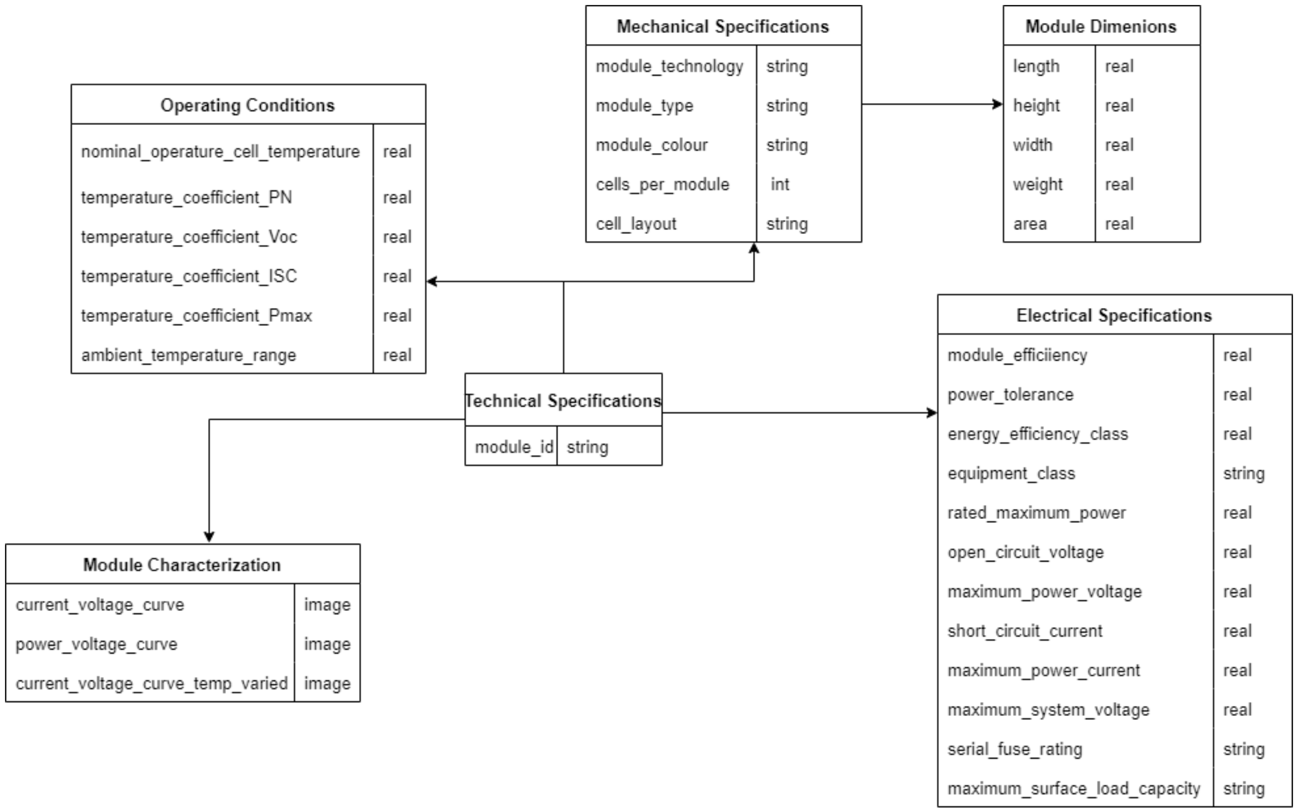
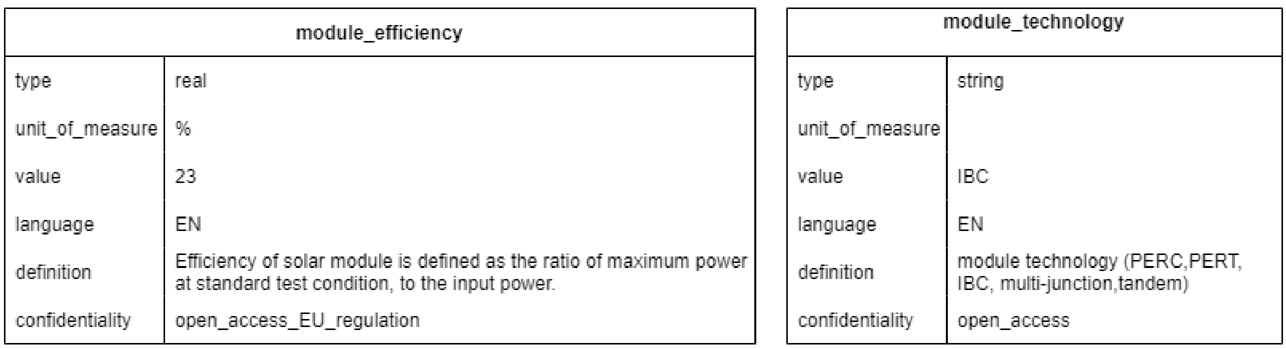


Figure 7: Technical Specifications SubModel

The sample properties for the technical specifications SubModel is shown in Figure 8



module_efficiency	
type	real
unit_of_measure	%
value	23
language	EN
definition	Efficiency of solar module is defined as the ratio of maximum power at standard test condition, to the input power.
confidentiality	open_access_EU_regulation

module_technology	
type	string
unit_of_measure	
value	IBC
language	EN
definition	module technology (PERC,PERT, IBC, multi-junction,tandem)
confidentiality	open_access

Figure 8: Sample Technical Specification SubModel Properties

3.1.3 Module Components SubModel:

The Module Components SubModel consists of several submodel element collections which are subdivided into all the relevant components that make up the PV module including solar cells, glass, encapsulants, connectors, etc. as shown in Figure 9. The information in this SubModel is highly confidential as it refers to the source and technology of the individual components which is a key differentiator in the Solar Module production. Hence this information is foreseen to be used only during the time of manufacturing for internal use and will not be made public.

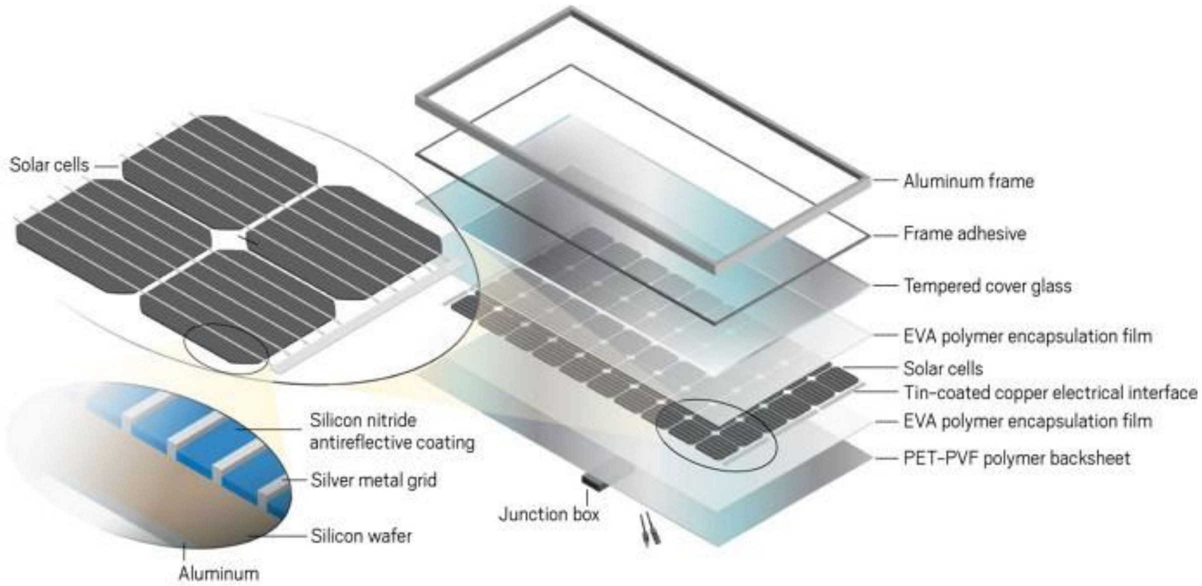


Figure 9: Overview of Solar Module Components
(Adapted from Nat. Energy 2020, DOI: 10.1038/s41560-020-0645-2)

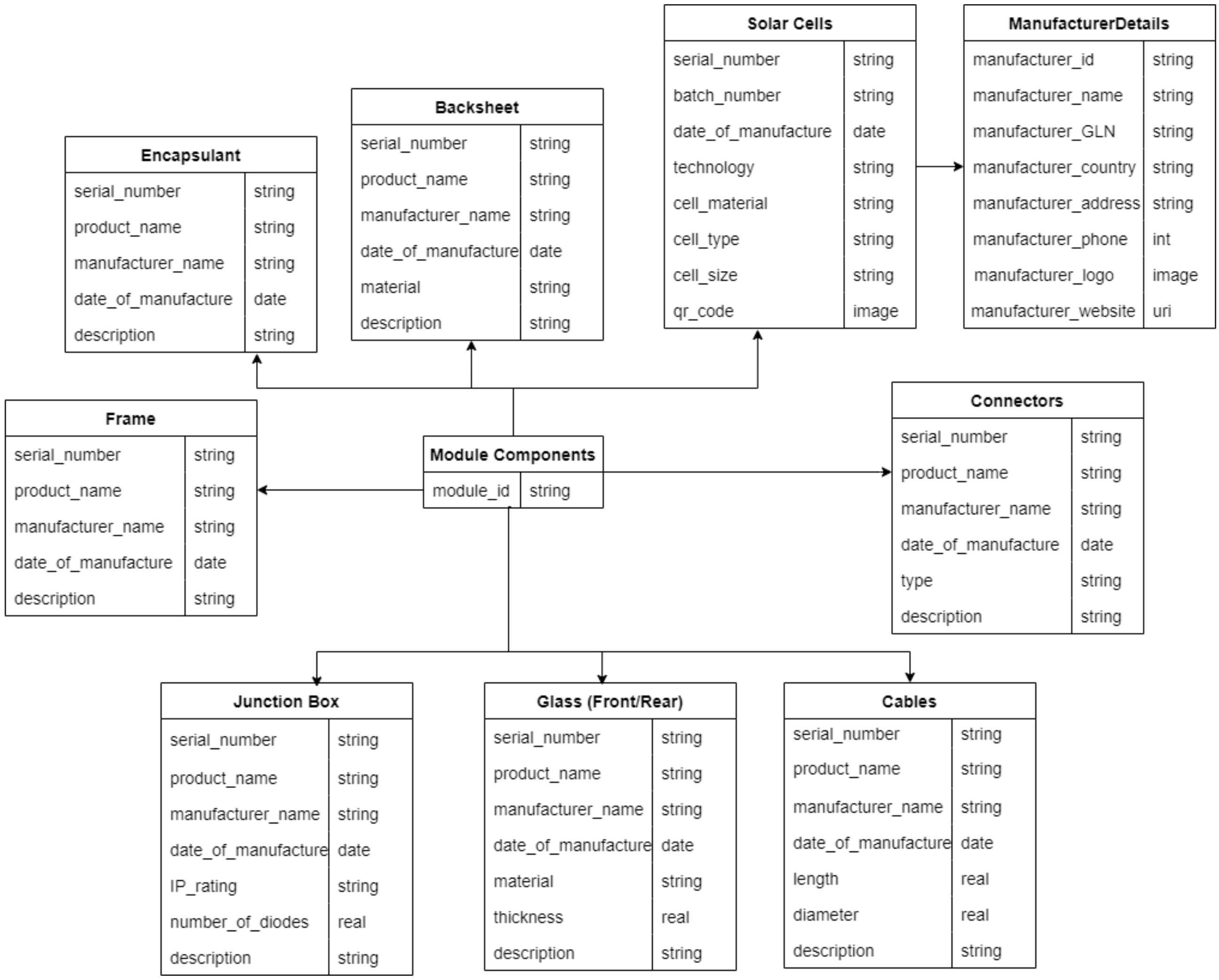


Figure 10: Module Components SubModel

3.1.4 EcoDesign SubModel:

The EcoDesign SubModel has its SubModel Elements and properties derived from the standardization activities elaborated in the previous sections. This includes a consolidated view of all the materials used in the manufacturing of the module along with the weight and the recyclability rate. The Recycling rate is calculated as the percentage of diverted Refuse that is recyclable.

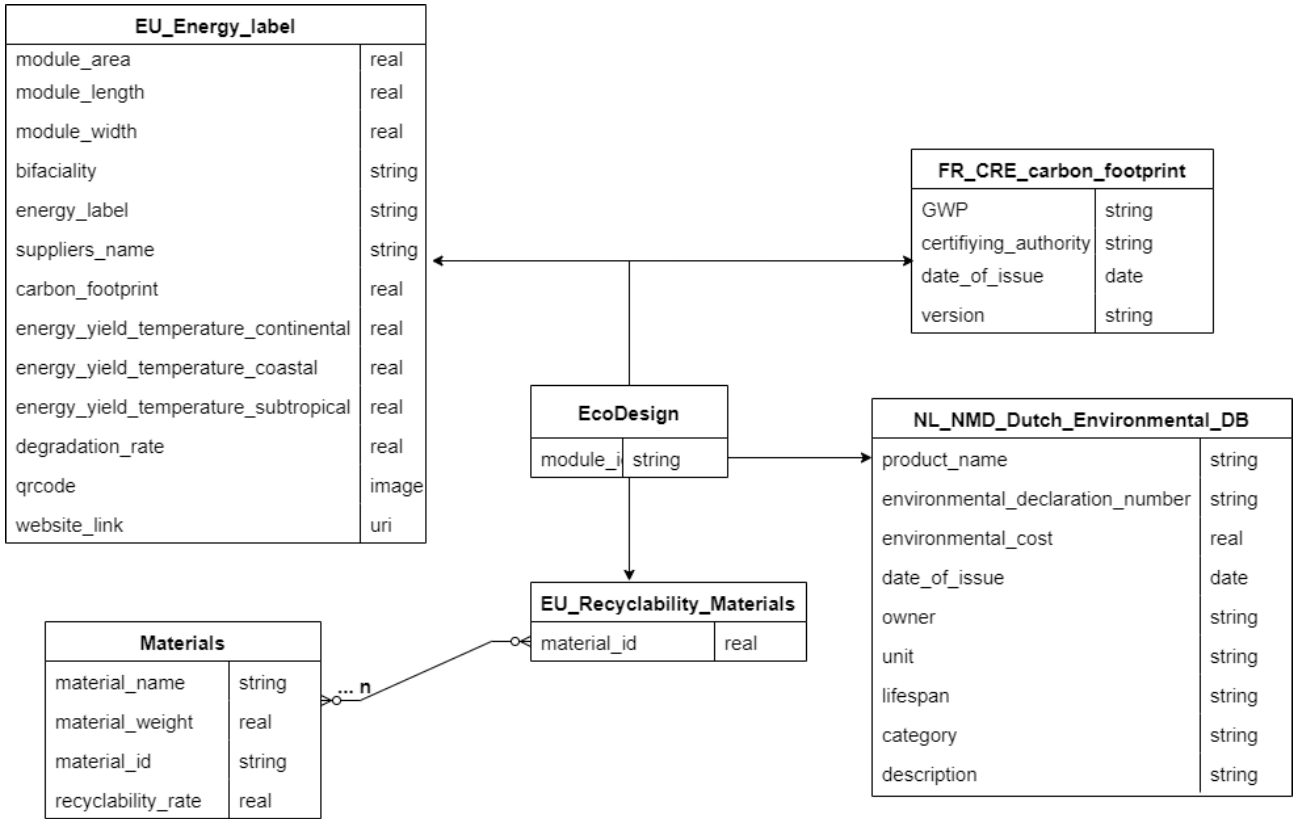


Figure 11: EcoDesign SubModel

3.1.5 Warranty SubModel:

The warranty SubModel aims to capture all the Guarantee and Warranty related details such as product and performance guarantee in years, available certifications for the module, etc.

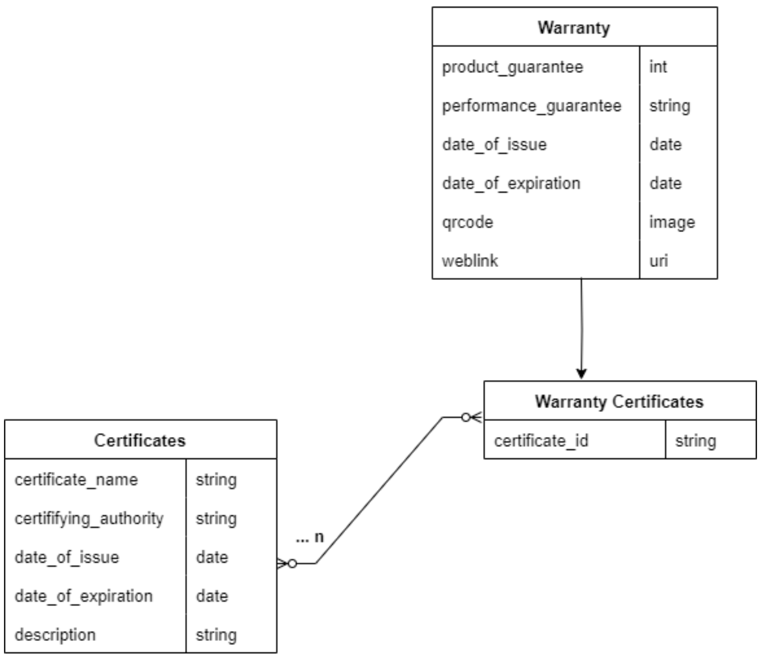


Figure 12: Warranty SubModel

3.1.6 *Documentation SubModel:*

All the relevant documents including technical specification, user-manuals, and warranty documents will be made available through the Documentation SubModel.

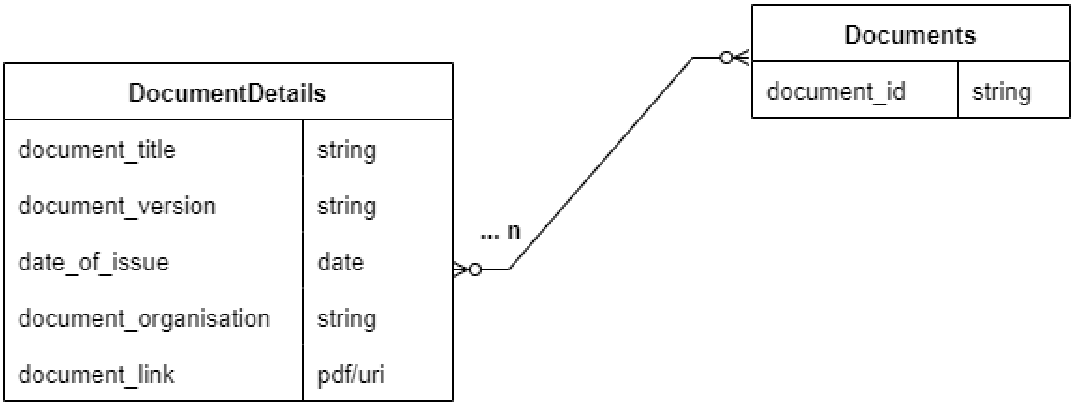


Figure 13:Documentation SubModel

4 Conclusions

In this subtask of WP5, the photovoltaic module parameters were investigated to create a base data model for creating Digital Twins of the modules. The current standardization activities relevant to the photovoltaic modules on aspects of sustainability and circularity are currently evolving. Given the expected rise in the solar module installations, this task initiates the requirements definition to define a strong repository which will facilitate activities that will support tracing and circularity in line with the regulations. The digital twin also facilitates maintaining a digital record of all the module details which is beneficial to the direct and indirect stakeholders and end-users. Every manufacturer stores only information relevant to their requirements and in accordance with the privacy and data confidentiality agreements. A standardized data model will help to provide an encompassing overview for all end applications – tracing source of materials, recycling, computing carbon footprint, etc. The document thus is a summary of all the relevant parameters which will be used for creating the first prototype of the digital twins and an associated repository, which will be validated and tested in one of the manufacturing partners involved in the WP5.

5 Glossary

AAS	Asset Administration Shell
PV	Photovoltaic
WEEE	Waste from Electrical and Electronic Equipment
RoHS	Restriction of Hazardous Substances in Electrical and Electronic Equipment
EU	European Union

Table 1: Glossary of Properties and Details in the Data Model

The table below provides examples of the photovoltaic module properties along with the

SubModel Collection	Property	Data Type	Unit	Access	Lang-uage	Definition	Value
Identification	module_id	string		Open Access		unique identifier of module	
	module_name	string		Open Access		unique name of the module	
	serial_number	string		Open Access		serial number of module at the time of manufacturing	ENGY090
	date_of_manufacture	date		Open Access		date of manufacture of module – follow uniform date formats	02.02.2024
	qrcode	image		Open Access		qr code to web-interface to view module details	
	weblink	URI		Open Access		URL to a web interface when available	
	manufacturer_name	string		Open Access (EU)	EN	name of the manufacturer	ISC
	manufacturer_GLN	string		Open Access (EU)	EN	Global Location number of the manufacturer	
	manufacturer_country	date		Open Access (EU)	EN	country of manufacturing	Germany

	manufacturer_address	string		Open Access (EU)	EN	Street, Number, City, Postal Code of manufacturer	Rudolf-DieselStr 15,Konstanz
	manufacturer_phone_number	string		Open Access (EU)		Phone number of Manufacturer	+49 (0) 7531 / 36 183
	manufacturer_logo	image/ URI		Open Access (EU)		Logo of the manufacturer provided as an image file or URI	ISC
	manufacturer_website	URI		Open Access			https://isc-konstanz.de/
Mechanical Specification	module_ technology	string		Open Access	EN	module technology (PERC, PERT, IBC, multi-junction)	IBC
	module_type	string		Open Access	EN	type of module (Glass, Frontsheet)	Glass-Glass
	cell_layout_type	string		Open Access	EN	describes the layout of cells in the module	Butterfly
	cells_per_module	integer		Open Access	EN	define the number of cells per module	60
	module_length	real	mm	Open Access	EN	length of the module	1700
	module_height	real	mm	Open Access	EN	height of the module	30
	module_width	real	mm	Open Access	EN		1130
	module_weight	real	kg	Open Access	EN		21
	module_area	real	m2	Open Access	EN		Full-black
	module_colour	string		Open Access	EN	Colour of module as defined in the manufacturer specific colour codes	
Electrical Specification	rated_maximum__power	real	W	Open Access	EN	Rated power output refers to the maximum power that a solar panel can generate under specific conditions	430
	open circuit voltage (voc)	real	V	Open Access	EN	The voltage output of a solar module under standard test condition, when the terminals of the modules are not connected with any load.	39
	maximum power voltage(vmp)	real	V	Open Access	EN	voltage that occurs when the module is connected to a load and is operating at its peak performance output under standard test conditions	32
	short_circuit_ current (isc)	real	A	Open Access	EN	The short-circuit current is the current through the solar cell when the voltage across the solar cell is zero	
	maximum_ power_current (imp)	real	A	Open Access	EN	t is the actual amperage you want to see when it is connected to an MPPT controller under standard test conditions in bulk-charge mode.	
	max_system_ voltage	real	V	Open Access	EN	Maximum system voltage is the maximum	

						voltage at which your solar system array should be operated.	
	Serial_fuse_rating	real	A	Open Access	EN		
	module_efficiency	real	%	Open Access	EN	Efficiency of solar module is defined as the ratio of maximum power at standard test condition, to the input power.	23
	power_ tolerance	string	W	Open Access	EN	Power tolerance is a measure of how much electrical power a solar panel can produce above or below its rated capacity at any time	
	energy_ efficiency_class	string		Open Access	EN	energy efficiency of the appliance is rated in terms of a set of energy efficiency classes from A to G	
	equipment_class	string		Open Access	EN	Four classes (Class 0, I, II and III) are defined in IEC 61140, "Protection against electric shock - Common aspects for installations and equipment."	Class II
	maximum surface load capacity			Open Access	EN		
Temperature Co-efficients	nominal_operating_cell_ temperature	string	℃	Open Access	EN		
	ambient_temperature_r ange	string	° C	Open Access	EN		
	temperature_ coefficient_of_pn		%/℃	Open Access	EN		
	temperature coefficient of isc		%/℃	Open Access	EN		
Module Characterizati on	current_voltage_curve	image		Open Access	EN		
	power_voltage_curve	image		Open Access	EN		
	power_voltage_curve_te mperature_varied	image		Open Access	EN		
SolarCells	serial_number	string		Confidential		All details of the solar cells in the module	
	batch_number	string		Confidential			
	date_of_manufacture	date					
	cell_technology	string		Open Access EU			
	cell_material	string		Open Access			
	cell_size	string		Open Access			
	cell_type	string		Open Access			
	cell_qrcode	image		Confidential			
	manufacturer_name	string		Confidential			
	manufacturer_GLN	string		Confidential			

	manufacturer_country	image		Confidential			
	manufacturer_URI	string		Confidential			
Encapsulant	serial_number	string		Confidential			EVA 450 µm
	product_name	string		Confidential			
	manufacturer_name	string		Confidential			First
	date_of_manufacture	date		Confidential			
	description	string		Open Access		Details on Encapsulants - provide adhesion between the solar cells, top surface and rear surface of a PV module	
Glass_front	serial_number	string		Confidential			
	product_name	string		Confidential			
	manufacturer_name	string		Confidential			
	date_of_manufacture	date		Confidential			
	description	string		Open Access			
	thickness	real	mm	Open Access			
	material	string		Open Access			
Glass_rear	serial_number	string		Confidential			
	product_name	string		Confidential			
	manufacturer_name	string		Confidential			
	date_of_manufacture	date		Confidential			
	thickness	real	mm	Open Access			
	material	string		Open Access			
	description	string		Open Access			
Backsheet	serial_number	string		Confidential			
	product_name	string		Confidential			
	manufacturer_name	string		Confidential			
	date_of_manufacture	date		Confidential			
	description	string		Open Access			
Frame	serial_number	string		Confidential			
	product_name	string		Confidential			
	manufacturer_name	string		Confidential			
	date_of_manufacture	date		Confidential			
	description	string		Open Access			
Connectors	serial_number	string		Confidential			
	product_name	string		Confidential			
	manufacturer_name	string		Confidential			
	date_of_manufacture	date		Confidential			
	description	string		Open Access			
	Type	string		Open Access			
Junction box	ip_rating	string		Open Access			

	num_of_diodes	real		Open Access			
	serial_number	string		Confidential			
	product_name	string		Confidential			
	manufacturer_name	string		Confidential			
	date_of_manufacture	date		Confidential			
	description	string		Open Access			
Cables	serial_number	string		Confidential			
	product_name	string		Confidential			
	manufacturer_name	string		Confidential			
	date_of_manufacture	date		Confidential			
	description	string		Open Access			
	Length	real	mm	Open Access			
	Diameter	real	mm^2	Open Access			
Repairability	Description	string /URI					
EU_Energy_ label	module_area	real	m2	Open Access EU	EN		1130
	module_length	real	m	Open Access EU	EN		21
	module_width	real	m	Open Access EU	EN		Full-black
	bifaciality	string		Open Access EU	EN		
	energy_label			Open Access EU	EN		
	suppliers_name	string		Open Access EU	EN		
	carbon_footprint	real	$kgCO_2$ eq/kWh	Open Access EU			
	energy_yield_temperate_continental	integer	kWh/ m^2 per annum	Open Access EU	EN		
	energy_yield_temperate_coastal	integer	kWh/ m^2 per annum	Open Access EU	EN		
	energy_yield_temperate_subtropical	integer	kWh/ m^2 per annum	Open Access EU	EN		
	qrcode	image		Open Access EU	EN		
	website_link	uri		Open Access EU	EN		
	EnergyYield_temperate_coastal	integer		Open Access EU	EN		
EU_Recyclability	recyclability_ index	string/ integer		Open Access EU	EN		A-G or 1-10
EU_Recyclability_Materials	material_id	string		Open Access EU			
	material_name	string		Open Access EU			Silver (Ag)

	material_weight	real	g	Open Access EU			20
	recyclability_rate	real	%	Open Access EU			
FR_CRE_carbon_footprint	GWP	real	kgCO2e/kWp	Open Access			
	certifiying_ authority	string		Open Access			
	date_of_issue	date		Open Access			
	version	string		Open Access			
NL_NMD_Dutch_Environmental_Database	product_name	string		Open Access			Solarge SOLO, 2.71 m2/st PV module, 500 Wp per stuk, mono-Si, incl. steun, excl. inverter + kabels
	environmental_declaration_number	string		Open Access			#nmd_92199
	environmental_ cost	real	€	Open Access			
	date_of_issue	date		Open Access			
	owner	string		Open Access			Solarge International BV
	unit	string		Open Access			
	lifespan	int	years	Open Access			25
	category	string					Categorie1
	description	string		Open Access			Lichtgewicht zonnepaneel (afmetingen: 2335 x 1159 x 45 mm) met c-Si cellen en montagebeugels rondom de module, o.a. te gebruiken voor installatie op platte daken en/of schuine daken.
Product Guarantee	product_guarantee	real	years	Open Access EU		A product warranty primarily covers defects in materials and workmanship. In the context of solar panels, this warranty safeguards against manufacturing flaws, ensuring that the panels meet specified quality standards	10~25
Performance Guarantee	performance_guanrantee	real	years	Open Access EU		performance warranty focuses on the solar panels' ability to generate electricity over time. This warranty guarantees a certain level of energy output, typically expressed as a percentage of the panel's original capacity, over a specified period.	

Certificates	certificate_name	string				All information related to the certificates are provided in the certificates submodel	
	certifying_authority	string					
	date_of_issue	string					
	date_of_expiration	date					
	description	string					
Manual	installation_manual	pdf/ url				All information related to the available documents are provided in the documentation submodel	
	document_version	string					
	document_title	string					
	document_date	date					
Warranty	warranty	pdf/ url		Open Access EU			
	document_version	string					
	document_title	string					
	document_date	string					

6 References

[1] Wang, Kai & Wang, Yamin & Li, Yizheng & Fan, Xiaohui & Xiao, Shanpeng & Hu, Lin. (2022). A review of the technology standards for enabling digital twin [version 1; peer review: awaiting peer review] Digital Twin. Digital Twin. 2. 10.12688/digitaltwin.17549.1.

[2] D. Polverini (2023), 'Ecodesign and Energy labelling requirements for photovoltaic modules and inverters', Sustainable Solar Europe 2023, Brussels, 7 December 2023.

[3] Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment (WEEE) (recast). EUR-Lex – 02012L0019-20180704 – EN – EUR-Lex (europa.eu)

[4] https://environment.ec.europa.eu/topics/waste-and-recycling/waste-electrical-and-electronic-equipment-weee_en#evaluation

[5] https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/green-deal-industrial-plan/european-critical-raw-materials-act_en

[6] https://environment.ec.europa.eu/topics/waste-and-recycling/rohs-directive_en

[7] University of Cambridge Institute for Sustainability Leadership (CISL) and the Wuppertal Institute. (2022). Digital Product Passport: the ticket to achieving a climate neutral and circular European economy? Cambridge, UK: CLG Europe.

[8] CRE(2023). Cahier des charges de l'appel d'offres portant sur la réalisation et l'exploitation d'Installations de production d'électricité à partir de l'énergie solaire « Centrales au sol ». AO PPE2 PV Sol. https://www.cre.fr/fileadmin/Documents/Appels_d_offres/import/CDC_PV_Sol_10_11_2023.pdf

[9] https://milieudatabase.nl/en/environmental-data-lca/

[10] https://www.plattform-i40.de/IP/Redaktion/DE/Downloads/Publikation /Details_of_the_Asset_Administration_Shell_Part1_V3.html