HORIZON EUROPE PROGRAMME
TOPIC HORIZON-CL5-2023-D3-01-02

GA No. **101136094**

Sustainable Photovoltaics Integration in buildings and Infrastructure for multiple applications

SPHINX - Deliverable report

MILESTONE No. 9 - Baseline of data collection determined for the LCA and value chain readiness

Funded by the European Union

1 Milestone Achievement

1.1 Title of Milestone

This document reports the achievements for Milestone MS9 of the SPHINX project which deals with the baseline of data collection determined for the LCA and value chain readiness.

1.2 Description of Milestone and means of verification

The milestone is related to work package WP6 with the topic "Economic, Environmental and Sustainability assessment and recommendations" and provides the data that is required for performing a life cycle assessment (LCA) of the IPV products of the partners of the SPHINX project. It identifies and summarizes the required data in a template that is circulated among the industrial partners, allowing to obtain direct feedback on the feasibility of the data collection process and identify possible gaps in the data procurement. Templates for the module designs of the four different IPV products envisioned by the partners in the SPHINX project are developed as excel sheets. The excel sheets include relevant data that has been collected up to the date of the milestone report.

The data collection is closely related to the second phase of a life cycle assessment (LCA), namely the life cycle inventory (LCI) model, through which data is collected and organized, see also below for the main phases of a LCA according to ISO standards DIN 14044 and ISO 14040:2006. [1,2]

The milestone is verified when the report including the templates for the data collection are reviewed and when the feedback on the collected data is provided by the partners of the SPHINX project.

The milestone report gives an overview of the required data of the module components of the IPV products of the partners of the SPHINX project within WP6. To ensure a high level of quality and reliability of the data, data sheets of the module components are used. Besides the data sheets specific processes steps for the four different IPV products are used for the LCA.

1.3 Methodology

1.3.1 Introduction

Aspects of sustainability gain more and more importance for the acceptance of new technologies and products and thus have a major impact on market penetration. Issues on energy consumption during the production of the raw materials and for the manufacturing process of IPV modules as well as the

[1] International Organization for Standardization, Environmental management: life cycle assessment; requirements and guidelines (ISO Geneva, Switzerland, 2006).
[2] D. I.N. ISO, 14040: Environmental management-Life cycle assessment-Principles and framework (ISO 14040: 2006). Deutsche und Englische Fassung EN ISO. 14040, 2006 (2006).

recycling ability and economy will be called into question by society and consumers. These aspects will be addressed in the course of the development of IPV products in a life cycle assessment (LCA) of the four different module designs of the partners of the SPHINX project. The LCA provides a framework for assessing the environmental performances of the IPV products by comparing the preliminary carbon footprint of the modules based on the bill of materials (BOM) provided by the partners, so that key materials and processes can be identified that will have a significant potential for further improvements.

1.3.2 Life cycle assessment

A life cycle assessment (LCA) is generally understood as a compilation and evaluation of inputs and outputs to identify potential environmental impacts of a product system throughout its life cycle. LCA studies always consist of four main phases, which are covered by ISO standards DIN 14044 and ISO 14040:2006. [3,4] The first step of the LCA is used to define the goal and scope of the study. The second step is a life cycle inventory (LCI) model through which data is collected and organized. The third step is the life cycle impact assessment (LCIA), used to understand the relevance of all the inputs and outputs in an environmental framework. The fourth step is the interpretation, which is a systematic technique to identify, check, and evaluate the information resulting from the LCIA as shown in Figure *1*.

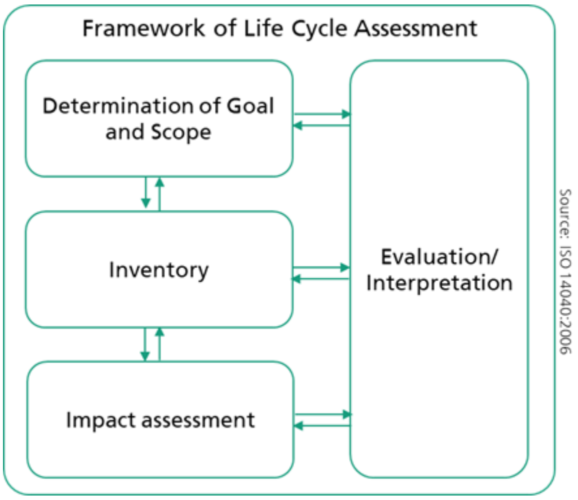

Figure 1: Life cycle assessment (LCA) framework.

The four main phases comprise in more detail the following steps:

1. Establishment of the objective and the scope of the assessment, in which the functional unit for the assessment and selection of the impact categories of environmental effects to be investigated is made.

[3] International Organization for Standardization, Environmental management: life cycle assessment; requirements and guidelines (ISO Geneva, Switzerland, 2006).
[4] D. I.N. ISO, 14040: Environmental management-Life cycle assessment-Principles and framework (ISO 14040: 2006). Deutsche und Englische Fassung EN ISO. 14040, 2006 (2006).

2. Life Cycle Inventory (LCI), in which all necessary data on energy and material flows as well as emissions in production during the product life cycle are recorded, including the transition from technosphere to ecosphere (extraction from and release to nature).
3. Life Cycle Impact Assessment (LCIA), which classifies and characterizes the emissions produced according to their contribution to selected impact categories, e.g., global warming potential, eutrophication, human toxicity, ecotoxicity, etc.
4. Evaluation and interpretation, in which the results are validated by various sensitivity and scenario analyses, and the corresponding evaluation and interpretation are performed with respect to key impact parameters, so-called hotspots.

The LCA takes into account DIN EN ISO 14040-4 and DIN EN 15804, as well as the recommendations of the International Energy Agency (IEA) PVPS Task 12 "Methodology Guidelines on Life Cycle Assessment of Photovoltaic Electricity", and the "Product Environmental Footprint Category Rules for Photovoltaics"(PEFCR-PV) of the European Commission. [5,6,7,8,9] Greenhouse gas emissions (kgCO_2-eq) will be used as an indicator of climate change contribution. The 100-year global warming potentials based on the IPCC 2021 V1.00 will be assumed, according to their radiative forcing capacity relative to the reference substance CO_2. Global warming potential (GWP) during the life cycle stages of the solar modules are estimated as an equivalent of carbon dioxide (CO_2). The GWP as the most important criterion is the potential contribution of a substance to the warming of the ground-level air layers to the so-called greenhouse effect. The contribution of the substance is expressed as a GWP value relative to the global warming potential of the substance carbon dioxide. The lower the value of the CO_2 equivalent, the lower the potential effect on global warming and the associated environmental impacts.

The calculations will be performed using the LCA software SimaPro 9.5 with ecoinvent 3.9 or the latest 3.10 version as the background database. [10,11] SimaPro is a process-oriented software, examining the material and energy flows of each step of the production chain.

For the data collection in terms of the Life Cycle Inventory (LCI) the most up-to-date inventory data by Fraunhofer ISE is used which investigates the current material input, for instance, for the processes of polysilicon for the solar cell production based on a detailed cost model of photovoltaic solar cell and module production facilities. [12]

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[5] International Organization for Standardization, Environmental management: life cycle assessment; requirements and guidelines (ISO Geneva, Switzerland, 2006).
[6] D. I.N. ISO, 14040: Environmental management-Life cycle assessment-Principles and framework (ISO 14040: 2006). Deutsche und Englische Fassung EN ISO. 14040, 2006 (2006).
[7] often shortened to EN 15804, Building Sustainability -- Environmental Product Declarations -- Basic Rules for the Product Category of Building Products (2016).
[8] R. Frischknecht, P. Stolz, G. Heath, M. Raugei, P. Sinha, M. de Wild-Scholten, Methodology Guidelines on Life Cycle Assessment of Photovoltaic (2020).
[9] T. Theologitis, L. Francke, R. Frischknecht, P. Stolz, J. Tian, Product Environmental Footprint Category Rules (PEFCR): Photovoltaic Modules used in Photovoltaic Power Systems for Electricity Generation (2019).
[10] Ecoinvent database v.3.9 / v.3.10 (available at https://www.ecoinvent.org/).
[11] PRé Sustainability, SimaPro Analyst v9.4 (available at https://simapro.com/).
[12] A. Müller et al., A comparative life cycle assessment of silicon PV modules: Impact of module design, manufacturing location and inventory. Sol Energ Mat Sol C. 230, 111277 (2021), doi:10.1016/j.solmat.2021.111277.

Due to a lack of industry data on process emissions, the emissions are based on the ecoinvent data base. The background data of is based on ecoinvent v3.9 or the latest 3.10 version.

Most of the solar cells as well as some module components are mostly produced in China, but some module components of the IPV products of the partners of the SPHINX project are obtained from suppliers not located in China. In such cases, the production of the module components and the materials used will be specified by the country of their origin. Sometimes module producers do not know the origin of the module components. In such cases, module components and the materials used will be obtained on a global market. Typically, the processes involved in solar cell manufacturing (metallurgical-grade silicon, polysilicon, Czochralski crystal, wafer and cell production) as well as in glass and silver paste production will be modelled considering the available inventory for the country specific origin, mostly China.

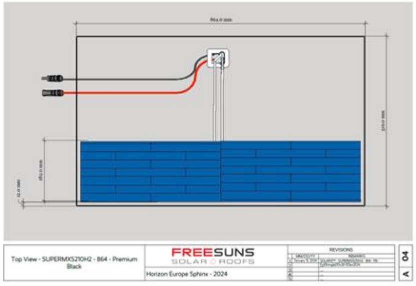
Noteworthy, for some module components, materials for the production are not always available in the ecoinvent data base. In such cases, the materials for the module components will be approximated by similar materials, including approximations for energy demands, etc.

Transport will be modelled for every module component of the IPV products of the partners of the SPHINX project along the whole photovoltaic process chain, including selected intermediate products. The module component, including packaging, are transported by train, truck and ship from the production location to the production location of the modules. The transport is based on the weight of packaged modules, consistent with the common modelling approach of transportation in ecoinvent date base and photovoltaic LCA reports. [13,14]

1.3.3 Data collection for life cycle inventory

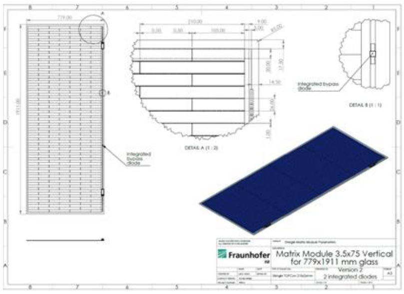
The inventory data for the module production is listed in the templates for the four different module designs of the partners of the SPHINX project. Modules for industrial building as a lightweight shingle matrix system, modules for integration in individual houses including façades as matrix shingle tiles roof and façade systems, modules for parking carport applications as semi-transparent matrix shingle and modules as integrated noise barrier with custom modules with current technology and bifacial semi-transparent module with shingle technology and anti-soil module will be investigated, see Figure 2.

[13] R. Frischknecht, P. Stolz, G. Heath, M. Raugei, P. Sinha, M. de Wild-Scholten, Methodology Guidelines on Life Cycle Assessment of Photovoltaic (2020).
[14] R. Frischknecht, R. Itten, P. Sinha, M.d. Wild-Scholten, J. Zhang, Life Cycle Inventories and Life Cycle Assessments of Photovoltaic Systems (2015).



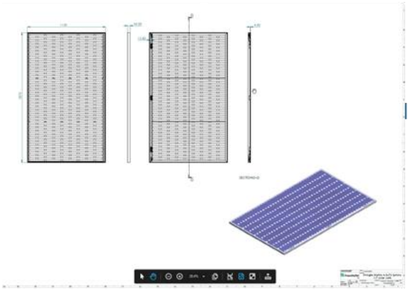
Module Designs

- Freesuns Rooftile



Module Designs

- Heliup Lightweight



Module Designs

- Voltec Carport

Module Designs

- Etway Noise Barrier

Figure 2: Technical Drawings of the module designs for the four different IPV products in the SPHINX project.

The inventory data for the module production is listed in the templates for the four different module designs of the partners of the SPHINX project, see Table 1.

Table 1 Inventory data for of the module designs for the four different IPV products in the SPHINX project and name of the corresponding template for the data collection

No.	Module design	Partner	Template
1	Matrix shingle noise barrier	Etway	2024_08_20_LCI_SPHINX_Etway.xlsx
2	Matrix shingle roof tiles	Freesuns	2024_08_20_LCI_SPHINX_Freesuns.xlsx
3	Matrix shingle lightweight	Heliup	2024_08_20_LCI_SPHINX_Heliup.xlsx
4	Matrix shingle carports	Voltec	2024_08_20_LCI_SPHINX_Voltec.xlsx

The templates include the various module components for the different production steps of the module of the partners of the SPHINX project and is circulated among the industrial partners, allowing to obtain direct feedback on the feasibility of the data collection process and identify possible gaps in the data procurement. The templates are developed as excel sheets. The excel sheets include relevant data that has been collected up to the date of the milestone report. An example of the templates is shown in the following for the matrix shingle roof tiles modules from Freesuns, see Figure 3, Figure 4 and Figure 5. Figure 3 shows the "general information" for the module design of the IPV product from the partner Freesuns while Figure 4 and Figure 5 show the example for data required for the "manufacturing of glass" and, additionally, a questionnaire related to the "manufacturing of glass" for the module design of the IPV product from the partner Freesuns.

DATA COLLECTION TEMPLATE FOR LIFE CYCLE ASSESSMENT

Fraunhofer ISE

This questionnaire was developed as a tool to obtain the necessary information towards the detailed LCA evaluation of glass, receiving funding from BMWK. Please fill in all information as accurate as possible and in as much detail. Do not hesitate to contact Fraunhofer ISE (details below) for further information.

Project	SPHINX

ISE details

Organisation name	Fraunhofer ISE
Role on the project	LCA specialist
Contact person	Laura Stevens & Christian Reichel
Contact details (email/tel)	

Partner's details

Organisation name	*Freesuns*
Role on the project	*(please specify)*
Contact person	*(please specify)*
Contact details (email/tel)	*(please specify)*

Main Product

One kilogram of Rolled glass

Reference Value

Amount (Main Product)	*1*
Units of reference value (e.g. Lt or Lt/h or kg or kg/h, etc.)	*kg*
If any by-product/co-product, please specify amount and unit	*(please specify)* *e.g. 1 kg of "by-product" zz*

Process Description

(please provide a thorough description of the processes of your pilot line for the main product manufacturing) e.g. manufacturing, assembly, etc.

Production Details

Production Capacity (if available)	*(please specify) e.g. 2*
Units (e.g. L/y or kg/batch, etc.)	*(please specify) e.g. pcs/ day*
TRL or scale (e.g. TRL 4 or lab-scale)	*(please specify)*
Country of operation	*(please specify)*

Process diagram

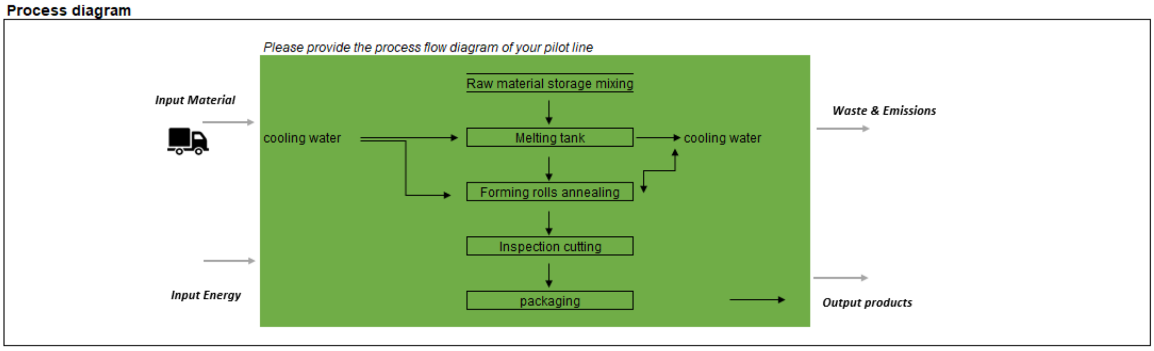


Figure 3: General Information in the excel sheet for the module design of the IPV product from the partner Freesuns in the SPHINX project.

Fraunhofer ISE

DATA COLLECTION TEMPLATE FOR LIFE CYCLE ASSESSMENT

Input data

Material inputs					Notes
Description	Amount	Units	Country of origin/estimated dist	Type of transport	
Sand	(specify)	e.g. tonne	(specify)	e.g. Truck	Please fill in each row with defining the input material data. Always use as a basis the reference flow, i.e. data for 1 pc of TC produced.
Soda ash	(specify)	e.g. m^3	(specify)	e.g. Train	
Limestone	(specify)	e.g. kg	(specify)	(specify)	
Dolomite	(specify)	e.g. kg	(specify)	(specify)	
Sodium sulphate	(specify)	e.g. kg	(specify)	(specify)	
Sodium nitrate	(specify)	e.g. kg	(specify)	(specify)	
Sodium antimonate	(specify)	e.g. kg	(specify)	(specify)	
Cullet	(specify)	e.g. kg	(specify)	(specify)	
Cooling water	(specify)	e.g. kg	(specify)	(specify)	
Others (please specify)					

Energy inputs					Notes
Description	Amount	Units	Link to specific unit operation	Comments	
Natural gas	(specify)	e.g. m^3	(e.g. "Melting")	e.g. per unit process or total	Please indicate the input energy data and all relevant information.
Electricity	(specify)	e.g. kWh	(e.g. "Melting")	e.g. national grid, location	
Heavy fuel oil	(specify)	e.g. kg	(e.g. "Melting")		
On site production (please specify)	(specify)	(specify)	(specify)	e.g. specify fuels	
Others (please specify)	(specify)	(specify)	(specify)	(specify)	
-	-	-	-	-	

Infrastructure					Notes
Description of Unit operation	Amount	Units	Number of workers / shift / Unit Operation (e.g. 0.2 workers / shift)	Comments (Please indicate machine manufacurer or model if available)	
Batching	(specify)	item	(specify)	Please indicate capacity of raw material mixing chamber	Please fill in each row with defining equipment and labour data.
Melting	(specify)	item	(specify)	Please indicate capacity of melting tank	
Forming rolls annealing	(specify)	(specify)	(specify)	Please indicate number of main rollers and transport rollers	
Inspection cutting	(specify)	(specify)	(specify)		
Coating					
Packaging	-	-	(specify)		
	-	-	(specify)		
			(alternatively specify total number of workers/ shift or batch)		

Output data

Outputs					Notes
Description	Amount	Units	Allocation	Comments	
Rolled glass	(specify)	e.g. tonne	e.g. sold to market	The defining material/energy amount	Please specify the main output and further product outputs (co-products / by-products, if any).
Waste glass	(specify)	e.g. tonne	e.g. sold to sub-market	e.g. co/ by-product	
Further product outputs	-	e.g. tonne	e.g. sold to sub-market	e.g. co/ by-product	

Emissions					Notes
Air emissions	Amount	Units	Description (linked to specific unit operation)	Waste treatment option	Please indicate if any gaseous or other emissions exist and their details. Please indicate waste data including waste water and solid waste and their treatment method in case.
Carbon dioxide	(specify)	e.g. kg	(specify)	n/a	
Carbon monoxide					
Hydrochloric acid					
Hydrogen flouride					
NMVOC					
Sulfur dioxide					
Particulate matter					
Fill in more rows if needed					
Water emissions	Amount	Units	Description (linked to specific unit operation)	Waste treatment option	
Water	(specify)	e.g. kg	(specify)	e.g. WWT plant on site	
(Please specify)	(specify)	e.g. kg	(specify)	n/a	
Fill in more rows if needed					
Waste					
Solid waste	Amount	Units	Description (linked to specific unit operation)	Waste treatment option	
Solid waste	(specify)	e.g. kg	(specify)	e.g. 2% of material sent to landfill	
(Please specify)	(specify)	e.g. kg	(specify)	n/a	
Fill in more rows if needed					
Wastewater	Amount	Units	Description (linked to specific unit operation)	Waste treatment option	
Wastewater	(specify)	e.g. m^3	(specify)	e.g. WWT plant on site	
(Please specify)	(specify)	e.g. kg	(specify)	n/a	
Fill in more rows if needed					

Figure 4: Example for the "manufacturing of glass" in the excel sheet for the module design of the IPV product from the partner Freesuns in the SPHINX project.

Fraunhofer ISE **DATA COLLECTION TEMPLATE FOR LIFE CYCLE ASSESSMENT**

No.	Question	Answer
1	Please provide details for the main product of your pilot line (i.e. form, dimensions).	e.g. TC xx by these materials, with these specific dimensions, etc.
2	Please provide any data related to the main product performance (i.e. U value), if available.	e.g. thermal conductivity of produced TC is λ = 20 mW/m K. density, etc.
3	Please provide any information available about the manufacturing equipment and its characteristics and operating conditions.	e.g. vacuum infusion, working for how long to produce which amount of TC, at which temperature, etc.
4	Are any of the materials used for production recycled? Please provide details (which materials, to what percent, where entering which process, etc.)	e.g. 50% recycled water
5	If any co-products/by-products, are they provided to other suppliers for other applications?	e.g. specific percentage of xx material produced going to other manufacturers.
6	What is the life expectancy of your manufacturing techology?	e.g. 20 years
7	What kind of data have you provided? Is it primary data (measured data) or secondary data (proxies, aggregated, estimated)?	e.g. measured production data
8	Is there any additional key element not described in this questionnaire? If so, please describe.	e.g. attached equipment specification pdf
9	Please provide any information you consider relevant for the sustainability assessment and necessary for understanding your operations.	e.g. attach previously conducted energy assessment or LCA, drawings, etc.

Figure 5: Example of a questionnaire related to the "manufacturing of glass" in the the excel sheet for the module design of the IPV product from the partner Freesuns in the SPHINX project.

Similar templates are also provided for the module design of the IPV products from the partners Etway, Heliup and Voltec.

1.4 Comments on completion

The milestone was achieved by collecting data for the module component of the IPV products from the partners of the SPHINX project and preparing a template that already include relevant data that has been collected up to the date of the milestone report. The templates include the various module components for the different production steps of the module designs and is circulated among the partners of the SPHINX project.

1.5 Other relevant information

Lead beneficiary	Fraunhofer ISE (Laura Stevens & Christian Reichel)
Linked WP	6
Achievement date in DoA	August 2024
Actual date	31. August 2024
Achieved	Yes
Reference documents	Mention relevant documents (if any)

1.6 Interconnections with deliverables

The milestone MS 9 is related to the upcoming deliverable D6.2 with the title "LCA report on SPHINX IPV products". The deliverable D6.2 has the aim to determine the sustainability of products at the creation stage in order to initiate improvements and an environmental life cycle assessment of the planned products is performed in the deliverable D6.2 which is based on the bill of material, yield and energy consumption. The deliverable D6.2 is be fulfilled with a full LCA report for all products.

The milestone MS 9 provides the required data for the bill of materials as a life cycle inventory (LCI), so that the LCA of all products can be performed.

2 Acknowledgement

The author(s) would like to thank the partners in the project for their valuable comments on previous drafts and for performing the review.

Project partners:

#	Partner short name	Partner Full Name
1	VOL	VOLTEC SOLAR
2	ETW	ETWAY S.R.L.
3	HLP	HELIUP
4	M10	M10 INDUSTRIES AG
5	UNR	UNIRESEARCH BV
6	Fraunhofer	FRAUNHOFER GESELLSCHAFT ZUR FORDERUNG DER ANGEWANDTEN FORSCHUNG EV
7	ICARES	ICARES CONSULTING
7.1	BI	BECQUEREL INSTITUTE FRANCE
8	CEA	COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES
9	FSUNS	Freesuns SA
10	CSEM	CSEM CENTRE SUISSE D'ELECTRONIQUE ET DE MICROTECHNIQUE SA - RECHERCHE ET DEVELOPPEMENT
11	EPFL	ECOLE POLYTECHNIQUE FEDERALE DE LAUSANNE
12	SOP	SOPREMA

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