Fronius GEN24 & GEN24 –
A Benefit for the Environment

Life Cycle Assessment (LCA)

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to4to together for tomorrow
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1 Introduction: A Sustainable Dream

Over the past few decades, global warming has become one of the greatest challenges that human societies face. Many consequences stem from this phenomenon, including accentuated natural disasters, climate refugees, air pollution issues, and much more. Furthermore, environmental damage is also associated with other major related issues, such as biodiversity loss, natural resources crises, increased human health catastrophes, etc. These threats challenge the balance of our societies and endanger the future of humanity. Many reports, which are continuously being published, describe the likelihood or perception of such threats by human societies, such as analyses from the IPCC[1] or the World Economic Forum[2].

Therefore, there is an urgent need to tackle these massive threats. Over the last few years, several measures have been decided with ambitious plans to reduce the environmental footprint of our societies, products, and services as much as possible. Typically, products and services should no longer follow the linear path "take-make-waste", but should have a circular design, for example, embodied in the Sustainable Development Goal 12 from the United Nations: "Responsible consumption and production". Furthermore, purely financial benefits can no longer be the sole criteria to consider; sustainability factors should also be taken into account.

In order to limit the devastating impacts of climate change, some important political institutions have implemented standards, laws, and strategies. To accompany this evolution and also to embrace its responsibility, Fronius has identified sustainability as one of its core values. The Fronius vision "24 hours of Sun", sees a future where 100% of the world's energy demand is covered by renewable sources. To realize this, Fronius is committed to developing sustainable and optimally designed products, taking into consideration all life cycle phases. To achieve this and enable future conscious decisions, a scientific and fact-based understanding of products' sustainability performance is needed. A Life Cycle Assessment is one of the most common and internationally standardized scientific methods to analyze the environmental influences of a product throughout its lifetime. In 2020, a new significant step was made with the completion of the first Fronius Life Cycle Assessment (LCA) for one of its inverter generations, the Fronius GEN24 [Plus].

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[1] Intergovernmental Panel on Climate Change: https://www.ipcc.ch/reports/ (accessed 04/19/2021)
[2] "The Global Risks Report" (2021): http://www3.weforum.org/docs/WEF_The_Global_Risks_Report_2021.pdf (accessed 04/19/2021)

Since Fronius uses the results of the life cycle assessment for the continuous optimization of product development, the actuality of this data is of particular relevance. For this reason, updates of the life cycle assessment are carried out as required and when needed. Since a high degree of transparency is required, especially when it comes to sustainability, ongoing communication of these updates is also essential for Fronius.

Date of LCA updates	**Updated content**
February 2023	– More details due to more intensive inclusion of primary data & update of Ecoinvent datasets to version 3.8 – New datasets of the carbon footprint of PV modules – Deeper integration of night-time power consumption – Even more accurate method for reference output of PV systems (PVSol) in different countries/regions – Hungary as additional country – Modeling of transports analogous to the latest life cycle assessment (LCA Tauro).

1.1 Objective

The objective of this paper is to present the concept of a Life Cycle Assessment, its application to the GEN24 [Plus] product family, and the most relevant results and interpretations. The paper aims to provide an overview of the most important LCA results without going into all the calculations and details in too much depth.

1.2 Definition of a LCA

The following sections will define the LCA, the information that can be learned from it, and its development and use in the European context.

1.2.1 What is a LCA?

A Life Cycle Assessment (LCA) is a scientific methodology that has been in development since the 1990s in order to conduct environmental analyses. The method consists of modelling the environmental impacts of all the inputs and outputs (material, energy, emission, resources, etc.) of a product (or a service) throughout its lifetime and aims to provide a comprehensive picture of a product's environmental performance. Two ISO standards (14040 and 14044) support the framework's structure, validity, and consistency. To ensure a complete lifecycle perspective, Fronius and its LCA partner, Harald Pilz from to4to[3] ("Together for tomorrow"), adopted a "cradle-to-grave" approach in the LCA, taking into account all lifecycle phases from sourcing through to production, usage and the End-of-Life (EoL) including transportation (as presented in Figure 1). To further increase and verify the quality of the Fronius LCA, a LCA review has been conducted in collaboration with Fraunhofer IZM[4] staff, one of the most renowned institutions for electronic product sustainability worldwide. As a result, this LCA provides a holistic, detailed and peer reviewed analysis of the product's environmental footprint.

1.2.2 Why is a LCA useful?

The LCA results obtained enable us to gain a deep understanding and knowledge of the product's strong environmental performance and potential limits.

The need for environmental product data continues to increase:

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[3] To4to - https://www.to4to.at/

[4] Website: https://www.izm.fraunhofer.de/ (accessed 04/19/2021)

- As Fronius aims to improve the sustainability performance of its existing and future products even further, there is a need to scientifically prove, monitor, and understand this evolution. LCAs are one of the few standardized and consistent methods to model environmental impacts and are therefore a strong solution. Using this evidence-based analysis, Fronius can play an active role in the implementation and fulfilment of the goals of "24 hours of Sun". As a consequence, more sustainable and efficient solutions can be developed, benefitting not only the customer but also the environment.

For this reason, Fronius has launched the program "Sustainability by Design" to accelerate these actions. This LCA process was the first step in this program's work.

Increasing awareness of and demand for evidence-based sustainable solutions can also be observed in several PV-market requirements:

- The European Commission has developed and sought to promote environmental guidelines for products, based on life cycle analyses (known as the PEFCR: "Product Environmental Footprint Category Rule"[5]). Furthermore, the European Commission is fighting sustainability claims that lack evidence and will also prepare consumers for the transition towards a green future[6].

- Recent PV tenders are prioritizing low carbon footprint products. For example, in 2021 CRE in France launched a new PV tender (700 MW) that requires modules to have low environmental impacts[7].

- Sustainability databases are being used more and more, where products that exhibit environmentally friendly performance are promoted above others. Upcyclea[8] in France or Byggvarubedömningen[9] in Sweden are some examples.

- National authorities are also increasing pressures to substantiate sustainability claims with, for example, the CMA (Competition & Markets Authority) in the United Kingdom asking companies to consider the full life cycle of the product, the repair index in France ("indice de réparabilité") or the Supply Chain Act from Germany ("Lieferkettengesetz")[10].

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[5] Source: https://ec.europa.eu/environment/eussd/smgp/PEFCR_OEFSR_en.htm#final (accessed 04/12/2021)
[6] Source: https://ec.europa.eu/commission/presscorner/detail/en/ip_21_269 (accessed 03/08/2022)
[7] Source: https://www.pv-magazine.com/2021/02/19/france-launches-700-mw-tender-for-large-scale-pv/ (accessed 04/19/2021)
[8] Source: https://www.upcyclea.com/ (accessed 04/09/2021)
[9] Source: https://byggvarubedomningen.se/ (accessed 04/09/2021)
[10] Sources: CMA: https://www.gov.uk/government/publications/green-claims-code-making-environmental-claims/environmental-claims-on-goods-and-services (accessed on 03/08/2022), repair index: https://www.ecologie.gouv.fr/indice-reparabilite (accessed on 03/08/2022), and Supply Chain Act: https://www.bmz.de/de/entwicklungspolitik/lieferkettengesetz (accessed on 03/08/2022)

In this sense, possessing a LCA with a solid scientific analysis (compared to "rough estimations") and with a LCA review will help achieve "24 hours of Sun" and support Fronius in making conscious decisions in the development process.

1.2.3 The LCA in the European context

Much more than a single initiative from an isolated company, Fronius is participating in a global context with increasing attention and awareness on energy system environmental footprints. At a European level, several documents already include guidelines for environmental evaluations, based on the LCA approach among others. Other European initiatives strengthen the need to build a sustainable future and operate an efficient energy transition:

- The EU Green Deal[11], published in 2019, sets the ambitious goal for Europe to be climate-neutral by 2050.

- The Ecodesign and Energy Labelling schemes[12] that the European Commission wants to implement by 2023-2024 for PV-systems: these labels will promote products with better environmental performance and devices that do not comply with the minimum requirements will not be allowed to be sold on the EU market.

- Existing legislation also favors the implementation of efficient and sustainable energy systems, such as the Renewable Energy Directive III (REDIII)[13] or the EU Taxonomy for EU Regulation 2020/852 ("Framework to facilitate sustainable investment")[14].

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[11] Source: https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1576150542719&uri=COM%3A2019%3A640%3AFIN (accessed 04/09/2021)
[12] For further information on the ongoing process: https://susproc.jrc.ec.europa.eu/product-bureau//product-groups/462/documents (accessed 04/09/2021)
[13] Source: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2018.328.01.0082.01.ENG&toc=OJ:L:2018:328:TOC (accessed 04/09/2021)
[14] Source: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:32020R0852 (accessed 04/09/2021)

2 LCA: The Quest for Environmental Data

In order to conduct a LCA, a key element is the collection of relevant data on the product being analyzed. This section describes the different life cycle phases modeled and the different considerations that were taken into account.

2.1 LCA for the GEN24 [Plus]

To support the vision “24 hours of Sun”, the Fronius GEN24 [Plus] product family was scrutinized to prove its environmental performance and benefits.

In this regard and based on the ISO standards for LCAs (ISO 14040/44), four main life cycle phases have been modeled and analyzed thoroughly, as can be seen in Figure 1:

- The sourcing of raw materials
- The production phase at Fronius sites
- The use phase
- The End-of-Life (EoL) phase

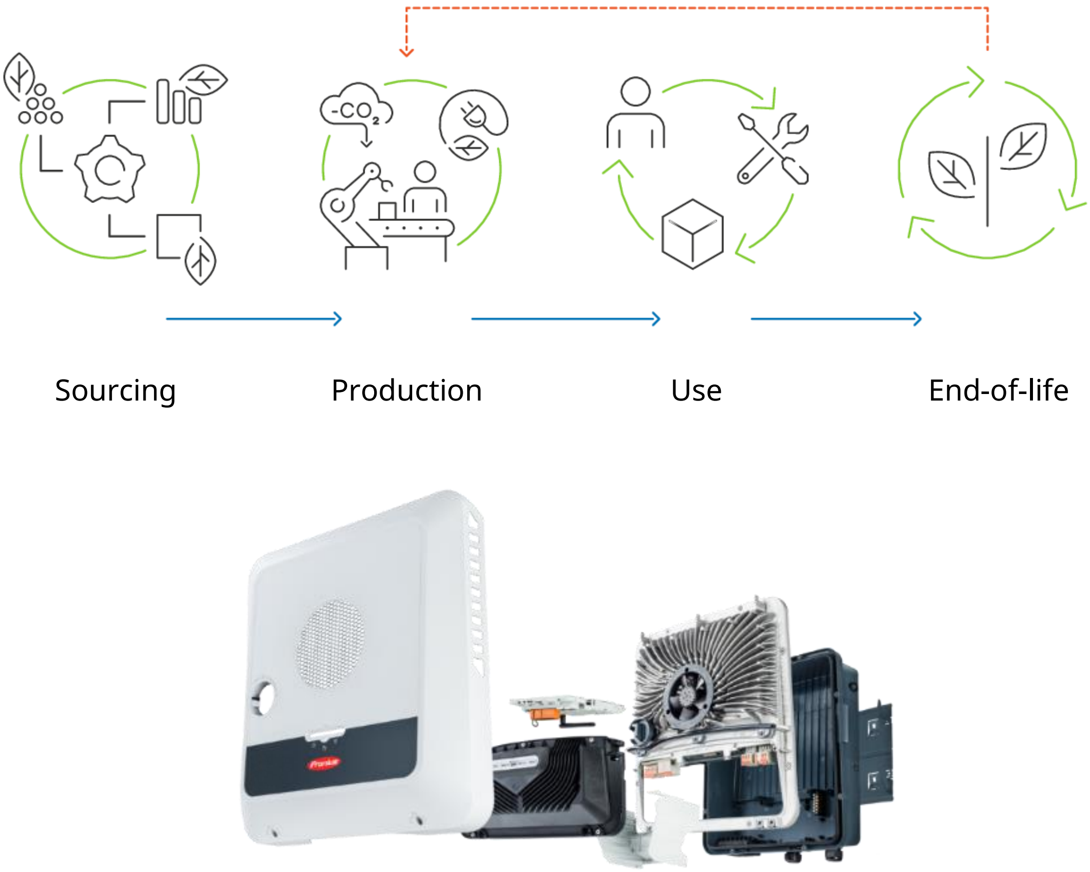


Figure 1: The GEN24 [Plus] and its different life cycle phases

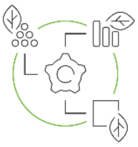
Environmental impact categories have been calculated based on the PEF/ILCD-2019/EF 3.0 guidelines (EPLCA, 2019[15]), such as:

- The Global Warming Potential (GWP), which models the greenhouse gases warming effect stemming from the product, throughout its lifetime (in kg CO_2 equivalent). "CO_2-equivalent" is the unit used to assess the impact of a product on the GWP. "Equivalent" means here that several greenhouse gases are combined and "translated" into equivalent effects of CO_2 on the GWP. For example, the emission of 1 kg of methane (CH_4) is equivalent to 28 kg of CO_2 over 100 years (based on the IPCC 2013 methodology considered in ecoinvent v3.8, Intergovernmental Panel on Climate Change[16]).
- The Cumulative Energy Demand (CED), which measures the direct and indirect energy required throughout the lifecycle of the product (in Megajoule equivalent).

A product's environmental impact is not just limited to CO_2 emissions or energy demand but relates to other categories as well. In order to gain a holistic and complete overview, the LCA conducted by Fronius also considered factors such as "metals resource depletion", "human toxicity", and "particulate matter emissions". However, for the sake of clarity, in the following sections, the paper will focus on the two most common and important impact categories: the Global Warming Potential and Cumulative Energy Demand.

The database used in the LCA for background processes (secondary data) is ecoinvent (version 3.8 2021[17]), one of the world's most complete and common LCI (Life Cycle Inventory) databases.

2.2 Sourcing



Firstly, the sourcing phase considers all relevant processes from raw material extraction and refining processes through to the production of components. In this phase, intensive discussions and research have been conducted with suppliers, in order to get as much primary data as possible. Material composition of the different components delivered to Fronius have been analyzed and modeled with primary data or with the ecoinvent database when needed. Nevertheless, intensive analyses have been conducted on components composition, in order to get the most detailed results possible. Analyses were particularly conducted on DC-disconnector, fuses, fans and others were dismantled for this purpose.

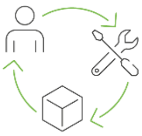
[15] Source: https://eplca.jrc.ec.europa.eu/LCDN/developerEF.xhtml (accessed 03/01/2022)
[16] Source: https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter08_FINAL.pdf (table 8.A.1, p.731, accessed 13/02/2023)
[17] Source: https://www.ecoinvent.org/ (accessed 02/16/2022)

2.3 Production

Secondly, the production phase considers the production of GEN24 [Plus] at the Fronius production sites. This production process has been modelled based on primary data, considering, for example, the power consumption on the production line, solder paste needs, the potential waste production and management, and the use of packaging. When needed, several data sets were extracted from the ecoinvent database to complete the modeling. Overall, LCA models have been developed for the following device types:

- Primo GEN24 3.0 and 6.0 as well as 3.0 and 6.0 Plus
- Symo GEN24 5.0 and 10.0 as well as 5.0 and 10.0 Plus

2.4 Use Phase



Thirdly, the use phase considers the time the GEN24 [Plus] is active in a PV system and potentially repaired. It therefore takes into account several factors such as:

- The lifetime of the inverter: established at a standardized value of 20 years.
- The countries where the system is used. This parameter influences the PV system power production capacity and the transport distance for the product. In the GEN24 [Plus] LCA, there are eight country options: Australia, Austria, Brazil, Germany, Hungary, Poland, USA (two sub-options, New York and Los Angeles).
- The inverter losses: this value is established based on the modeling of PVSol for each scenario, in order to provide the most realistic modeling (2022)[18]. PVSol, in comparison to some standardized EU-benchmarks, provides more realistic results depending on the country and parameters but also makes it possible to model the oversizing of the PV-system (see section 3.1).
- The night (or stand-by) consumption needed for data collection or access to the user interface (8.2 W for Primo devices and 10 W for Symo devices).
- Repair processes have also been modeled with the following scenarios:
    - Exchange of the fan or the data communication unit (so-called “Pilot”) (both on-site)
    - Exchange of four varistors on the power stage set
    - Replacement of the complete power stage set (both at the Fronius International Repair Center)

The defective element is either sent to waste treatments or sent back to Fronius sites for repair.

[18] Source: https://valentin-software.com/produkte/pvsol-premium/ (accessed 02/16/2022)

2.5 End-of-life

Fourthly, the End-of-Life (EoL) phase considers the possibilities for the product to be treated or recycled. For this, five main scenarios have been established to model the possible EoL treatments:

- Landfill
- Waste incineration
- Combination of metal recycling with incineration
- Recycling without prior dismantling (of 5 main pieces of GEN24 [Plus])
- Recycling with prior dismantling (of 5 main pieces of GEN24 [Plus])

Based on the selected alternative, the environmental impact or benefit varies. For example, the landfill option generates more environmental impacts than recycling with dismantling (see Section 3.1).

3 LCA: The Environmental Performance of the GEN24 [Plus]

Now that all the relevant data has been collected, the next sections describe the environmental performance and the LCA results for the GEN24 [Plus] in more detail. More specifically, the carbon footprint will be detailed, and the benefits of a PV-system with the GEN24 [Plus] will be described.

3.1 The Carbon Footprint of the GEN24 [Plus]

Naturally, an inverter, as opposed to a tree for example, cannot extract CO_2 (or other harmful pollutants) from the atmosphere. Nevertheless, an inverter connected in a PV system enables much fewer CO_2 emissions to be emitted than the alternative being considered - drawing electricity from the grid. Through this comparison (PV system vs. the national grid), we can assess the reduction in CO_2 emissions through the use of solar energy. In this white paper, one specific scenario is used, for clarity's sake and in order to provide a concrete idea of what can be understood from a LCA model[19].

Table 1: Scenario options (bold marked options are the scenario considered in the whitepaper)

1. Fronius Inverter	2. Location used	3. End-of-life strategy	4. Additional parameter
– Primo GEN24 [Plus] 3.0 kW – Primo GEN24 [Plus] 6.0 kW – Symo GEN24 [Plus] 5.0 kW – **Symo GEN24 [Plus] 10.0 kW**	– **Australia** – Austria – Brazil – Germany – Hungary – Poland – USA – NY – USA - LA	– Landfill – Waste incineration – **Combination of metal recycling with incineration** – Recycling without dismantling – Recycling with dismantling	– Life expectancy: **20 years** – **Averaged repair process** – **Electricity mix for night consumption**

<u>A "PV-System" Perspective</u>

First of all, it is meaningful in a LCA to bear in mind the limitations of the results: an inverter is only one part of a PV system. An overview at the PV-system level is therefore provided below in order to give an idea of the relative contributions of the different parts of a PV system (modules, inverter, etc.). Information on the PV modules' carbon footprint was taken from the LCA database ecoinvent, combined with literature research

[19] All scenario variations and specific values could not be reviewed by Fraunhofer IZM staff, due to the complexity and the large number of results (at least several thousand detailed variations possible). Nevertheless, the general structure and modeling of the LCA has been reviewed and all scenarios follow the same methodology, ensuring the best possible consistency.

performed by Fronius. Therefore, Figure 2 gives an overview at the system level, keeping in mind that the proportions may vary slightly (by a few percent) based on the data or scenarios. Balance of Systems ("BoS" in Figure 2) considers additional components needed for a PV-system (supporting infrastructure, wiring, cables, etc.).

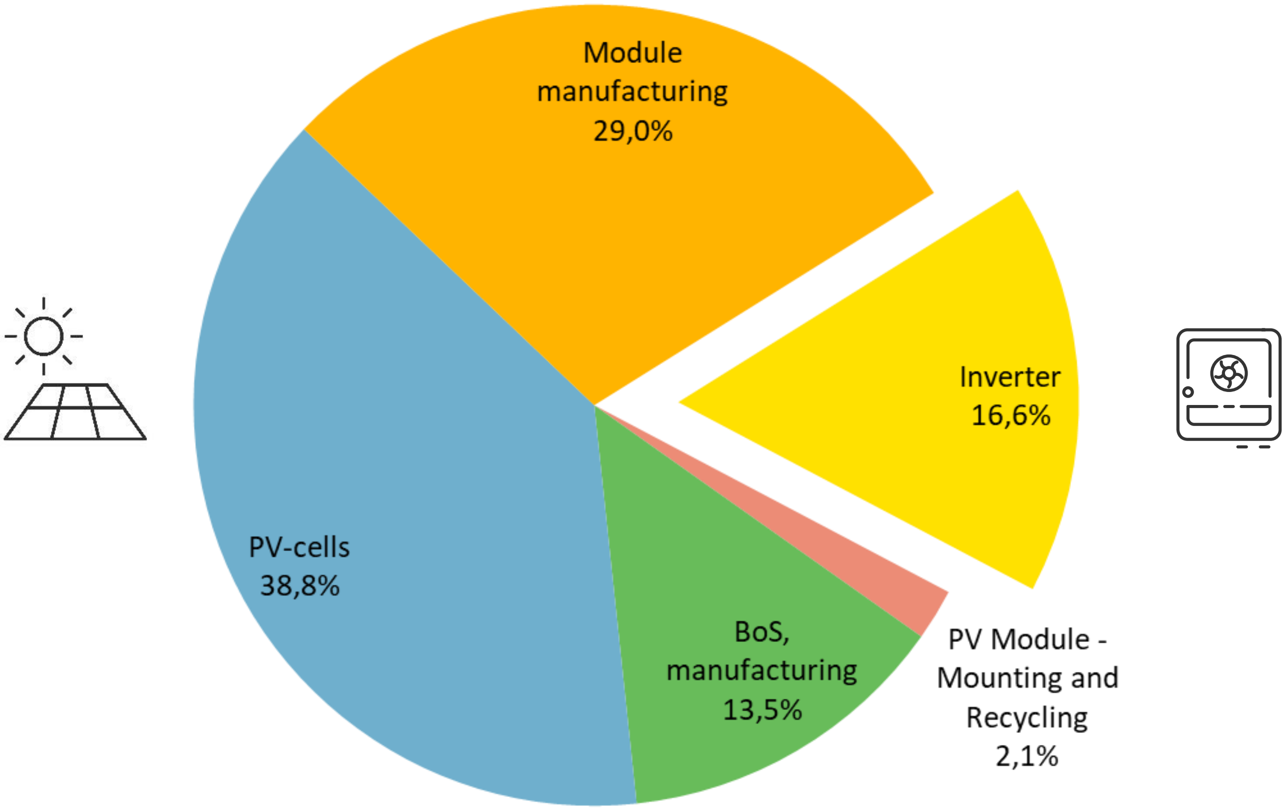


Figure 2: Relative contribution of the PV inverter (Australian scenario) on the PV-system carbon footprint ("PV system perspective")

In the selected scenario, the inverter is responsible for 16.6% of the environmental impact of the total PV system (this can vary between 9.30% and 34.54% depending on the scenario).

<u>The Carbon Footprint of the Symo GEN24 [Plus] 10.0 kW Lifecycle Phases</u>

In the following graphs, the focus will be on the inverter, where primary and reliable data could be collected, and most detailed analyses were conducted. The following graph shows the carbon footprint of the inverter alone (but connected to a PV system) in absolute values of kg CO_2-equivalent (kg CO_2e).

Carbon footprint (kg CO_2e)

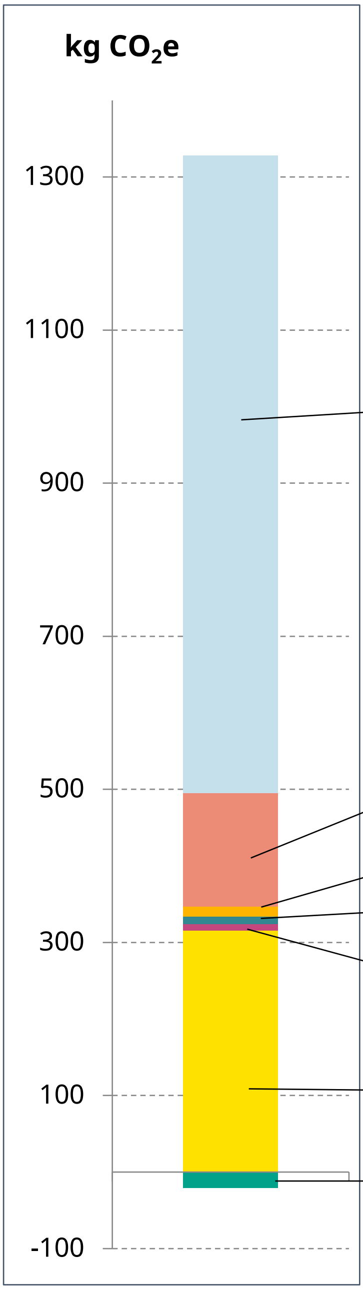


Figure 3: Carbon footprint of Symo GEN24 10.0 [Plus] in absolute values and in relative contributions by life cycle phases. The figure stresses the importance of the sourcing phase and use phase.

As seen in Figure 3, the total carbon footprint of GEN24 Symo 10.0 is 1307.0 kg CO_2e (1327.9 kg CO_2e with an environmental "credit" of -20.9 kg CO_2e from the waste management). Moreover, several important messages or interpretations can be deduced:

- The components manufacturing phase: the manufacturing processes required for the components (metals, electronic components, plastics, etc.) contribute significantly (almost a quarter) to the total carbon footprint of the inverter. This result highlights the importance of the supply chain's influence and the need to develop a joint effort with all stakeholders along the supply chain to keep improving the environmental performance of inverters in the future. In this vein, relevant measures have already been implemented at Fronius with, for example, more than 90% of recycled aluminum being used in the main metallic component of the inverter.

- The production phase: the assembly of the inverter at the Fronius production site represents only a limited proportion of the carbon footprint (0.7% in this scenario). This proves that the assembly process is already optimized. In addition, the energy used at the Fronius production site comes from renewable energy sources (green electricity contract & local PV installation). With the PV systems at the production sites, Fronius produces more than 2000 MWh of solar energy per year.

- The transport of components to Fronius and the transport of Fronius inverters to customers: these steps also represent a limited share of the inverter´s carbon footprint. The main reason for this is that Fronius avoids air freight as much as possible and favors trains, trucks, or sea freight, resulting in a consequently relatively small carbon footprint (less than 2% combined).

- The losses: each product has its own carbon footprint (that can be compared to a "CO_2 backpack" or "CO_2 debt"), which comes from all background manufacturing processes, transport, and so on. As a consequence, electricity that comes from a PV system also has a CO_2 backpack (with a value of around 15-80 g CO_2e/kWh) which is lower than the CO_2 backpack of the electricity from the grid (in the range of approx. 100-1200 g CO_2e/kWh, depending on the country). The GEN24 Symo 10.0 is modeled with a losses value defined by the software PVSol, taking into account the country's solar radiation levels (more granular than the Euro-efficiency). In the Australian scenario, the inverter losses value is set at 2.25%, meaning that a certain amount of electricity from the PV modules, with its CO_2 backpack, is lost as heat. 2.25% is a relatively low value (the range is 2.25 – 4.30%, depending on the scenario), but the PV inverter is used for 20 years, meaning that the losses have to be added for the whole lifetime. Even with the high efficiency of the GEN24 Symo 10.0 (97.75%, based on PVSol modelling), this effect results in the losses (from the use phase) making it a significant contributor to the total carbon footprint result (11.3%).

- The night consumption: in this scenario, it is assumed that the PV-plant is connected to the Australian grid mix, with a yearly average of 12.10 hours/day of "night mode" for the PV-inverter. Due to the relative high carbon footprint of the Australian grid mix, the carbon footprint from night consumption is significative (833.0 kg CO_2e, equivalent to 63.7% of the global carbon footprint of the inverter). However, if the electricity for the night consumption was taken from a renewable electricity supplier, the related carbon footprint of the night consumption would be much smaller (38.3 kg CO_2e, leading to a share of ca. 7.5%). The relative environmental impact contribution of the PV-inverter towards the rest of the PV-system will therefore also decrease, falling in the range of 6,94% - 15,76% depending on scenarios (instead of 9.30% - 34.54%, see notes below Figure 2). Therefore, the carbon footprint of the night consumption of the PV-inverter has to be limited as much as possible with, for example, a renewable electricity supply.

– The Waste management: Fronius follows the WEEE Directive and seeks to increase the recyclability of its products. Therefore, an environmental credit (negative value in the bar chart of Figure 3) can be gained through the substitution and avoidance of new raw material extraction and reduced energy needs. The responsible and conscious use of the Earth's resources is a core obligation of Fronius and increases environmental benefits.

Comparison Between the Weight and the Carbon Footprint

The results of the LCA can also be used to understand the relative contribution of each component of the Symo GEN24 10.0 [Plus] inverter itself, as shown in the figures below:

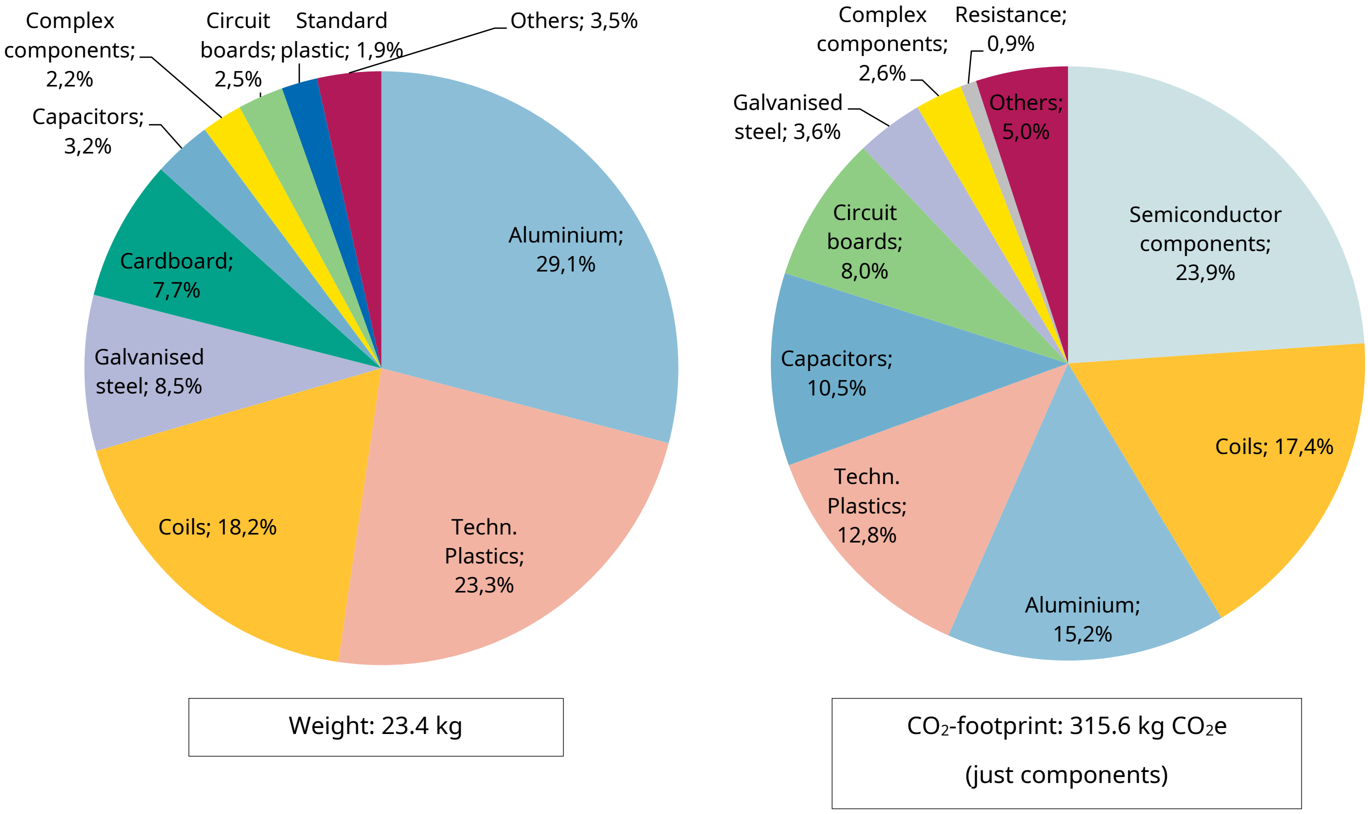


Figure 4: **Relative contribution of the Symo GEN24 10.0 [Plus] components by mass (left, in % kg) and by the carbon footprint (right, in % kg CO_2e).** The figure shows that some elements with a relatively small weight contribution may have a significant carbon footprint share.

As can be seen in Figure 4, on the one hand, the aluminum represents the largest contributions to the mass but shares a relatively lower contribution to the carbon footprint of the Symo GEN24 10.0 [Plus] , almost twice smaller. On the other hand, the capacitors represent only 3.2% of the mass but are responsible for 10.5% of the carbon footprint. The semiconductors (ICs and transistors) are even more striking with 0.1% share of the mass but 23.9% of the carbon footprint. This LCA result shows that elements with a low mass can have a significant environmental influence due to the energy-intensive processes coming from upstream stages (manufacturing, refining, etc.). In comparison, technical plastics also have a relatively low carbon footprint (12.8%) in relation to their mass (23.3%).

<u>End-of-life Management</u>

Concerning the waste management, the LCA results also indicate that the more extended the End-of-Life management process is, the larger the environmental benefits are, as shown in Figure 5. The negative values represent the credit for substituting primary materials or fossil-energy use.

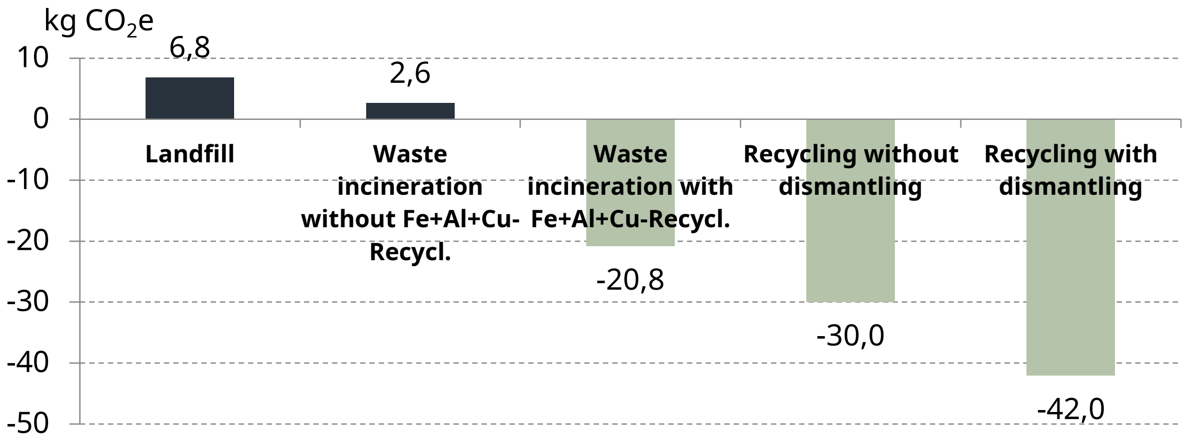


Figure 5: **Environmental End-of-Life costs or benefits for Symo GEN24 10.0 [Plus] .** The landfill option brings additional emissions. The environmental benefit increases with metal recycling and is optimal with dismantling.

Furthermore, the LCA results confirm that repair processes conducted by Fronius provide environmental benefits compared to a replacement of the whole product. For example, when the power stage set is replaced after 20 years, it enables a lifetime extension for the inverter of 20 years. As the service life of the inverter depends primarily on the function of the power stage set, when this repair is conducted, all the other parts of the inverter may then be used for a longer period. Besides, repairing an existing device enables to avoid the emissions of manufacturing a whole new device (in case of an exchange), saving up to ca. 300 kg CO_2-eq.

3.2 Benefits of the Symo GEN24 10.0 [Plus]

Now that the overview of the Symo GEN24 10.0 [Plus] carbon footprint has been provided, the benefits of the device will be described.

Using electricity from a PV system with a Symo GEN24 10.0 [Plus] in Australia would result in an average carbon footprint of **21.07 g CO_2e/kWh**. In comparison, using electricity from the **Australian grid mix** would result in a carbon footprint in the range of **600 - 950 g CO_2e/kWh** (approx. 28-45 times higher, due to coal use, among other things)[20].

In comparison, as a rough estimation, the CO_2 emissions saved by the whole PV system over 30 years (not only the inverter) are equivalent to approx. 1,200 trees planted[21]. Another rough comparison is possible with gasoline-powered cars where an averaged use of 5 l/100 km is considered. Based on the ecoinvent database, the benefit of a PV system using the Symo GEN24 10.0 [Plus] in Australia for 30 years (benefit of the whole PV system, not just that allocated to the inverter) would save CO_2 emissions equivalent of approx. to **3,663,083 km** travelled by car. For the same PV system use scenario, there would be a CO_2-emissions saving equivalent to approx. **240 roundtrip flights from Vienna to New York[22].**

Based on the LCA results, the **CO_2 payback time** (time needed for the CO_2 emissions avoided to offset the product's CO_2 emissions) for the whole PV-system (30 years – 1,5 inverters) is in the range of **0.7 – 3.3 years**, depending on the scenario. For the scenario presented in Australia, the value is 0.7 years. After this payback time, a **PV System with a Symo GEN24 10.0 [Plus] owner is saving CO_2 emissions, compared to the alternative with power from the grid**, and thus generates a positive impact for the environment. When a PV System uses a Symo GEN24 10.0 [Plus] inverter for 30 years, the total amount of CO_2e **emissions avoided** can be up to **44.9 times higher** than the total amount of CO_2 emissions needed for the whole lifecycle of the whole PV-system.

The **energy payback time** is within the range of **0.6 – 1.8 years** (0.7 years for the present scenario). When reaching this payback time, the PV system has produced the amount of energy needed for its whole lifetime (energy needed for manufacturing, transport, etc.). After that, the PV system produces "extra energy" that brings **added energy value to the ecosystem**.

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[20] Average based on: https://www.electricitymap.org/map, ecoinvent, http://www.cleanenergyregulator.gov.au/NGER/National%20greenhouse%20and%20energy%20reporting%20data/electricity-sector-emissions-and-generation-data/electricity-sector-emissions-and-generation-data-2020-21

[21] Based on the following document: Nam et al. 2016: "Allometric Equations for Aboveground and Belowground Biomass Estimations in an Evergreen Forest in Vietnam" (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4910975/)

[22] Flight emissions calculations based on: https://co2.myclimate.org/en/flight_calculators/new. The values for trees, car trips in km, and plane trips are included here simply as a means of comparison and are not standardized or reviewed values (depending on the source used).

When a PV system uses a Symo GEN24 10.0 [Plus] inverter for 30 years, the total amount of **energy produced** can be up to **43.0 times higher** than the total amount of energy needed for the whole lifecycle of the whole PV-system.

3.3 Results of the LCA across different scenarios

Since the results of the life cycle assessment are dependent on many different factors, there is also a wide variety of scenarios. The following table shows the most important results for a very practical scenario based on several countries.

Data basis for the scenarios:

Device	Symo GEN24 10.0 [Plus]
Lifetime (Inverter)	20 years
Lifetime (PV-system & modules)*	30 years
Embedded carbon footprint of the PV-modules	984 kg CO_2e/kWp
End of life option for the inverter	Combination of metal recycling with incineration
End of life option for the cardboard packaging	Waste incineration
End of life option for the plastic packaging	Waste incineration
Night consumption	From the national grid mix

*For the lifetime of a whole PV system (inverter, modules etc.), 1.5 inverters are calculated, since the assumed lifetime of the inverter is 20 years and that of the PV modules is 30 years.

Country	Australia	Austria	Brazil	Germany	Unit
Carbon footprint PV-inverter	1307,04	787,01	695,25	953,19	kg CO_2-eq
Relative carbon footprint share PV-inverter/PV system (30 years)	16,61%	10,71%	9,58%	12,69%	%
Energy Payback Time PV-inverter (20 years)	0,47	0,95	0,57	0,69	years
Energy Payback Time PV-system (30 years)	0,71	1,43	0,86	1,03	years

CO_2-Payback Time PV-inverter (20 years)	0,45	1,74	1,69	1,19	years
CO_2-savings PV-inverter (20 years)	-58,49	-9,03	-8,25	-15,98	tonnes CO_2-eq
CO_2-Payback Time PV-System (30 years)	0,67	2,62	2,53	1,79	years
CO_2-savings PV-system (30 years)	-528,10	-126,40	-129,10	-188,94	tonnes CO_2-eq
Country	**Hungary**	**Poland**	**USA - NY**	**USA - LA**	**Unit**
Carbon footprint PV-inverter	915,89	1423,49	703,58	847,53	kg CO_2-eq
Relative carbon footprint share PV-inverter/PV system (30 years)	12,25%	17,83%	9,69%	11,44%	%
Energy Payback Time PV-inverter (20 years)	0,43	0,78	0,46	0,60	years
Energy Payback Time PV-system (30 years)	0,64	1,16	0,69	0,90	years
CO_2-Payback Time PV-inverter (20 years)	1,26	0,69	1,91	1,00	years
CO_2-savings PV-inverter (20 years)	-14,50	-41,10	-7,36	-16,96	tonnes CO_2-eq
CO_2-Payback Time PV-System (30 years)	1,90	1,04	2,87	1,50	years
CO_2-savings PV-system (30 years)	-177,53	-345,79	-113,96	-222,39	tonnes CO_2-eq

4 Conclusion: The Step Beyond

Now that a LCA has been successfully conducted, information is provided below on the further use of the LCA and on the next steps on Fronius' sustainability pathway.

4.1 Use and Quality of the LCA

The GEN24 [Plus] LCA represents a significant new step for sustainability activities at Fronius. Clear knowledge, based on scientific facts, has been gained on the inverter, which can be used to develop further products with an even lower environmental impact. Moreover, the LCA results prove the impressive environmental performance of the Fronius GEN24 [Plus] and can be used as evidence for requests regarding sustainability demands (requirements, tenders, etc.).

As LCAs will become more and more common in the coming years, there will most likely be attempts to compare LCA results from different companies. In this regard, a cautious and critical approach should be adopted. Comparisons between LCAs can be particularly challenging, since the scope of the system being analyzed can differ and the methodology applied, or the data sources used can diverge significantly. There is not yet a uniform, internationally recognized LCA framework (especially when it comes to the methodology applied), which enables potentially variable results. In this regard, there is a need for clear transparency and communication on LCA modeling, the system definitions, and the methodology applied. Despite the current difficulties faced in the LCA methodological world, Fronius strived to produce high-quality results that are as representative and valid as possible. The LCA has been conducted in partnership with Harald Pilz (to4to), an expert in sustainability assessments with wide-ranging experience in LCAs. The ISO 14040/44 LCA review process conducted with Fraunhofer Institute IZM staff – an external third-party – is a further concrete step that supports this approach. The LCA review aimed to verify, confirm, and support the quality and consistency of the LCA work conducted. Fraunhofer IZM is a well-established institution and is internationally recognized for its knowledge and expertise in the field of electronics and PV systems, including LCAs and review processes[23]. During the Fronius LCA review, extensive research and discussions took place regarding electronic components, material content and recovery, and secondary data validity. The LCA report and the general modeling structure have been checked and a review report from Fraunhofer IZM is available on the Fronius website: Review Report

Furthermore, Fronius is actively participating in discussions with European bodies and associations to promote a consistent and uniform LCA framework in Europe. In the

[23] Example of a LCA for mobiles phones: https://www.fairphone.com/wp-content/uploads/2020/07/Fairphone_3_LCA.pdf

meantime, it is possible to draw some conclusions or points of comparison as long as caution is exercised and on a case-by-case basis.

4.2 The Next Steps Forward: On the Way to Sustainability

Thanks to the deeper knowledge and awareness of the environmental performance of the GEN24 [Plus], the LCA highlighted several opportunities to increase the sustainability performance of future Fronius devices even further.

Based on these findings, specific requirements will be defined and tackled by product development processes and confirm Fronius' commitment to sustainability. A strong emphasis will be put on the long service life, efficiency, repairability, and recycling possibilities of the electronic equipment. Investment will be made to further optimize material as well as energy efficiency along the supply chain, and production and use phases through the use of sustainable and recycled products. In this way, the performance will not only benefit the customer, but also the environment. Fronius aims to keep successfully enhancing the sustainability performance of its portfolio even further.

To conclude, the GEN24 [Plus] LCA project enabled Fronius to gain a deep knowledge of its product environmental performance at different levels (component, process, etc.). This analysis can be actively used to develop even more sustainable products and comply with a wide variety of sustainability demands and requirements for inverters and PV systems.

The LCA will strengthen the leading position of Fronius in sustainability for PV systems and can facilitate the implementation of environmentally friendly PV systems with scientific and fact-based elements.

The level of detail, the scale of the scope, the flexibility of the scenarios, and the quality/transparency of the whole GEN24 LCA process has rarely been applied before in an LCA and is unique in the world of PV inverters.