Sunny Highpower PEAK3

Life cycle assessment (LCA)

Contents

1. Preface

The ever more dramatic progress of the global climate crisis, environmental destruction, species extinction and scarcity of raw materials due to a linear economic system practiced for centuries present humanity with unprecedented challenges. In light of all these factors, the circular economy is becoming the subject of increasing attention from politicians, business, consumers and the general public. With its Circular Economy Action Plan (CEAP) as one of the basic building blocks of the European Green Deal, the European Union is setting the course for a "green" transformation of the economy, the creation of material cycles and greater transparency along the entire value chain.

These objectives need to be a top priority for manufacturers of technologies for renewable energies as well. The rapid and intensified expansion in global generation capacity for renewable energies is a pivotal factor in the fight against the global climate crisis and in preventing environmental degradation caused by the extraction of fossil fuels. At the same time, however, that urgently needed increase in capacity inevitably is associated with a high expenditure of natural resources. For a sustainable transformation of the world's energy supply structures, it is therefore elementary to design the necessary technologies as sustainably and efficiently as possible over their entire life cycle in line with the principles of the circular economy.

There is a deep understanding of this firmly established within the SMA Group. With approximately 3,500 employees in 20 countries, we have been playing a major part in the transition to a climate-friendly electricity supply based on renewable energies worldwide for more than 40 years. Our products and solutions are used all over the world for sustainable and efficient power generation, storage and use. In off-grid areas that do not yet have their own utility grids, SMA stand-alone solutions provide a reliable electricity supply, paving the way to economic and social development. As such, the SMA Group's business activities directly contribute to UN Sustainable Development Goal 7, "Affordable and clean energy," and play an active part in combating the global climate crisis.

The objective of integrated sustainability with the aspiration of practicing sustainability in all areas of the company and taking a leading role in shaping a better future is at the heart of our corporate strategy. To us, sustainable business means responsible and respectful treatment of people, the environment and resources while making greater use of decentralized renewable energy sources in the supply of electricity across all areas of the value chain.

It is important to us to know what impact our products have on the environment so that we can identify action to be taken on this basis and improve product sustainability. Life cycle assessments (LCAs) help us identify the factors that influence the sustainability performance of our products throughout the product life cycle. To deliver greater transparency and objectivity for our customers as well, we have, for the first time, had external experts from the Fraunhofer Institute for Building Physics (IBP) prepare an LCA for our Sunny Highpower PEAK3 string inverter. This LCA has also been independently certified.

In this white paper, we summarize the procedure for compiling the LCA and present the key findings and outcomes, focusing on the environmental footprint (EF3.0 impact category: Climate Change) of the Sunny Highpower PEAK3.

2. What is an LCA and what are its benefits?

A life cycle assessment is an established scientific method of quantifying the environmental impact of processes, products and services. ISO 14040 and ISO 14044 standardize the methodology for the LCA, ensuring a consistent approach and the transparency needed to deliver a comprehensive representation of the sustainability performance of the product assessed. An LCA study takes place in four main stages:

1. Definition of objective and scope
2. Life cycle inventory analysis (LCI)
3. Life cycle impact assessment (LCIA)
4. Evaluation and interpretation of the results

The definition of the objective establishes the general purpose of the LCA study, which must be reflected in the scope of the study. In accordance with this framework, the LCI is used to gather a comprehensive set of data regarding inputs and outputs of material and energy throughout the process chain. In the LCIA, these inputs and outputs are classified according to their contributions to various environmental impact categories, arranged in order of composition expressed as percentages and added together to determine potential impact on the basis of characterization factors according to their actual impact. Based on this, the results of an LCA provide in-depth information on the environmental impacts throughout the life cycle of the assessed product, identify hotspots and potential benefits and risks, and enable the derivation of measures for further improving the sustainability performance of the product line under investigation.

3. Objective and scope of the summarized LCA

The objective of the LCA summarized here is to identify and assess all types of environmental impact that could potentially occur throughout the life cycle of a Sunny Highpower PEAK3 string inverter. To allow informed decisions aimed at improving the sustainability performance of future product generations to be made, the analysis should be used as a basis for identifying hotspots and relevant parameters in the life cycle of the inverter.

The Sunny Highpower PEAK3 is representative of the SMA range of string inverters across a power output spectrum ranging from 150 kW to 225 kW of nominal power. It is designed for use in decentralized photovoltaic power plants with a system voltage of 1,500 V DC and has a high power density owing to its compact design. The European weighted efficiency of the Sunny Highpower PEAK3 is 98.8 percent. Provided the system is installed and operated correctly, we can give proof of a lifetime of 25 years for the inverter on the basis of extensive age simulations. A shorter service life of 20 years, typical for PV power plants, was assumed for this LCA.

Independent certification

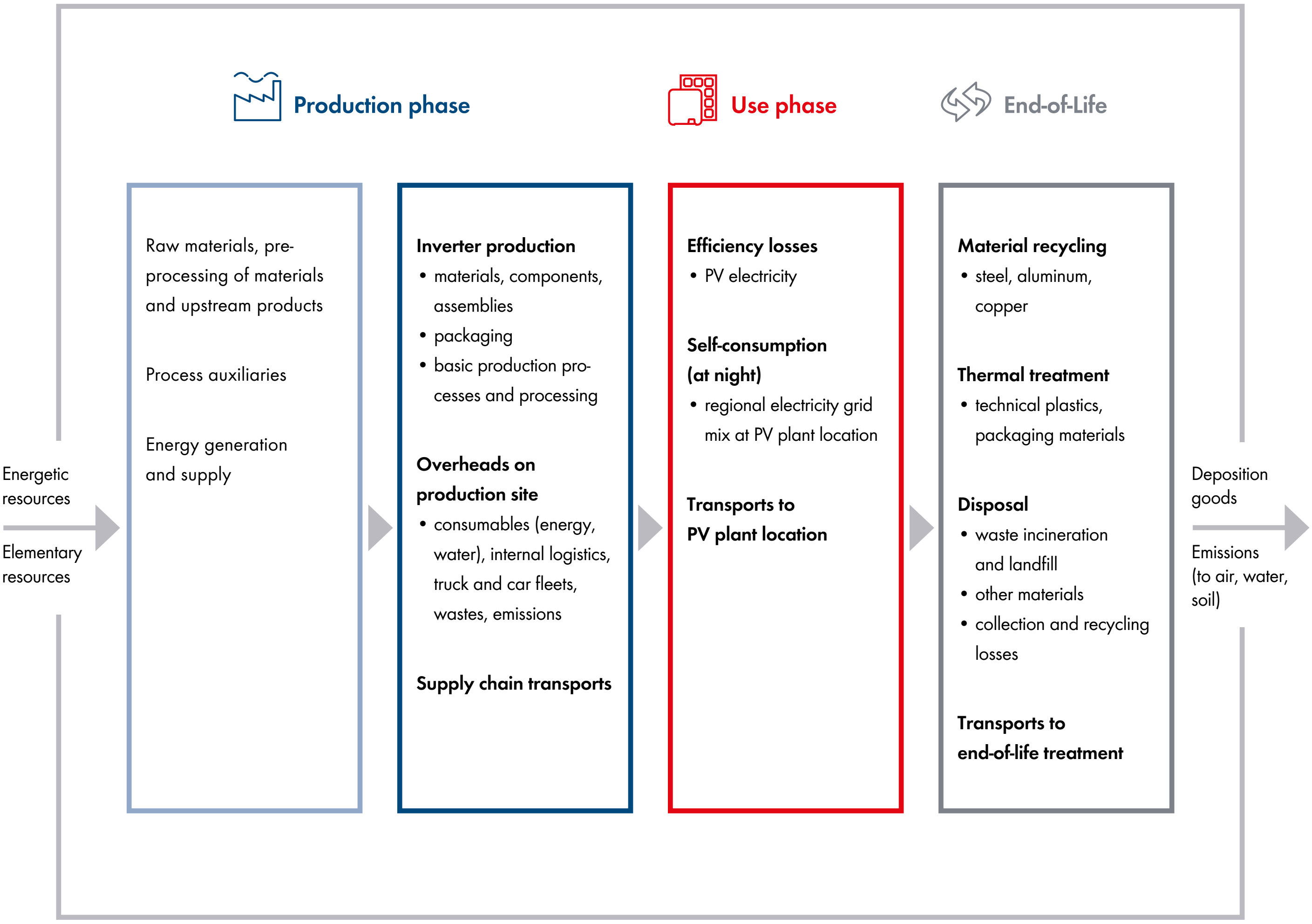
The LCA summarized in this white paper has been independently reviewed and certified by DEKRA Assurance GmbH. In addition to the LCA having been drawn up in conformity with the requirements of ISO 14040 and ISO 14044, DEKRA confirms an overall professional approach in accordance with the current state of the art as well as a considerable amount of detail. The underlying data, the life cycle model as well as the assumptions and calculations are also classed as appropriate and valid and, in the reviewer's opinion, they result in plausible outcomes as well as relevant conclusions and recommendations.

4. Life cycle inventory analysis

4.1 Life cycle phases analyzed

The collection of data for the analysis of the environmental impact of the Sunny Highpower PEAK3 encompasses the entire life cycle (cradle to grave) of the inverter, incorporating the three life cycle phases of production, use and end of life. In addition to the direct manufacturing of the inverter itself, the production phase includes upstream processes such as the extraction of raw materials and the treatment and production of materials, upstream products and purchased components. In the use phase, the focus was on efficiency losses and the power consumption of the inverter in standby mode overnight. The end-of-life phase involved analyzing the recycling, recovery and disposal processes. The relevant means of transportation in the various life cycle phases were also included in the analysis.

System boundaries of the LCA study



4.2 Data quality

To ensure the most exhaustive data recording possible as well as a very high level of data quality and transparency throughout the entire life cycle of the inverter, SMA provided data concerning product configuration, the materials used, production and the use phase. This included a detailed bill of materials (BOM) as well as further information regarding the components and materials used, information about suppliers, detailed documentation for the entire SMA inverter production process and simulated operation profiles for the use cases analyzed, with high-resolution data on the key technical parameters at the various operating points on a minute-by-minute basis.

Additional information was gathered in interviews with SMA experts from the product development, supply chain management, material compliance, purchasing and sustainability teams. The data was reviewed by the experts from the Fraunhofer IBP and checked to ensure that it was credible.

Wherever primary data was not available regarding background processes (the production of supplier materials and electronic components, processing aids and the provision of energy in the upstream process chain), the acclaimed LCA for Experts (GaBi) product sustainability software was used and supplemented by LCI models from the Fraunhofer IBP. With more than 15,000 region- and country-specific records, the GaBi databases are among the biggest consistent databases on the market. All records are created in accordance with ISO 14044 and updated annually. An additional database with more than 250 records is available for life cycle assessments on electronic products, allowing the most precise possible mapping of electronic assemblies. Good or very good correlation with the LCA database was achieved for more than 95 percent of the components used by SMA (based on mass and carbon footprint), with estimates required only in a very small number of cases. Accordingly, DEKRA attested that the LCA exhibited excellent data quality.

4.2.1 Production phase

The entire process of creating an inverter was analyzed for the production phase, from the acquisition of raw materials to delivery to the customer. The basis for modeling the production phase was the bill of materials for the Sunny Highpower PEAK3. This provides detailed information about the product tree structure, the materials used and the types of mechanical and electronic components and assemblies. Additional primary data was taken from sources such as bills of materials from choke suppliers and database extracts regarding the product design of the printed circuit boards used, technical datasheets for the mechanical and electromechanical components used, as well as from the SiliconExpert compliance tool. This allowed the complete mass balance of the inverter to be mapped in the inventory data. This approach also kept the detailed product tree structure as represented in the BOM.

The impact of transportation was calculated on the basis of the total mass of the components in question that had been delivered from the countries where the various suppliers were located to the SMA inverter production facility at its headquarters in Niestetal, near Kassel, Germany.

To calculate the general use of resources at the production facility, the aggregated data regarding energy usage, water usage, fleet fuel consumption and waste for the entirety of SMA inverter production at the Niestetal headquarters was broken down into one inverter unit (nominal power: 150 kW).

4.2.2 Use phase

Since the use phase covers a long period, it is a significant factor in the environmental impact of an inverter. The Sunny Highpower PEAK3 is designed to be operated in PV power plants with decentralized architectures. The environmental impact during the use phase heavily depends on the useful life and specific boundary conditions of the individual installation – for example, the geographic location of the PV power plant and the specific boundary conditions there; the plant design; the PV modules and other plant components used; and the regional fuel mix of the grid electricity used to provide reactive power overnight.

Various utilization scenarios were therefore considered in modeling the use phase. These were based on data from PV systems in operation at the time of the preparation of the study, in boundary conditions typical of those expected in the use of the Sunny Highpower PEAK3. The systems were situated in the following locations in the main target markets for the inverter:

- Tucson, U.S.
- Denver, U.S.
- San Francisco, U.S.
- Seville, Spain
- Kassel, Germany

The use cases in question considered the fact that a Sunny Highpower PEAK3 inverter with a nominal power of 150 kW can be connected to a PV array with a power of 225 kW (oversizing of 150 percent). This is common practice for optimizing the use of the inverter's capacity.

For the calculation of the environmental impact during the use phase, the losses during the conversion of the direct current generated in the solar modules into alternating current by the inverter as well as the electricity drawn from the grid at night in the standby mode of the inverter are the most significant factors. For modeling the use phase, the applicable regional electricity generation processes from photovoltaics were therefore used to calculate the potential environmental impact of efficiency losses, and the respective regional and national fuel mixes were used for the electricity consumption from the utility grid overnight based on the relevant GaBi records. Transportation from the production facility in Niestetal to the inverter installation sites were also incorporated into the analysis of the use phase. Maintenance and repair, however, were not included.

4.2.3 End-of-life-phase

The analysis of the potential environmental impact at the end of an inverter's life cycle was based on a generic LCA model used to map the material-specific recycling, recovery and disposal processes. This involved classifying the materials installed in the inverter according to the extent to which they can be recovered. The material-specific recycling, recovery and disposal processes were mapped using the available records from the GaBi databases, since no primary data was available in this case. Based on this model, a simplified analysis was conducted on the various end-of-life treatment options, including recycling, incineration with energy recovery, disposal and landfill.

A recycling rate of 95 percent was assumed for steel, iron, aluminum, copper and copper alloys. The remaining 5 percent of loss was treated as materials disposed of to landfill. Incineration with energy recovery was assumed for plastics, organic materials, populated printed circuit boards and electronic assemblies.

An average distance of 300 km by truck between the location of the PV system where the inverter was used and the location of recovery/disposal was assumed for the purpose of calculating the impact of transportation in the end-of-life phase.

5. Life cycle impact assessment – Impact along the life cycle

5.1 Environmental impact categories analyzed

Working from the baseline data described, the environmental impact of the Sunny Highpower PEAK3 was analyzed on the basis of the 16 recommended environmental impact categories of the European Environmental Footprint (EF3.0). This very wide-ranging set of impact assessment methods covers the analysis of potential environmental impact in the following categories: climate change, acidification, eutrophication, ozone depletion, ozone formation, water use, land use, resource use, toxicity, ionizing radiation and particulate matter.

The goal of EF3.0 is to provide a harmonized methodology and a range of environmental impact categories allowing for comparable calculation of the environmental footprints of systems and products in the most effective way possible. The environmental impact categories of the EF3.0 method set will take on greater importance in future European LCA activities and requirements (e.g., PEF, OEF etc.). This will also improve the comparability (which is currently still very limited) of the results of LCA studies concerning the environmental impact of products and systems.

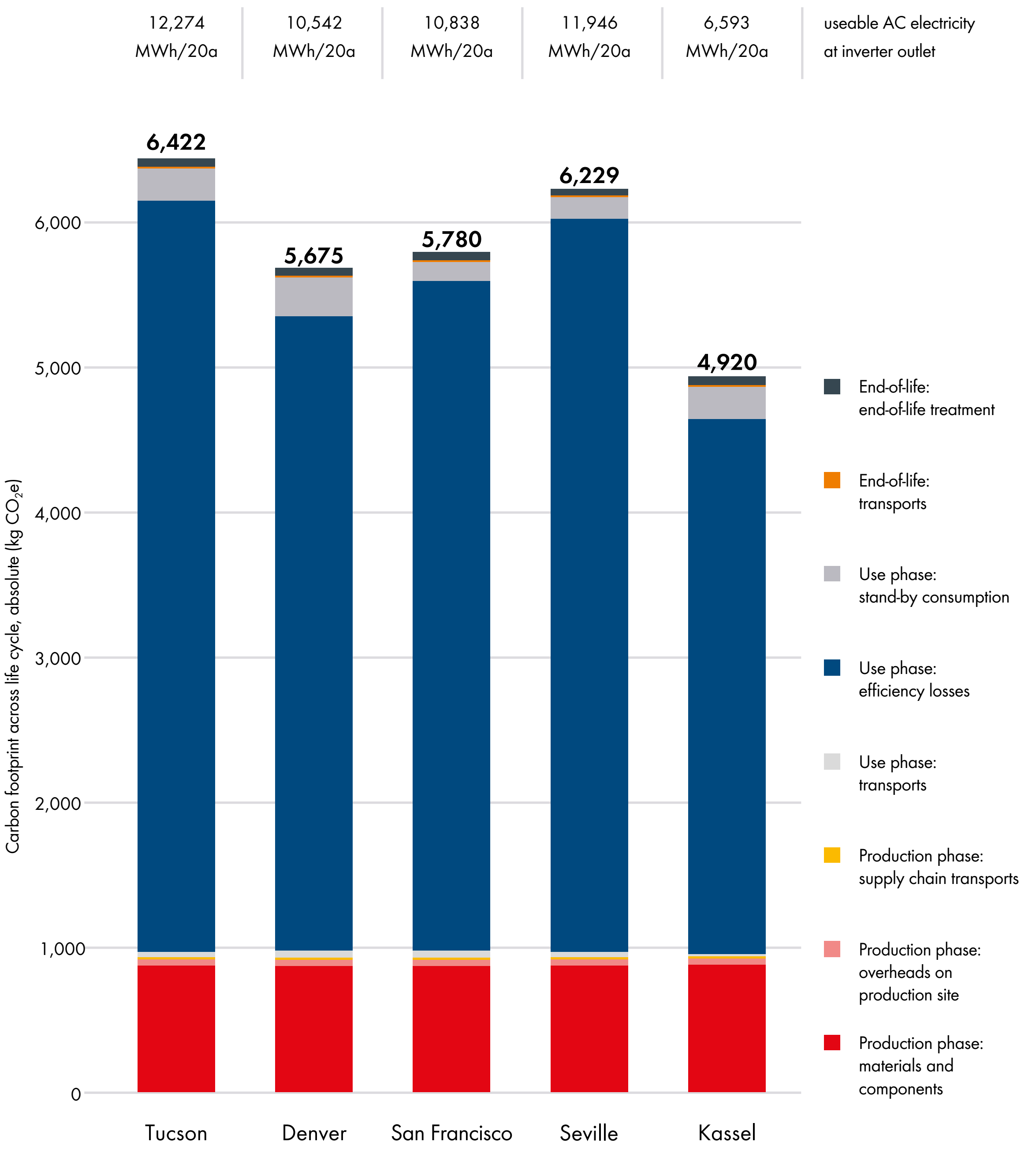
The LCA results for the Sunny Highpower PEAK3 as presented below focus on the "climate change" impact category. This involved analyzing the greenhouse gas emissions caused by an inverter across its entire product life cycle. The figures are presented in kilograms of CO_2 equivalent (kg CO_2e).

5.2 Results in the "climate change" environmental impact category

The results of the life cycle impact assessment show that the inverter's use phase, covering a service life of 20 years, accounts for by far the biggest share of the total environmental impact in all use cases investigated and in almost all impact categories. This is due primarily to the efficiency loss that occurs over this lengthy period despite the fact that at 98.8 percent, the inverter has a very high European weighted efficiency.

Analyzing the environmental impact of the Sunny Highpower PEAK3 in the "climate change" impact category yields greenhouse gas emissions figures ranging from 4,920 kg CO_2e (Kassel use case) to 6,420 kg CO_2e (Tucson use case) across the entire life cycle of an inverter. Differences between the different use cases can be attributed to the considerable variance in the boundary conditions of the use cases analyzed, some of which balance each other out to some extent. For example, CO_2e emissions in the Kassel use case at first glance stand out as lower and thus better, but they are to be attributed to the significantly lower energy yields at that site. Accordingly, conversion loss over the 20-year use phase is much lower than it is in Tucson. The chart below illustrates how much the various boundary conditions in the use phase influence the carbon footprint of the inverter.

Carbon footprint of the Sunny Highpower PEAK3



◦ CO_2e emissions of a Sunny Highpower PEAK3 across its entire life cycle in the five use cases analyzed (Sunny Highpower PEAK3 in 225 kW PV system, not including end-of-life credits, absolute).

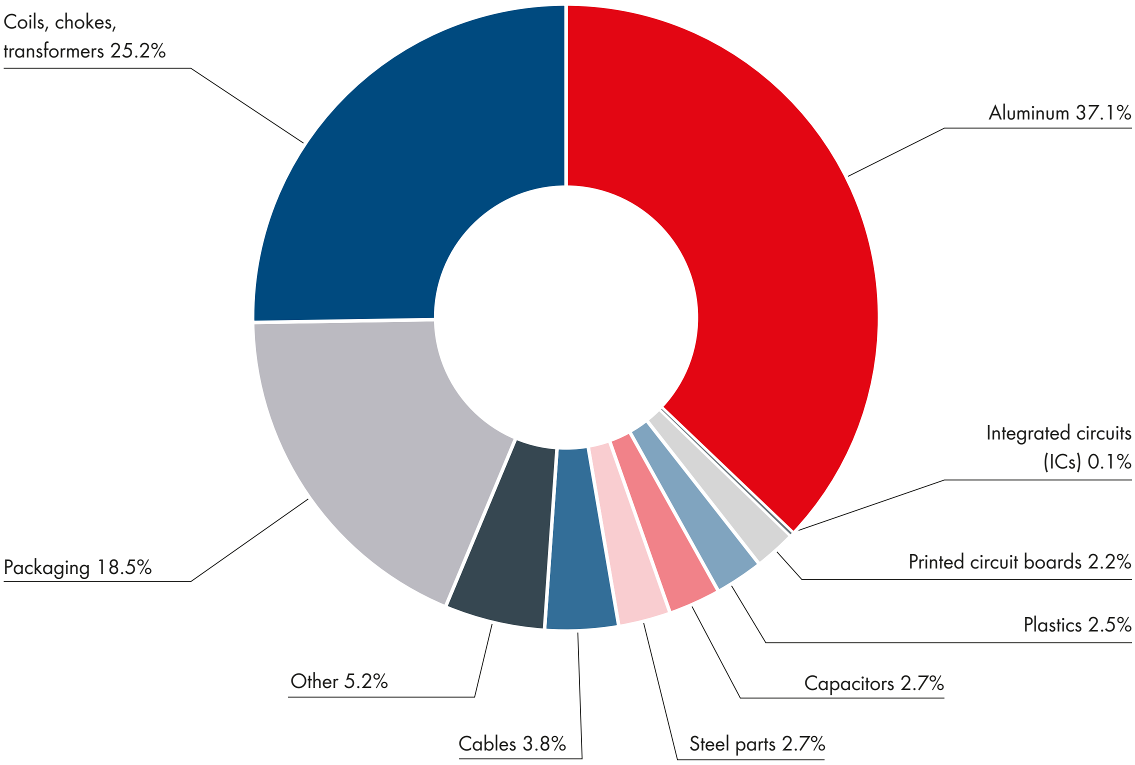
Only when the results are applied to the functional unit of 1 kWh of the alternating current converted by the inverter, which is relevant for decision-making regarding improvements to sustainability performance, can the carbon footprints of the various use cases be directly compared. For every 1 kWh of alternating current at the inverter output, 0.523 g CO_2e were emitted for the Sunny Highpower PEAK3 in the Tucson use case; in the Kassel use case, however, the figure was 0.746 g.

5.2.1 Production phase

At between 15 percent (Tucson use case) and 19 percent (Kassel use case), the production phase accounts for the second largest proportion of the carbon footprint of the Sunny Highpower PEAK3. While inverter production at the SMA headquarters in Niestetal is supplied with carbon-neutral electricity and heat and therefore barely registers in that figure, the extraction and manufacturing processes for the materials and components used tip the balance significantly, with emissions of 903 kg CO_2e. Consequently, the analysis of the percentages by mass of the various materials and components as well as their CO_2e emissions as a proportion of the overall footprint of the inverter is crucial for identifying hotspots in the production phase.

As the chart below shows, aluminum parts account for by far the largest percentage by mass of the Sunny Highpower PEAK3, at 37.1 percent. This is followed by coils, chokes and transformers, with a percentage by mass of 25.2 percent, and packaging, at 18.5 percent. By contrast, bare printed circuit boards and integrated circuits account for the lowest percentages by mass of the inverter, at 2.2 percent and 0.1 percent respectively.

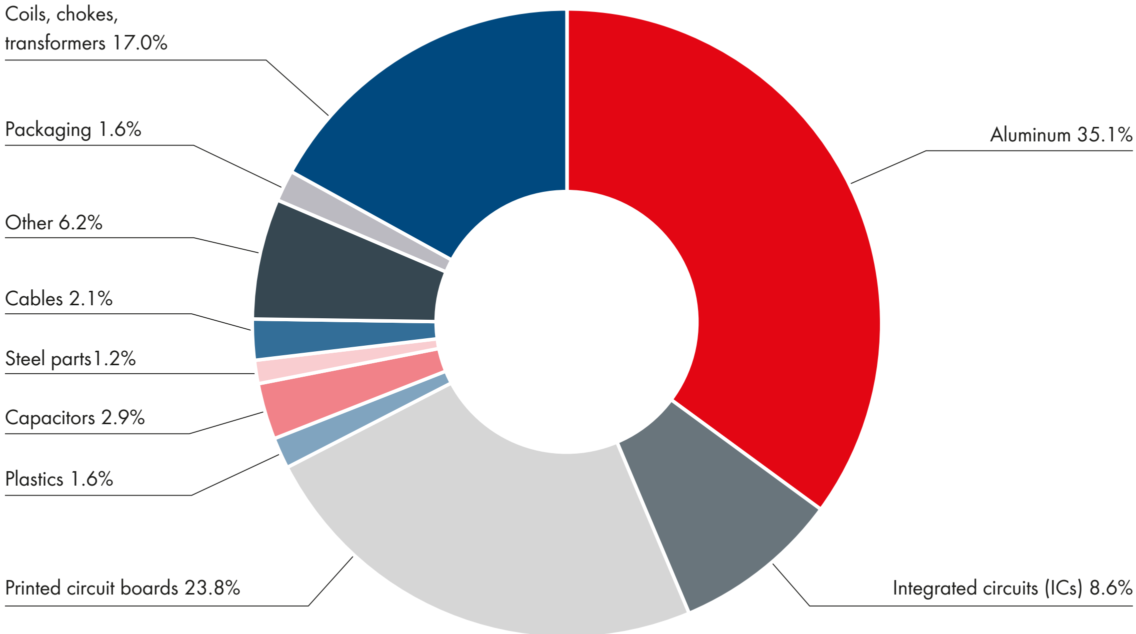
Percentages by mass of the Sunny Highpower PEAK3



◦ Percentages by mass of the individual materials and components of a Sunny Highpower PEAK3; total weight: 120.4 kg (including packaging)

However, considering the percentages of CO_2e emissions attributable to the individual materials and components produces a different picture – very different, in some cases. An in-depth analysis reveals that the biggest environmental impact is caused by components with energy-intensive production processes that also account for significant percentages by mass of the inverter as a whole. Accordingly, the aluminum parts of the enclosure (although they already consist of 80 percent recycled material), the heat sink, other sheet metal parts and mechanical components as well as aluminum parts used in the choke modules make up the biggest single share of the CO_2e emissions, at 35.1 percent. However, at 23.8 percent, bare printed circuit boards account for the second biggest share of the carbon footprint despite representing a percentage by mass of just 2.2 percent. At 8.6 percent, integrated circuits also account for a percentage of the carbon footprint of the materials and components many times higher than their percentage by mass of the inverter (0.1 percent). In both cases, this is due to the energy-intensive manufacturing processes required, such as the processes for galvanizing multi-layer printed circuit boards or producing chip layouts in cleanrooms.

Percentages of CO_2e emissions broken down by materials and components



° Percentages of the individual materials and components used in the total emissions of 903 kg CO_2e per inverter caused by all materials and components.

Consequently, the hotspot analysis shows that the aluminum parts (17 parts in the inverter) and bare printed circuit boards (14 parts) in particular offer considerable potential for further improving the sustainability performance of the Sunny Highpower PEAK3. Numerically speaking, these parts together account for less than 1 percent of all the parts used in the inverter (which contains a total of 5,870 parts), but they contribute around 59 percent of the carbon footprint of the materials and components.

5.2.2 Use phase

As outlined above, the use phase of the inverter is the source of the biggest environmental impact by some distance. Depending on the use case, it accounts for between 80 percent (Kassel) and 85 percent (Tucson) of the carbon footprint of the inverter over its life cycle. The Sunny Highpower PEAK3 has a very high European weighted efficiency of 98.8 percent. Despite this, 1.2 percent of the direct current generated in the PV modules is lost in the form of heat during conversion to grid-compatible alternating current by the inverter and therefore is not fed into the utility grid. Over the useful life of 20 years, that amounts to around 197,000 kWh in the Tucson use case, in which the use phase makes up the largest proportion of the total due to the high level of power generation. Since even solar power generation is not entirely carbon-neutral owing to the resources required, the CO_2e emissions for this loss are estimated at approximately 25 g/kWh based on the environmental profile for solar power in Tucson from the GaBi database. That means estimated CO_2e emissions of roughly 5,190 kg for efficiency loss over the entire useful life.

Furthermore, the inverter sources electricity from the local utility grid when it is in standby mode overnight during the use phase. The GaBi record provides a figure of approximately 500 g CO_2e/kWh for the fuel mix in Tucson. Assuming that 442 kWh of electricity is obtained from the utility grid over a service life of 20 years results in CO_2e emissions of roughly 222 kg. This equates to 3.5 percent of greenhouse gas emissions over the entire life cycle of the Sunny Highpower PEAK3 in the Tucson use case. The composition of the electricity from the utility grid has a direct impact on this, because the greater the proportion of the electricity stemming from renewable sources, the lower the CO_2e emissions.

The results of the LCA study also make it possible to calculate the payback period for the inverter – that is, the time it takes for the amount of CO_2e saved by the generation of solar power in a PV system to offset the amount of CO_2e caused by the inverter over its life cycle. In the Tucson use case, the payback period for the Sunny Highpower PEAK3 is 1.0 years, whereas it is 1.4 years in the Kassel use case. After that period, inverter operation over the remainder of the use phase helps to save CO_2 relative to electricity sourced from the utility grid.

5.2.3 End-of-life-phase

With CO_2 emissions of approximately 41 kg, the end-of-life phase amounts to less than 1 percent of the carbon footprint of the Sunny Highpower PEAK3. It includes the transportation of the inverter from the PV system site to the recycling or disposal facility, as well as the disassembly and treatment of the recovered materials and waste. This approach takes into account the further treatment of waste by means of material-specific processing, but not the potential environmental benefits of recycling or energy recovery from materials. It does not consider the potential environmental impact of the production of secondary materials, the environmental credits for the substitution of primary material production or the generation of energy from incineration. The largest proportion of the carbon footprint in the end-of-life phase, approximately 53 percent, comes from chokes and coils. They are followed by plastic parts, at around 17 percent, and fan modules, at roughly 8 percent.

6. Conclusions and measures derived

The findings from the LCA study summarized here underline the importance of the factors that we have already focused on – namely the responsible use of materials in the production phase and the high quality and long service life of the inverter – in the inverter's sustainability performance.

In the **production phase**, action aimed at further optimizing the product design and replacing materials with alternatives with lower environmental footprints offers considerable potential for improving sustainability performance. This should focus in particular on the materials and components identified in the LCA as having the biggest environmental impact. The hotspot analysis provided some important indicators regarding the relevant components and for identifying and prioritizing improvements. The results of the LCA are also being incorporated into a project that has already been launched aimed at developing internal design tools that will provide our developers with even better support in making decisions that are in the interests of environmental protection right from the conception of SMA products and services. There is further potential in working closely with our suppliers to, for example, increase the use of renewable energies as a means of further cutting CO_2e emissions at the upstream stages of the value chain.

As a manufacturer, SMA has only very limited influence on the **use phase**, which accounts for the biggest proportion by far of the environmental impact of the Sunny Highpower PEAK3 due to the parameters of efficiency losses and sourcing of electricity from the utility grid overnight. In addition to the specific regional boundary conditions at the site of the PV system, such as solar irradiation or the fuel mix of the grid electricity obtained overnight in standby mode, planners and installers can make decisions during system planning and installation that enable inverter operation to be optimized and so reduce environmental impact. Examples include optimizing the size of the PV power plant (225 kWp for a Sunny Highpower PEAK 3) and using suitable, efficient and technologically advanced PV modules as well as assembly structures and other BOS components with low environmental impact in production and at the end of the life cycle. We offer our customers support in pursuit of these goals in the form of Sunny Design software for optimized system planning and seminars through the SMA Solar Academy.

Although the **end-of-life phase** plays only a very small part in the overall analysis of the impact of the Sunny Highpower PEAK3 on the climate, making sure that as many of the materials used as possible are recycled is very important to SMA. This helps us become less dependent on raw material extraction, which involves working and environmental conditions that are difficult to control, and simultaneously enhance our supply reliability. To ensure that we can recycle as many used components and items of equipment as possible and return parts that are no longer usable to the material cycle, we have developed the following process: Defective equipment that cannot be repaired in the field is sent to our Global Repair Center to be restored to the greatest possible extent and transferred to our replacement device pool. Components and assemblies that we can re-use are removed from decommissioned and irreparable devices and re-used for repair purposes.

ENERGY
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CHANGES

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