



# Fronius Tauro ECO – A Benefit for the Environment

Life Cycle Assessment (LCA)

DI Mag. Harald Pilz

**to4to**  
together for tomorrow

 **Fraunhofer**  
IZM

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Gender-specific wording refers equally to female and male forms.

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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<sup>1</sup> or the World Economic Forum<sup>2</sup>.

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, as 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 and continued in 2022 with the completion of a LCA for a commercial inverter: Tauro ECO 100 (variants “D” and “P”).

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<sup>1</sup> Intergovernmental Panel on Climate Change: <https://www.ipcc.ch/reports/> (accessed 04/19/2021)

<sup>2</sup> “The Global Risks Report” (2021): [http://www3.weforum.org/docs/WEF\\_The\\_Global\\_Risks\\_Report\\_2021.pdf](http://www3.weforum.org/docs/WEF_The_Global_Risks_Report_2021.pdf) (accessed 04/19/2021)

## 1.1 Objective

The objective of this paper is to present the concept of a Life Cycle Assessment, its application to the Tauro inverters, 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 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<sup>3</sup> ("Together for tomorrow"), adopted a "cradle-to-grave" approach in the LCA, taking into account all 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<sup>4</sup> 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 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:

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<sup>3</sup> To4to - <https://www.to4to.at/>

<sup>4</sup> 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 the 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”<sup>5</sup>). Furthermore, the European Commission is fighting sustainability claims that lack evidence and will also prepare consumers for the transition towards a green future<sup>6</sup>.
- 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<sup>7</sup>.
- Sustainability databases are being used more and more, where products that exhibit environmentally friendly performance are promoted above others. Upcyclea<sup>8</sup> in France or Byggvarubedomningen<sup>9</sup> 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”)<sup>10</sup>.

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<sup>5</sup> Source: [https://ec.europa.eu/environment/eusd/smgp/PEFCR\\_OEFSR\\_en.htm#final](https://ec.europa.eu/environment/eusd/smgp/PEFCR_OEFSR_en.htm#final) (accessed 04/12/2021)

<sup>6</sup> Source: [https://ec.europa.eu/commission/presscorner/detail/en/ip\\_21\\_269](https://ec.europa.eu/commission/presscorner/detail/en/ip_21_269) (accessed 03/08/2022)

<sup>7</sup> Source: <https://www.pv-magazine.com/2021/02/19/france-launches-700-mw-tender-for-large-scale-pv/> (accessed 04/19/2021)

<sup>8</sup> Source: <https://www.upcyclea.com/> (accessed 04/09/2021)

<sup>9</sup> Source: <https://byggvarubedomningen.se/> (accessed 04/09/2021)

<sup>10</sup> 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

It is so 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<sup>11</sup>, published in 2019, sets the ambitious goal for Europe to be climate-neutral by 2050.
- The Ecodesign and Energy Labelling schemes<sup>12</sup> that the European Commission wants to implement by 2023-2024: 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)<sup>13</sup> or the EU Taxonomy for EU Regulation 2020/852 (“Framework to facilitate sustainable investment”)<sup>14</sup>.

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<sup>11</sup> Source: <https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1576150542719&uri=COM%3A2019%3A640%3AFIN> (accessed 04/09/2021)

<sup>12</sup> For further information on the ongoing process: <https://susproc.jrc.ec.europa.eu/product-bureau//product-groups/462/documents> (accessed 04/09/2021)

<sup>13</sup> 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](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)

<sup>14</sup> 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 an 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 fo the Tauro ECO 100

To support the vision “24 hours of Sun”, the Fronius Tauro product 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

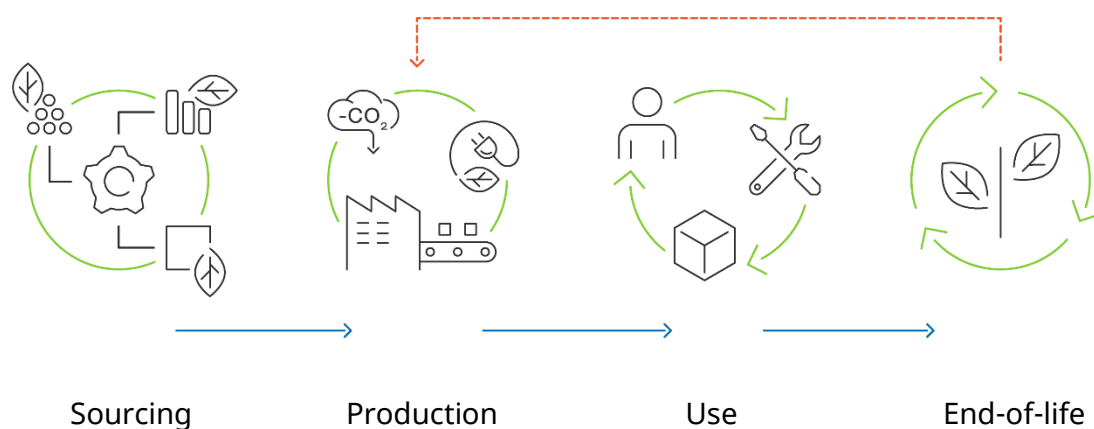


Figure 1: The Tauro ECO 100 and its different life cycle phases

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

- The Global Warming Potential (GWP), which models the greenhouse gases warming effect stemming from the product, throughout its lifetime (in kg CO<sub>2</sub> equivalent). “CO<sub>2</sub>-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<sub>2</sub> on the GWP. For example, the emission of 1 kg of methane (CH<sub>4</sub>) is equivalent to 27.9 kg of CO<sub>2</sub> (based on the methodology from the IPCC, Intergovernmental Panel on Climate Change<sup>16</sup>).
- 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<sub>2</sub> 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<sup>17</sup>), one of the world’s most complete and common LCI (Life Cycle Inventory) databases.

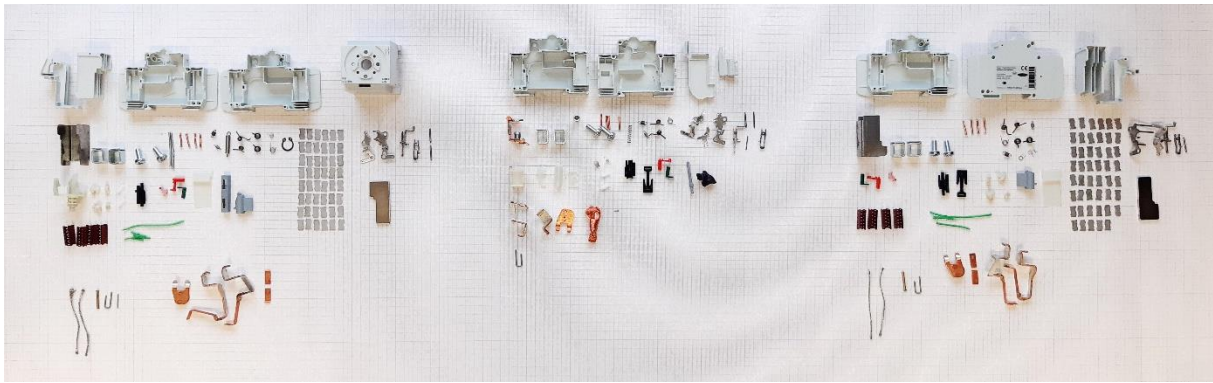
## 2.2 Sourcing

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 semi-conductors and the use of gold in electronics and cables, DC-disconnector, fuses, fans and others were dismantled for this purpose. (see Picture 1 below).

<sup>15</sup> Source: <https://eplca.jrc.ec.europa.eu/LCDN/developerEF.xhtml> (accessed 03/01/2022)

<sup>16</sup> Source: [https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC\\_AR6\\_WGI\\_Full\\_Report.pdf](https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Full_Report.pdf) (table 7.SM.7, p.1842, accessed 03/15/2022)

<sup>17</sup> Source: <https://www.ecoinvent.org/> (accessed 02/16/2022)



Picture 1: Detailed dismantling of a DC-disconnector from Tauro ECO, for further LCA modelling

## 2.3 Production

The production phase considers the production of Tauro ECO 100 at the Fronius production sites. The production of the Tauro ECO 100 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. When needed, several data sets were extracted from the ecoinvent database to complete the modelling. Overall, LCA models have been developed for the following device types:

- Tauro ECO 100 – D variant (“Direct”), enabling a decentralized design of the PV-system
- Tauro ECO 100 – P variant (“Precombined”), enabling a centralized design of the PV-system

## 2.4 Use Phase

Secondly, the use phase considers the time the Tauro ECO 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 Tauro ECO LCA, there are seven country options: Australia, Austria, Brazil, Germany, Poland, Spain and Italy.
- 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)<sup>18</sup>. PVSol, in comparison to some standardized EU-benchmarks, provides more realistic

<sup>18</sup> Source: <https://valentin-software.com/produkte/pvsol-premium/> (accessed 02/16/2022)

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 (15 W)
- Repair processes have also been modeled with the following scenarios:
  - Exchanging the power unit
  - Exchanging the power unit's external fan
  - Exchanging the data communication unit
  - Exchanging the control board

All exchanges can take place on-site by the installer and the defective element is either sent to waste treatments or sent back to Fronius locations for repair

## 2.5 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
- Metal recycling with downstream waste incineration
- Recycling without prior dismantling (of the main pieces of Tauro ECO-100<sup>19</sup>)
- Recycling with prior dismantling (of the main pieces of Tauro ECO-100)

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).

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<sup>19</sup> The main pieces are: 5 aluminium components (heat-sink + 4 metal sheets), 3 galvanised sheets, 3 cable assemblies, 5 power stacks + data communication unit + control board

### 3 LCA: The Environmental Performance of the Tauro ECO 100

Now that all the relevant data has been collected, the next sections describe the environmental performance and the LCA results for the Tauro ECO 100 in more detail. More specifically, the carbon footprint will be detailed, and the benefits of the Tauro ECO 100 will be described.

#### 3.1 The Carbon Footprint of the Tauro ECO 100

Naturally, an inverter, as opposed to a tree for example, cannot extract CO<sub>2</sub> (or other harmful pollutants) from the atmosphere. Nevertheless, an inverter connected in a PV system enables much fewer CO<sub>2</sub> 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<sub>2</sub> 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 a LCA model<sup>20</sup>.

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
<ul style="list-style-type: none"> <li>- Tauro 100-P</li> <li>- <b>Tauro 100-D</b></li> </ul>	<ul style="list-style-type: none"> <li>- Austria</li> <li>- Germany</li> <li>- Poland</li> <li>- Brazil</li> <li>- <b>Australia</b></li> <li>- Spain</li> <li>- Italy</li> </ul>	<ul style="list-style-type: none"> <li>- Landfill</li> <li>- Waste incineration</li> <li>- <b>Metal recycling with downstream waste incineration</b></li> <li>- Recycling without dismantling</li> <li>- Recycling with dismantling</li> </ul>	<ul style="list-style-type: none"> <li>- Life expectancy: <b>20 years</b></li> <li>- <b>Averaged repair process</b></li> <li>- <b>Electricity mix for night consumption</b></li> </ul>

In addition, PV-systems of commercial scales are usually “over-sized” between the PV-modules capacities and the PV-inverter power range. In this scenario, based on Fronius experience, a standard oversizing ratio is chosen at 130%, i.e., a Tauro ECO 100 kW connected to a PV-plant of 130 kWp.

<sup>20</sup> 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.

## A "PV-System" Perspective

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 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.).

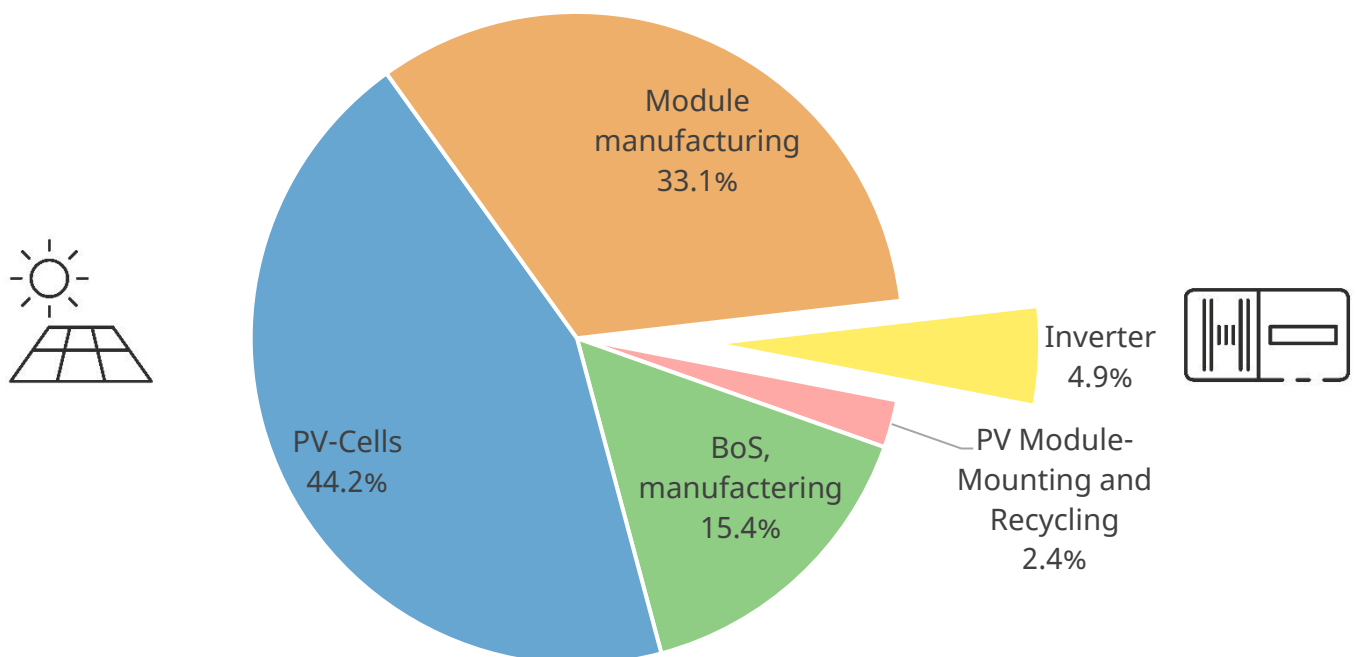


Figure 2: Relative contribution of the PV inverter (Australian scenario) on the PV-system carbon footprint ("PV system perspective")

In the selected scenario, the inverter is responsible for 4.9% of the environmental impact of the total PV system (this can vary between 3.5 and 5.3% depending on the scenario). Thus, 4.9% of the environmental benefit of the total PV system is allocated to the inverter.

## The Carbon Footprint of the Tauro ECO 100-D Lifecycle Phases

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<sub>2</sub>-equivalent (kg CO<sub>2</sub>e).

### Carbon footprint (kg CO<sub>2</sub>e)

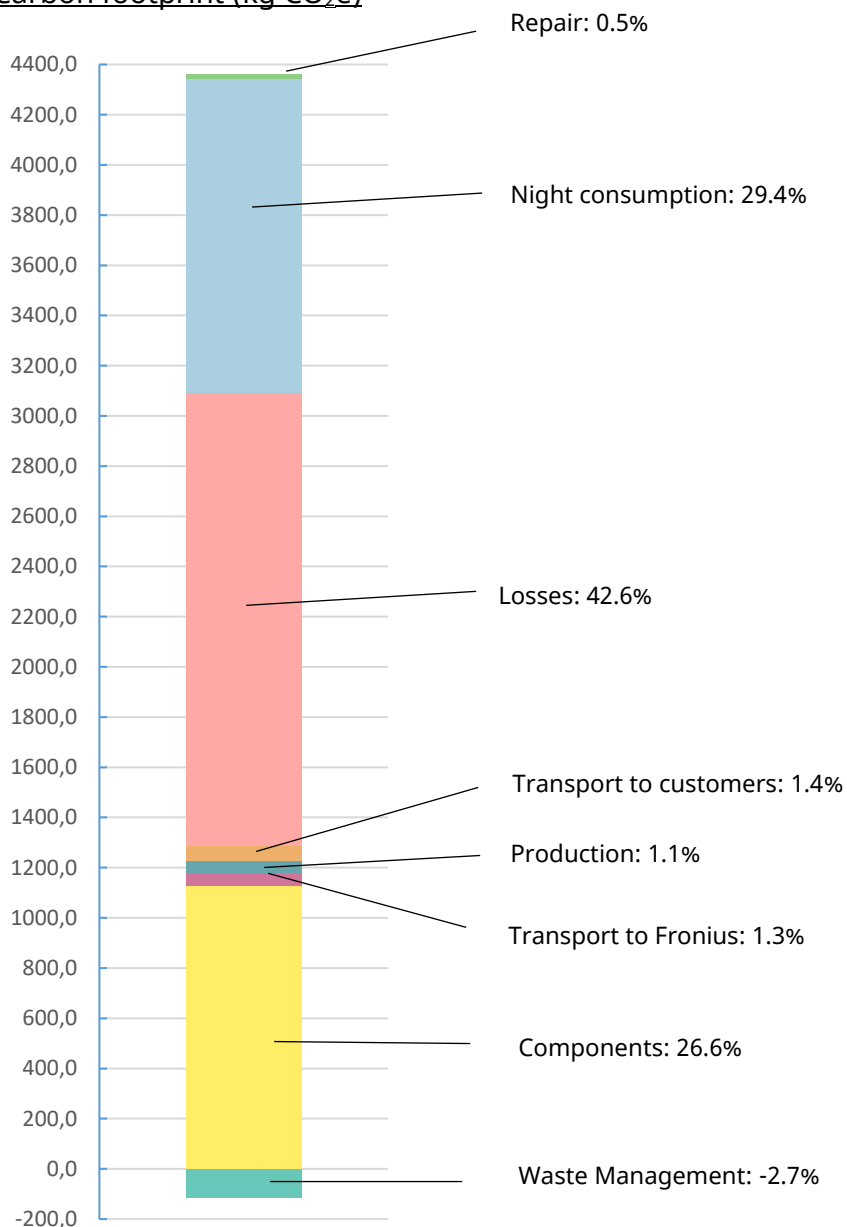


Figure 3: Carbon footprint of Tauro ECO 100-D in absolute values and in relative contributions by life cycle phases. The figure stresses the importance of the sourcing phase and use phase.

As seen in Figure 3, the total carbon footprint of Tauro ECO 100-D is 4247.8 kg CO<sub>2</sub>e (4362.7 kg CO<sub>2</sub>e with an environmental “credit” of -114.9 kg CO<sub>2</sub>e 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 (more than 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, 70% of the heat sink being made of recycled aluminum .
- The production phase: The assembly of the inverter at the Fronius production site represents only a limited proportion of the carbon footprint (1.1% in this scenario). This proves that the assembly process is already optimized. In addition, 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 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 relatively small carbon footprint (less than 3% combined).
- The losses: each product has its own carbon footprint (that can be compared to a “CO<sub>2</sub>backpack” or “CO<sub>2</sub> 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<sub>2</sub> backpack (with a value of around 15-80 g CO<sub>2</sub>e/kWh) which is lower than the CO<sub>2</sub> backpack of the electricity from the grid (in the range of approx. 100-1200 g CO<sub>2</sub>e/kWh, depending on the country). The Tauro ECO-100 is modeled with a losses value defined by the software PVSol, taking into account the country’s solar radiation levels and the oversizing of the PV-system. In the Australian scenario, the inverter losses value is set at 2.19%, meaning that a certain amount of electricity from the PV modules, with its CO<sub>2</sub>backpack, is lost as heat. 2.19% is a relatively low value (the range is 2.12 – 2.48%, 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 Tauro ECO-100 (97.81%, based on PVSol modeling), this effect results in the losses (from the use phase) making it the largest contributor to the total carbon footprint result (42.6%).

- 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 significant (1249.5 kg CO<sub>2</sub>e, larger than the carbon footprint of all Tauro components and production and equivalent to 29.4% of the global carbon footprint of the inverter). However, if the electricity for the night consumption is taken from a renewable electricity supplier, the related carbon footprint of the night consumption would be much smaller (an order of magnitude of about 56 kg CO<sub>2</sub>e, leading to a share of ca. 1.8%). 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.
- Repair: Different repair scenarios were modeled (see section 2.4) and an average value of repair possibilities is considered here. The positive environmental impact of a repair process, even though it is negligible (0.5% in this scenario) is mostly dominated by the need for transport and the production of the component to be replaced. Based on the type of repair needed, the range of the additional carbon footprint for repair equates to: 5.91 – 167.7 kg CO<sub>2</sub>e. Nevertheless, repair options avoid the “worst-scenario” where the full inverter is replaced, which would massively increase the carbon footprint due to the inverter’s production phase, transport, etc. In comparison, repair does bring some carbon footprint benefit even after 17 years of use (an inverter is built to have a standard lifetime of 20 years). As a concrete example, if the data communication unit is replaced after 10 years, the carbon footprint related to the repair process would be 26.4 kg CO<sub>2</sub>e. The alternative (replacing the whole inverter) would bring an extra carbon footprint of 1189.9 kg CO<sub>2</sub>e (due to components, production, transport and waste management), an impact that would be 45 times larger. Therefore, repair brings significant environmental benefits.
- 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 to the Carbon Footprint of each component of the Tauro ECO 100-D inverter itself, as shown in the figures below:

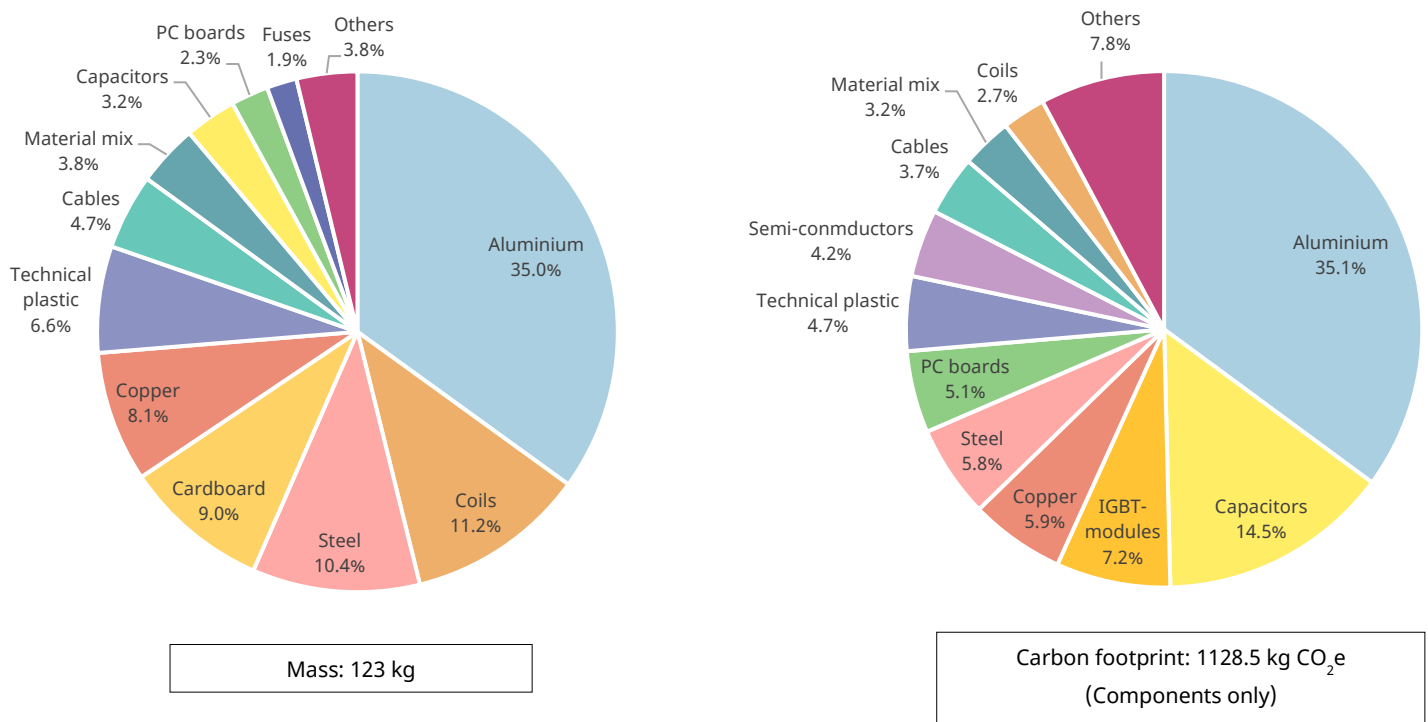


Figure 4: **Relative contribution of the Tauro ECO 100-D components by mass (left, in % kg) and by the carbon footprint (right, in % kg CO<sub>2</sub>e).** The figure shows that some elements with a relatively small weight contribution may have a significant carbon footprint share.

As can be seen in Figure 4, the aluminum represents the largest contribution to the mass and to the carbon footprint of the Tauro ECO 100-D. The capacitors are an interesting case as they represent only 3.2% of the mass but are responsible for 14.5% of the carbon footprint (IGBT-modules even more with 0.2% of mass but 7.2% 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, coils have a low carbon footprint (2.7%) in relation to their mass (11.2%).

## End-of-life Management

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.

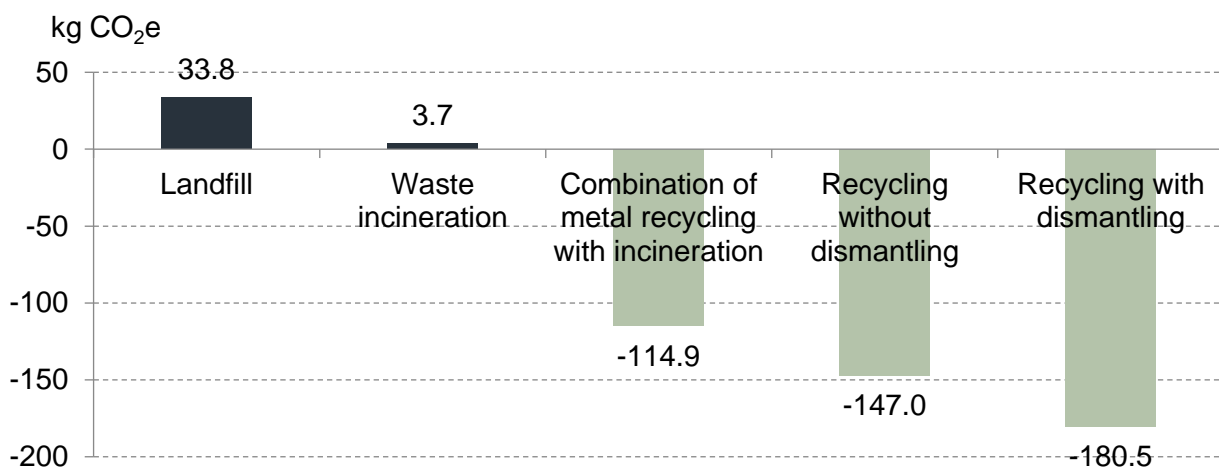


Figure 5: **Environmental End-of-Life costs or benefits for Tauro ECO 100-D.** The landfill option brings additional emissions. The environmental benefit increases with metal recycling and is optimal with dismantling.

## 3.2 Benefits of the Tauro ECO 100-D

Now that the overview of the Tauro ECO 100-D carbon footprint has been provided, the benefits of the device will be described.

Using electricity from a PV system with a Tauro ECO 100-D in Australia would result in an average carbon footprint of **18.1 g CO<sub>2</sub>e/kWh**. In comparison, using electricity from the **Australian grid mix** would result in a carbon footprint in the range of **600 - 950 g CO<sub>2</sub>e/kWh** (approx. 33-56 times higher, due to coal use, among other things)<sup>21</sup>.

<sup>21</sup> 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>

In comparison, as a rough estimation, the CO<sub>2</sub> emissions saved by the whole PV system over 20 years (not only the inverter) are equivalent to approx. 10,323 trees planted<sup>22</sup>. 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 Tauro ECO 100-D in Australia for 20 years (benefit of the whole PV system, not just that allocated to the inverter) would save CO<sub>2</sub> emissions equivalent of approx. to **30,791,513 km** travelled by car. For the same PV system use scenario, there would be CO<sub>2</sub> emissions saving equivalent to approx. **2018 roundtrip flights from Vienna to New York**<sup>23</sup>.

Based on the LCA results, the **CO<sub>2</sub> payback time** (time needed for the CO<sub>2</sub> emissions avoided to offset the product's CO<sub>2</sub> emissions) in the range of **0.4 - 1.9 years**, depending on the scenario. For the scenario presented in Australia, the value is 0.4 years. After this payback time, a **Tauro ECO 100 owner is saving CO<sub>2</sub> emissions, compared to the alternative with power from the grid**, and thus generates a positive impact for the environment. When a Tauro ECO 100 inverter is used for 20 years, the total amount of CO<sub>2</sub>e **emissions avoided** can be up to **52.9 times higher** than the total amount of CO<sub>2</sub> emissions needed for the whole lifecycle of the device.

The **energy payback time** is within the range of **0.3 - 0.8 years** (0.34 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**.

When a Tauro ECO 100 inverter is used for 20 years, the total amount of **energy produced** can be up to **62.7 times higher** than the total amount of energy needed for the whole lifecycle of the device.

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<sup>22</sup> 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/>)

<sup>23</sup> Flight emissions calculations based on: [https://co2.myclimate.org/en/flight\\_calculators/new](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).

## 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' sustainability pathway.

### 4.1 Use and Quality of the LCA

The Tauro ECO 100 LCA represents a significant new step for sustainability activities at Fronius, following the successful completion of the LCA for the GEN24 Plus in 2020<sup>24</sup>. 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 Tauro ECO 100 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<sup>25</sup>. 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

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<sup>24</sup> LCA Gen 24 Plus White paper: [https://www.fronius.com/~/downloads/Solar%20Energy/Whitepaper/SE\\_WP\\_LCA\\_GEN24\\_Plus\\_EN.pdf](https://www.fronius.com/~/downloads/Solar%20Energy/Whitepaper/SE_WP_LCA_GEN24_Plus_EN.pdf)

<sup>25</sup> Example of a LCA for mobile phones: [https://www.fairphone.com/wp-content/uploads/2020/07/Fairphone\\_3\\_LCA.pdf](https://www.fairphone.com/wp-content/uploads/2020/07/Fairphone_3_LCA.pdf)

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 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 Tauro ECO 100, 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 Tauro ECO 100 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 Tauro ECO 100 LCA process, which had already begun with the LCA for GEN24 Plus, has rarely been applied before in an LCA and is unique in the world of PV inverters.