Technology factsheets

Technological, environmental and economic key values

Deliverable 6.1

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This work has been carried out by:

WP	*6*	
WP, Task number	*6,1*	
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Executive Summary

This report provides the specifications defined for the Life Cycle Assessment (LCA) and Life Cycle Economics (LCE) on the technologies investigated in Work Package 2 (*WP2 - Development of the innovative technology components*) of RES4BUILD (under grant agreement No 814865). A summary on the specifications and results for both assessment methods is provided in this report and will be separated for each technology later in the project. A draft for the factsheets was created, but will be reworked by a professional designer for dissemination, when results from WP6.2 and WP6.3 can be included towards the end of the project.

WP2 focuses on the development of three prototype technologies and their optimization in regards to performance and function within integrated systems for building energy production. The creation of factsheets falls under WP6 – Life cycle analysis and validation of the platform. The specifications will serve the environmental and economic assessment of the prototype systems in WP5 – *Design and testing of the prototype systems*, as well as the simulation process in WP3 – *Integrated generation, storage and flexibility management*, whereas the factsheets will be used to disseminate the technologies' environmental and economic related attributes to the public. The specifications for the LCA refer to EN ISO 14044 and ISO 14040 standards, while the specification on the economic assessment (LCE) refer to VDI 2885 and VDI 2067 guidelines.

The created information for the factsheets correspond to the photovoltaic-thermal collector (PVT) developed by MG Sustainable Engineering, the magneto-caloric heat pump (MCHP) by the Technical University of Denmark (DTU), and the vapour compression heat pump (VCHP) developed by PSYCTOTHERM.

Information provided by the technology developers and used as input for the environmental and economic assessments has pointed out that the specifications for each technology are only partly similar due to differences in their development stages. A direct comparison of the LCA and LCE specifications and results between the three technologies is not traceable, not comprehensible and therefore not recommended.

The presented information for the factsheets relates to the construction or structural composition of the technologies (in LCA: modules A1-A3 for manufacture, module C for disposal and module D for credits and benefits after the end-of-life). Information and results from the assessment of the use-stage (in LCA: module B) of the technologies is currently under study. Related results will be included later in D6.2 – *Integrated environmental and economic assessment* and in the updated versions of the factsheets.

As such, the definition of LCA and LCE specifications still contain an amount of uncertainty, depending highly on the technology development throughout the project, data availability and data consistency provided from partners.

The technologies are modelled in the environmental assessment software – GaBi (Version: 10.5.1.124, Schema: 8007) using its professional database (CUP 2021.2).

Technological key values

The photovoltaic thermal (PVT) collector

Product description

The innovative photovoltaic thermal collector (PVT) Double Mareco (DM) represents one of the key technologies in the integrated energy system (IES) (*Figure 1 - The C-PVT collector*). The innovation lies in the combination of a standard PV module and a solar thermal collector allowing simultaneous production of heat and electricity. As such it requires electrical and hydraulic connection in place. The device includes optimized concentrating mirrors to capture sunlight and deliver it afterwards to PV cells. This is a stationary concentrating photovoltaic-thermal (C-PVT) collector that uses the patented reflector design "Maximum Reflector Concentration (MaReCo)", based on Compound Parabolic Reflectors (CPC). With an energy yield 40-50% higher than that of the technologies taken separately for the same total area considered, the DM – PVT collector proves to be highly efficient.

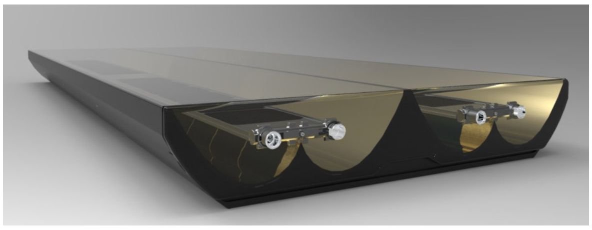

Figure 1 - The C-PVT collector

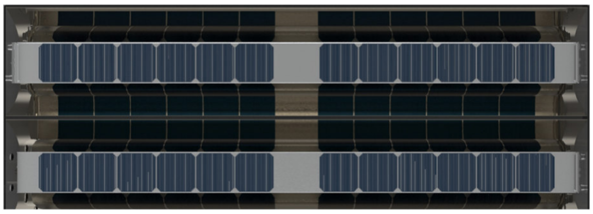

Figure 2 - Preliminary PV cell string layout

Provider

MG Sustainable Engineering developed the DM-PVT collector within the context of the RES4BUILD research project.

Application

It can be installed in flat roofs and on the ground with a minimum of 5˚ and a maximum of 20˚ tilt. It is recommended to install the device in groups of four, and depending on available area and orientation, other arrangements are also possible. Minimum or no shading has to be considered when installing. The device has to have plumbing connections and must therefore be installed close to water grid and electricity grid.

Technical data

Technical specifications of the Double MaReCo PVT collector are presented in Table 1.

Table 1– Technical specifications of the DM PVT collector

Description	Value	Unit
Dimensions (W, L, H)	1054x2443x241	mm
Weight (Empty)	≈65	kg

Aperture area	2.15	m^2
Gross area	2.37	m^2
Number of one-third cells	152	-
Cell area	1.23	m^2
Cell dimensions	52x156	mm
Max. power rating P_{mpp} at STC	260+ 5%	W_p
Maximum power current (I_{mpp})	6.5	A
Maximum power Voltage (V_{mpp})	40	V
Short circuit Current (I_{sc})	7.83	A
Open circuit Voltage (V_{oc})	48.1	V
Temperature coefficient Power	-0.336	%/ºC
Thermal heat loss coefficient	$a_1 = 3.9$ $a_2 = 0.03$	$W/m^2.K$ $W/m.K^2$
Peak thermal power	1560	W
Capacity antifreeze	1.4	L
Maximum working pressure	10	bar
Stagnation temperature	120	˚C

Composition

Material composition of the DM-PVT collector is presented in *Figure 3 – Share of materials in the DM-PVT collector*.

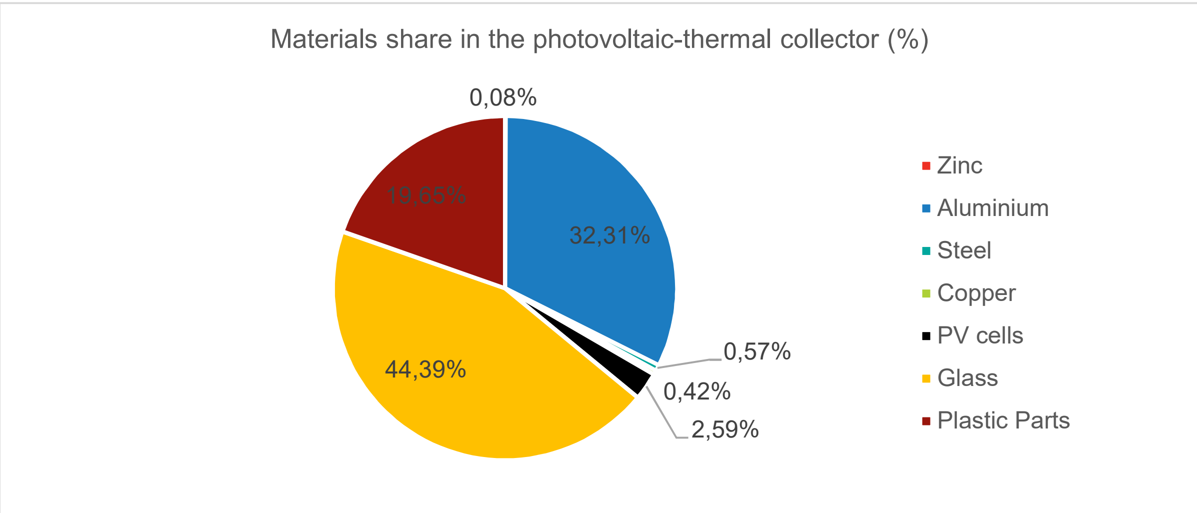

Figure 3 – Share of materials in the DM-PVT collector

The magneto caloric heat pump (MCHP)

Product description

The magneto caloric heat pump (MCHP) developed by the Technical University of Denmark (DTU), is one of the novel technologies that will be applied in the RES4BUILD system.

The magneto caloric effect (MCE) in which a temperature change of a suitable material is caused by exposing the material to a changing magnetic field drives the technology. The specific magneto caloric materials used are $La(Fe,Mn,Si)_{13}H_y$ alloys. This material family allows for optimization of the MCE and of the operating temperature through chemical doping. Thus, a series of materials can be produced, with the MCE tuned to a specific desired temperature range.

As in a vapour compression heat pump (VCHP), where the change in temperature from compression is utilised, the MCHP utilises the temperature change from magnetisation in its thermodynamic cycle. However, in an MCHP there is no gaseous refrigerant, and thus no adverse environmental effect related to leakage of the refrigerant. In addition, the reversibility of the MCE will allow for the MCHP to work at a higher efficiency than the conventional heat pumps. The highest performing magneto caloric devices are based on a rotary motion which facilitates a rapid switching of the magnetic field, coupled with accurate control of the flow of heat transfer fluid.

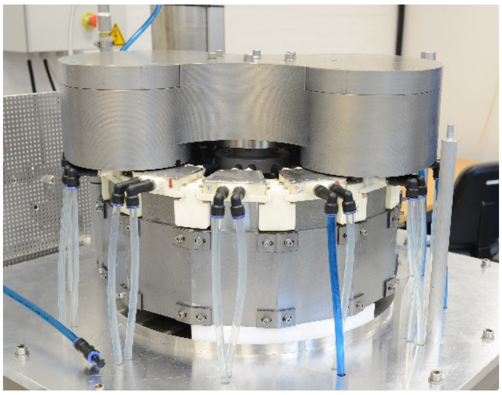

Figure 4 - The magneto-caloric heat pump

The specific heat pump addressed here has thirteen containers with porous magneto caloric materials optimised for a specific temperature range. These are successively magnetised and unmagnetised by a large rotating magnet (Figure 4). Careful design of the cycle allows heat at a lower temperature to be moved to a higher temperature reservoir, giving a useful heating effect. Accurate control and timing of the fluid flow is realised by solenoid valves.

Provider

The MCHP is a prototype developed by DTU, within the RES4BUILD project, and a previous Danish research project. The technology behind the MCHP has been realised by DTU, based on many years of research within the field.

Application

The intended application for the MCHP is domestic heating, specifically of a single family house. However, the technology can be scaled, such that the performance matches other heating requirements.

As a domestic heating source, the MCHP would be installed in the house to be heated. The hot side would be connected to the heating system of the house, preferably underfloor heating. The cold side would be connected to an external source of heat, e.g., a ground loop, or a borehole.

In the context of the RES4BUILD project a hybrid system has been considered, where the MCHP is connected to a borehole thermal energy storage system on the cold side and to a conventional VCHP on the hot side. The VCHP is then connected to the building heating system.

Technical data

As the device is a prototype, there is a lot of volume, and weight, which could be reduced through optimisation. The present device is constructed to facilitate research on the device.

Table 2 - Technical specifications of the MCHP

Description	Value	Unit
Outer dimensions	1 x 1 x 1.5	m
Total weight	750	kg
Magnet volume	10	litres
Magnetocal. material volume	0.5	litres
Amount of heat transfer fluid	~7	Litres

Composition

The structural part of the MCHP is made primarily from stainless steel, aluminium and polymers. The permanent magnet supplying the magnetic field is sintered NdFeB. The magneto caloric materials are spheres (ø ~ 0.5 mm) of the $La(Fe,Mn,Si)_{13}H_y$ family, with Fe~11.5, Mn~0.5, Si~1 and Hy~1.6. The material composition of MCHP is depicted in Figure 2.

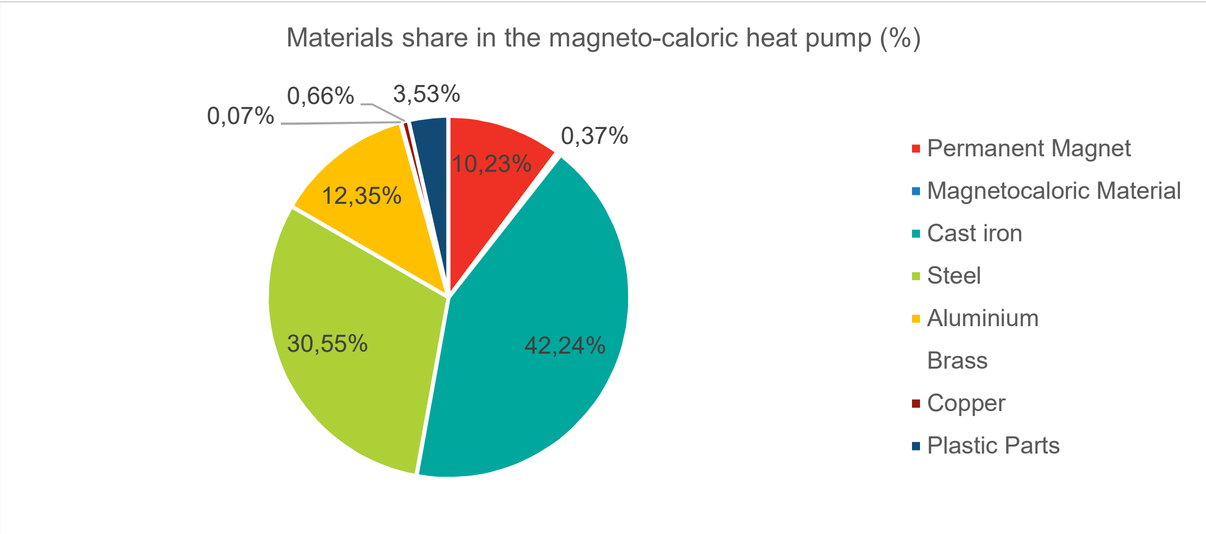

Figure 5 - Share of materials in the magneto-caloric heat pump

The vapour compression heat pump (VCHP)

Product description

The heat pumps of RES4BUILD are developed to match the supply temperatures of typical buildings. Space heating and cooling is delivered to the building through either hot or chilled water, preferably using fan coil appliances that allow to reduce the water temperature at heating mode and thus improve the performance. These temperature levels follow the relevant standards (e.g. EN14511-2018) and are highlighted next:

- Space heating delivery. Supply temperature of 45°C that varies within the range of 35-50°C to account for the flexibility needs.
- Domestic hot water (DHW). Supply temperature of 55°C that can be varied within the range of 45-55°C to account for the flexibility needs, which ensures an adequate hot water supply to the users.
- Space cooling delivery. Supply temperature of 7°C that varies, within the range of 7-12°C to account for the flexibility needs.

The Coefficient of Performance (COP) depends on the temperature levels at the cold and hot sides of the heat pump. A COP up to 6 for a low temperature lift is possible using R454C with a very low Global Warming Potential (GWP) as working medium (when not considering the auxiliary consumptions).

The main advantages of the developed VCHP compared to products in the market are:

- Use of an environmental-friendly refrigerant
- The option to exploit various heat sources resulting to a multi-source unit (air or water). This is achieved with the use of 3-way valves and the developed software of the PLC unit.

Provider

The prototype technology of the VCHP is investigated by G. Ligeros and SIA OE -PSYCTOTHERM in collaboration with the National Center for Scientific Research "DEMOKRITOS" (NCSRD) within the context of RES4BUILD project.

Application

The heat pump at heating mode can be supplied with heat from either Borehole Thermal Energy Storage (BTES) or ambient air or any other heat source of very low temperature (below 25°C), such as from a solar buffer tank. Similarly at cooling mode, the possible heat sinks are the ground and ambient air. It can be scaled from few kW (minimum of 6-8 kW of heat) up to few hundred kW, with the latter capacity meeting the needs of very large buildings.

Technical data

Table 3 - Technical specifications of the VCHP

Description	Value	Unit
Dimensions	m	1.5x1.5
Weight (Empty)	kg	90
Weight (Full)	kg	127,6

Composition

Material composition of the VCHP is depicted in Figure 6 *- Share of materials in the vapour-compression heat pump*:

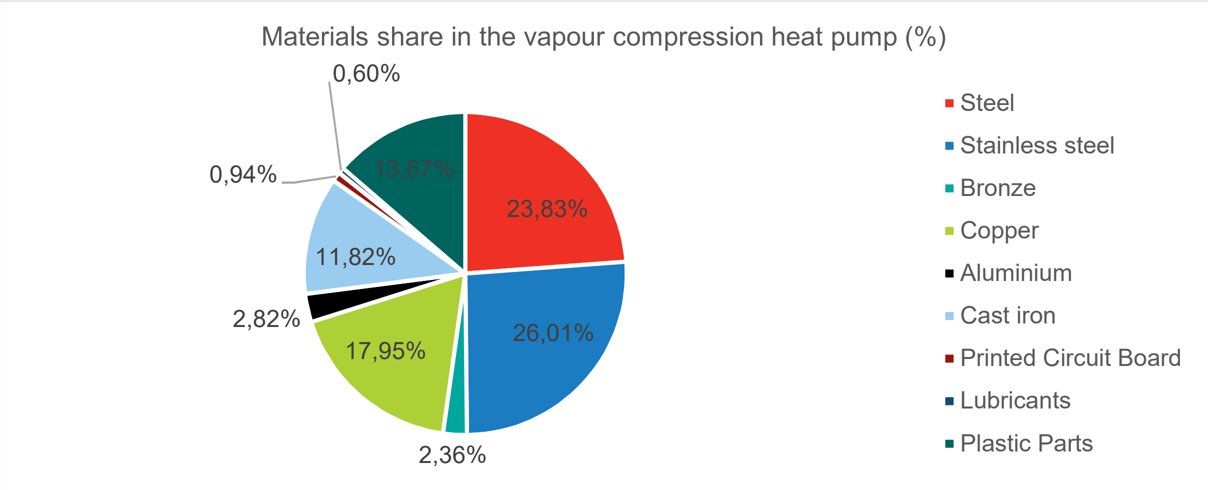

Figure 6 - Share of materials in the vapour-compression heat pump

Environmental impact of the technologies

Post-use phase

The materials used can be partly recycled after material separation. The return of materials to the material cycle depends on the user.

Disposal

Thermal utilization is possible for plastic parts, while all components can nevertheless be directed to landfill.

PVT collector: Glass can be partially recycled and partially sent to landfill. Solar (PV) cells can be sent to landfill.

MCHP: Magnets can be recycled and/ or reused from the developer based on circularity of components within technology development processes from the same or similar developers/institutions for testing and simulation purposes.

VCHP: The refrigerant can be directed to incineration due to material mix.

Further information

More information on the technologies can be found on the website: https://res4build.eu/

Life Cycle Assessment (LCA) specifications

Functional Unit (FU)

The life cycle assessment study is based on a piece of technology:

PVT collector: 1 piece of PVT collector

MCHP: 1 piece of MCHP

VCHP: 1 piece of VCHP

The results presented in the factsheets correspond to the construction model of one single technology and are not related to their performance (e.g., energy generated).

System boundary

For the environmental assessment of each technology, a cradle-to-grave system boundary is considered which includes upstream, core and downstream processes. The life cycle stages taken into account include: the product stage (modules A1-A3), the end of life stage (modules C1-C4), as well as benefits and loads beyond the system boundary (module D). The system boundary is depicted in Figure 7 *- System boundary for the LCA of the technologies based on EN 15804:2012+A1:2013/ FprA2:2019 (E)*.

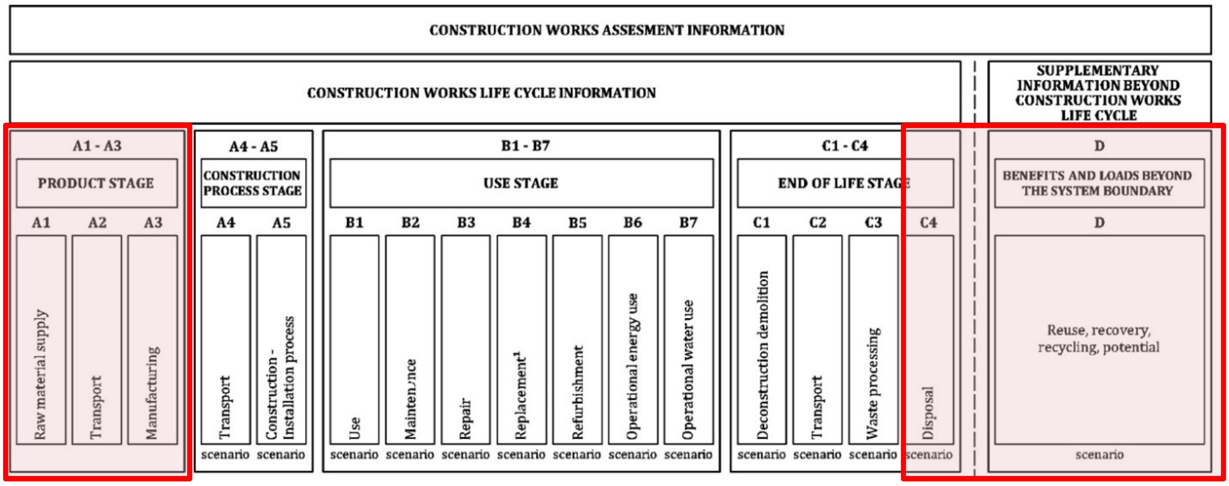

Figure 7 - System boundary for the LCA of the technologies based on EN 15804:2012+A1:2013/ FprA2:2019 (E)

Modules A1-A3

Life cycle module A1 covers all processes related to the extraction of raw materials and precursors. Life cycle module A2 includes all relevant transport processes of the raw materials and precursors to the production site. In life cycle module A3 the manufacture of the declared product at the production site or instalment facility is considered.

Module B1-B5

Energy or mass flows which occur during the use of the product are not included in the present LCA study. The assessment of the use-stage is left out of the system boundary in this phase of the study but will be included in the updated version of the Fact Sheet. Inspection and maintenance are not taken into consideration and no improvement or modernization is foreseen for the RSL.

Modules C1-C4

The life cycle module C1- dismantling of the product; and C2- transport to waste treatment, are not considered in this study. Life cycle module C3 does not require any environmentally relevant energy and mass flows. Life cycle module C4 covers the disposal of the individual components. Metal scrap can be recycled again. Plastics are sent to waste incineration. Considered scenarios for disposal of components according to their material composition are displayed in *Table 4 - End of life scenarios for materials (module C4 and D)*.

Table 4 - End of life scenarios for materials (module C4 and D)

Material	End-of-Life scenario
Steel and Iron	Recycling with 10 % loss on landfill, credit for the initial primary material (25-35 %)
Stainless steel	Downcycling with 10 % loss on landfill, credit for primary steel material
Plastics	80 % incineration with energy recovery, 20 % loss on landfill
Light weight metals (sheet and cast parts)	Recycling with 10 % loss on landfill, credit for the initial primary material
Non-ferrous metals (e.g.: copper)	Recycling with 10 % loss on landfill, credit for primary material
Solar cells	Landfill
Glass	Downcycling, credit for 30 % primary material, 70 % landfill
Electronics	Incineration with energy recovery
Refrigerant	Incineration with energy recovery

Magnets and magneto-caloric materials	Reuse

Module D

Life cycle module D includes reuse, recovery and/or recycling potentials. These are stated as net flows and benefits. The recycling potentials of the primary material used, consisting of stainless steel, steel as well as aluminium, are credited in this module. In addition, an electricity credit is generated resulting from the incineration of the primary plastic materials, electronic parts and the refrigerant.

Biogenic carbon

Packaging is not included in the Bill of Materials (BoM), so components such as wood and cardboard, which contain biogenic carbon, are not taken into consideration and their impact is not calculated.

Cut-off criteria

As stated in the Product Category Rules PCR 2020 for Electricity, Steam and Hot Water Generation and Distribution, UN CPC 171, 173 2007:08 Version 4.0, all data regarding elementary input and output flows of the product system which are responsible for a minimum of 99% of the resulting environmental impacts shall be included in the system. In terms of mass, 95% of the total mass shall be included in the system. Secondary data were used to model the LCA model. The data sets used in the background system come from the GaBi 10 database.

Data quality

Data on the input flows for the calculation of the environmental impacts are provided from MG Sustainable Engineering for the PVT collector, from DTU for the MCHP and from PSYCTOTHERM for the VCHP. Data are provided in an excel spreadsheet in the form of the BoM and the following specifications on the components' composition are given: amount of pieces, mass (kg), total volume (m^3), total mass (kg) and also the country of origin. The technology is modelled in GaBi 10 version of the software, thus the database used is the professional GaBi database (CUP 2021.2). All data collected in the foreground system were collected at the same level of detail. The data used in both the foreground and background systems represent regional mean data (EU datasets). The input and output flows of all mass and energy flows and the associated processes and data sets are documented.

Period under consideration

Most of the primary data for mass and energy flows were collected in 2020. Some energy data were already collected in 2019, but since no significant technology changes are known, the data are still considered representative for 2020. The data in the background system are from the GaBi database (CUP 2021.2) and are also representative for the specified period.

Reference service life (RSL)

RSL is based on the Product Category Rules PCR 2020 for Electricity, Steam and Hot Water Generation and Distribution, UN CPC 171, 173 2007:08 Version 4.0. The RSL for each technology is considered to be as follows:

- PVT collector: 30 years for solar technologies
- MCHP: 20 years
- VCHP: 20 years

Data on input and output flows are calculated for the whole defined RSL.

Allocation

No other by-products or co-products result in the foreground system and the associated production processes. Therefore, no allocations had to be made. When using background data from the GaBi database, it cannot be ruled out that no allocations were applied in the data records. No allocations were applied in the data sets.

Comparability

The technologies under study are innovative technologies, developed within RES4BUILD for research purposes. The technologies are investigated and fine-tuned for connecting with the rest of technologies and working in synergy for energy generation in the building context. Technical and performance values of the DM PVT, the MCHP and the VCHP are not equal to market available technologies. In this sense, a comparative approach of the LCA results is in principle not recommended to be carried out directly, rather only if the technologies (PVT collector and VCHP) under comparison share same performance (with relevance to energy production) and location (with relevance to climate-cultural context). A comparative analysis of the MCHP presented here with a conventional heat pump is not comprehensible because of the development stage of the MCHP.

Results of the impact assessment

LCA results for the production (A1-A3) and end-of-life (C+D) for the PVT collector

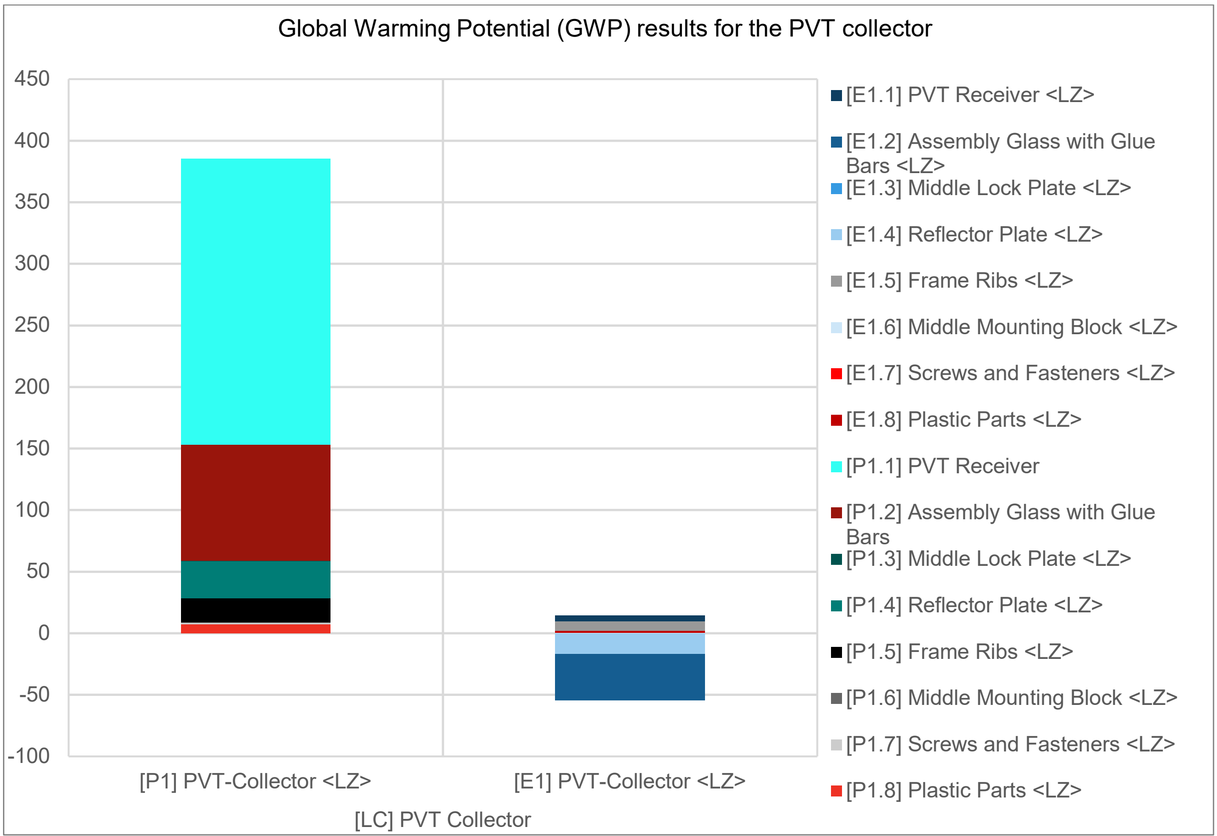

Figure 8 - LCA results for the production (A1-A3 modules) and End-of-Life (modules C+D) of the PVT collector. [E] – End-of-Life, depicts the End-of-Life models for each assembly and for the whole technology; [P] – Production, depicts the Production models for each assembly and for the whole technology; [LC] - Life Cycle; <EoL> - End-of-Life

LCA interpretation for the PVT collector

Results in *Figure 8 - LCA results for the production (A1-A3 modules) and End-of-Life (modules C+D) of the PVT collector*represent the Global Warming Potential (GWP) expressed in kg CO_2 eq., for 1 piece of PVT collector, throughout its whole life cycle (30 years). Environmental impact expressed in GWP during the End-of-Life of the PVT collector are shown in the right half, and impact caused during the production of the technology are shown in the left half part of the chart.

The technology is assessed separately and not in a building context, results are therefore presented for a 30 year life span, and not for a year time frame.

Highest GWP is caused by the production of the PVT receiver - *[P1.1] PVT Receiver*, with an amount of 232,4 kg. CO_2 eq. After the PVT receiver, the highest contribution to GWP comes from the production of the glass and bars assembly - *[P1.2] Assembly Glass with Glue Bars*, with 94,4 kg. CO_2 eq. The reflector plate - *[P1.4] Reflector Plate <LZ>* and the frame ribs - *[P1.5] Frame Ribs <LZ>* come next, contributing with 30,6 kg. CO_2 eq. and 19,3 kg. CO_2 eq. respectively.

As the results show, highest impacts in the context of GWP are caused by the production of the PVT receiver which contains the solar cells, and metals (copper, aluminium and steel). The middle lock plate, middle mounting block, screws and fasteners and the plastic parts (PMMA, ABS, rubber, silicon, EPDM, etc.) contribute a very low value of around 8,9 kg CO_2 eq. in GWP. The production stage (A1-A3) of the PVT collector amounts to a total of 385,5 kg CO_2 eq.

In the End-of-Life stage (C+D modules) negative values to the GWP are caused by a couple of components (glass and glue bars assembly and reflector plate) due to consideration of recyclability and/or reuse scenarios for the metal components, as well as benefits and credits in energy from incineration of plastics.

In analogy to the production stage, the highest negative value comes from the glass and glue bars assembly - *[E1.2] Assembly Glass with Glue Bars <LZ>*, in the End-of-Life stage as well, with an amount of -37, 4 kg CO_2 eq. For glass a combined recycling and landfill scenario is considered, with 30% of material sent for recycling and 70% in landfill. For the aluminium components in glass assembly, a recycling scenario with 10% material loss is taken into account. Credits are therefore gained for the initial primary material. A high negative value to the GWP, comes also from the reflector plate - *[E1.4] Reflector Plate <LZ>*, with -16,9 kg CO_2 eq. The frame ribs - *[E1.5] Frame Ribs <LZ>,* and the PVT receiver - *[E1.1] PVT Receiver <LZ>,* cause high environmental impacts (GWP values are positive) with 7,6 kg CO_2 eq. and 4,7 kg CO_2 eq. respectively. Since disposal and credits (benefits) from the incineration and recycling are presented together in a summed value, the reason for the positive values during the EoL of the above mentioned materials, lies to low credits gained in the background processes of EoL, which do not compensate for the high impacts.

The End-of-Life of the PVT collector adds up to an amount of -40,5 kg CO_2 eq. Contribution to GWP from the life span of the PVT technology is quantified to 344,9 kg CO_2 eq.

LCA results for the production (A1-A3) and end-of-life (C+D) of the MCHP

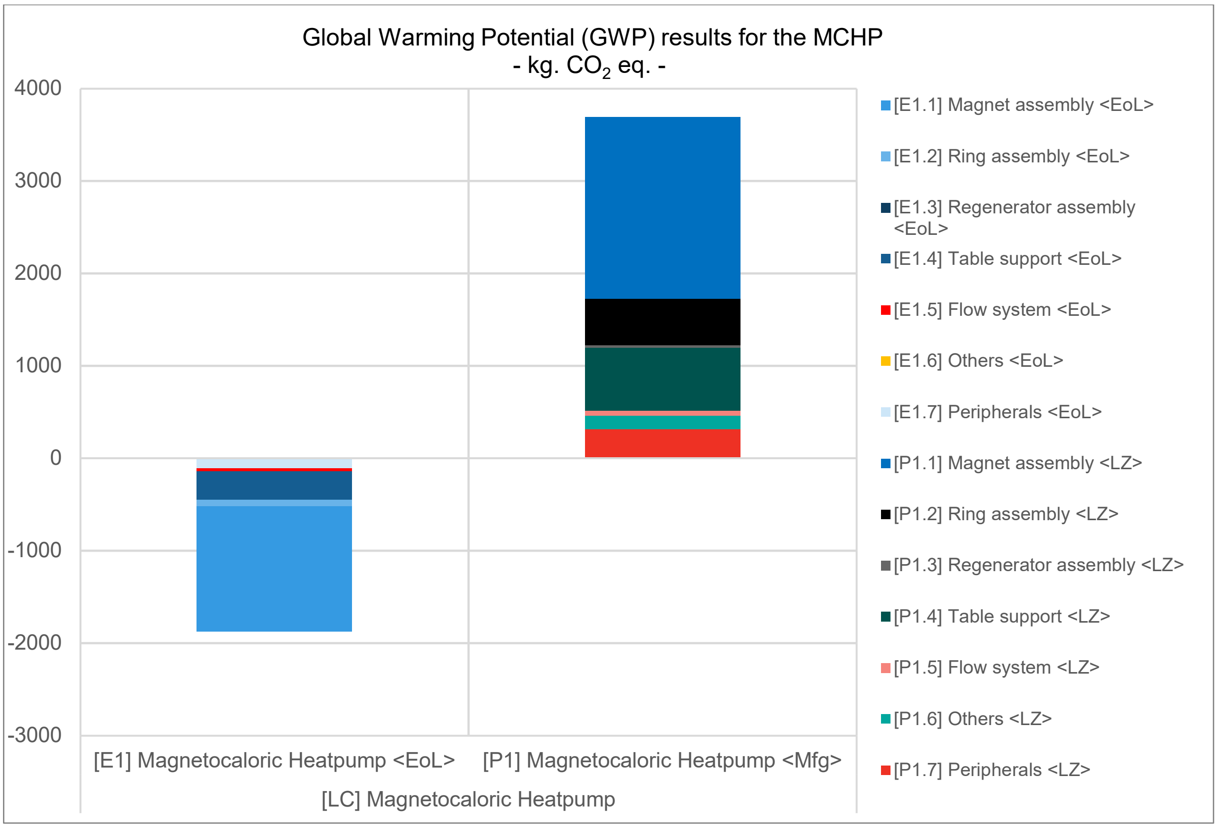

Figure 9 - LCA results for the production (A1-A3 modules) and End-of-Life (modules C+D) of the MCHP

Legend: [E] – End-of-Life, depicts the End-of-Life models for each assembly and for the whole technology; [P] – Production, depicts the Production models for each assembly and for the whole technology; [LC] - Life Cycle; <EoL> - End-of-Life

LCA interpretation for the MCHP

Results in *Figure 9 - LCA results for the production (A1-A3 modules) and End-of-Life (modules C+D) of the MCHP* represent the Global Warming Potential (GWP) expressed in kg CO_2 eq., for 1 piece of MCHP, throughout its whole life cycle (20 years). Environmental impact expressed in GWP during the production/ manufacture of the MCHP are shown in the right half, and impact caused during the End-of-Life (EoL) of the technology are shown in the left half part of the chart.

The technology is assessed separately and not in a building context, results are therefore presented for a 20 year life span, and not for a year time frame.

Highest GWP is caused by the production of the magnet assembly - *[P1.1] Magnet assembly <LZ>*, with an amount of 1964,2 kg. CO_2 eq. Second after the magnets, the highest contribution to GWP comes from the production of the table support assembly - *[P1.4] Table support <LZ>*, with 683,7 kg. CO_2 eq. The ring assembly - *[P1.2] Ring assembly <LZ>* and the Peripherals - *[P1.7] Peripherals <LZ>* come next in the list with a contribution of 499,1 kg. CO_2 eq. and 316,2 kg. CO_2 eq. respectively.

As the results show, highest impacts in the context of GWP are caused by the production of the rare earth magnets and cast iron (Magnets= 77 kg and Cast iron= 216 kg) which make up the magnet assembly. The table support, ring and the peripherals (fasteners, washers, spacers etc.) although they contribute in total almost the same amount as the magnet assembly itself, the cause of such high impact can be referred to the high share of metal components in them. The production stage (A1-A3) of the MCHP amounts to a total of 3689,2 kg CO_2 eq.

In the End-of-Life stage (C+D modules) mainly negative contributions to the GWP can be observed due to consideration of recyclability and/or reuse scenarios for the metal components, as well as benefits and credits in energy from incineration of plastics.

In analogy to the production stage, the highest negative impact comes from the magnet assembly - *[E1.1] Magnet assembly <EoL>*, in the End-of-Life stage as well, with an amount of -1351,6 kg CO_2 eq. For the magnets a reuse scenario is considered, while for the cast iron a recycling scenario with 10% material loss is taken into account. Credits are therefore gained for the initial primary material. Second highest negative contribution to the GWP during the End-of-Life of the MCHP, comes from the table support assembly - *[E1.4] Table support <EoL>*, with -309,9 kg CO_2 eq. The ring assembly - *[E1.2] Ring assembly <EoL>,* and the peripherals - *[E1.7] Peripherals <EoL>,* come next, contributing lower benefits during the End-of-Life stage with -71,6 kg CO_2 eq. and -111,4 kg CO_2 eq. respectively.

The End-of-Life of the MCHP adds up to an amount of -1868,4 kg CO_2 eq. Contribution to GWP from the life span of the MCHP technology is quantified to 1820,84 kg CO_2 eq.

LCA results for the production (A1-A3) and end-of-life (C+D) for the VCHP

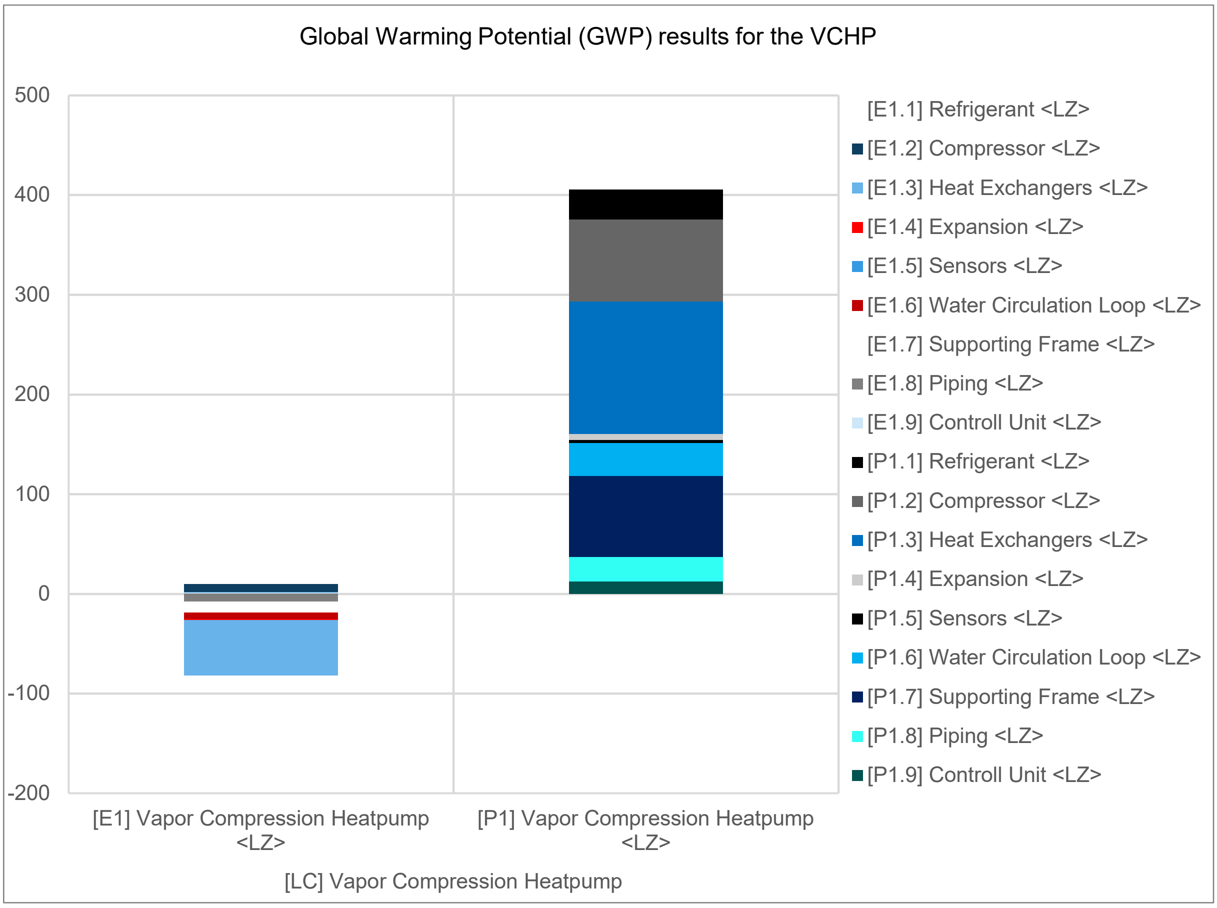

Figure 10 - LCA results for the production (A1-A3 modules) and End-of-Life modules (C+D) of the VCHP. [E] – End-of-Life, depicts the End-of-Life models for each assembly and for the whole technology; [P] – Production, depicts the Production models for each assembly and for the whole technology; [LC] - Life Cycle; <EoL> - End-of-Life

LCA interpretation for the VCHP

Results in *Figure 10 - LCA results for the production (A1-A3 modules) and End-of-Life modules (C+D) of the VCHP* represent the Global Warming Potential (GWP) expressed in kg CO2 eq., for 1 piece of VCHP, throughout its whole life cycle (20 years). Environmental impact expressed in GWP during the production/ manufacture of the VCHP are shown in the right half, and impact caused during the End-of-Life (EoL) of the technology are shown in the left half part of the chart.

The technology is assessed separately and not in a building context, results are therefore presented for a 20 year life span, and not for a year time frame.

Highest GWP is caused by the production of the heat exchangers- *[P1.3] Heat Exchangers <LZ>*, with 12,8 kg. CO_2 eq. After the heat exchangers, the highest contribution to GWP comes from the production of the compressor - *[P1.2] Compressor <LZ>*, and the supporting frame - *[P1.7] Supporting Frame <LZ>*, the contribution of which is almost equal: 82, 2 kg CO_2 eq. for the compressor and 81,0 kg CO_2 eq. for the supporting frame. Less impact in comparison to the above mentioned assemblies, are caused by the water circulation assembly - *[P1.6] Water Circulation Loop <LZ>,* and the refrigerant - *[P1.1] Refrigerant <LZ>,* with 33,3 kg CO_2 eq. and 29,6 kg CO_2 eq. respectively.

High GWP is caused by the production of the metals (mainly stainless steel and copper) used for heat exchange and make up a high share in the total material composition of the technology. The rest of the assemblies (expansion valves, sensors, piping and control unit) have a low share in the overall weight. Their contribution to GWP for the production stage is less relevant (total of four assemblies equals to 46,1 kg CO_2 eq.) than the above mentioned assemblies compared to the whole technology. The production stage (A1-A3) of the VCHP amounts to a total of 405,2 kg CO_2 eq.

In the End-of-Life stage (C+D modules) mainly negative contributions to the GWP can be observed due to consideration of recyclability and/or reuse scenarios for the metal components, as well as benefits and credits in energy from incineration of plastics.

In analogy to the production stage, the highest negative value comes from the heat exchanger - *[E1.3] Heat Exchangers <LZ>*, in the End-of-Life stage as well, with an amount of -55,3 kg CO_2 eq. Metals used for heat exchange are directed to a recycle/reuse route with 10% material loss and gained credits for the initial primary material. A lower negative value during the End-of-Life of the VCHP, comes from the supporting frame assembly- *[E1.7] Supporting Frame <LZ>*, with -11,1 kg CO_2 eq. On the other hand, the End-of-Life of the compressor - *[E1.2] Compressor <LZ>,* and the End-of-Life of the refrigerant - *[E1.1] Refrigerant <LZ>,* lead to positive impact values. Since disposal and credits (benefits) from the incineration (of refrigerant and plastics in the compressor) and recycling of metals (steel in the compressor) are presented together in a summed value, the reason for the positive values during the EoL of the above mentioned materials, lies to low credits gained in the background processes of EoL, which do not compensate for the high impacts.

The End-of-Life of the VCHP adds up to an amount of -65,9 kg CO_2 eq. Contribution to GWP from the life span of the VCHP technology is quantified to 339,2 kg CO_2 eq.

Life Cycle Economics (LCE) specifications

Based on the methodology of Life Cycle Costing (LCC) as defined in the VDI 2885 and VDI 2067 Guidelines, an economic life cycle assessment (LCE) is carried out for the technologies. The term “Life Cycle Costs” implies the total costs generated by a system during its service life from the operator point of view.

Taking into account the level of detail of provided economic and price data on the prototype technologies as well as available standards for LCC, the life cycle economics assessment is carried out for the life cycle phases presented in *Table 5 - Cost types considered for the LCE*.

Table 5 - Cost types considered for the LCE

Life cycle phase	Cost type
Before utilisation	Procurement price per machine
During utilisation	- Freight costs / 1.000 km - Energy costs - Operating material costs
After utilisation	- Disposal costs - Recycling potential

Decisions on each cost type are based on different data sources:

Freight costs are based on average data for transport by truck and EU average diesel price. Energy costs are built up based on the case studies and the simulations. For the operating materials, costs are based on statistical percentages according to VDI 2067 (including maintenance). Costs for disposal of materials on landfill are based on EU average prices, whereas the recycling potential costs are based on the amounts on recyclable materials and EU average prices for secondary material and scrap.

For a comprehensive interpretation of the LCA and LCE for the technologies, results of the economic analysis will be coupled with the environmental impact assessment results in a later phase. This is especially important for the analysis of the use-stage (Module B) of the technology. In this context, results of the LCE will be attached to the LCA results for the utilization phase and presented in the updated version of the Fact Sheet.

Discussion and Outlook

The Double MaReCo photovoltaic-thermal collector (DM-PVT), the magneto caloric heat pump (MCHP) as well as the vapour compression heat pump (VCHP) are prototype technologies developed within the context of RES4BUILD project and are currently being investigated for optimization in order to achieve the highest performance and efficient applicability for the project's objectives.

Therefore, the life cycle economics (LCE) assessment can only be carried out using average and statistical data, implying that no market price can be currently delivered for these innovative technologies.

LCA results provide important indications for the technologies' optimization potential in regards to environmental impact.

<u>PVT collector:</u> The production of solar cells as part of the PVT receiver assembly contributes significantly to GWP. Since the application of such materials cannot be compromised due to their functional importance, it is then relevant to consider End-of-Life scenarios which can compensate for the high impact coming from their production.

<u>MCHP:</u> Considerable use of metals other than the magnets (such as: cast iron, aluminium and steel) contribute significantly to GWP. Positive impact can be achieve through reduction of metals mass (weight) in the overall material composition. Considering reuse for the End-of-Life of magnets has a positive contribution to environmental impact. Nevertheless, this does not imply that such a scenario is performed in practically every case, since it depends on the user's decisions. Continuous contact with the user and informative discussion regarding the importance of sending the magnets back to producer/ developer for reuse, and not just choosing the landfill route, can compensate significantly for the negative environmental impacts caused during the magnets production.

<u>VCHP:</u> Metals used for heat exchange (steel, copper and bronze), contribute significantly to GWP through their production stage, more so due to the high material share in the technology. Since the

application of such materials cannot be compromised due to their functional importance, it is then relevant to consider End-of-Life scenarios which can compensate for the high impact coming from their production. Recyclability and reuse of these materials can lead to lower environmental impacts.

Since the technologies are still under development, LCA results are not recommended to be applied or used for comparison purposes unless same settings (performance and instalment location) are applied in the case of the PVT collector and the VCHP. In the case of the MCHP, considering that the prototype is not optimized for series production, a comparative analysis is not recommended to be carried out with standard similar products.