



SOPHIA

Sustainable Off-grid solutions for
Pharmacies and Hospitals In Africa

LIFE CYCLE ASSESSMENT AND SUSTAINABILITY ASSESSMENT

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ABBREVIATIONS

LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
EF	Environmental Footprint
GWP	Global Warming Potential
IPCC	Intergovernmental Panel on Climate Change
PV	Photovoltaic
MCDI	Membrane Capacitive Deionization



EXECUTIVE SUMMARY

The SophiA project has set objectives to provide sustainable off-grid energy supplies and clean drinking water for rural and remote health facilities in Africa, thereby accelerating sustainable development, growth, and economic transformation, and ensuring improved access to energy and health services for all. SophiA developed and locally manufactured innovative, modular, flexible, affordable, and efficient solar containers to provide the local population in four rural health centers located in four different climatic regions where help is most needed, offering sustainable solutions adapted to the African context and then transferable to the whole of Sub-Saharan Africa. Led by Hochschule Karlsruhe (HKA), the SophiA consortium consists of 13 project partners from three European and four African countries (France, Germany, Switzerland, Burkina Faso, Cameroon, Uganda, and South Africa).

This report was made in the frame of Work Package 7 “Task 7.1 (Life Cycle Assessment (LCA) and Sustainability Assessment possibly using Copernicus Services)”, led by SPF-OST and describes the environmental footprint of the SophiA system outputs using IPCC 2021 GWP 100a V1.02 and Environmental Footprint (EF) 3.1 methodologies.

The general objective of this LCA study was to investigate the environmental performance of the raw material extraction and manufacturing processes of the SophiA system, as well as the environmental impacts associated with its use and end-of-life phases. The scopes of this LCA study are:

- To find out the specific environmental impact associated with the lifecycle of the SophiA system from cradle to grave.
- To know how well the 100% renewable-driven SophiA system performs from an environmental point of view compared to a fossil fuel-powered or grid-powered system.
- To identify improvements that could be made to enhance the environmental performance of the SophiA system.

The SophiA system fulfills multiple functions by continuously providing renewable, off-grid refrigeration at different temperature levels (+5 °C, -30 °C, -70 °C) using a cascaded cooling system including ice storage, steam at 150 °C using PVsteamCube system, and freshly cooled clean drinking water at 20 °C using water treatment system to various hospitals in Africa, without disruption or power outages.

The inventory analysis for material and energy input was carried out using the ecoinvent database and data collected from different partners involved in designing and manufacturing the SophiA technologies. The Life Cycle Inventory (LCI) of the SophiA technologies was imported into SimaPro to simulate the Life Cycle Impact Assessment (LCIA).

The environmental impact according to the IPCC 2021 GWP 100a methodology for SophiA system outputs were:

- 100.7 gCO₂-eq for 1 kWh_{th} of cooling at +5 °C with a total cooling volume of 37 m³
- 126.6 gCO₂-eq for 1 kWh_{th} of cooling at -30 °C with a total cooling volume of 15 m³
- 62.3 gCO₂-eq for 1 kWh_{th} of cooling at -70 °C with a total cooling volume of 0.2 m³
- 0.2 gCO₂-eq for 1 L of clean drinking water at 20 °C



- 51.1 gCO₂-eq for 1 kg of steam at 150 °C with PVsteamCube Iron
- 50.9 gCO₂-eq for 1 kg of steam at 150 °C with PVsteamCube Aluminium

With both IPCC 2021 GWP 100a V1.02 and EF 3.1 methodologies, the environmental impact of 1 kWh_{th} of thermal output at -30 °C is the highest, followed by 1 kWh_{th} of thermal output at +5 °C, followed by 1 kWh_{th} of thermal output at -70 °C, followed by 1 kg of steam at 150 °C and the lowest impact is observed for 1 L of clean drinking water at 20 °C.

The LCIA using the EF 3.1 methodology showed that the highest impacts are observed in the impact categories of resource use (metals and minerals) followed by human toxicity non-cancer, eutrophication of fresh water, ecotoxicity of fresh water, acidification, and human toxicity cancer.

The SophiA system is designed for off-grid operation, powered by a 100% renewable energy supply. To evaluate its performance, we analyzed and compared alternative energy sources: a) off-grid diesel backup, b) on-grid diesel backup, and c) grid electricity supply. Results indicate a substantial increase in environmental impact when replacing the 100% PV/battery off-grid supply with these alternatives, specifically: a) 92% PV/battery with diesel backup (off-grid), b) 100% diesel backup (on-grid), and c) 48% grid electricity-diesel backup (on-grid). Each alternative mix introduces higher emissions and resource consumption, emphasizing the environmental benefits of a fully renewable PV/battery configuration. On average, the solar-powered SophiA system reduces greenhouse gas emissions by 5% to 23% compared to a, 28% to 69% compared to b, and 56% to 87% compared to c. Thus, the SophiA system demonstrates the lowest environmental impact among the evaluated energy supply scenarios.

The environmental performance of the SophiA system can be improved by looking at the possibilities of replacing components that are resource intensive (both material and energy inputs). Replacement of steel with some less energy-intensive metals such as aluminium can be considered, for example, the ice storage subsystem could be made of aluminium or other less energy-intensive material instead of steel if possible. Alternatives for components such as the thermosyphon and expansion vessel can also be considered to reduce the impact of cooling at -30 °C. In addition, alternatives for the semiconductor in the MCDI module can be explored to reduce the environmental impact of clean drinking water.



1. INTRODUCTION

This report (D7.1) is part of Task 7.1 and describes the Life Cycle Assessment (LCA) performed to evaluate the environmental performance of the SophiA technologies installed in the cooling and water containers.

The first steps of this task were to define the goal and scope of the LCA for the SophiA systems and to collect data on the different material and energy inputs required for different components to build the SophiA systems. The cooling container consists of refrigeration systems providing cooling at different temperatures of +5 °C, -30 °C and -70 °C powered with the electricity from solar photovoltaic (PV) system as described in the deliverable D1.3 “Design Specifications for SophiA Water, Cooling and Electricity Systems” (Schmid, 2022). The water container consists of PVsteamCube generation and water treatment systems powered by the solar PV system. All the systems installed in the container are supplied with renewable PV electricity. Only in case of a system failure, a diesel generator will be used as a backup. As the SophiA systems are new technologies integrated into a container as a container solution for cooling, steam, and clean drinking water, the evaluation of the environmental performance is essential not only to assess the carbon footprint of such technologies but also to analyse options to optimise the environmental performance. Therefore, a so-called cradle-to-grave LCA is carried out for all the technologies to evaluate their environmental impact from resource extraction to end-of-life efforts. The resulting environmental impact will provide an understanding of how to improve the system to reduce its impact.

Furthermore, the LCA was conducted to assess the SophiA system powered by solar energy, comparing its environmental impact with that of SophiA systems powered by a conventional diesel system and a grid supply.

2. LIFE CYCLE ASSESSMENT METHODOLOGY – GENERAL DESCRIPTION

This section provides a description of the LCA methodology in general without giving any reference to specific outputs under study.

LCA is a comprehensive method, that collects all material, energy, and emission flows related to a product or a service like the provision of MJ heat or cold of a specific quality. These flows are then grouped according to the potential harm they may impose on ecological systems or individuals, and the impacts related to e.g., climate change, toxicity, acidification, and ozone depletion are quantified. So-called “direct” emissions and other burdens are caused by the operation of heat or cold generation units, while “indirect” emissions and other burdens are caused by processes in the energy chain (e.g., fuel or material supply) as well as consumption of fuels, electricity, materials, and transport services for all processes within the energy chain. The latter are so-called “background processes”, which are taken from a background LCA database like ecoinvent (Wernet 2019).

This LCA is performed according to the ISO standards with appropriate system boundaries and methodological choices adapted to each application and a geographical focus on the South African region (ISO 14040 2006; ISO 14044 2006). Calculations were done with SimaPro.



In general, there are four phases in a LCA study, as represented in Figure 1, which are performed iteratively.

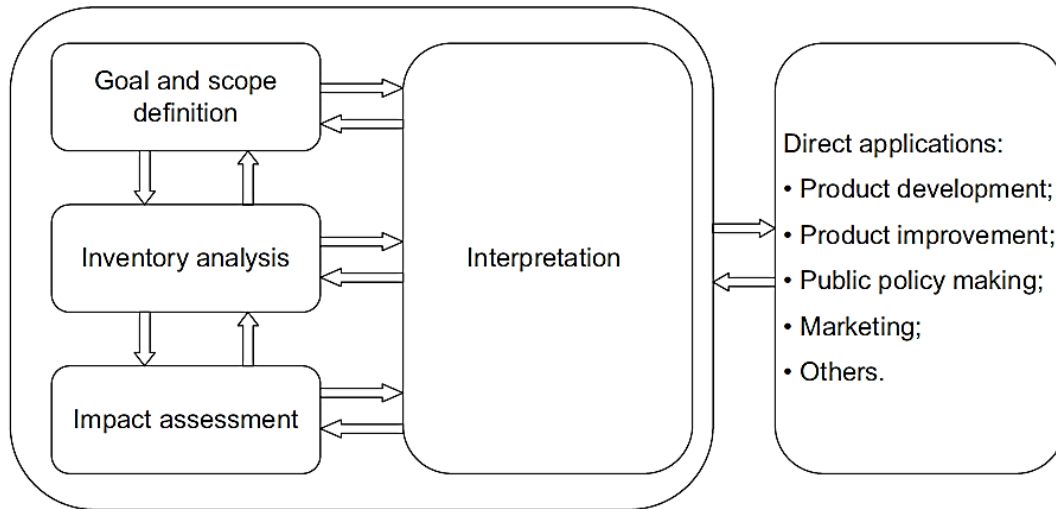


Figure 1 Different phases of LCA as per ISO 14040:2006

The sections that follow describe each stage.

2.1 Goal and scope definition

LCA study begins with the definition of the goal and scope. The objectives of the study are formulated, and the output products are defined. To achieve the goal of the study, scopes are defined. The definition of the scope includes details of the product under study and the functional unit of the output product. The system boundaries of the study and different stages of the life cycle to be included in the assessment (like cradle to gate, cradle to grave, grave to cradle, cradle to cradle, or gate to gate) should be chosen.

2.2 Inventory Analysis

The second phase of LCA is about inventory analysis which involves the data collection and calculation procedures to quantify the inputs and outputs of a product or a process under study throughout its life cycle. The inventory analysis involves creating an inventory of flows from and to nature for a product system. The inventory analysis requires the quantification of the following elements:

- Raw material requirements
- Energy input requirements
- Water input requirements
- Emissions to water, air, and land
- Solid wastes
- Other releases to the environment

This phase of the LCA is very important and is the most time-consuming phase, as it requires data to be collected from partners through questionnaires, material listings, separate meetings, reviews of product descriptions, etc. to obtain good results.



2.3 Impact Assessment

In this phase of the LCA study, the magnitude of the potential environmental impacts is quantified for a product or system throughout its life cycle. The gathered data are analysed here in this step with an impact assessment method to analyse the potential effects on the environment and human health due to the consumption of the resources for the product. There are several steps to conducting an impact assessment:

- Selection and definition of the impact category, e.g. Global Warming Potential (GWP), Ozone Depletion Potential (ODP), Acidification Potential (AP).
- Classification of the inventory table into selected impact categories.
- Characterization, where the impact of a product is quantified in each selected impact category.
- Normalization, where the effect of the emissions is compared to a certain reference environmental impact value (optional).
- Weighting, where the impact categories are weighted to the relative importance assigned to it (optional).

2.4 Interpretation of results

The results of the LCA must be thoroughly evaluated and interpreted in line with the study's goal and scope. This includes identifying the data elements that contribute most significantly to each impact category. Additionally, a sensitivity analysis should be conducted on these key data points to assess their quality and completeness.

3. GOAL AND SCOPE DEFINITION OF SOPHIA LCA STUDY

The general objective of this LCA study was to investigate the environmental performance of the raw material extraction and manufacturing processes of the SophiA system, as well as the environmental impacts associated with its use and end-of-life phases. Thus, the following research questions were analysed:

- What are the specific environmental impacts associated with the life cycle of the SophiA system from cradle to grave?
- What possible improvements could be made to enhance the environmental performance of the SophiA system?
- How well does the 100% renewable-driven SophiA system perform from an environmental point of view compared to a fossil fuel-powered or grid-powered system?

4. SYSTEM DEFINITION AND SYSTEM BOUNDARY

The SophiA system fulfills multiple functions by continuously providing renewable, off-grid refrigeration at different temperature levels (-70 °C, -30 °C, 5 °C), heat (steam), and freshly cooled clean drinking water to various hospitals in Africa, without disruption or power outages. Figure 2 and Figure 3 show the overview of the SophiA systems installed in the cooling and water containers respectively.



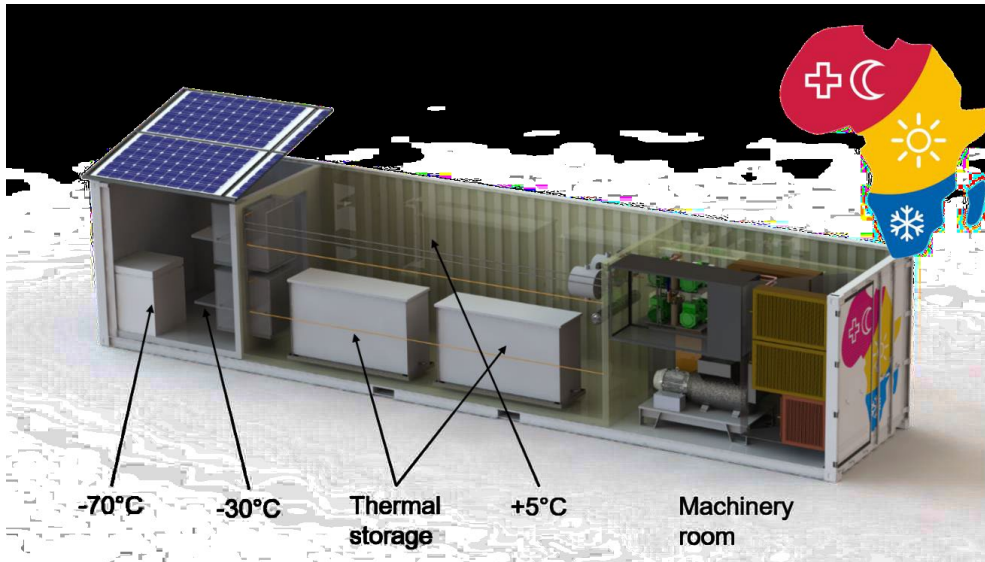


Figure 2 Schematic CAD of the SophiA cooling container

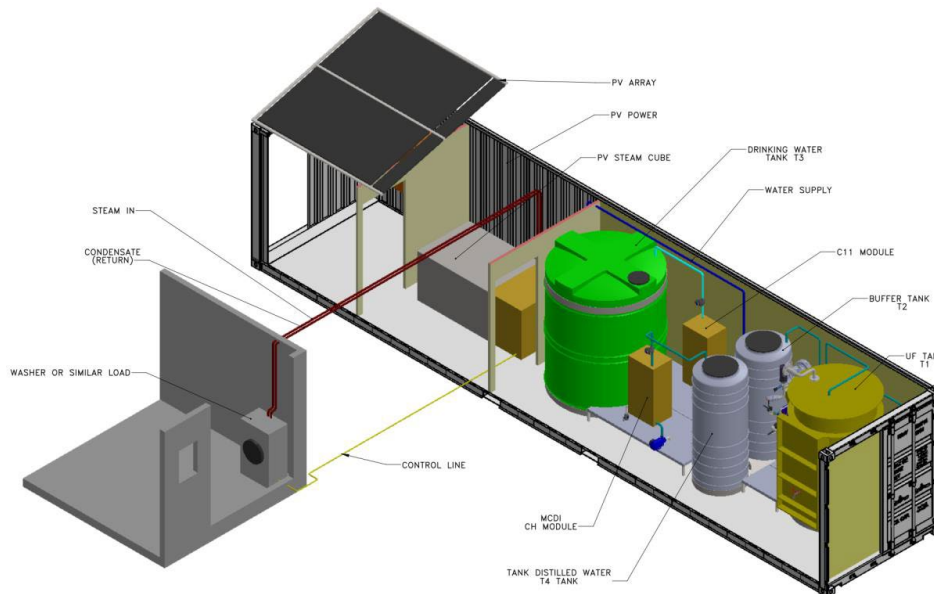


Figure 3 Schematic CAD of the SophiA water treatment container (Drawn by Anton du Nois, Everflo)

Figure 4 illustrates the system boundary of the SophiA system with its functional units. The geographical boundary selected for the SophiA system in Africa. The lifetime considered for the SophiA system was chosen to be 25 years.



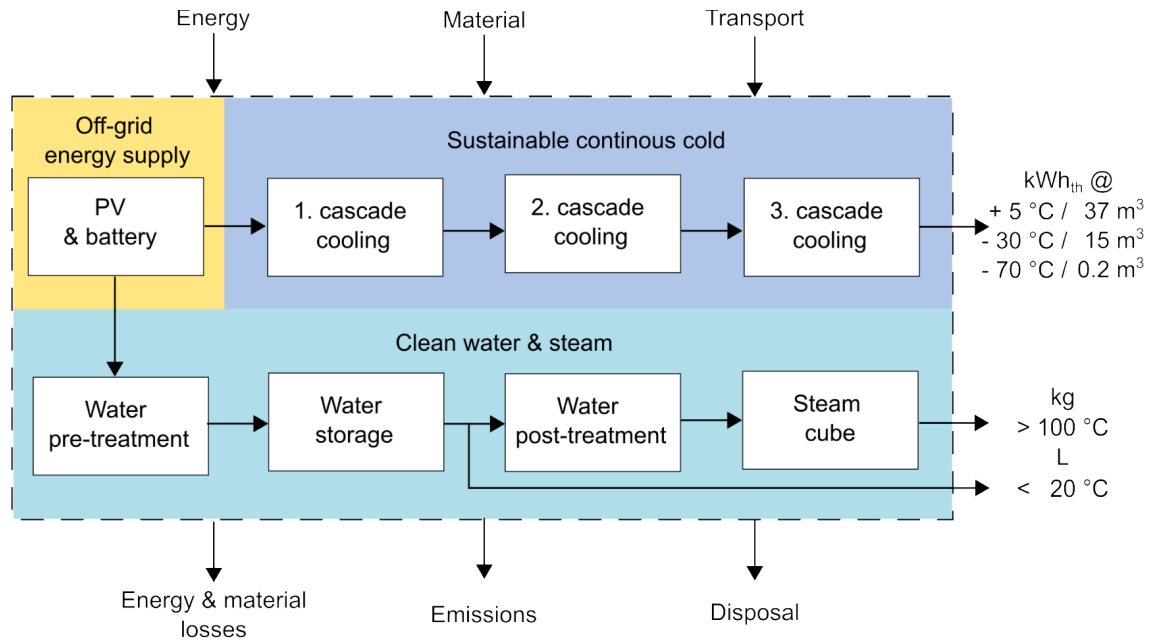


Figure 4 System boundary of the SophiA system including its two-container providing sustainable continuous cold, heat, and clean water.

The SophiA system has different outputs generated from the different subsystems installed in the cooling and water containers. The functional unit for the refrigeration part of the SophiA system that is manufactured and operated in Africa is **1 kWh_{th} of thermal energy at a temperature of +5 °C, -30 °C, and -70 °C**. The functional unit chosen for the steam generation part is **1 kg of steam** and for the clean drinking water part is **1 L of water**.

5. SOFTWARE AND EVALUATION METHODOLOGY

For the LCA study of the SophiA system, SimaPro software with version 9.5 and ecoinvent database 3.9.1 is used. The impact assessment methods for this study are *IPCC 2021 GWP100 with version 1.02* and *Environmental Footprint (EF) 3.1*. In IPCC 2021 GWP100, there are three impact categories, while the EF 3.1 method includes 16 different impact categories.

6. INVENTORY ANALYSIS

The inventory analysis is the most important step which consists of the quantification of the materials and energy inputs and outputs for all the SophiA subsystems listed below. All the SophiA subsystems are installed in the SophiA containers powered by a Photovoltaic (PV) battery system. The cooling container consists of the refrigeration system delivering thermal outputs at +5 °C, -30 °C and -70 °C. The water container consists of a water treatment system for drinking water and deionized water for steam generation using PVsteamCube. Both containers are recycled.

6.1 Photovoltaic (PV) System

The installed PV capacity on each container in Lèo, Burkina Faso is approximately 26.3 kWp with a total battery storage capacity of 53.6 kWh. The PV system consists of 56 PV panels with



a capacity of 470 W each, three battery inverter modules with a capacity of 6 kW each, a PV inverter with a capacity of 25 kW, and a steel mounting structure for the PV panels, batteries, and inverters.

6.1.1 PV Module

This section describes the material, energy, and transportation inputs required to produce 2.25 m² of a PV panel (Table 1 and Table 2). The lifetime of the PV module is assumed to be 25 years, and no replacement within the lifetime of the SophiA system is considered.

Table 1 Material list for 2.25 m² of a PV Panel

Type of material	Weight/Dimension	Unit
Monocrystalline PV cell	2.1	m ²
Aluminium alloy	4.2	kg
Copper	0.2	kg
Diode	0.01	kg
Silicone	0.24	kg
Tin	0.03	kg
Lead	0.001	kg
Solar glass	17.2	kg
Tempering flat glass	17.2	kg
Glass fibre reinforced plastic	0.6	kg
Polyethylene	0.7	kg
Ethylvinylacetate foil	1.7	kg
Polyvinylfluoride film	0.2	kg
Tap water	9.8	kg
Hydrogen fluoride	0.1	kg
Propanol	0.03	kg
Isopropanol	0.0003	kg
Potassium Hydroxide	0.1	kg
Soap	0.02	kg
Corrugated board	1.49	kg
EUR-flat pallet	0.1	unit

Table 2 Energy and transportation inputs to manufacture 2.25 m² of a PV Panel

Energy input	Electricity at medium voltage	27.3 kWh
	Diesel	0.02 MJ
Transport	Freight Lorry	283.6 tkm
	Freight Rail	93.4 tkm

6.1.2 Battery

The battery used for the project is a Lithium Iron Phosphate battery with a continuous rated power of 6.7 kW and with an energy capacity of 13.4 kWh per module. Figure 5 shows the modular battery from CEGASA. The estimated material input for such a battery is shown in



Table 3, and Table 4 shows the energy and transportation inputs for a CEGASA battery module. Each battery module weighs approximately 105 kg.



Figure 5 CEGASA modular battery used in the PV system

Table 3 Material list for a CEGASA battery module

Type of material	Weight/Dimension	Unit
Single-cell for Lithium-Ion battery	63.0	kg
Battery management system	45.0	kg
Battery cooling system	4.3	kg
Steel low alloyed	12.1	kg
Nylon 6	0.1	kg
Nylon 66	5.6	kg
Steel product manufacturing	12.1	kg
Injection moulding	8.6	kg
Aluminium	12.2	kg
Anodising Aluminium sheet	0.5	m2
Sheet rolling Aluminium	11.9	kg
Copper	1.0	kg
Acrylonitrile-butadiene-styrene copolymer	0.7	kg
Synthetic rubber	0.4	kg
Polypropylene	2.2	kg

The batteries are assumed to be replaced twice during the 25-year lifetime of the Sophia system.

Table 4 Energy and transportation inputs to manufacture a CEGASA battery module

Energy Input	Electricity at medium voltage	0.04 kWh
Transport	Freight Lorry >32 ton	23.5 tkm
	Freight Lorry >16 ton	0.5 tkm
	Freight Transoceanic Ship	71 tkm



6.1.3 Inverter

For the PV system installed in each container, the three modules of SMA battery inverter of 6 kW capacity weighing 21 kg each and one SMA PV inverter weighing 61 kg are used. Table 5 shows the estimated material inputs for a unit of battery and PV inverter. Table 6 shows the energy and transportation inputs required to manufacture the inverters shown in Figure 6.



Figure 6 Inverters used in the SophiA PV system (left: battery inverter, right: PV inverter)

Table 5 Material list for a battery inverter and a PV inverter modules

Type of material	Battery Inverter, 6 kW	PV-Inverter, 25 kW	Unit
Aluminium	26.7	25.9	kg
Aluminium alloy	1.2	1.2	kg
Copper	10.7	10.4	kg
Steel low alloyed	5.1	4.9	kg
Polypropylene	4.9	4.8	kg
Polycarbonate	1.1	1.1	kg
Cables	0.7	0.7	m
Inductor	4.9	4.7	kg
Integrated circuit	0.37	0.4	kg
Ferrite	0.2	0.2	kg
Plugs for cables	20	19	Unit
Glass fibre reinforced plastic	0.7	0.7	kg
Printed circuit board	1	1	Unit
Steel sheet rolling	5.1	4.9	kg
Steel	0.11	0.1	kg
Aluminium bar	26.7	25.9	kg
Corrugated board	3.7	3.6	kg
Packaging film	0.06	0.06	kg
Folding boxboard	6.5	6.3	kg



The inverters are assumed to be replaced only once during the 25-year lifetime of the SophiA system.

Table 6 Energy and transportation inputs to manufacture a battery inverter and a PV-inverter modules

		Battery Inverter, 6 kW	PV-Inverter, 25 kW	Unit
Energy Input	Electricity at medium voltage	59.1	57.3	kWh
	Light fuel oil	1.3	1.2	MJ
	Natural gas	20.0	19.4	MJ
	Heat from natural gas-fired industrial furnace	51.6	50.0	MJ
Transport	Freight Lorry	3.8	3.7	tkm
	Freight Rail	25.2	12.2	tkm
	Freight Transoceanic Ship	0.5	110.1	tkm

6.1.4 Energy production

From Task 1.3 “Solar radiation modeling and expected energy for the four trials location”, the annual energy generation per m² of the module is 384 kWh/m² (Bohara, 2022). The electricity production from the installed capacity of 32 kWp for 25 years is around 1.2 GWh.

6.2 Refrigeration System

The description of the refrigeration system is explained in deliverable D1.3 “Design Specifications for SophiA Water, Cooling and Electricity Systems” (Schmid, 2022). The refrigeration system is a two-stage cascaded system providing temperatures at -70 °C, -30 °C and +5 °C. The refrigeration system embedded in the cooling container is shown in the schematic layout of the cooling container in Figure 2. There are three rooms; a machinery room with an ambient air temperature, a +5 °C room with two ice storage units, and a -30 °C room which also consists of a freezer that produces -70 °C. Table 7 shows the dimensions of each compartment, with the volume occupied by +5 °C being the largest. The machinery room consists of different compressors, oil separators, condensers, piping, evaporators, expansion valves, insulation, and other small components used for producing temperatures of +5 °C and -30 °C. Hence, all the components are allocated to +5 °C and -30 °C according to the need of the components for the cooling output at the respective temperatures. The allocation process considered the information given from SophiA partners; mainly from Everflo and the University of Karlsruhe. The additional reinforcement done in the machinery compartment of the container is allocated to +5 °C with 60% of the material input for reinforcement and the remaining 40% to -30 °C.

Table 7 Dimensions of different compartments in a cooling container

Compartments of the container	Length (m)	Width (m)	Height (m)	Volume (m ³)
Machinery Room	3.4	2.4	2.4	20.1
+5 °C	6.3	2.4	2.4	37.2
-30 °C	2.5	2.4	2.4	14.8
-70 °C*	0.9	0.5	0.5	0.2

* - 70 °C is produced using a chest freezer with a capacity of 0.2 m³.



6.2.1 Material and energy requirements for thermal output at +5 °C temperature

This section describes the components with their material type and the electrical energy needed to provide the thermal output at +5 °C. The refrigerant used for this thermal output is Propane (R290). The daily average cooling load at +5 °C including an ice storage is **72.4 kWh_{th}** and the daily average electrical energy needed to provide that cooling load is **33.2 kWh_{el}**. Table 8 summarizes the different components and respective materials for the +5 °C thermal output.

Table 8 List of components and their material type for thermal output at +5 °C

Components	Type of material	Weight (kg)
Insulation	Polyurethane	288
	Polystyrene	6
Additional steel for reinforcement	Carbon Steel	568
Copper pipes	Copper	11.5
Stainless steel pipes	Stainless Steel	11.4
Frames for the R290 compressor	Carbon Steel	2.8
	Stainless Steel	53.7
Doors compressor and R290 condensers	Carbon Steel	360.5
R290 compressors	Cast Iron	131
	Stainless Steel	44
	Aluminium	3.8
	Copper	6.4
	Brass	0.4
	Plastic	3.2
	Oil	4
Oil separator Propane loop	Carbon Steel	26.9
Thermosyphon	Stainless Steel	97.5
Ice storage tanks housing	Stainless Steel	795
Ice storage tanks heat exchanger	Stainless Steel	841.3
Welding	Copper	1
	Stainless Steel	2
	Carbon Steel	2.5
Cables	Copper	300
Cable channel	Plastic	6
Floor	Aluminium	123.2

Of all the components mentioned in the table above, the oil separator is to be replaced once, within the lifetime of 25 years considered for the SophiA system.

6.2.2 Material and energy requirements for thermal output at -30 °C temperature

This section describes the components, their material type, and the electrical energy required to provide the thermal output at -30 °C. The refrigerant used for this thermal output is CO₂ (R744). The daily average cooling load at -30 °C is **17.6 kWh_{th}** and the daily average electrical



energy needed to deliver that cooling load is **4.7 kWh_{el}**. Table 9 summarises different components and the respective materials for -30 °C thermal output.

Table 9 List of components and their material type for thermal output at -30 °C

Components	Type of material	Weight (kg)
Insulation	Polyurethane	150.4
Additional steel for reinforcement	Carbon Steel	378.7
Copper pipes	Copper	55.7
Stainless steel pipes	Stainless Steel	24.9
Frames for the R744 compressor	Carbon Steel	2.8
	Stainless Steel	53.7
R744 compressors	Cast Iron	155.2
	Stainless Steel	34.6
	Aluminium	1.8
	Copper	4.4
	Brass	0.2
	Plastic	4
	Oil	2.4
Desuperheater	Aluminium	16.1
	Carbon Steel	8.8
	Copper	9.7
Oil separator CO ₂ loop	Carbon Steel	11.9
R744 evaporator	Aluminium	32.5
	Carbon Steel	120.8
	Copper	155
	Polystyrene Panels	8.4
R744 Expansion Vessel (-30°C room)	Stainless Steel	192
	Copper	48
Thermosyphon expansion vessels	Stainless Steel	610.5
Cables	Copper	200
Cable channel	Plastic	4
Floor	Aluminium	48.9

Of all the components mentioned in the table above, the following components are to be replaced once, within a lifetime of 25 years considered for the SophiA system:

1. Oil separator
2. Thermosyphon expansion vessels
3. R744 evaporator
4. R744 expansion vessel

6.2.3 Material and energy requirements for thermal output at -70 °C temperature

This section describes the components with their material type and the electrical energy required to have the thermal output at -70 °C. A freezer with a volume of around 93 L, driven



by an ethane compressor, is used to provide the thermal output at $-70\text{ }^{\circ}\text{C}$. The refrigerant used for this thermal output is ethane (R- 170). The daily average cooling load at $-70\text{ }^{\circ}\text{C}$ is **1.4 kWh_{th}** and the daily average electrical energy needed to provide this cooling load is **0.7 kWh_{el}**. Table 10 summarises different components and corresponding materials for the $-70\text{ }^{\circ}\text{C}$ thermal output. Of all the components in the table, only the ethane compressor is assumed to be replaced once, within a lifetime of 25 years for the SophiA system.

Table 10 List of components and their material type for thermal output at $-70\text{ }^{\circ}\text{C}$

Components	Type of material	Weight (kg)
Ethane compressor	Cast Iron	6.8
	Stainless Steel	2.3
	Aluminium	0.2
	Copper	0.3
	Brass	0.02
	Plastic	0.2
	Oil	0.4
-70° Freezer	Carbon Steel	33
	Aluminium	4.6
	Plastics	12.5
	Copper	1
	Polyurethane	4.9

6.2.4 Comparison of material and energy input requirements for thermal output at $+5\text{ }^{\circ}\text{C}$, $-30\text{ }^{\circ}\text{C}$, and $-70\text{ }^{\circ}\text{C}$ temperature

The final summary of the material input required for different SophiA thermal outputs is shown in Figure 7 which shows that the steel, insulation, and aluminium sheet requirements are highest for $+5\text{ }^{\circ}\text{C}$. The requirement of cast iron, copper, and aluminium is highest at $-30\text{ }^{\circ}\text{C}$. The requirement of the materials per volume of the cooling capacity is highest for $-70\text{ }^{\circ}\text{C}$ as it is a small unit of chest freezer. Also, the energy input requirement for the thermal output at $-70\text{ }^{\circ}\text{C}$ is highest (see Figure 8 and Figure 9).



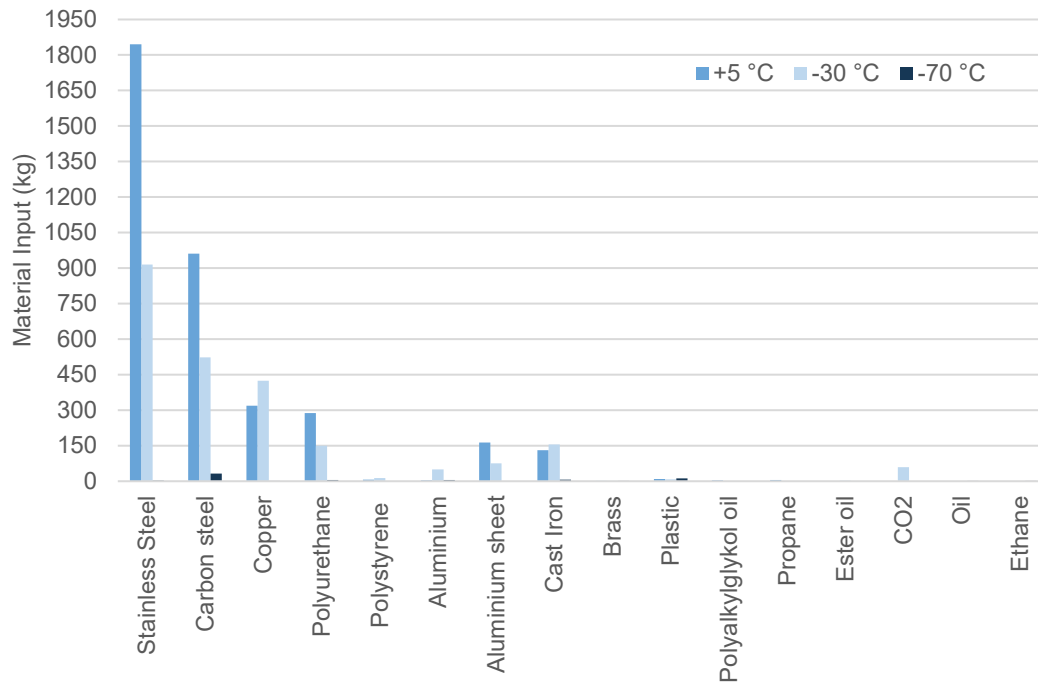


Figure 7 Comparison of material input requirement for thermal outputs at +5 °C, -30 °C, and -70 °C

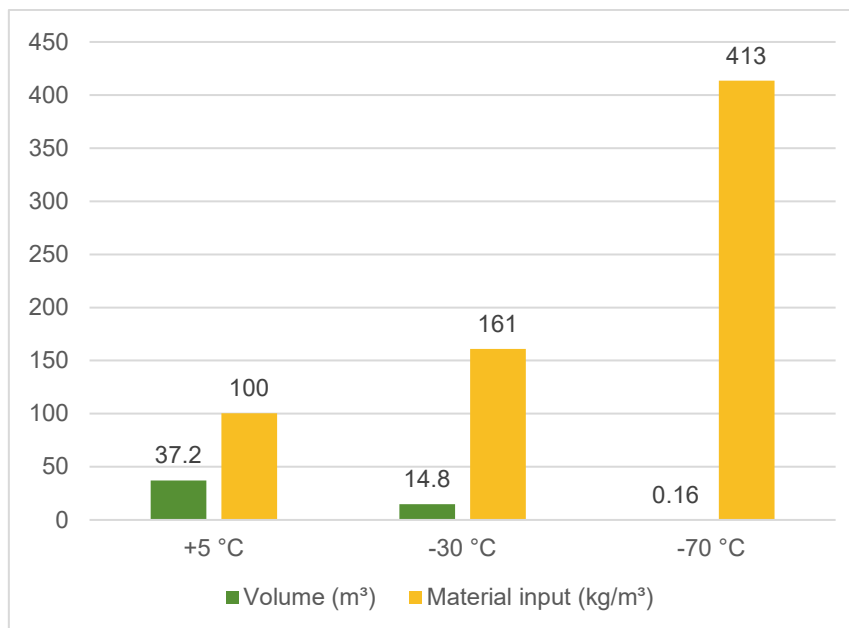


Figure 8 Comparison of material input requirement per total volume of cooling capacities at different temperatures



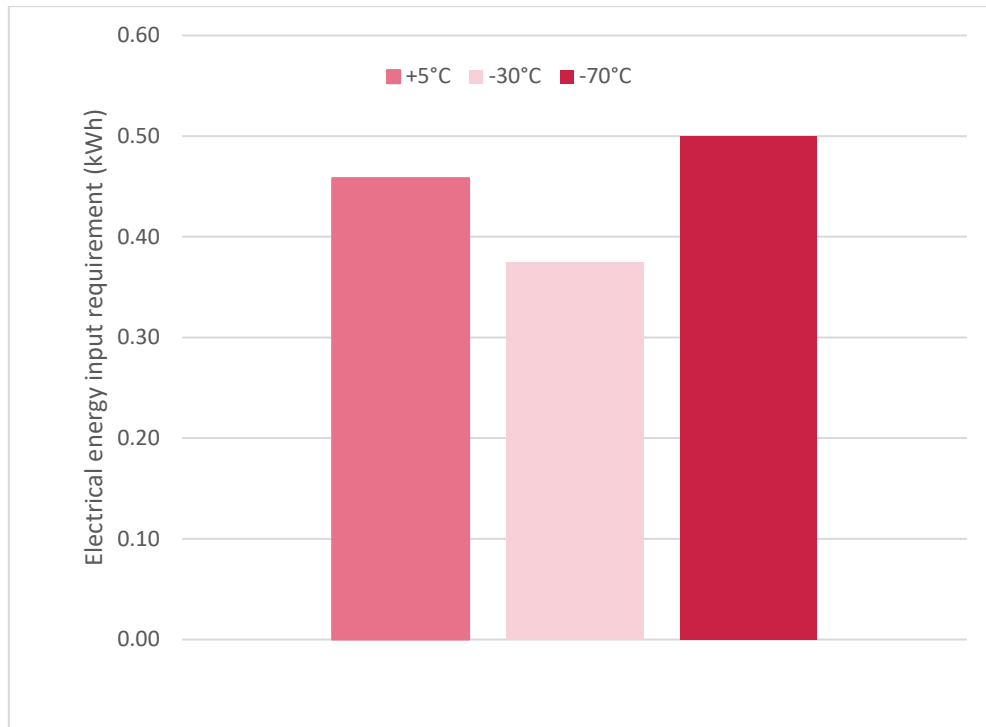


Figure 9 Comparison of electrical input requirement for different thermal outputs

6.3 Water Treatment System

The water treatment systems installed in the water container are used for clean drinking water and deionized water for steam generation. This section describes the components with their material type and electrical energy needed for producing hygienic clean and cool drinking water and deionized water. The details about the water treatment technology installed in the water container are described in deliverable D1.3 “Design Specifications for SophiA Water, Cooling and Electricity Systems” (Schmid, 2022). The material input for the components installed in the water treatment system is shown in Table 11.

Table 11 Component list with its material type for water treatment system for clean water and deionized water as outputs.

Components	Type of material	Weight of the material used for clean drinking water (kg)	Weight of the material used for deionized water (kg)
Water tank type 5.25 m ³	Plastic	70	0
Water tank 1 m ³	Plastic	30	10
Transparent double-stage cartridge housing	Acrylonitrile Butadiene Styrene (ABS) Plastic	1.2	3.6
	Rubber	0.3	0.9
Ultrafiltration (UF) membrane module	Polyvinyl Chloride (PVC)	30	90
	Rubber	1.9	5.6
	Stainless steel	5.6	16.9
UF tank	Plastic	17.5	52.5



Submersible UV	Glass	0.2	0.6
	Plastic	0.3	0.9
Online UV	Glass	0.2	0.6
	Plastic	0.3	0.9
Booster pump 90 W	Steel	1.2	3.6
	Plastic	0.2	0.7
	Rubber	0.08	0.2
Booster pump 30 W	Steel	0.4	1.2
	Plastic	0.08	0.2
	Rubber	0.02	0.08
Motorized ball valve	Steel	0.5	1.6
	Plastic	0.2	0.7
MCDI module	Steel	31.5	31.5
	Plastic	26.3	26.3
	Rubber	5.3	5.3
	Semi-conductor like Si	21	21
	Inert metals for electrode	21	21
Control system	Plastic	0.8	2.3
	Rubber	0.1	0.4
	Semi-conductor like Si	0.4	1.1
Pressure sensor	Plastic	0.2	0.5
	Rubber	0.03	0.08
	Semi-conductor like Si	0.08	0.2
Conductivity sensor	Plastic	0.2	0.5
	Rubber	0.03	0.08
	Semi-conductor like Si	0.08	0.2
Electrical Cabinet	Plastic	2.5	7.5
	Steel	8.75	26.3
	Semi-conductor like Si	1.3	3.8
Electrical cable	Copper	2	6
	PVC	0.5	1.5
Ball Valves (hand valve)	PVC	1.3	3.8
PVC pipes	PVC	1.3	3.8
T-connector	PVC	1.3	3.8
Elbows	PVC	1.3	3.8
Thread connector	PVC	1.3	3.8
Union	PVC	1.3	3.8

6.4 PVsteamCube System

This section describes the components with their material type and electrical energy needed for generating steam at 400 °C using PVsteamCube made from aluminium and iron. The PVsteamCube systems are installed in the water container shown in Figure 4. The details about the PVsteamCube system are described in deliverable D1.3 “Design Specifications for



SophiA Water, Cooling and Electricity Systems” (Schmid, 2022). Since PVsteamCube made from iron will be installed in a site in Uganda, LCA for PVsteamCube made from iron is carried out. The average electrical energy required to generate 1 kg of steam in the steam cube at temperatures from 130 °C to 400 °C is **0.7 kWh_{el}**. Table 12 and Table 13 summarise different components with material type for PVsteamCube made from aluminium and iron respectively. In addition, the additional reinforcement done in the water container is allocated to PVsteamCube systems as well with 50% of the total material input for reinforcement.

Table 12 Component list with its material type of PVsteamCube Aluminium

Components	Type of material	Weight (kg)
Steam cube core with supporting structure	AlMgSi0.5	650
Steel for structures	Stainless Steel	14
	Carbon steel	76
Insulation	Epoxy Resin Insulator	62.7
	Rockwool	11.8
Plywood panel film	Phenolic Resin	62.5
Steam cube controller	Sheet Steel	2
	Plastic	1.3
	Stainless Steel	0.2
	Aluminium	0.2
	Copper	4
	Polyvinyl Chloride (PVC)	1

Table 13 Component list with its material type of PVsteamCube Iron

Components	Type of material	Weight (kg)
Steam cube core with supporting structure	Stainless Steel	1'130
Insulation	Epoxy Resin Insulator	30.9
	Rockwool	5.9
Plywood panel film	Phenolic Resin	42
Steam cube controller	Sheet Steel	2
	Plastic	1.3
	Steel	0.2
	Aluminium	0.2
	Copper	4
	PVC	1

6.5 ecoinvent database

Table 17 in Annex 1 summarises the ecoinvent reference products used for the inventory inputs for SophiA systems installed in both cooling and water containers. The system model here is the “Allocation, cut-off by classification” where waste handling is the producer's responsibility.

Since the lifetime considered for the SophiA system is limited (25 years), it is important to consider how the waste generated after the lifetime or within the lifetime due to the replacement of the components or wastes generated as outputs are handled. This study simulates waste management as it is currently practised in Africa. In general, waste handling is not developed in Africa; most of the wastes are disposed of in landfills or dumping sites. The following



assumptions are made for SophiA systems waste handling within or after the lifetime in the LCA calculation (Linnenkoper, 2019). Table 18 in Annex 2 shows the ecoinvent database used for different types of waste.

- 70% of the metals are recycled, and 30% go to the landfill site.
- 30% of the plastics are recycled and the rest 70% goes to the landfill site.
- Polyurethane, polystyrene, glass, semi-conductors like Silicon, inert metals for electrodes, rubber, epoxy resin insulators, rock wool, and phenolic resin go to the landfill site.
- Refrigerants and lubricating oils are considered as hazardous waste.
- Wastewater from cleaning the PV panels and from refrigeration cycles are released into a sewage system.

7. LIFE CYCLE IMPACT ASSESSMENT RESULTS AND INTERPRETATION

7.1 PV system

The total environmental impact for **1 kWh_{el}** AC output using the PV system including batteries and mounting system is around 84 gCO₂ equivalent under IPCC GWP 100a methodology. Figure 10 shows that most of the impact, around 39%, is coming from the PV module and around 35% from the batteries used in the system for storage.

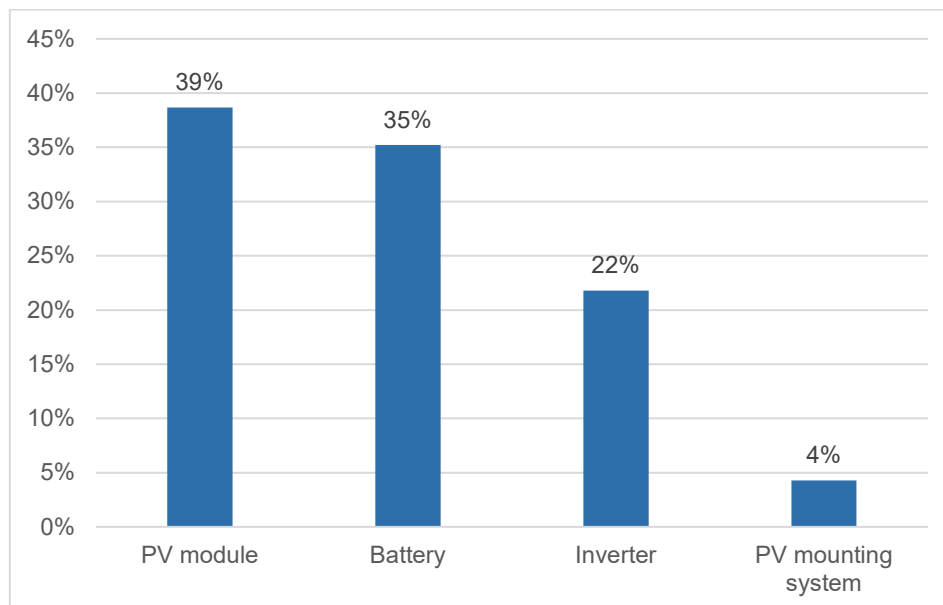


Figure 10 Environmental impact from different main components of a PV system for 1 kWh of electrical output

7.2 Refrigeration System

Table 14 below shows the environmental impact of **1 kWh_{th}** of cooling at respective temperatures of + 5 °C, -30 °C, and -70 °C with their respective cooling space when supplied with the electricity from the PV and battery system installed in the SophiA container.



D7.1: Life cycle assessment and sustainability assessment

Table 14 Environmental impact of 1 kWh thermal outputs at different temperatures using IPCC 2021 GWP 100a method

Thermal outputs	IPCC GWP 100 environmental impact results (gCO ₂ -eq/kWh)
1 kWh of cooling at + 5 °C per 37 m ³ of cooling space	100.7
1 kWh of cooling at - 30 °C per 15 m ³ of cooling space	126.6
1 kWh of cooling at - 70 °C per 0.2 m ³ of cooling space	62.3

Figure 11 shows that most of the impacts are coming from the PV electricity, steel, copper, aluminium, and polyurethane used for different components.



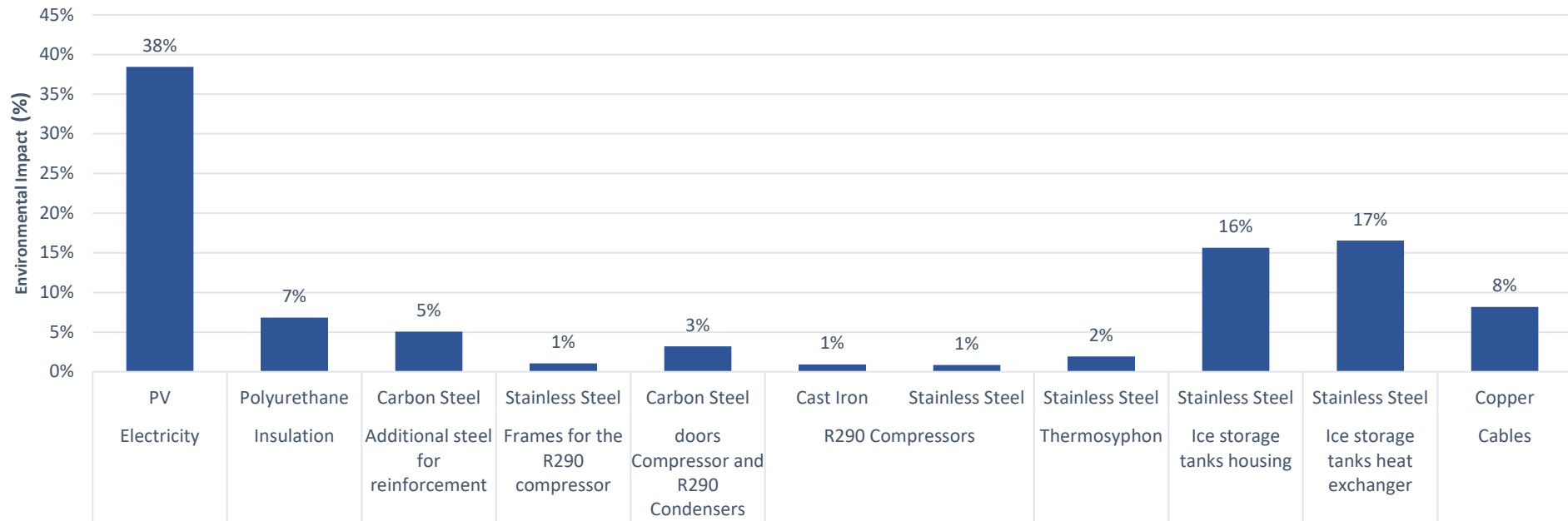


Figure 11 Environmental impact from used components for the thermal output at + 5 °C according to IPCC 2021 GWP 100a methodology

For the thermal output at + 5 °C, when only looking at the impact from the components used, most of the impact is coming from ice storage tanks and their housing, copper cables, polystyrene used for insulation, and carbon steel for additional reinforcement. For the thermal output at – 30 °C, most of the impact is coming from the R744 expansion vessel unit, copper cables, R744 evaporators, polyurethane for insulation, and carbon steel for additional reinforcement. The -70 °C cooling is only a chest freezer unit which has high electricity consumption (0.5 kWh) to deliver 1 kWh_{th} at -70 °C, therefore, most of the impact is coming from the electricity use (>66%) and the use of carbon steel, aluminium, polyurethane, etc. used for manufacturing chest freezer.



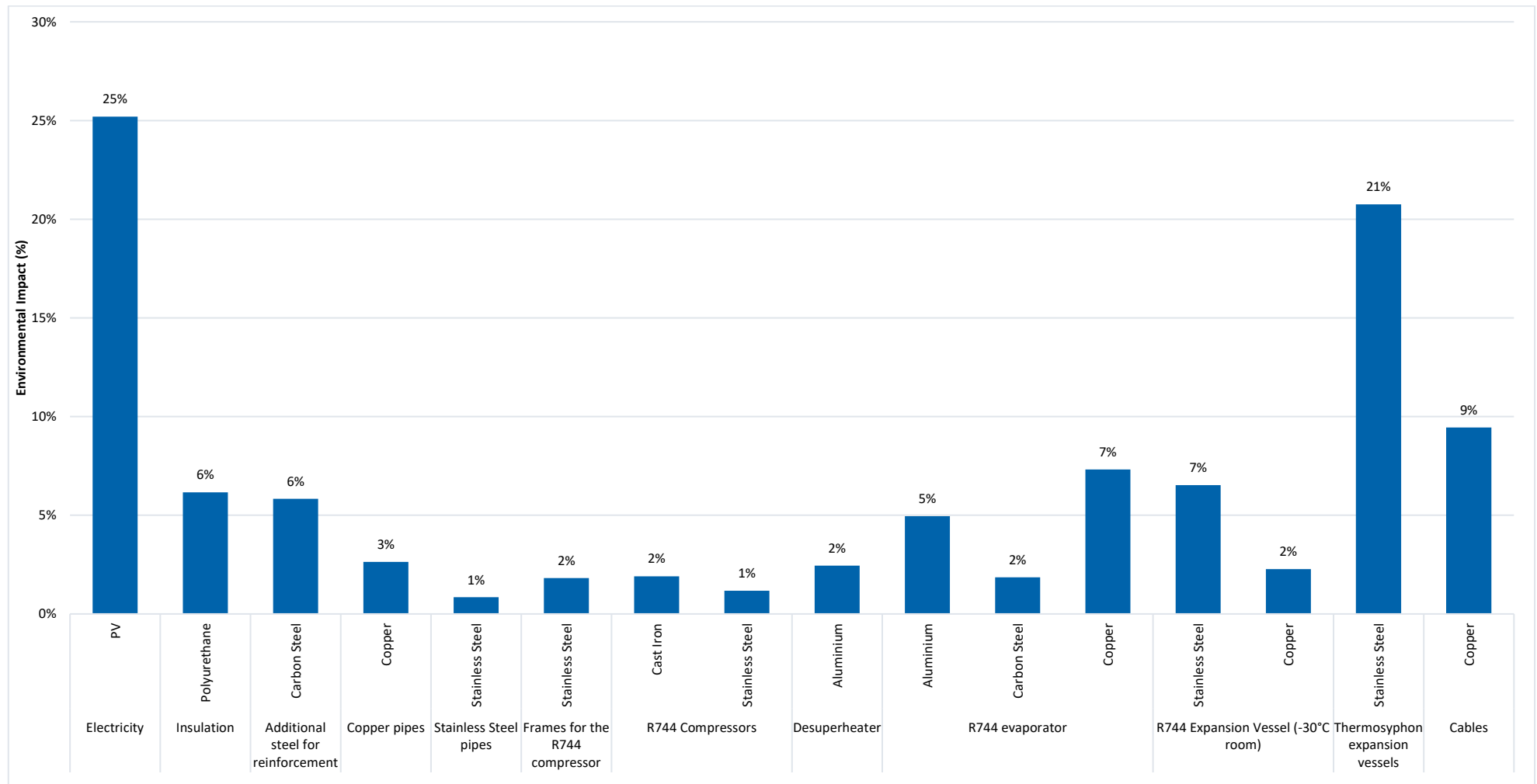


Figure 12 Environmental impact from used components for the thermal output at - 30 °C according to IPCC 2021 GWP 100a methodology



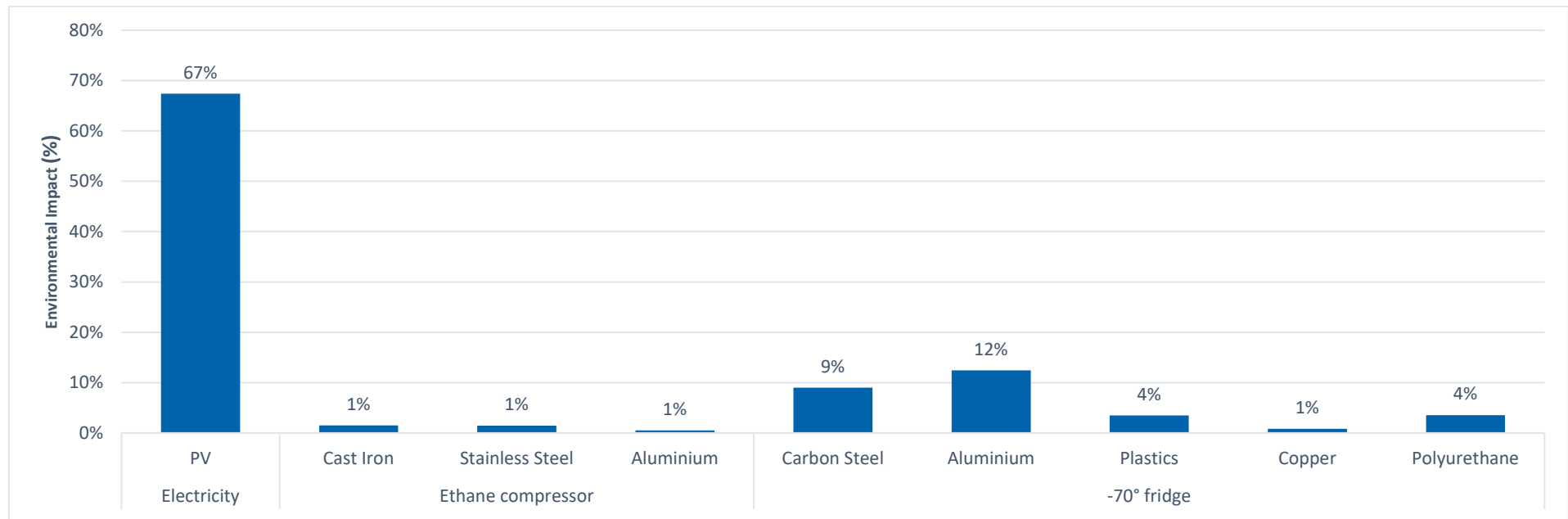


Figure 13 Environmental impact from used components for the thermal output at - 70 °C according to IPCC 2021 GWP 100a methodology



Additionally, the potential environmental impact from the thermal outputs at temperatures of +5 °C, -30 °C, and -70 °C, are compared using 16 categories within EF method v3.1. The comparison shows that -30 °C has the highest potential impact among the thermal outputs in all 16 categories. It is observed from Figure 14 that the highest impact is observed for the category resource use, minerals and metals, human toxicity (both cancer and non-cancer), eutrophication of freshwater, ecotoxicity of freshwater, and acidification.

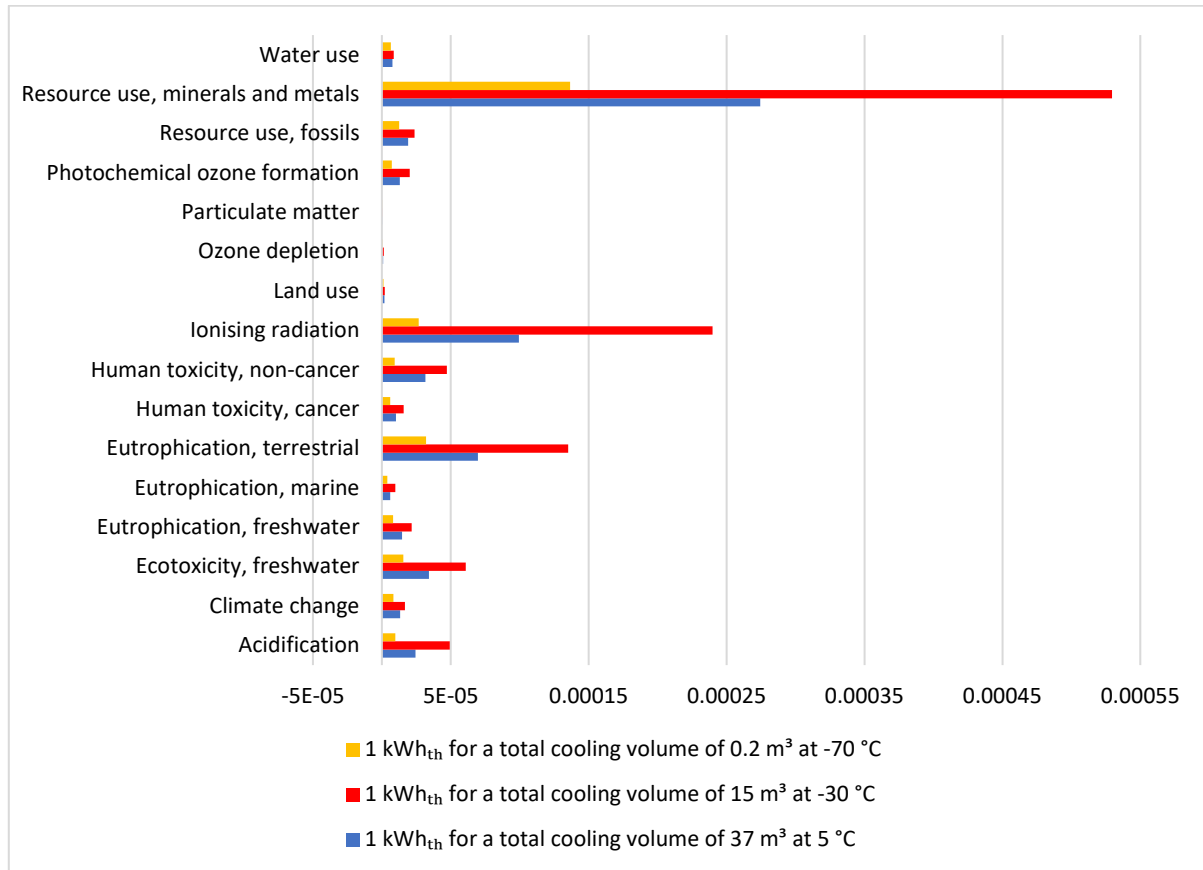


Figure 14 Environmental impact of thermal outputs at different temperatures using EF methodology with normalization

Both the IPCC 2021 GWP 100a and EF methodologies show that the environmental impact of 1 kWh_{th} output is highest for -30 °C, followed by +5 °C and lowest for -70 °C.

7.3 Water treatment system

The environmental impact calculated using IPCC 2021 GWP 100a for 1 L of clean drinking water at 20 °C with the water treatment system supplied with PV electricity is 0.2 gCO₂-eq, which is quite minimal. Figure 15 shows that most of the GPW is coming from the use of various construction materials like semiconductors for the MCDI module and electrical cabinets. Since the wastewater is discharged back into the environment, it shows a negative value of around 0.09 gCO₂-eq in an impact category which states that it is beneficial rather than causing a negative environmental impact.



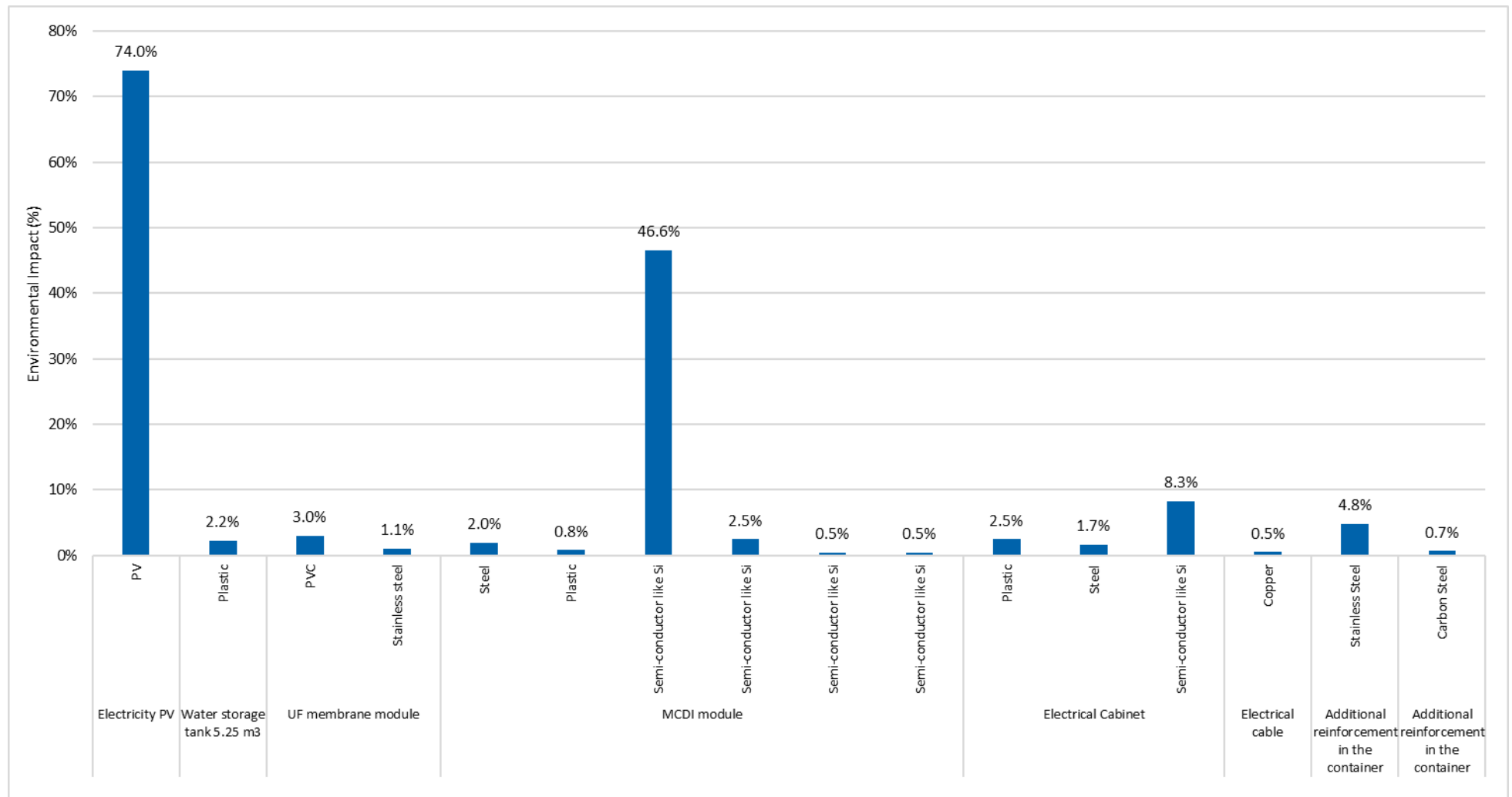


Figure 15 Environmental impact from used components for 1 L of water at 20 °C according to IPCC 2021 GWP 100a methodology



Additionally, the environmental impact of 1 L of clean drinking water was observed in 16 different impact categories using the EF method and is shown in Figure 16. The highest environmental impact is observed in water use and resource use like minerals and metals.

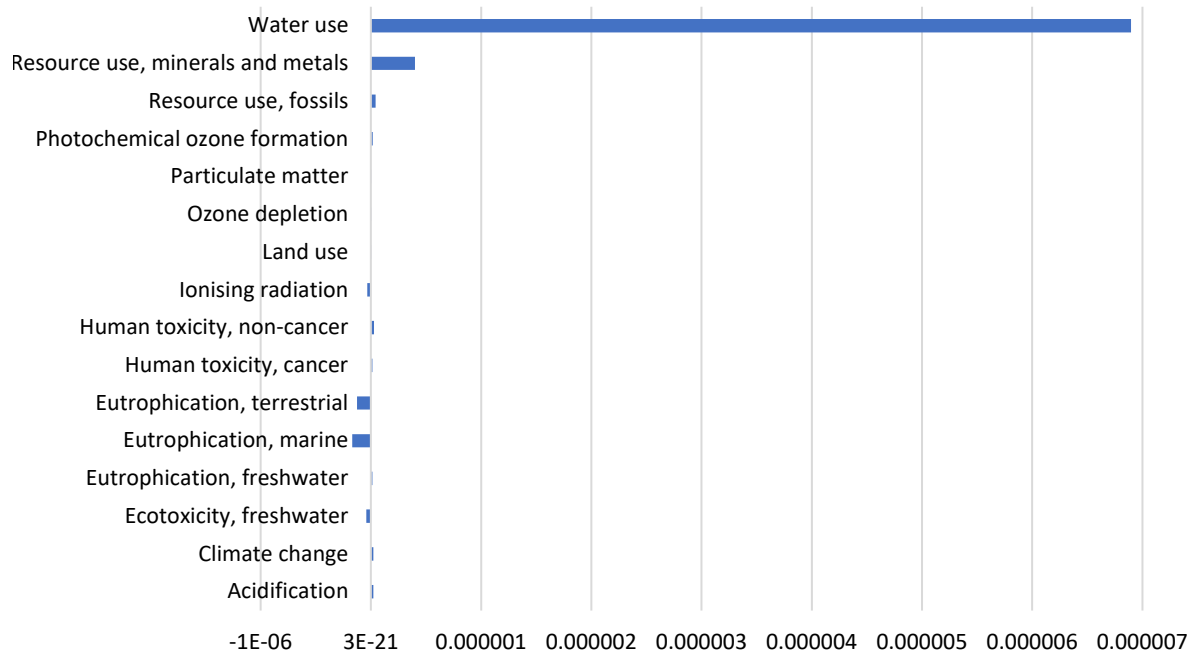


Figure 16 Environmental impact of 1 L of clean drinking water at 20 °C according to EF methodology with normalization

7.4 PVsteamCube System

Two PVsteamCube systems—one aluminum and one iron—were assessed for the environmental impact of producing 1 kg of steam at 150 °C. The PVsteamCubes operate without electrical batteries, relying solely on daytime PV electricity to generate and store steam. According to the IPCC 2021 GWP 100a methodology, emissions from both systems differ by only 0.2%, as shown in Table 15. Over 73% of the total environmental impact arises from electricity use, around 1% from the deionized water treatment, and the remainder from system components (Figure 17 and Figure 18).

Table 15 Environmental impact of steam generation using IPCC 2021 GWP 100a method

	Total environmental Impact (g CO ₂ -eq)
1 kg of steam at 150 °C using PVsteamCube aluminium	50.9
1 kg of steam at 150 °C using PVsteamCube iron	51.1



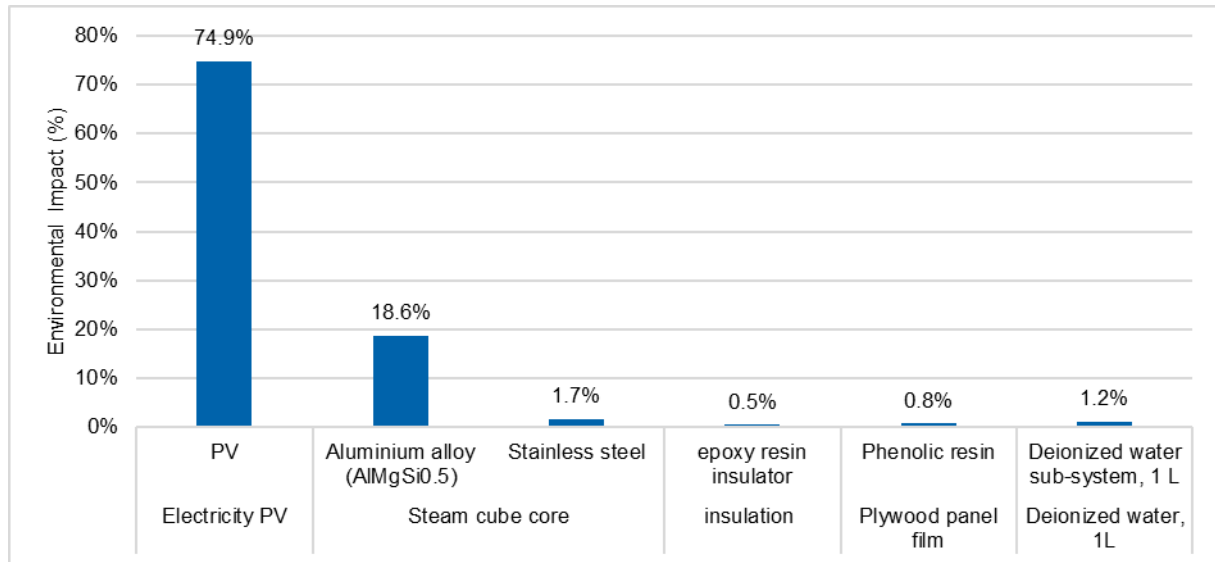


Figure 17 Environmental impact from different components for 1 kg of steam output at 150 °C using PVsteamCube Aluminium according to IPCC 2021 GWP 100a methodology

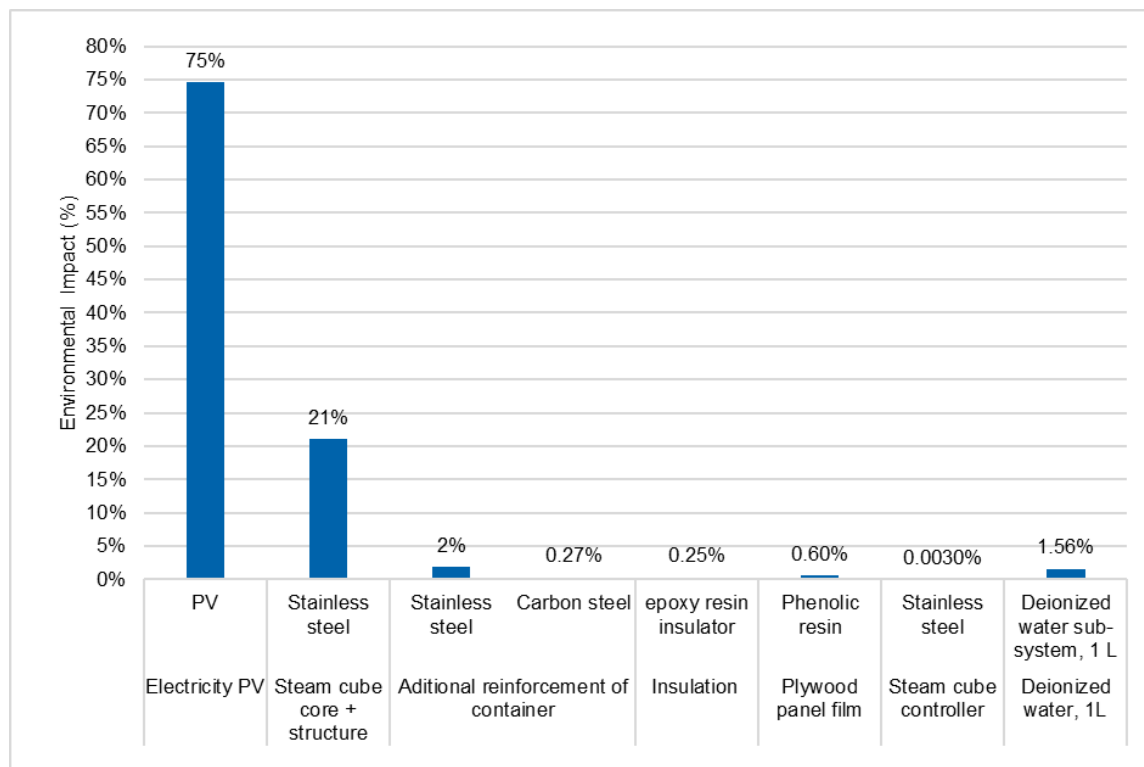


Figure 18 Environmental impact from different components for 1 kg of steam output at 150 °C using PVsteamCube Iron according to the IPCC 2021 GWP 100a methodology

Additionally, the environmental impact of 1 kg of steam at 150 °C using PVsteamCube made from aluminium and iron was observed using EF methodology. Figure 19 shows that the PVsteamCube system has the highest impact on resource consumption such as minerals, metals, fossils, water use, ionizing radiation, eutrophication, ecotoxicity of fresh water, etc.



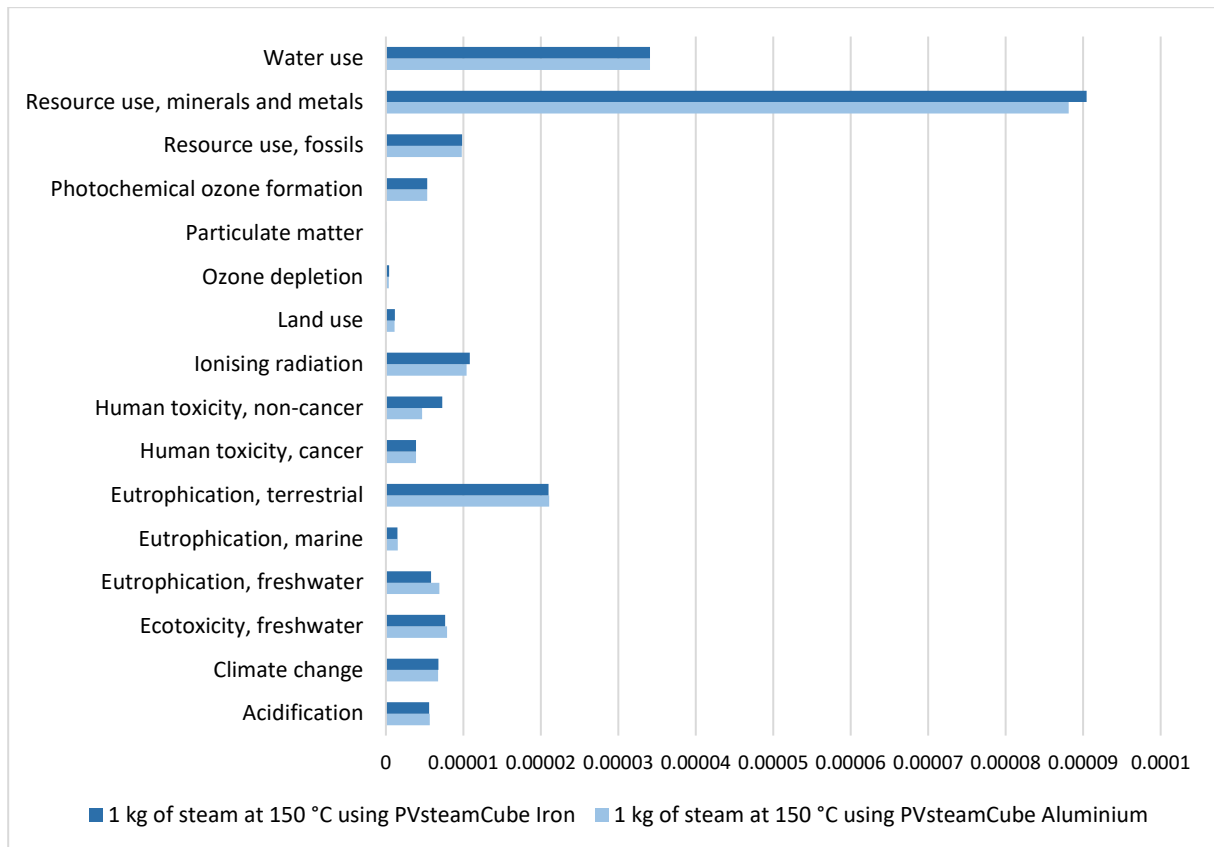


Figure 19 Environmental impact of 1 kg of steam at 150 °C using PVsteamCubes according to EF methodology with normalization

7.5 Comparison of the environmental impact of all outputs of the SophiA system

Comparing the environmental impact of all SophiA system outputs based on the impact categories from both IPCC 2021 GWP 100a and EF methodologies (see Figure 20 and Figure 21), results show that the environmental impact of 1 kWh_{th} of thermal output at – 30 °C were the highest, followed by 1 kWh_{th} of thermal output at + 5 °C, followed by 1 kWh_{th} of thermal output at – 70 °C, followed by 1 kWh_{th} of thermal output at - 70 °C, followed by 1 kg of steam at 150 °C and the lowest impact is observed for 1 L of clean drinking water at 20 °C.

The LCIA using the EF 3.1 methodology shows that the highest impacts are observed in the impact categories resource use of metals and minerals followed by human toxicity non-cancer, eutrophication of fresh water, ecotoxicity of fresh water, acidification, and human toxicity cancer.



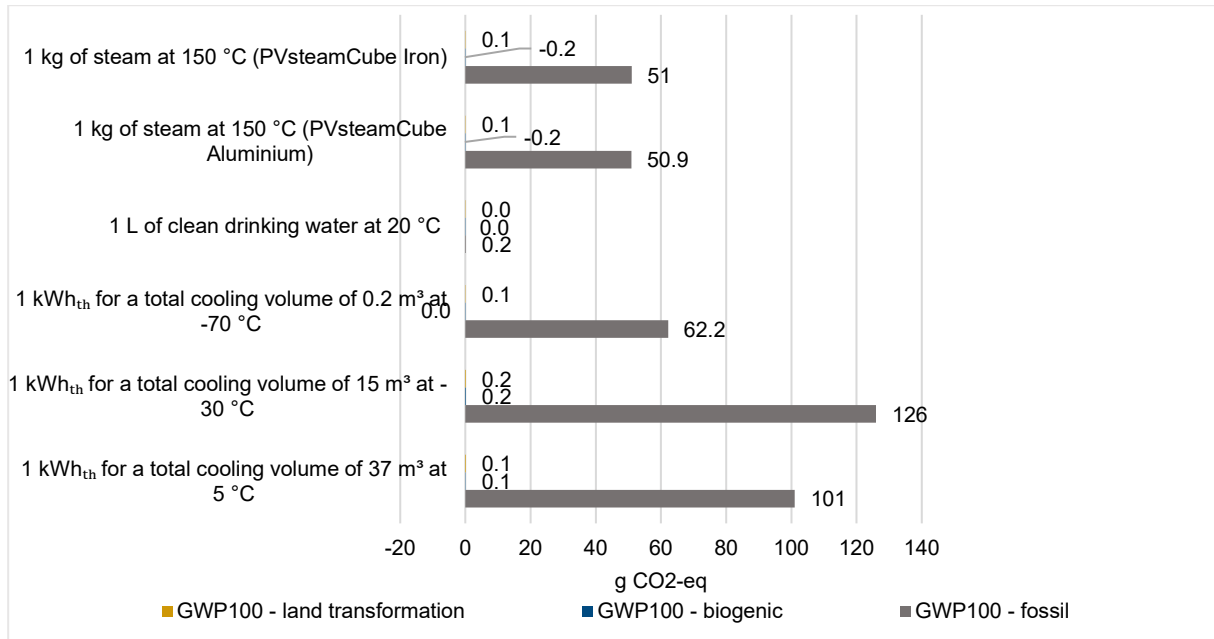


Figure 20 Comparison of the environmental impact of all outputs of the SophiA system according to the IPCC 2021 GWP 100a methodology

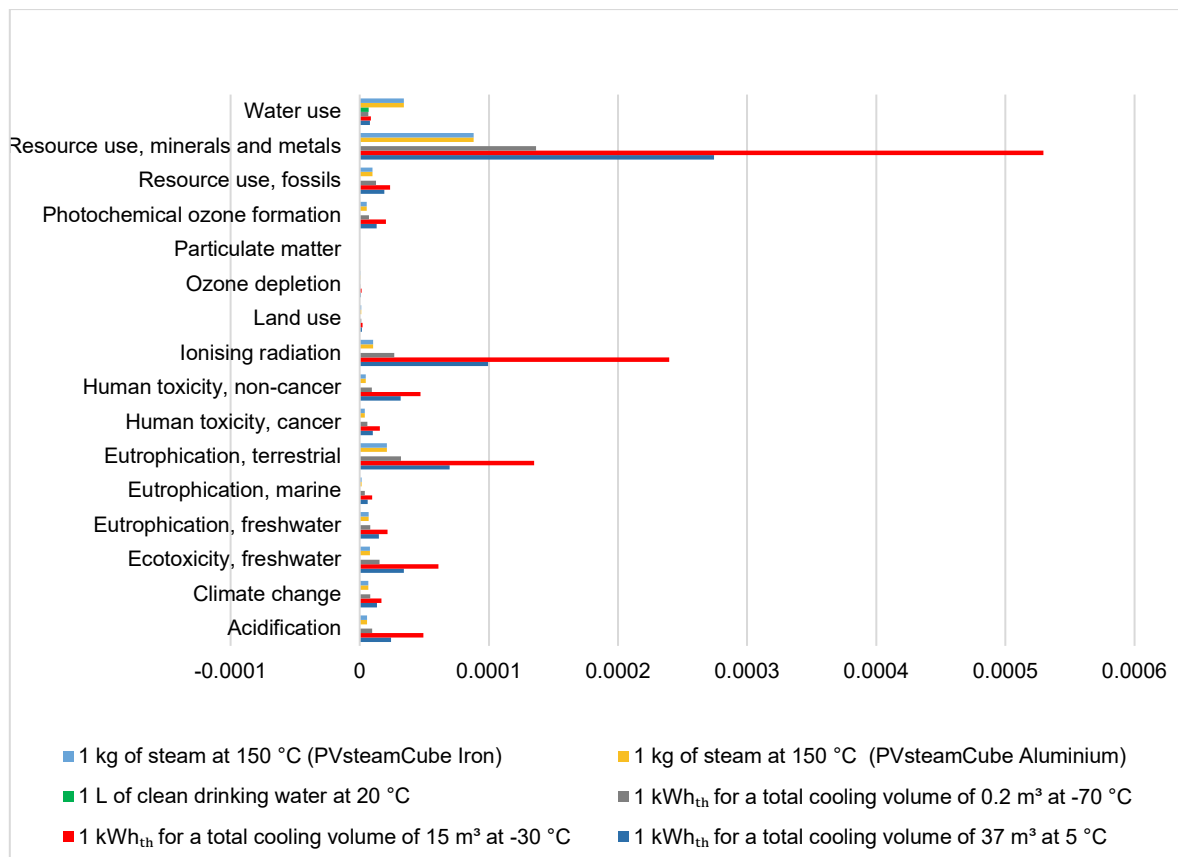


Figure 21 Comparison of the environmental impact of all outputs of the SophiA system according to the EF methodology with normalization



7.6 Environmental impact of SophiA system with alternative energy input scenarios

The SophiA systems installed in the containers are off-grid-based systems supplied by the PV power system installed on the containers. From a report (Leuthold, 2022), it is analysed that due to the cloudy sky conditions, the SophiA system will have to be supplied with a diesel backup system installed in the container for 8% of the time in a year. Therefore, the scenario with a 92% PV electricity supply and the rest with a diesel backup supply is studied. It was also analysed how the PV-powered SophiA systems performed compared to 100% diesel-powered off-grid and grid-powered systems.

The grid power in the SophiA demonstration sites is not very reliable. The statistics show that grid unreliability is 27% in Burkina Faso, 58% in Cameroon, 88% in Malawi, and 35% in Uganda (Chingwete et al., 2019). Therefore, in the grid supply scenario, it is assumed that, on average 48% will be directly supplied with grid electricity and the rest will be supplied with diesel generators as a grid backup. In summary, the following scenarios are considered to compare the performance of the SophiA systems.

- 92% PV with battery electricity with diesel backup off-grid
- 100% diesel electricity off-grid (not from backup)
- 48% grid electricity with diesel backup on-grid

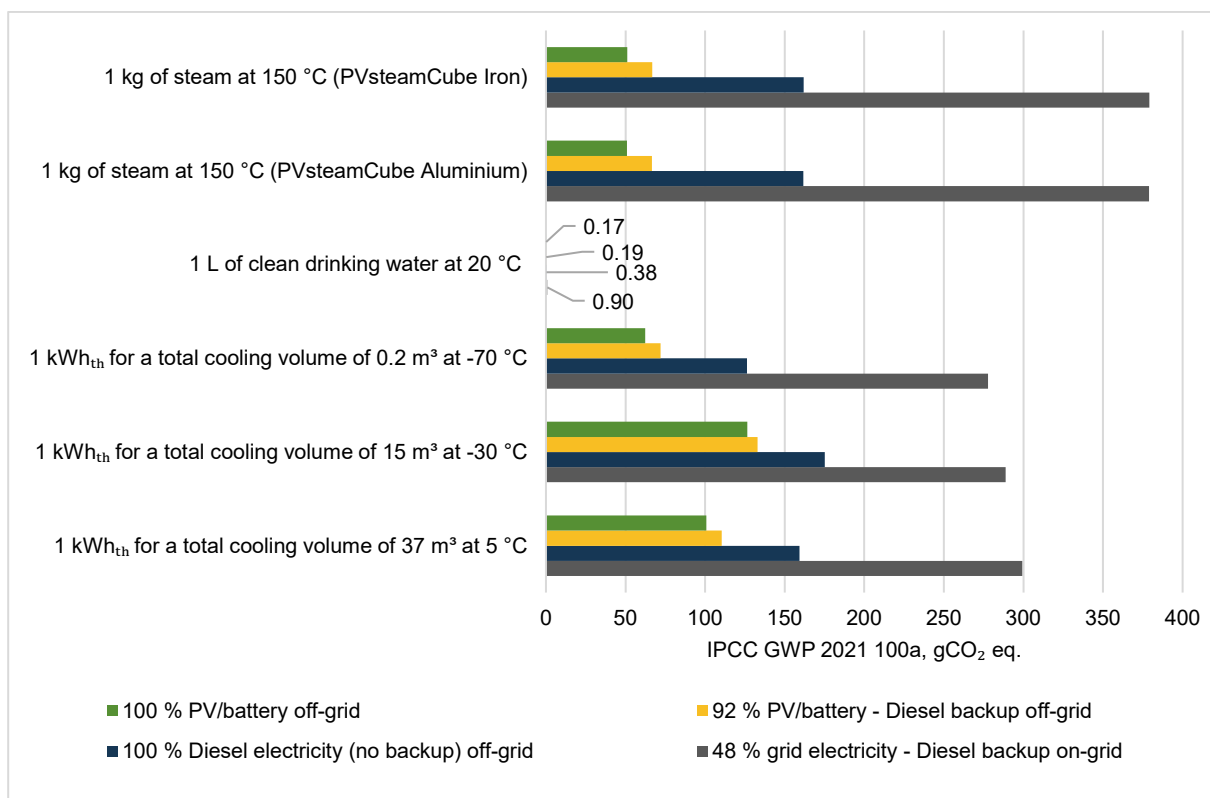


Figure 22 Environmental impact according to the IPCC 2021 GWP 100a methodology of different outputs of the SophiA system manufactured and operated in Africa

Figure 22 shows that in all the scenarios, the environmental impact of 1 L of clean drinking water is the lowest compared to other SophiA outputs. In these scenarios of alternative electricity inputs, the environmental impact is higher when grid electricity with on-grid diesel



backup is used to run the SophiA systems than with 100% off-grid diesel electricity. The analysis showed that the environmental impact of the SophiA outputs is lowest when powered by a 100% PV/battery system.

8. CONCLUSIONS

The environmental impact according to the IPCC 2021 GWP 100a methodology for SophiA system outputs of 1 kWh_{th} for a total cooling volume of 37 m³ at + 5 °C is 100.7 gCO₂-eq, for 1 kWh_{th} for a total cooling volume of 15 m³ at - 30 °C is 126.6 gCO₂-eq, for 1 kWh_{th} for a total cooling volume of 0.2 m³ at - 70 °C is 62.3 gCO₂-eq, 1 L of clean drinking water at 20 °C is 0.2 gCO₂-eq, 1 kg of steam at 150 °C with PVsteamCube Iron is 51.1 gCO₂-eq. and 1 kg of steam at 150 °C using PVsteamCube Aluminium is 50.9 gCO₂-eq. Table 16 shows the increase in the environmental impact of the SophiA system outputs when the 100% PV-battery off-grid supply is replaced with the selected alternative energy scenarios **a) 92% from PV/battery plus diesel backup off-grid supply, b) 100% diesel backup off-grid supply, and c) 48% grid electricity-diesel backup on-grid**. The solar-powered SophiA system reduced the environmental impact considerably when compared to these alternative energy supply sources. On average, with PV/battery supply, the environmental impact of SophiA system outputs is reduced by about 5% to 23% compared to scenario a), about 28% to 69% compared to scenario b), and about 56% to 87% compared to scenario c).

Table 16 Increment in emissions observed for different SophiA system outputs with alternative energy supply scenarios (according to IPCC 2021 GWP 100a methodology)

	1 kWh _{th} per m ³ for a total volume of 37 m ³ cooling space at 5 °C	1 kWh _{th} per m ³ for a total volume of 15 m ³ cooling space at - 30 °C	1 kWh _{th} per m ³ for a total volume of 0.16 m ³ cooling space at - 70 °C	1 L of clean drinking water at 20 °C	1 kg of steam at 150 °C (Al)	1 kg of steam at 150 °C (Iron)
GPW 100% PV/battery off-grid (gCO₂-eq.)	100.7	126.6	62.3	0.2	50.9	51.1
Change in GWP for scenario a)	+ 9%	+ 5%	+ 13%	+ 13%	+ 23%	+ 23%
Change in GWP for scenario b)	+ 37%	+ 28%	+ 51%	+ 55%	+ 69%	+ 68%
Change in GPW for scenario c)	+ 66%	+ 56%	+ 78%	+ 81%	+ 87%	+ 87%

The environmental impact of the different outputs of the SophiA system can be reduced by looking at the component levels of the different sub-systems that provide cold, heat, and clean water as outputs. Since the thermosyphon and expansion vessels have the highest impact at the component level to provide cooling at -30 °C, replacement with less material and energy-intensive components such as aluminium can be considered. Similarly, to reduce the environmental impact of cooling at +5 °C, the use of steel in the manufacturing of ice storage units can be replaced with aluminium or other materials where possible. Additionally,



alternatives for the use of semiconductors in the MCDI module can be explored to reduce the environmental impact of clean drinking water. The environmental impact at the component level for the steam output at 150 °C comes from the use of steel or aluminium alloy for PVsteamCubes, and the alternatives of these materials can also be considered, such as considering green steel or aluminium.

9. DEVIATIONS FROM THE WORKPLAN

No deviations from the work plan have occurred.



10. ANNEXES

10.1 Annex 1

Table 17 ecoinvent database used for the input material for the SophiA systems

Input	Ecoinvent reference product name
Stainless Steel	steel production, electric, chromium steel 18/8 - RoW - steel, chromium steel 18/8
Carbon steel	steel production, low-alloyed, hot rolled - RoW - steel, low-alloyed, hot rolled
Copper	copper production, cathode, solvent extraction, and electrowinning process - GLO -copper, cathode
Polyurethane	polyurethane, rigid foam
Polystyrene	polystyrene production, general-purpose - RoW - polystyrene, general purpose
Aluminium	aluminium ingot, primary, to aluminium, cast alloy market - GLO - aluminium, cast
Aluminium sheet	sheet rolling, aluminium - RoW - sheet rolling, aluminium
Cast Iron	cast iron production - RoW - cast iron
Brass	brass production - RoW - brass
Plastic	polypropylene production, granulate - RoW - polypropylene, granulate
Plastic	polyethylene production, low density, granulate
Polyalkylglykol oil	lubricating oil production - RoW - lubricating oil
Propane	natural gas liquids fractionation - GLO - Propane
Ester oil	lubricating oil production - RoW - lubricating oil
CO2	carbon dioxide production, liquid - RoW - carbon dioxide, liquid
Oil	lubricating oil production - RoW - lubricating oil
Ethane	natural gas liquids fractionation - GLO - ethane
Diesel generator set	diesel-electric generating set production 18.5kW - GLO - diesel-electric generating set, 18.5kW
Epoxy resin insulator	epoxy resin insulator, SiO2 production
Rockwool	stone wool production, packed
Phenolic resin	phenolic resin production - RoW - phenolic resin
Sheet steel	sheet rolling, steel
PVC	polyvinylchloride production, bulk polymerisation
Semi-conductor like Si	gallium, semiconductor-grade
Inert metals for electrode	graphite production
Rubber	synthetic rubber production
Glass	glass fibre production
Photovoltaic single-Si wafer cell	Photovoltaic cell, single-Si wafer -GLO- market for photovoltaic cell, single-Si wafer
Aluminium alloy	Aluminium alloy, AlMg3 - RER- aluminium alloy production, AlMg3
Copper wire	Wire drawing, copper - RER- wire drawing, copper
Diodes	Diode, auxiliaries and energy use -GLO- diode production, auxiliaries and energy use
Silicon	Silicone product - RER- silicone product production
Tin	Tin -RoW- tin production
Lead	Lead concentrate stockpiling- RoW- lead concentrate stockpiling



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Solar glass	Solar glass, low-iron -RER- solar glass production, low-iron
Tempering glass	Tempering, flat glass -RER- tempering, flat glass
Glass fibre reinforced plastic	Glass fibre reinforced plastic, polyester resin, hand lay-up -RER- glass fibre reinforced plastic production, polyester resin, hand lay-up
Polyethylene	Polyethylene terephthalate, granulate, amorphous -RER- polyethylene terephthalate production, granulate, amorphous
Polyethylene granulate	Polyethylene, high density, granulate -RER- polyethylene production, high density, granulate
Ethylvinylacetate foil	Ethylvinylacetate, foil -RER- ethylvinylacetate production, foil
Polyvinylfluoride film	Polyvinylfluoride, film -RER- polyvinylfluoride, film production
Hydrogen Fluoride	Hydrogen fluoride -RER- hydrogen fluoride production
Propanol	1-propanol -RER- 1-propanol production
Isopropanol	Isopropanol -RER- isopropanol production
Potassium hydroxide	Potassium hydroxide -RER- potassium hydroxide production
Soap	Soap -RER- soap production
Corrugated board box	Corrugated board box -RER- corrugated board box production
EUR-flat pallet	EUR-flat pallet -RER- EUR-flat pallet production
Polycarbonate	Polycarbonate -RER- polycarbonate production
Inductor	Inductor, ring core choke type - GLO- inductor production, ring core choke type
Integrated circuit	Integrated circuit, logic type -GLO- integrated circuit production, logic type
Ferrite	Ferrite -GLO- ferrite production
Glass fibre reinforced plastic	Glass fibre reinforced plastic, polyester resin, hand lay-up -RER- glass fibre reinforced plastic production, polyester resin, hand lay-up
Printed wiring board	Printed wiring board, for through-hole mounting, Pb free surface - GLO- printed wiring board production, for through-hole mounting, Pb free surface
Transistor	Transistor, surface-mounted -GLO- transistor production, surface-mounted
Capacitor	Capacitor, film type, for through-hole mounting -GLO- capacitor production, film type, for through-hole mounting
Capacitor, electrolyte type, > 2cm height	Capacitor, electrolyte type, > 2cm height -GLO- capacitor production, electrolyte type, > 2cm height
Transformer, low voltage use	Transformer, low voltage use -GLO- transformer production, low voltage use
Sheet rolling, steel	Sheet rolling, steel -RER- sheet rolling, steel
Section bar extrusion, aluminium	Section bar extrusion, aluminium -RER- section bar extrusion, aluminium
Folding boxboard carton	Folding boxboard carton -RER- market for folding boxboard carton
Glass fibre reinforced plastic	Glass fibre reinforced plastic, polyester resin, hand lay-up -RER- glass fibre reinforced plastic production, polyester resin, hand lay-up
Resistor	Resistor, surface-mounted -GLO- resistor production, surface-mounted
Resistor	Resistor, wirewound, through-hole mounting -GLO- resistor production, wirewound, through-hole mounting
Battery cell	Battery cell, Li-ion, LFP -GLO- market for battery cell, Li-ion, LFP
Battery management system	Battery management system, for Li-ion battery -GLO- battery management system production, for Li-ion battery
Nylon 66	Nylon 6-6 -RER- nylon 6-6 production



Nylon 6	Nylon 6 -RER- nylon 6 production
Metal working, average for steel product manufacturing	Metal working, average for steel product manufacturing -RER- metal working, average for steel product manufacturing
Injection moulding	Injection moulding -RER- injection moulding
Anodising, aluminium sheet	Anodising, aluminium sheet -RER- anodising, aluminium sheet
Acrylonitrile-butadiene-styrene	Acrylonitrile-butadiene-styrene copolymer -RER- acrylonitrile-butadiene-styrene copolymer production
Metal working, average for copper product manufacturing	Metal working, average for copper product manufacturing -RER- metal working, average for copper product manufacturing
Metal working, average for aluminium product manufacturing	Metal working, average for aluminium product manufacturing -RER- metal working, average for aluminium product manufacturing
Freight transport	Transport, freight, lorry >32 metric ton, EURO3 -RER- market for transport, freight, lorry >32 metric ton, EURO3
Freight transport	Transport, freight, lorry 16-32 metric ton, EURO3 -RER- market for transport, freight, lorry 16-32 metric ton, EURO3
Freight transport	Transport, freight train -RER- market group for transport, freight train
Transoceanic transport	Transport, freight, sea, container ship -GLO-market for transport, freight, sea, container ship
Electricity	Electricity, medium voltage -RoW- electricity production, medium voltage, petroleum refinery operation
Electricity	Electricity, medium voltage -RAS- market group for electricity, medium voltage
Electricity	Electricity, medium voltage -CN- market group for electricity, medium voltage
Natural gas	Natural gas, burned in gas turbine -DE- natural gas, burned in gas turbine
Heat	Natural gas, burned in gas turbine -DE- natural gas, burned in gas turbine
Diesel	Diesel, burned in building machine -GLO- diesel, burned in building machine

10.2 Annex 2

Table 18 ecoinvent database used for the waste handling for the SophiA systems

Outputs to technosphere as wastes	Ecoinvent reference product name
Stainless Steel and Carbon Steel	Scrap steel -RoW- market for scrap steel
Copper	Scrap copper -RoW- market for scrap copper
Aluminium	Scrap aluminium -RoW- market for scrap aluminium
Cast Iron	Waste bulk iron, excluding reinforcement -RoW- market for waste bulk iron, excluding reinforcement
Polypropylene	Waste polypropylene-ZA-market for waste polypropylene Waste polypropylene -RoW- treatment of waste polypropylene, sanitary landfill
Propane, Ethane, Lubricating Oil, Carbondioxide, Isopropanol, Potassium hydroxide	Hazardous waste, for incineration -RoW- market for hazardous waste, for incineration
Stainless Steel, Carbon Steel	Scrap steel -RoW- treatment of scrap steel, inert material landfill
Copper, Brass, Tin	Inert waste, for final disposal -RoW- treatment of inert waste, inert material landfill
Polystyrene	Waste polystyrene -RoW- treatment of waste polystyrene, sanitary landfill
Polyurethane	Waste polyurethane-ZA-market for waste polyurethane



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Aluminium	Waste aluminium -RoW- treatment of waste aluminium, sanitary landfill
Wastewater	Wastewater, average -RoW- treatment of wastewater, average, wastewater treatment
Polyethylene	Waste polyethylene terephthalate-ZA-market for waste polyethylene terephthalate
Rubber	Waste rubber, unspecified-ROW-treatment of waste rubber, unspecified, municipal incineration
PVC	Waste polyvinylchloride-ZA-market for waste polyvinylchloride Waste polyvinylchloride -RoW- treatment of waste polyvinylchloride, sanitary landfill
Glass	Waste glass-ZA-market for waste glass
Semi-conductors	Inert waste, for final disposal-ROW-treatment of inert waste, inert material landfill
Rockwool	Waste mineral wool, for final disposal-ROW-treatment of waste mineral wool, inert material landfill
Solid wastes that end up in the sanitary landfill	Municipal solid waste-ROW-treatment of municipal solid waste, sanitary landfill
Glass fibre reinforced plastic, Ethylvinylacetate foil	Waste plastic, mixture-ROW-treatment of waste plastic, mixture, municipal incineration
Mineral oils	Waste mineral oil-ROW-treatment of waste mineral oil, hazardous waste incineration
EUR-flat pallet	Waste wood, untreated-ROW-market for waste wood, untreated
Corrugated board	Waste paperboard-ZA-market for waste paperboard
Solar glass, tempering glass	Waste glass-ZA-market for waste glass
Printed circuit boards	Used printed wiring boards-GLO-market for used printed wiring boards
Li-ion battery	Used Li-ion battery-GLO-market for used Li-ion battery
Electronics scrap	Electronics scrap from control units-GLO-market for electronics scrap from control units





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