Heliatek
INDEPENDENT. GREEN. FUTURE.

Organic Photovoltaics – Truly Green Energy:

“Ultra-Low Carbon Footprint”

WHITEPAPER
March 2020

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Remark: All HeliaSol values refer to a TÜV certified Life Cycle Assessment (LCA) of HeliaSol type “1270-6000” with 10% APE – certified towards end of 2023. We are currently preparing for the certification of our latest generation of HeliaSol 436-2000 with an APE of ~8.5%, that will result in a slightly higher carbon footprint.

Executive Summary

The global warming effect is unequivocal, and solar energy will play a major role in the most important battle of the 21st century: enabling increased energy consumption while minimizing the impact on our environment. In order to achieve the climate protection targets as soon as possible, the environmental impacts must be quantified and should be effectively integrated into the competitive process. TÜV Rheinland (Germany) has certified the environmental impact of the solar film HeliaSol® to be below 16 kg CO_2e/m^2 through a Life Cycle Assessment (LCA). The result is an ultra-low carbon footprint ranging from 15 up to 3 g CO_2e/kWh depending on the solar irradiation of a location.

Brown Coal	Natural Gas	Silicon based PV (mono)	Hydro	OPV
				
1.008 g CO_2e/kWh	409 g CO_2e/kWh	80 g CO_2e/kWh	3 g CO_2e/kWh	3-15 g CO_2e/kWh

Through the continuous increase of the solar cell efficiency, Heliatek will bring the carbon footprint of their solar films even further down to reach the lowest carbon footprint among all energy sources. This makes it a truly green product!

The OPV pioneer is currently installing its series production line for the manufacturing of their unique organic solar films. The line is in the ramp-up phase and will produce organic solar films with an annual capacity of up to 1 million m^2 from 2020.

1 Letter from our CEO

For a sustainable future, the advancing climate change must be halted. One of the most important pillars to achieve the climate protection goals is the turnaround of the energy sector to low carbon technologies. Heliatek brings an innovative organic solar film solution as a powerful means for the decarbonization of the energy sector. The unique features ultra-light, ultra-thin and flexible allow completely new application possibilities for the solar energy supply: virtually any surface, from flat to curved and from horizontal to vertical, can be turned into decentralized electricity generators.

With the vision to enable every building to be 100% energy neutral trough access to an independent supply of green electricity, our mission is to be the world's first mass producer of organic thin-film solar solutions. We want to set an uncompromising objective for the decarbonization of the energy sector to encourage curbing climate change.

In order to evaluate the innovative organic solar film in terms of environmental impacts, we performed an extensive Life Cycle Assessment (LCA) in accordance with ISO 14040/44. These international standards provide a structured, comprehensive method for quantifying the potential environmental impact of material and energy flows throughout the product life cycle. Due to the proven negative impact of the climate change on our environment, economies and societies, we are proud to present the following positive results of the CO_2e saving potential through our unique energy solution HeliaSol®.

Guido van Tartwijk – CEO Heliatek

2 Climate Change – The Global Challenge

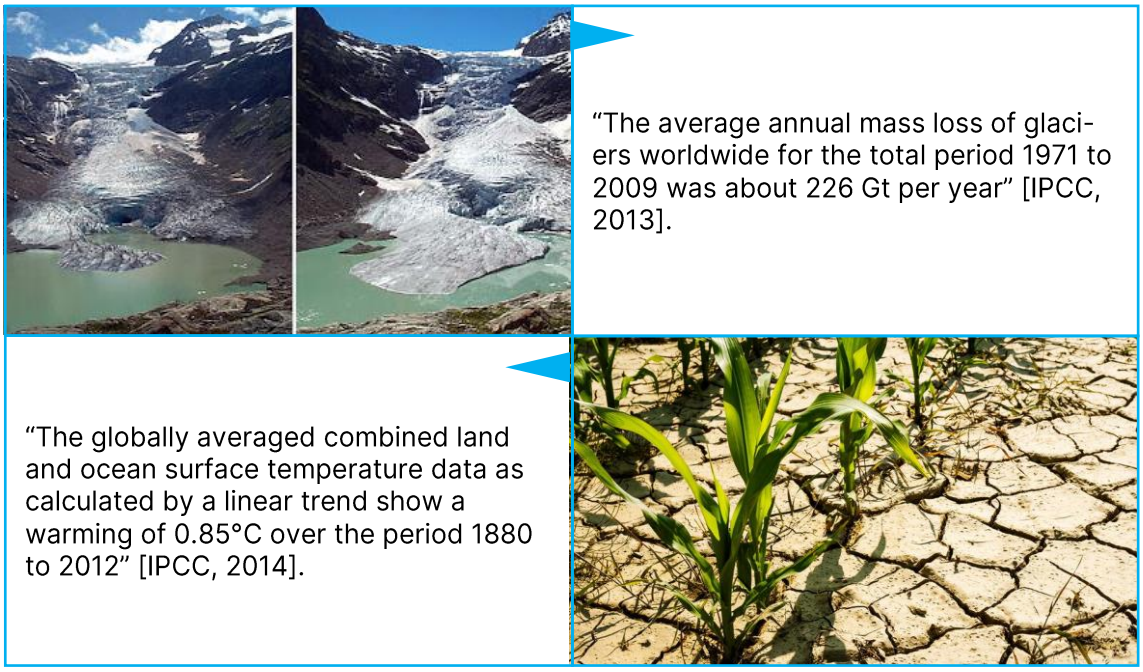

Figure 1 – Hard facts about climate change

Hard facts from the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) show us the consequences of our energy-intensive way of life since the beginning of industrialization. “Atmospheric concentrations of greenhouse gases (GHGs) are at levels that are unprecedented in at least 800,000 years. Concentrations of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) have all shown large increases since 1750 (40%, 150% and 20%, respectively)” [IPCC, 2014]. These changes in the chemical composition of the atmosphere lead to the so-called greenhouse effect. Global warming is reflected in the increasing risks of heat stress, storms and extreme precipitation as well as flooding, landslides, air pollution, drought and water scarcity.

It is widely recognized in global societies that we have to curb this trend. The exclusive reduction of primary energy demand through decreased energy consumption is limited by the high energy requirements of our advanced societies. As a result, renewable energies have to master the toughest and most important battle of the 21st century: to enable an increasing energy consumption while generating no further negative impact on global warming.

3 A Truly Green Energy Solution

As the technology leader in organic photovoltaics (OPV), Heliatek develops, produces and distributes industrial-grade OPV solar solutions for virtually any building surface (horizontal or vertical, curved or flat, rigid or flexible). Heliatek stands for energy solutions designed for various traditional or never been possible before applications based on its unique key features (see Figure 2).

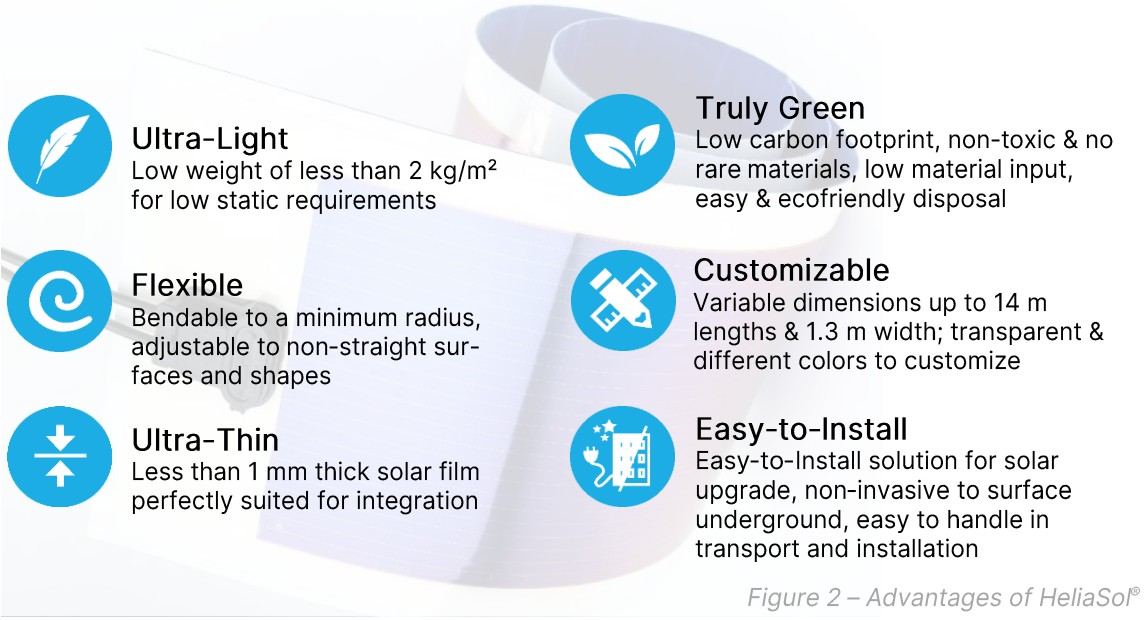

Figure 2 – Advantages of HeliaSol®

Since 2014, the organic solar films have been used in around 30 pilot installations with more than 2,000 m² installed area in Germany, France, Spain, South Korea, Singapore and Mexico. The pilot projects were realized on various building materials such as glass, concrete, aluminum, steel and PVC membranes. In 2020, Heliatek will launch its first commercial product HeliaSol® based on the unique OPV technology.

Figure 3 – Pilot installations from all over the world

4 Ultra-Low Carbon Footprint

Life Cycle Assessment (LCA)

The environmental impacts of produced goods or services must be quantitatively measurable to maintain the ecological viability through defined protection targets and specific limits. The LCA according to ISO 14040/44 standardises the methodical procedure for quantifying the potential environmental impacts of a product system throughout the product life cycle. LCA studies are conducted iteratively through four phases (see Figure 4). In the Goal and Scope phase the overall goal and a clear description of the product system are defined. Subsequently, the Life Cycle Inventory (LCI) phase complies and quantifies the inputs and outputs for the product system throughout its life cycle. Then the Life Cycle Impact Assessment (LCIA) phase evaluates the magnitude and significance of the potential environmental impacts for the LCI results. In the final phase, Interpretation, the results are assessed in relation to the defined goal and scope in order to reach conclusions and recommendations.

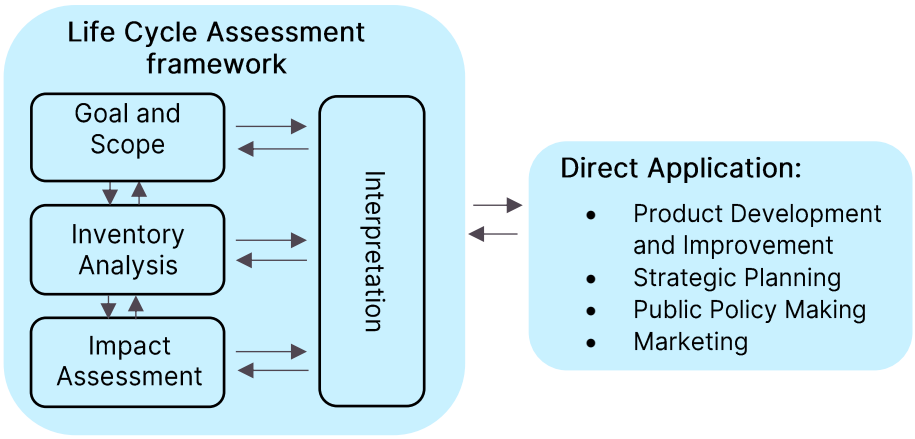

Figure 4- Stages of a LCA [ISO 14040]

A comprehensive LCA analysis has a number of impact categories, such as eutrophication potential (EP), acidification potential (AP) and abiotic depletion (ADP) in the LCIA phase. The first issue "Ultra Low Carbon Footprint" of Heliatek´s sustainability documents "Organic Photovoltaics – Truly Green Energy" concentrates on climate change as the ecological and political driving element for the energy turnaround. The assessment of the impact category climate change is quantified by the impact indicator value CO_2 equivalents (CO_2e). The characterisation model of the IPCC assigns a global warming potential (GWP) as characterisation factor to all relevant greenhouse gases (CO_2, CH_4 and N_2O as well as the Kyoto gases SF_6, NF_3, perfluorocarbons (PFCs) and fluorocarbons (HFCs)) over a fixed time horizon. The Kyoto Protocol recommends a time horizon of 100 years.

Based on the radiation properties of greenhouse gases over a 100-year time horizon, the GWP_{100} indicates the “warming effect" compared to the most important anthropogenic greenhouse gas, carbon dioxide (CO_2, characterization factor 1). The CO_2 equivalents is the result of multiplying the mass of the greenhouse gas by the corresponding GWP. The sum of greenhouse gas emissions and removals in a product system, based on LCA and expressed as CO_2 equivalents is defined as carbon footprint according to ISO 14067.

Goal and Scope

Given the rising importance of limiting greenhouse gas emissions to mitigate growing climate change, the Life Cycle Assessment of energy production technologies should become a mandatory evaluation criterion. Only in this way, political (e.g. emissions trading as well as CO_2 taxes) and consumer-oriented decisions can be made based on a well-founded assessment of the environmental impact by energy generation. Thus, an LCA study was conducted to evaluate the environmental performance of the HeliaSol® product and to further optimize the product and processes.

Heliatek's innovative solar film solution, HeliaSol®, is based on nanoscale carbon-based (organic) molecules that enable ultra-thin, ultra-light and flexible products. The sensitive Organic Stack is protected against external environmental influences such as oxygen, water and mechanical stress by the Barrier Encapsulation. An additional Mechanical Encapsulation provides UV protection and improved protection against mechanical stress to prevent degradation of the solar film over lifetime. The self-adhesive backing (Backside Adhesive) completes the ready-to-use solar film solution (see Figure 5) for buildings with restrictions on weight, statics, access, insulation, guarantee and penetration of the roof.

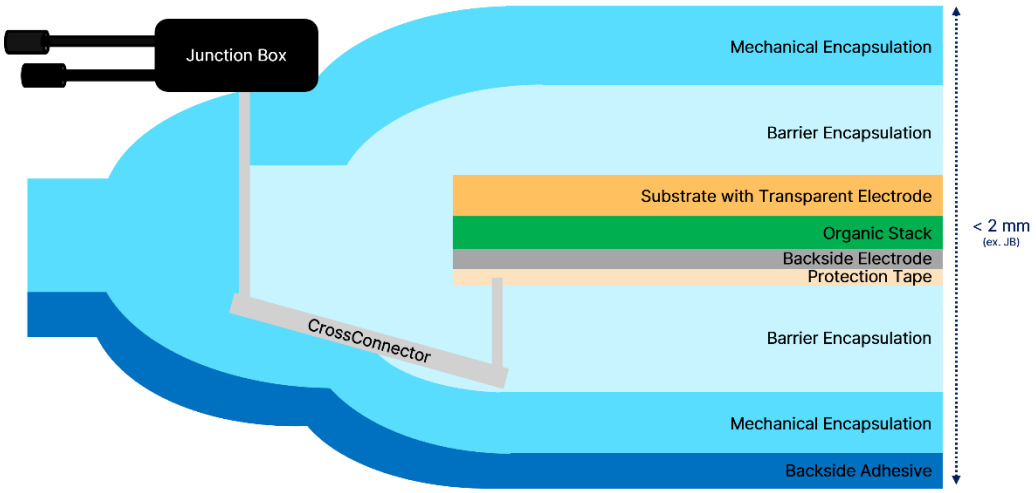

Figure 5 - Layer structure HeliaSol®

The definition of the scope of a product system is not strongly standardised through the ISO 14040/44, which leads to fluctuations of results and interpretations. As Heliatek is committed to its product responsibility, all possible environmental impacts over the entire product life cycle ("from cradle to grave", see Figure 6) were examined. The functional unit, which quantified performance of a product for use as a reference unit, is set to 1 m² Heli*aSol®*.

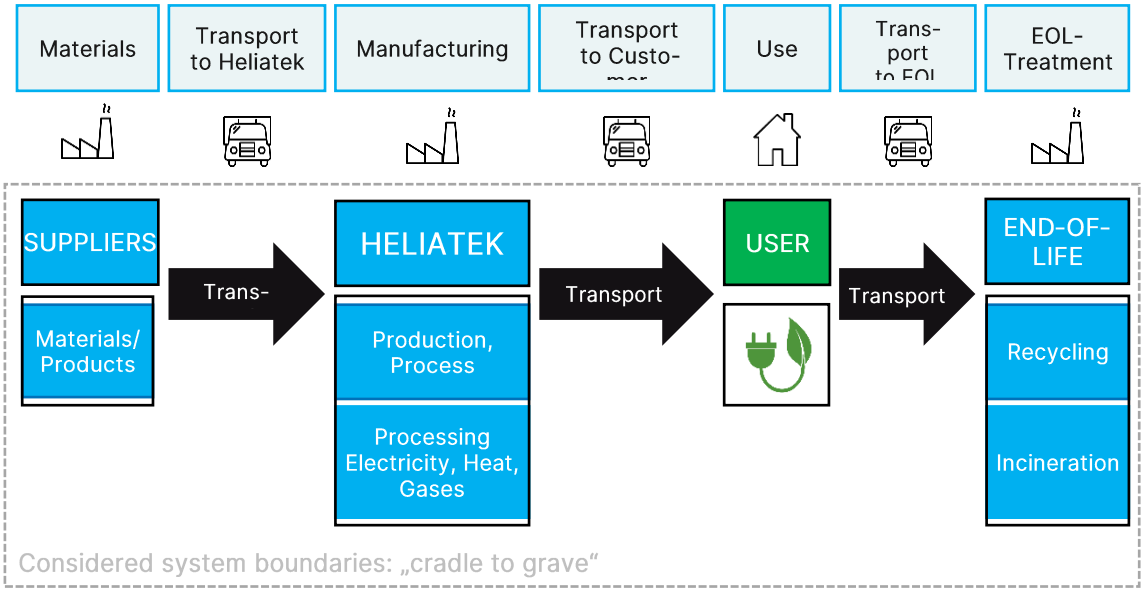

Figure 6 – Product system HeliaSol®

A comprehensive product life cycle analysis should identify all potential environmental impacts, covering also the end-of-life (EOL) treatment of PV modules. In the LCA of HeliaSol®, it was assumed, that cables are recycled and the solar film is incinerated. The flexible solar solution offers a high potential for energy recovery due to its high polymer content of about 98%[1]. With the net calorific value of about 22 MJ/kg, a higher energy generation is achieved through incineration than with wood pellets. The remaining 2%[1] of the films are metal based (copper and tin) and can be extracted from the ash. The study “Incineration of organic solar cells” [Espinosa et al., 2016] proves that complex acid-related recycling processes for the recovery of metals from OPV are associated with 20% higher environmental impacts than by ash extraction.

The organic solar solution does not contain any rare materials and is free of toxic heavy metals such as lead and cadmium. All in all, these are indications that incineration seems to be the most economical and environmental friendly end-of-life treatment for the Heliatek OPV films. Nevertheless, Heliatek is working on a feasibility study for a high quality recycling process to evaluate a more resource efficient end-of-life treatment.

[1] After dismantling/cutting of the cable and feeding it into established recycling plants.

Life Cycle Inventory (LCI)

The LCI includes data collection and calculation methods for quantifying all relevant input and output flows of the product system. Figure 7 shows the percentage weight of the needed input materials for 1 m² HeliaSol® based on the layer structures (see Figure 5). For example, the organic material required for vacuum evaporation of the photoactive triple stack is less than 1 g for 1 m² HeliaSol® (≙ 0.02 weight%).

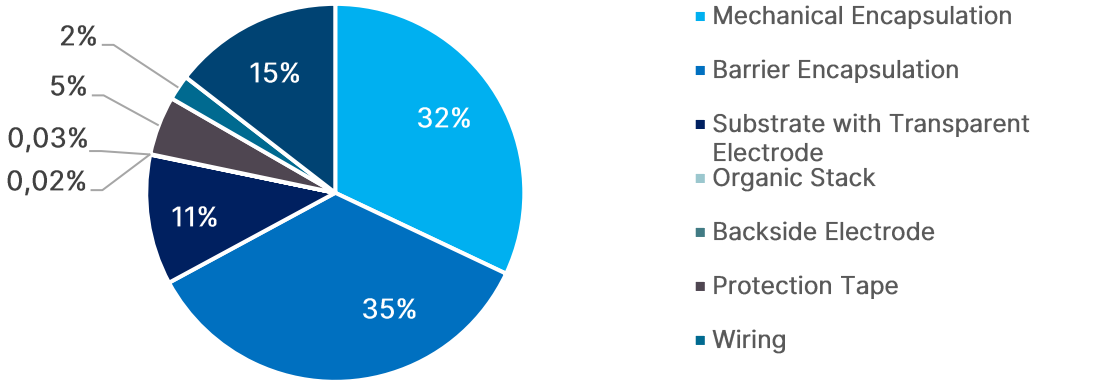

Figure 7 – Input materials HeliaSol®

The efficient roll-to-roll process with heat recovery, closed cooling circuits and solvent-free processes reduce production-related requirements for energy and materials. In addition, the entire production of the organic solar film as well as most material suppliers (see Figure 8) are based in Germany, reducing import dependencies. This has an additional positive effect on the environment due to reduced transport loads.

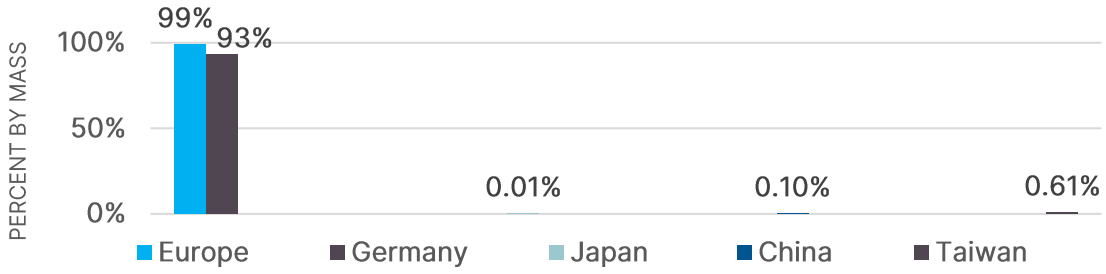

Figure 8 – Origin of materials

Life Cycle Impact Assessment (LCIA)

The LCIA links the results of the material balance to specific impact categories and their implied category indicators. The aim is a quantified evaluation of potential environmental impacts using selected characterisation models.

"All LCIA methodologies have an impact category climate change, and they all use the global warming potentials developed by the IPPC" [JRC, 2011] as characterization model. The IPCC has three, periodically published versions of the method, indicating three different timeframes (20, 100 and 500 years). Thereby GWP figures for 100 years are common.

The results of the in-house LCA[1] for HeliaSol® for the various processes of the life cycle stages are presented below (see Figure 9).

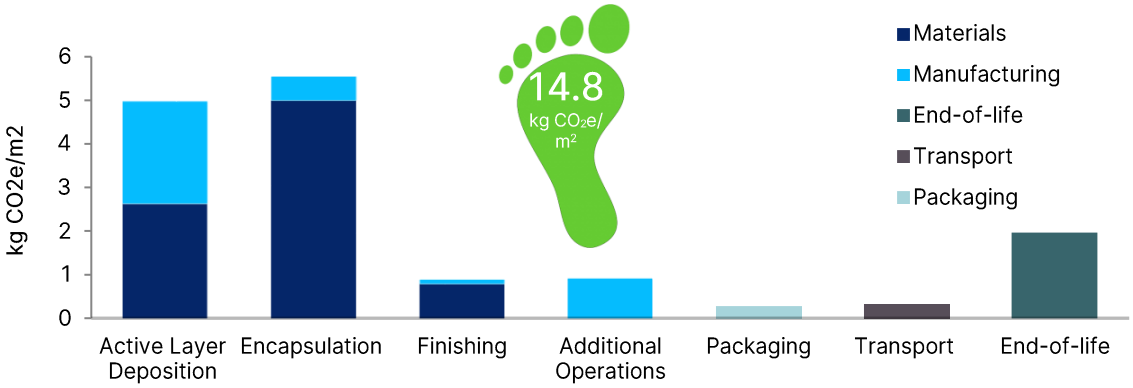

Figure 9 – In-house evaluated carbon footprint for 1 m² HeliaSol®

The LCA indicates that the material inputs used are mainly responsible for the resulting environmental impacts with the main impact from energy for material production. In addition, the energy used during the production process at Heliatek contributes with 25% to the result. In comparison, transport processes (2%) and the packaging (5%) for products and input materials have only a minor influence.

In order to increase the credibility of the in-house LCA through a neutral third party, TÜV Rheinland carried out a comprehensive LCA including certification for the product HeliaSol®. For the certification, external and recognised critical examiners checked the data and the procedure of the LCA carried out by TÜV Rheinland in form of a critical review. The data collection for the LCI was subject to the same examination framework as for the in-house LCA and thus leads to the same LCI results for the product HeliaSol®. The carbon footprint results certified by TÜV Rheinland for the use of 1 m² HeliaSol® are presented in Table 1.

Life Cycle Stages	TÜV certified Carbon Footprint [kg CO_2e/m^2]	In-house LCA Carbon Footprint [kg CO_2e/m^2]
Materials	8.26	8.41
Manufacturing	3.90	3.90
Packaging	0.26	0.26
Transport	0.28	0.32
End-of-life	1.82	1.95
Total	**14.52**	14.84

Table 1 - TÜV certified carbon footprint for 1 m² HeliaSol®
Calculation based on 100-year global warming potential (GWP100) [IPCC, 2013]

[1] based on the free-accessible process-oriented database for environmental management systems (ProBas) from the Umweltbundesamt (UBA) and the International Institute for Sustainability Analysis and Strategy (IINAS)

Interpretation

The carbon footprint, expressed as CO_2 equivalent for the use of 1 m^2 HeliaSol® offers several advantages. The reference to the module area is not subject to intrinsic dependencies and offers a high degree of robustness in the first step of quantification. To relate the carbon footprint to the performance of a solar product the results have to be converted into g CO_2e/kWh over lifetime. This conversion reveals the true environmental profile of energy generating technologies.

The energy generation of solar installations depends above all on the module efficiency, location, orientation and inclination as well as the lifetime of a solar module. Consequently, carbon footprint varies depending on the location of installation. For example, in Germany solar installations can generate about 1,100 kWh per kWp-installed capacity per year (specific annual yield), while in United Arabic Emirates solar installations can generate up to 1,900 kWh per kWp-installed capacity per year. For this reason, the following geographical mapping (see Figure 10) shows the low carbon footprint of HeliaSol® [1] expressed as CO_2e per kWh across the globe.

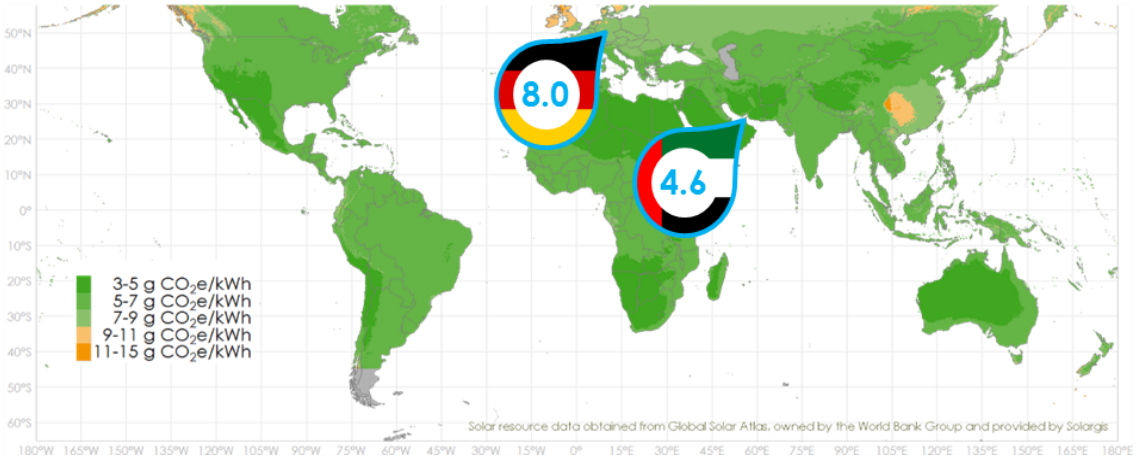

Figure 10 - Geographical mapping of the ultra-low carbon footprint of HeliaSol® (aperture efficiency 10 %, lifetime 20 years, degradation 1 %, optimal tilt) [Conversion using Global Solar Atlas]

The map indicates that Heliatek´s organic solar films have a carbon footprint ranging from 3 g CO_2e/kWh in locations with high solar irradiation to 15 g CO_2e/kWh at some very few exceptional locations. By displacing coal and gas-fired power plants from the electricity grid [UBA, 2018], each kilowatt-hour produced by HeliaSol® can save 667 up to 678 g CO_2e. The higher the CO_2e savings potential, the greater the contribution to the decarbonization of the energy sector. Consequently, the high CO_2e saving potential and the ultra-low CO_2e impact of around 15 kg CO_2e/m^2 enable to payback the greenhouse gas emissions of HeliaSol® within a short period of 1-5 months around the world. This is called carbon payback time (CPBT).

[1] HeliaSol® (14.52 kg CO2e/m^2), including the efficiency ramp until 2021

Comparison

Since 1990, electricity consumption in Germany has increased by about 10% despite the introduction of numerous efficiency standards and energy-saving measures. The transport sector alone will lead to an increase in electricity consumption due to the switch to electromobility. The path for the internationally agreed target to curb global warming to 2 °C or less compared to pre-industrial levels is the reduction of greenhouse gas emissions through the transformation of the economy, especially the energy industry. Therefore, greenhouse gas emissions must be reduced by 40 % - 70 % by 2050 compared to 2010 levels and reach close to or below zero by 2100 [IPCC, 2014]. We need close to zero carbon technologies, which is the pathway of Heliatek`s OPV.

Figure 11 shows a ranking of the greenhouse gas emissions of energy sources and indicates that HeliaSol® have an ultra-low carbon footprint comparable to hydropower, the greenest source of renewable energy.

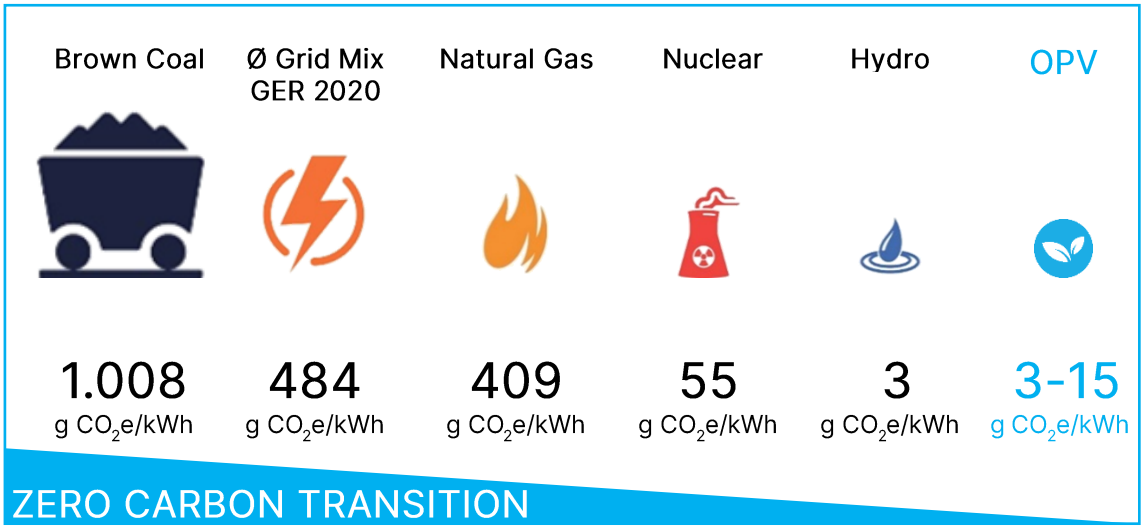

Figure 11 – Zero carbon transition [Values from GEMIS 4.95, 2017]

In general, the use of solar energy is one of the cornerstones of global efforts to curb climate change, reduce air pollution and provide access to energy for all. The following Figure 12 shows the comparison of greenhouse gas emissions of common solar technologies and HeliaSol® on module base including mounting structures over the entire lifecycle. The carbon footprint values for the comparison were selected from the benchmarks of the latest Product Environmental Footprint Category Rules (PEFCR) for "Photovoltaic modules used in photovoltaic power systems for electricity generation" [PEFCR v1.1, 2019]. The PEFCR provides detailed and comprehensive technical guidance established by the European Commission (EC) to find a harmonized way to allow conscious policy and consumer decisions when it comes to solar electricity generation.

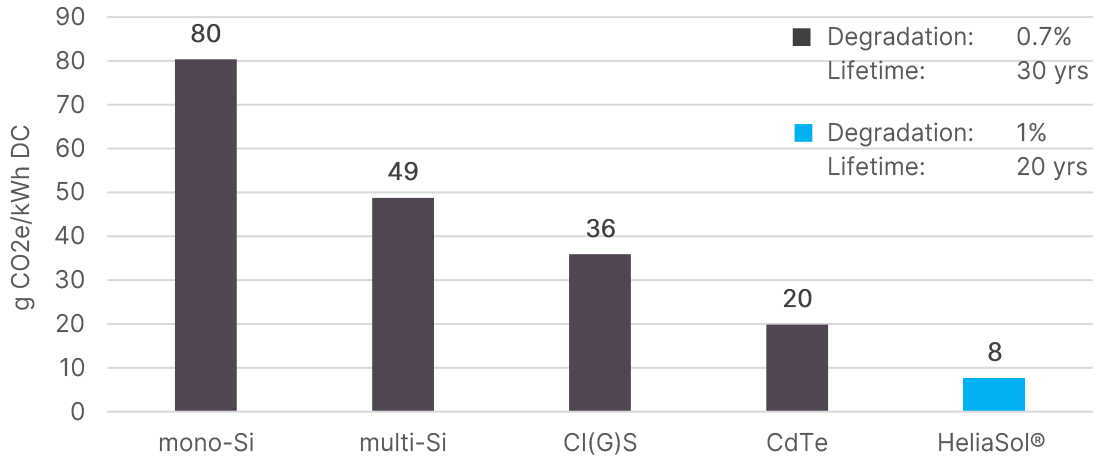

Figure 12 – Lowest carbon footprint of all solar technologies (average yield at optimal angle in urban European areas: 1090 kWh/kWp) [Values from PEFCR v1.1, 2019]

The comparison indicates that Heliatek`s OPV delivers solar energy with the lowest carbon footprint of all solar technologies, despite the high potential for improvement in lifetime and product efficiency due to the young age of the technology. It is important to note that, since "statistical data on the recycling of PV modules were not available in 2017, the end-of-life of PV modules was modelled by the disposal on an inert material landfill" [PEFCR v1.1, 2019]. This raises the question of whether this assumption within a LCA reflects all potential environmental impacts over the entire product life cycle.

Heliatek`s OPV is on threshold of providing the energy market with an ultra-light, flexible, ultra-thin and truly green energy solution. The LCA study of HeliaSol® assesses that organic PV solar solutions must be one of the threshold to curb the climate change. However, the potential for sustainability is far from being exhausted. For example, within a scenario analysis carried out by TÜV Rheinland it was shown that the use of 100% green electricity for Heliatek production alone leads to a significant reduction of the carbon footprint of HeliaSol® by up to 25%. With the continuing improvement of our truly green solar solutions, we have the potential to reduce the carbon footprint even further down and establish HeliaSol® as the greenest energy source among all.

5 Conclusion

The climate change is happening right now, with the energy sector being one of the key causes. In order to curb the effects of climate change, our increasing global energy demand needs to be supplied with low carbon, eco-friendly, renewable energy sources like solar. But even among renewable energy sources there are differences how green they really are. Heliatek as the pioneer in organic photovoltaics has developed an innovative generation of solar technology that abandons toxic materials such as lead and does not use rare materials.

Heliatek has conducted a Life Cycle Assessment (LCA) for its unique solar film, HeliaSol®. This analysis provides detailed information of potential environmental impacts in each stage of the product life cycle – from material supply over the production and usage up to end-of-life treatment including all transportation/delivery routes. Compared to other solar technologies, the results show that Heliatek's OPV is the greenest of all solar technologies with a global carbon footprint ranging from 3-15 g CO_2e/kwh. Thereby an annual production of Heliatek will be able to offset around 2,000,000 t of CO_2e, comparable to 150,000 ha of forest area.

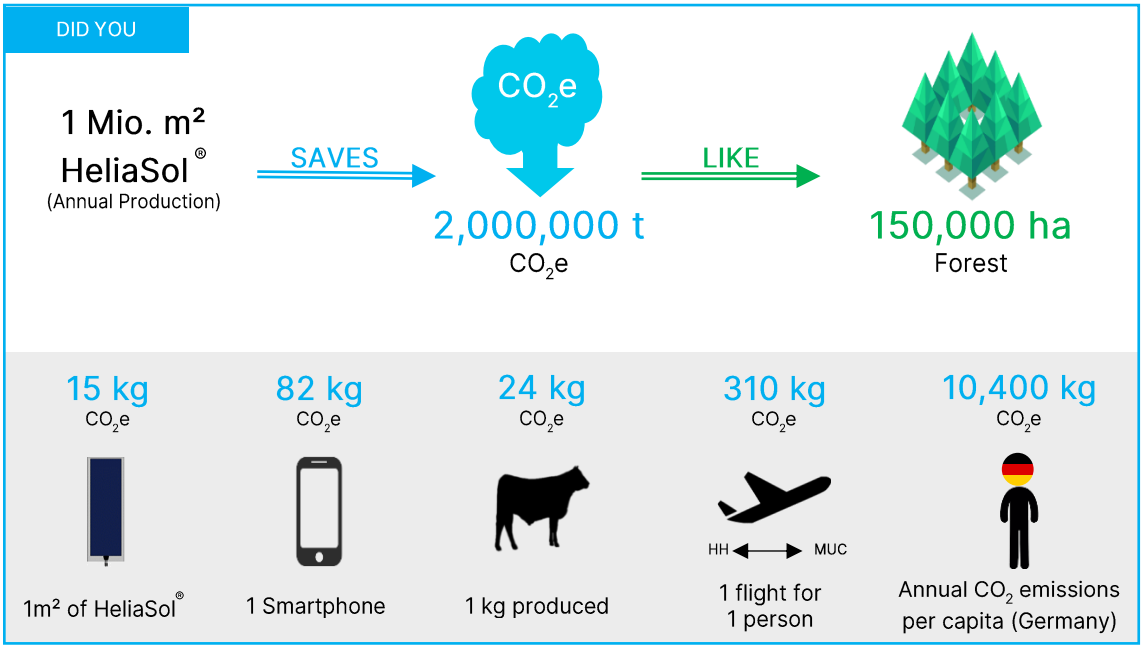

Figure 13 – Did you know? A consumer oriented comparison

Heliatek, as one of the first solar companies has done a LCA with TÜV Rheinland to confirm the truly green character of HeliaSol®. These LCA results place Heliatek´s OPV solar technology to one of the greenest of all energy sources, comparable to hydropower.

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List of Abbreviations

ADP	abiotic depletion
AP	acidification potential
CO_2	carbon dioxide
CO_2e	CO_2 equivalent
CPBT	carbon payback time
EC	European Commission
EOL	end-of-life
EP	eutrophication potential
GEMIS	Globales Emissions-Modell Integrierter Systeme
GHG	greenhouse gas
GWP	global warming potential
HFC	fluorinated hydrocarbons
IINAS	International Institute for Sustainability Analysis and Strategy
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
JRC	Joint Research Centre
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
OPV	organic photovoltaics
PEFCR	Product Environmental Footprint Category Rules
PFC	perfluorocarbons
ProBas	Process-oriented database for environmental management systems
UBA	Umweltbundesamt

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