/ Perfect Welding / Solar Energy / Perfect Charging

FRONIUS GEN24 PLUS – A BENEFIT FOR THE ENVIRONMENT

LIFE CYCLE ASSESSMENT (LCA)

DI Mag. Harald Pilz

to4to
together for tomorrow

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Business Unit Solar Energy / System Technology
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1 INTRODUCTION: A SUSTAINABLE DREAM

For 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. A Fronius vision, named “24 hours of Sun”, summarizes a future where 100% of the world’s energy demand is covered by renewable sources. To realize this ideal situation, 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 product family, the Fronius GEN24 Plus.

1.1 Objective

The objective of this paper is to present the concept of 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.

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

1.2 Definition of an 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 an 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 phases from sourcing to production to usage to the End-of-Life (EoL) including transportation (as presented in Figure 1). To further increase and verify the quality of the Fronius LCA, an 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 reviewed analysis of the product's environmental footprint.

1.2.2 Why is an 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:

- 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 "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 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]).

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[3] To4to - https://www.to4to.at/
[4] Website: https://www.izm.fraunhofer.de/ (accessed 19/04/2021)
[5] Source: https://ec.europa.eu/environment/eussd/smgp/PEFCR_OEFSR_en.htm#final (accessed 12/04/2021)

- 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 with low environmental impacts[6].
- Sustainability databases are being used more and more, where products that exhibit environmentally friendly performance are promoted. Upcyclea[7] in France or Byggvarubedömningen[8] in Sweden are some examples.

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

1.2.3 The LCA in the European context

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[9], published in 2019, establishes the ambitious goal for Europe to be climate-neutral by 2050.
- The Ecodesign and Energy Labelling schemes[10] that the European Commission wants to implement by 2023-2024: these labels will promote products with better environmental performance and a device not complying with the minimum requirements will not be allowed to be sold on the EU market.
- Forthcoming legislation will also favor the implementation of efficient and sustainable energy systems, such as the Renewable Energy Directive II (REDII)[11] or the EU Taxonomy for the EU Regulation 2020/852 ("Framework to facilitate sustainable investment")[12].

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[6] Source: https://www.pv-magazine.com/2021/02/19/france-launches-700-mw-tender-for-large-scale-pv/ (accessed 19/04/2021)
[7] Source: https://www.upcyclea.com/ (accessed 09/04/2021)
[8] Source: https://byggvarubedomningen.se/ (accessed 09/04/2021)
[9] Source: https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1576150542719&uri=COM%3A2019%3A640%3AFIN (accessed 09/04/2021)
[10] For further information on the ongoing process: https://susproc.jrc.ec.europa.eu/product-bureau//product-groups/462/documents (accessed 09/04/2021)
[11] 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 09/04/2021)
[12] Source: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:32020R0852 (accessed 09/04/2021)

2 LCA: THE QUEST FOR ENVIRONMENTAL DATA

In order to conduct an LCA, a key element is the collection of relevant data on the product being analyzed. This section describes the different life cycle phases modelled and the different considerations 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), three main life cycle phases have been modelled and analyzed thoroughly, as can be seen in Figure 1:

- The production phase (including sourcing)
- The use phase
- The End-of-Life (EoL) phase

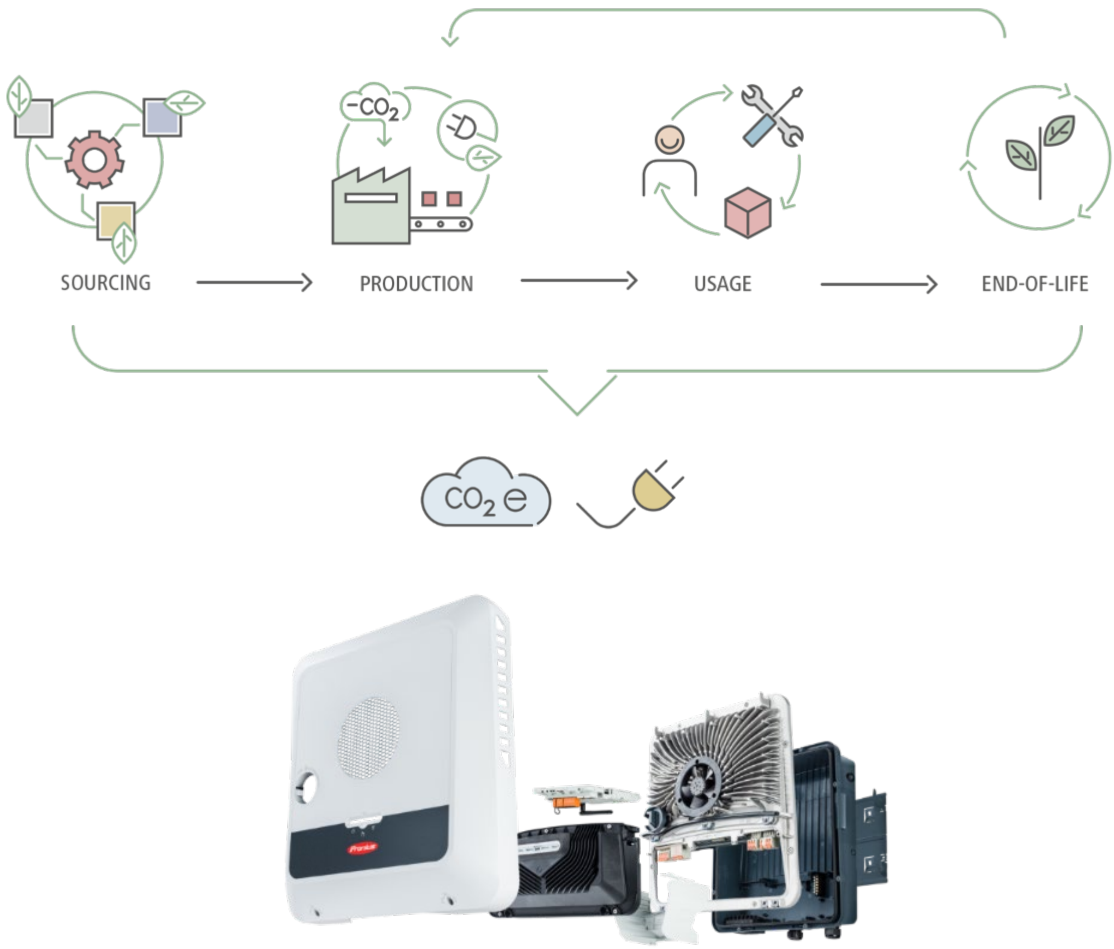


Figure 1: The GEN24 Plus and its different life cycle phases

Environmental impact categories have been calculated based on the ILCD methodology (ILCD, 2018[13]), 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).
- The Cumulative Energy Demand (CED), which measures the direct and indirect energy required throughout the lifecycle of the product (in MJ equivalent).

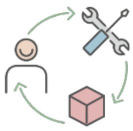
A product's environmental impact is not just limited to CO_2 emissions or energy demand, but relates to other categories as well. In order to gain a holistic and complete overview, the LCA conducted by Fronius also considered factors like "metals resource depletion", "human toxicity", and "particulate 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 3.7.1, 2020[14]), one of the world's most complete and common LCI (Life Cycle Inventory) databases.

2.2 Production

Firstly, the production phase takes into account all relevant processes from raw material extraction, refining and preparation, components production, and the GEN24 Plus production stage at the Fronius production sites. Several data sets were extracted from the ecoinvent database as required. The production of the GEN24 Plus at Fronius production sites 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. Overall, LCA models have been developed for the following device types:

- Primo GEN24 Plus 3.0 and 6.0 kW
- Symo GEN24 Plus 5.0 and 10.0 kW

2.3 Use phase



Secondly, 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 six country options: Australia, Austria, Brazil, Germany, Poland, and the USA (two sub-options, New York and Los Angeles).
- The losses of the inverter: this value is established at a standard level of 3% (97% efficiency).
- Repair processes have also been modelled with the following scenarios:

[13] Source: https://eplca.jrc.ec.europa.eu/index.html#menu1 (accessed 20/04/2021)
[14] Source: https://www.ecoinvent.org/ (accessed 20/04/2021)

- / 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)

2.4 End-of-Life

Thirdly, 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 without metal recycling
- / Combination of Fe+Al+Cu metal recycling with incineration
- / Recycling without prior dismantling (of 5 main pieces of GEN24)
- / Recycling with prior dismantling (of 5 main pieces of GEN24)

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 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 in order to provide a concrete idea of what can be understood from an LCA model[15].

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

Table 1: Scenario description

Fronius Inverter	Location of Usage	Lifetime of the inverter	End-of-life strategy
Symo GEN24 10.0	Australia	20 years	Recycling without dismantling

First of all, it is meaningful in an LCA to bear in mind the limitations of the results: an inverter is only one part of the PV system. An overview at 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 performed by Fronius. Therefore, Figure 2 gives an overview at system level, keeping in mind that the proportions may vary slightly (by a few percent) based on the data or scenarios.

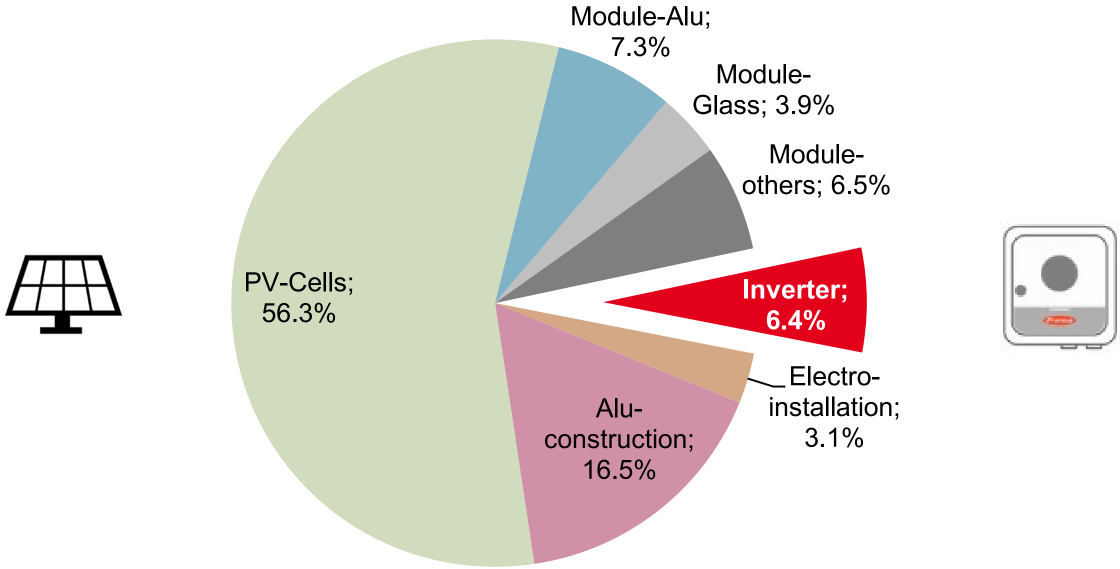


Figure 2: Relative contribution of the PV inverter (Australian scenario) and PV modules to the carbon footprint ("PV system perspective")

In the selected scenario, the inverter is responsible for 6.4% of the environmental impact of the total PV system (this can vary between 6-8% depending on the scenario). Thus, 6.4% of the environmental benefit of the total PV system is allocated to the inverter.

In the following graphs, the focus will be put 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-eq.

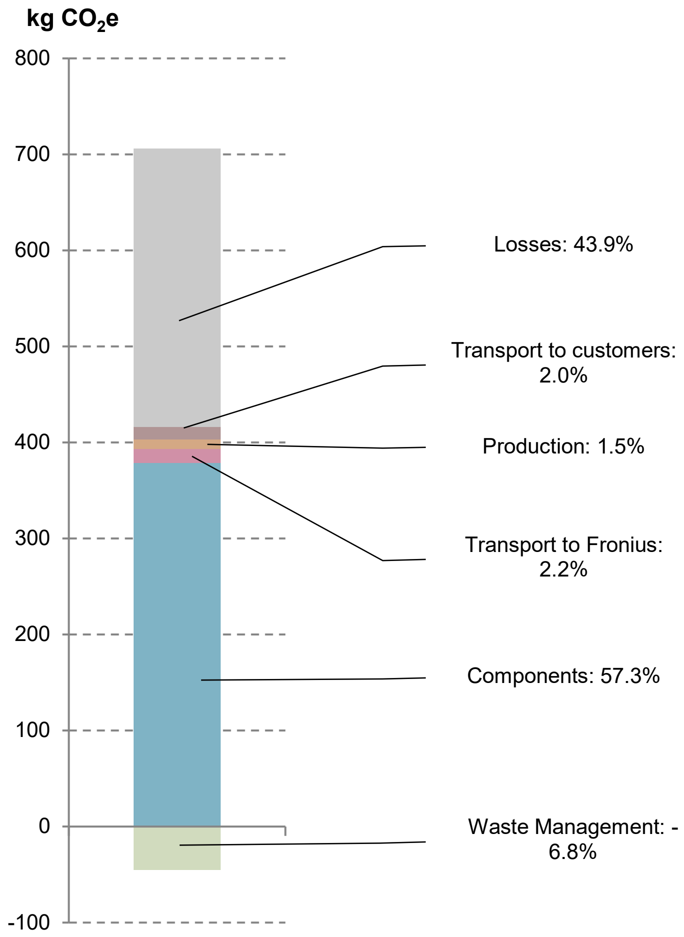


Figure 3: Carbon footprint of Symo GEN24 10.0 Plus in absolute values and in relative contributions by life cycle phases

From this graph, 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 to the 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. This proves that the assembly process is already optimized. Besides, the energy used at the production site comes from renewable energy sources (green electricity contract + local PV installation). With the PV systems at the production sites, Fronius produces almost 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.

- **The losses:** Each product has its own carbon footprint (that can be compared to a “CO_2 backpack” or “CO_2 debt”) coming from all background manufacturing processes, transport, and so on. As a consequence, electricity coming from a PV system also has a CO_2 backpack (with a value of around 20-80 g CO_2-eq/kWh) lower than the CO_2 backpack of the electricity from the grid (in the range of approx. 100-1200 g CO_2-eq/kWh, depending on the country). The GEN24 Plus is modelled with a 3% losses value, meaning that a certain amount of electricity from the PV modules, with its CO_2 backpack, is lost as heat. 3% is a relatively low value, 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 Plus (97%), this effect results in the losses (from the use phase) contributing significantly to the total carbon footprint result.
- **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 fewer energy needs. The responsible and conscious use of the earth’s resources is a core obligation of Fronius and increases environmental benefits.

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

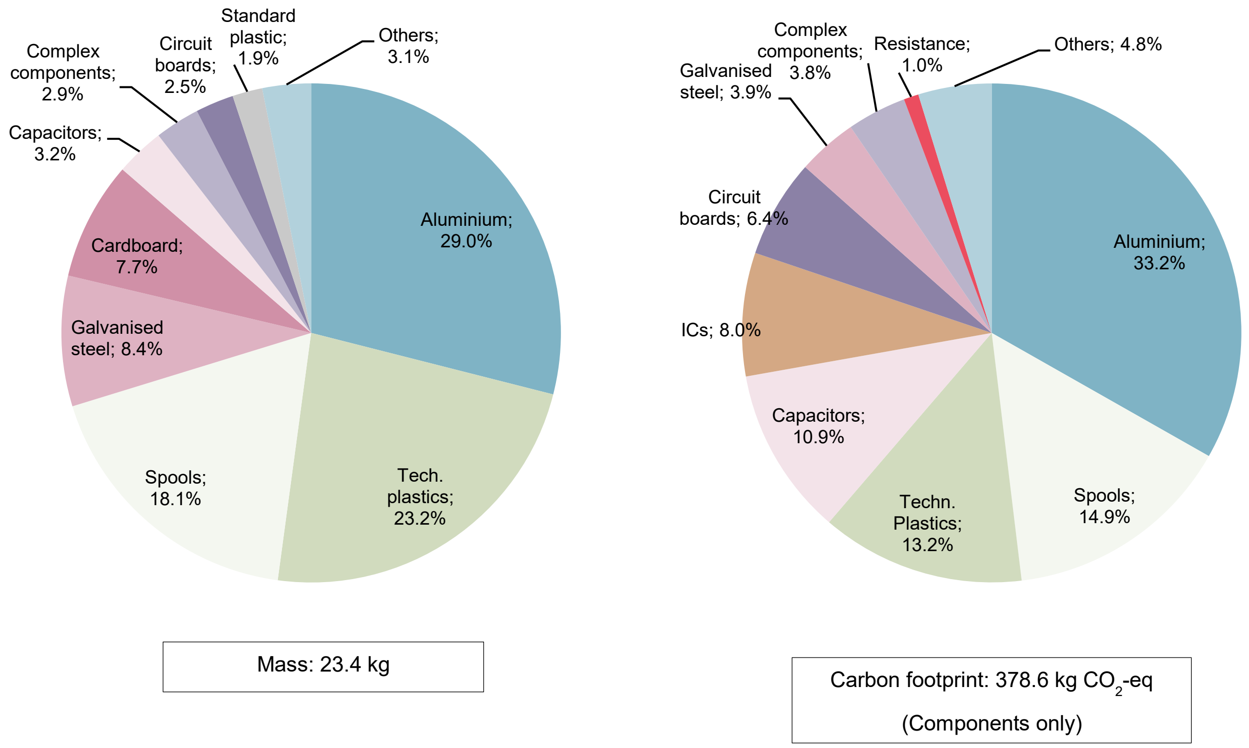


Figure 4: Relative contribution of the Symo GEN24 10.0 Plus components by **mass** (left, in % kg) and by the **carbon footprint** (right, in % kg CO_2-eq).

As can be seen in Figure 4, the aluminum, technical plastics, and spools represent the largest contributions to the mass and to the carbon footprint of the Symo GEN24 10.0 Plus. The capacitors are an interesting case as they represent only 3.2% of the mass but are responsible for 10.9% of the carbon footprint *(ICs even more so with a few grams of mass and lots of kilograms of CO_2-eq)*. 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, etc.). In comparison, technical plastics have a low carbon footprint in relation to their mass.

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

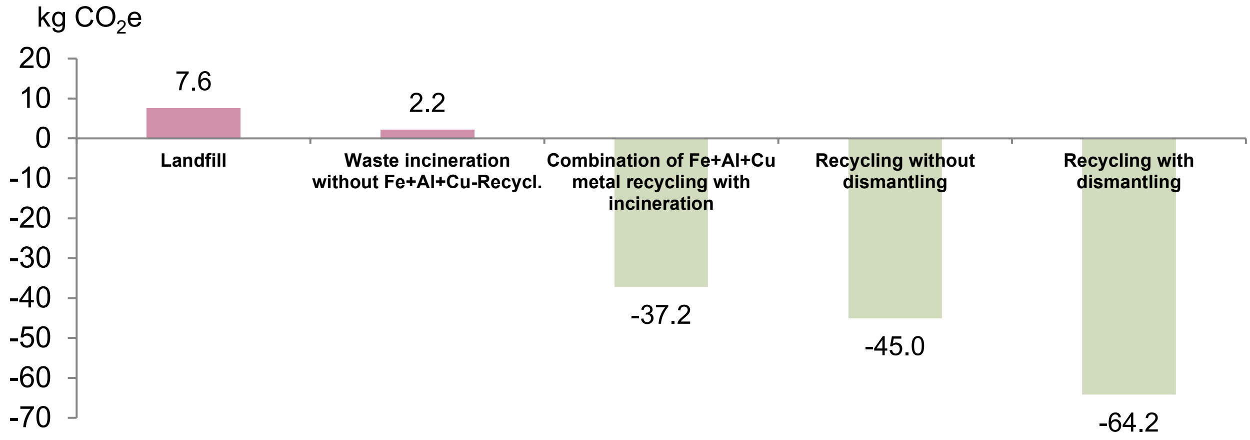


Figure 5: End-of-Life processes environmental costs or benefits for Symo GEN24 10.0 Plus

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. As a consequence, the carbon footprint of the inverter within its service life is even decreased by approx. 70 kg CO_2-eq (initially, the total carbon footprint of the inverter's production is worth approx. 660 kg CO_2-eq), due to an extended service life.

It should be noted that all previous graphs considered the Global Warming Potential impact category only. The same analysis can be conducted for other impact categories (human toxicity, metals resource depletion, particulate matter, etc.).

3.2 Benefits of the GEN24 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 induce an average carbon footprint of **38.0 g CO_2-eq/kWh**. In comparison, using electricity from the **Australian grid mix** would result in a carbon footprint in the range of **600-1000 g CO_2-eq/kWh** (approx. 15-25 times higher, due to coal use, among other things)[16].

In comparison, as a rough estimation, the CO_2 emissions saved by the whole PV system over 20 years (not only the inverter) are equivalent to approx. 600 planted trees[17]. Another rough comparison is possible with gasoline 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 Fronius Symo GEN24 Plus 10.0 in Australia for 20 years (benefit of the whole

[16] 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-2019-20

[17] 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/)

PV system, not just that allocated to the inverter) would save the CO_2 emissions equivalent of approx. 1,800,000 km travelled by car. For the same PV system use scenario, there would be a CO_2 emissions saving equivalent to approx. 100 roundtrip flights Vienna-New York[18]. 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).

Based on the LCA results, the **CO_2 payback time** (time needed for the CO_2 avoided emissions to offset the CO_2 emissions of the product) is in the range of **0.8-3.7 years**, depending on the scenario. For the scenario presented in Australia, the value is 0.8 years. After this payback time, a **GEN24 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 GEN24 Plus inverter is used for 20 years, the total amount of CO_2-eq emissions **avoided** can be up to **26 times higher** than the total amount of CO_2 emissions needed for the whole lifecycle of the device.

The **energy payback time** is within the range of **0.9-2.2 years** (for the present scenario: 0.9 years). 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 **energetic added value to the ecosystem**.

When a GEN24 inverter is used for 20 years, the total amount of **energy produced** can be up to **21 times higher** than the total amount of energy needed for the whole lifecycle of the device.

4 CONCLUSION: THE STEP BEYOND

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

4.1 Use and quality of the LCA

The GEN24 Plus LCA represents a significant step for sustainability activities at Fronius. Clear knowledge, based on scientific facts, has now 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 product family 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 can diverge significantly. There is not yet a uniform, internationally recognized LCA framework (especially when it comes to the methodology applied),

[18] Flight emissions calculations based on: https://co2.myclimate.org/en/flight_calculators/new

which enables potentially variable results. In this regard, there is a need for clear transparency and communication on the LCA modelling, the system definition, and the methodology applied. Despite the current difficulties faced in the LCA methodological world, Fronius strived to ensure the results were of the highest possible level of quality and validity. 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 action 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[19]. 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 modelling structure have been checked and a review report from Fraunhofer IZM is available on the Fronius website (Link).

Furthermore, Fronius is actively participating in discussions with European bodies and associations to promote a consistent and uniform LCA framework in Europe. In the 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 GEN24 Plus environmental performance, the LCA highlighted several opportunities to increase the sustainability performance of the device even further.

Based on these findings, specific requirements will be defined and tackled by product development processes and confirm the engagement of Fronius towards 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 Plus LCA process has rarely been applied before in an LCA and is unique in the world of PV inverters.

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