**Resource Efficiency and Waste Management for Off-grid Solar Products in Kenya (REWMOS)**

# Preliminary Results of LCA Study on Best Practices for Off-grid Solar Products

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***in collaboration with:***

myclimate
shape our future

myclimate, Zurich, May 23, 2019

# 1. Carbon Footprint and Total Environmental Impact of Off-grid Solar Home Systems

The Government of Kenya has set out plans to achieve universal energy access by 2020, but with the current electricity generation and grid capacity, only 20% of Kenyans have access to electricity. For those reasons, Kenya is one of the most vibrant markets for the solar industry in Africa, with off-grid solar products reaching 15%-20% of households (SOFIES 2017 "Cost-Benefit Analysis E-Waste Solar Kenya"). However, access to energy, Internet and information leads to growing discarded Solar Home Systems (SHS), calling for a sound e-waste management system. The REVMOS project, financed by REPIC Switzerland, investigates on the environmental impact of these SHS, to help improve the ways to a better e-waste management.

The company Solibrium-Solar sells different Solar Home Systems (SHS) to customers in the Kakamega region, 350 kilometres northwest of Nairobi, Kenya. Over the past few years, the sale volumes of these SHS have been increasing all over Africa, and especially in Kenya. This trend is very likely to continue, as various reports show. In order to improve the environmental performance of these SHS from cradle-to-grave, this project aims at defining best-practices for each life-phase, thus production, transport, use and end-of-life treatment. The use-phase in this study is equal to a system life-time of the SHS of 20 years. This figure has been supported by a number of studies (e.g. Alsema et al. 2000), some even speak of 30 years of system life-time (www.nrel.gov). Depending on the scenario and the quality of maintenance and repair over that life-time, certain components have to be replaced. This aspect has been taken into account to quantify the impact of the use-phase (compare also Chapter 2.4).

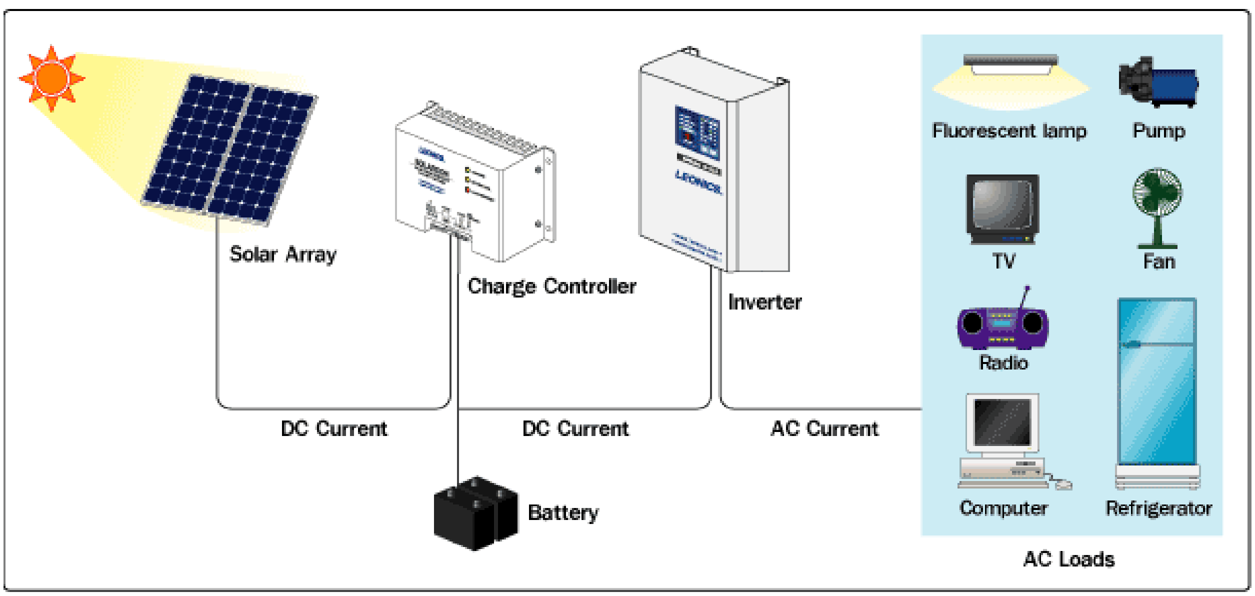



*Figure 1: Description of a Solar Home System (Quelle: www.leonics.com)*

myclimate has calculated the carbon footprint (IPCC 2013 method) and total environmental impact (ILCD method) of two different SHS. The total environmental impact encompasses impacts on acidification, eutrophication, global warming potential, ozone depletion, photochemical ozone creation potential or primary energy use. The primary product data for the Simplicity Pack 4 Lights (producer Omnivoltaic Energy Solutions, China) and the Sun King Home 60 EB (producer GreenLight Planet Kenya Limited) were provided by Solibrium. Figure 1 describes the concept of a SHS schematically; Table 1 lists the features of the two SHS looked at.

*Table 1: Features of the two SHS assessed in this study*

| SHS Name | Sun King | TV 19'' Pack |
|---|---|---|
| ***Exact Description*** | A system with 6Ah battery and 6W panel that powers 3 lights and phone charging | A system with 12Ah battery and 55W panel that powers 4 lights, a 19'' TV and phone charging |
| ***Manufacturing Company*** | GreenLight Planet Limited | Omnivoltaic Energy Solutions |
| ***Country of Origin*** | Kenya | China |
| ***Weight*** | 2.2 kg | 11.58 kg |
| ***Power Output*** | 19.8 Wp | 144 Wp |
| ***Number of Separate Units*** | 9 | 37 |
| ***Reference (Website)*** | https://www.greenlightplanet.com/shop/home-60/ | http://omnivoltaic.com/oves_products/ |

# 2. Impact of SHS in Different Life-cycle Phases

The study results shown in this report are of preliminary nature and will be refined during the course of the project based on workshop findings, interviews and external expert opinions. However, it can be stated that the highest greenhouse gas emissions occur during the production and use-phase, mainly because over a life-time of 20 years, a number of components of the SHS have to be replaced. This statement is not true with regard to the total environmental impact, as SHS components being dumped have a severe effect on water and soil, sometimes only after decades or centuries. Consequently, the end-of-life stage is of major interest, despite the fact that long-term emissions are hard to measure. One of the main targets of this project is to extend the life-time of the products through improved maintenance and repair services, and to avoid any environmental impact of obsolete products after their first system life during the end-of-life treatment phase.

## 2.1. Results over Entire Life-Cycle

The following Figure 2 describes the carbon footprint of the Omnivoltaic 19' TV-pack as well as the much smaller Sun King product (4 lights) over the entire life-cycle of the product. The share of the TV (LCD-screen) is by far the highest, however, if the life-time of the TV-set can be increased (e.g. from 3 TVs to 1 in 20 years), the use-phase impact can be reduced drastically.

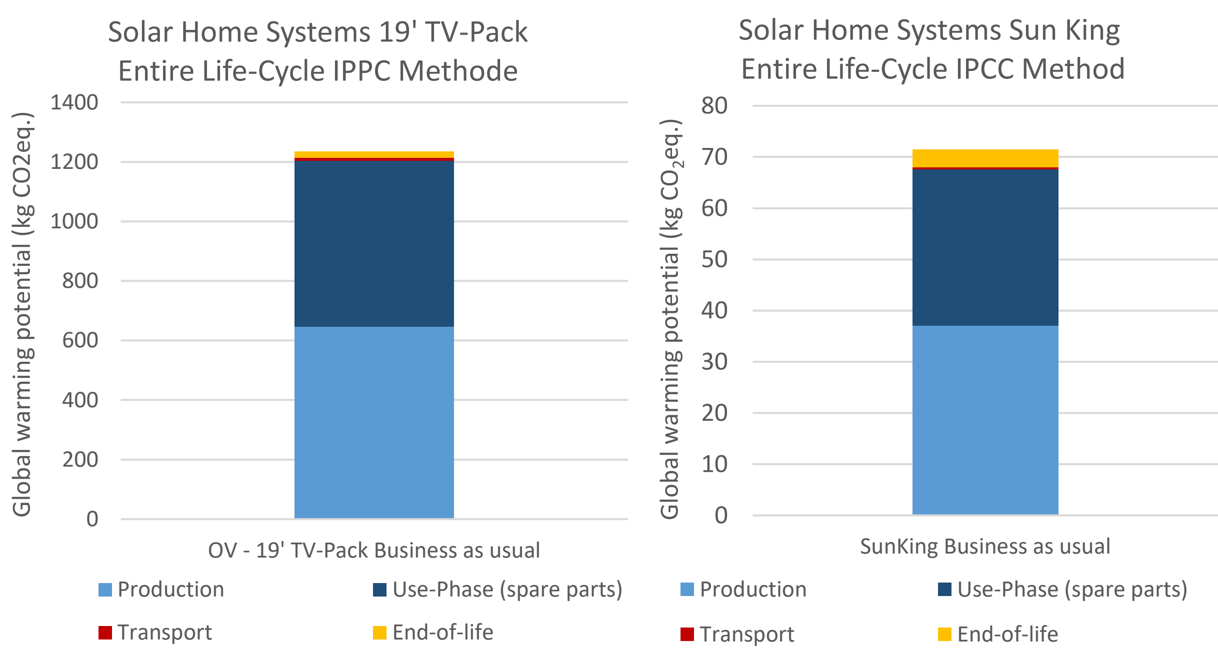



*Figure 2: Entire life-cycle Carbon Footprint of two SHS according to IPCC 2013 method. Attention: different scale reading.*

The production phase is responsible for approximately half of the total Global Warming Potential of the Solar Home System (52 %), another 45 % emerges during the use-phase, the rest stems from the end-of-life phase, modelled by a landfill scenario.

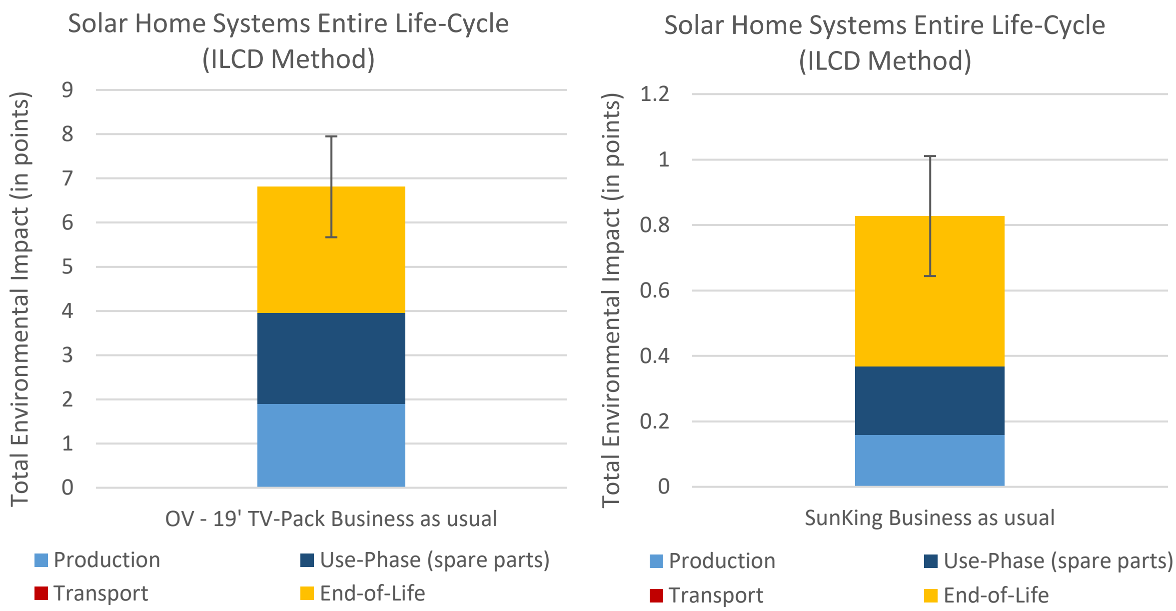



*Figure 3: Total Environmental Impact over the entire life-cycle of two SHS according to ILCD method. Attention different scale reading.*

The calculations for the Total Environmental Impact (Figure 3) indicate similar proportions for the Business-as-usual case of the OV and Sun King products. The *production phase* is responsible for roughly a quarter of the Total Environmental Impact (19 - 28 %) while the *use-phase* with all the required spare-parts over a life-time of 20 years has an equal share on the overall emissions (25 – 30 % ILCD method). For the end-of-life phase, the Business-as-usual case of landfill (open dump) has been chosen, showing an impact share on the overall results of 42 % (OV TV-Pack) and 55 % (Sun King).

In contrary to the Global Warming Potential, the end-of-life phase has a major impact on the results, due to emissions to water and soil (see also Chapter 2.5.). For that reason, the end-of-life treatment requires special attention in this REWMOS project; the business models for SHS will reflect that appropriately. The transport activities are, compared to the other life-cycle phases of the SHS, of minor importance.

## 2.2. Production Phase

The production of the SHS has been divided into the 5 components solar panel, battery, TV (LCD), cables and other units. The two calculated products are both produced in Asian countries (mainly China or India), which means the power-mix consists of a relatively high share of coal power. The impact of the production phase could therefore be reduced, if a producer with a renewable energy mix could be chosen. The components were assessed on the basis of the processed raw materials, combined with a production process (injection moulding etc.) where needed. Figure 4 shows the global warming potential (CO2e) and the total environmental impact of the two products.

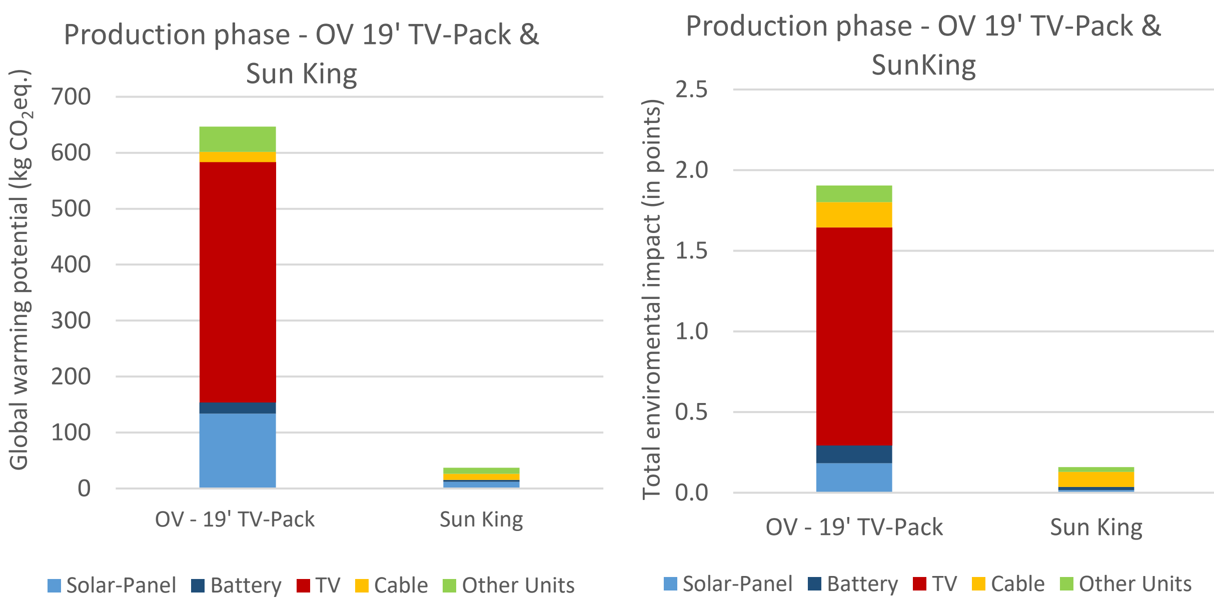



*Figure 4: Carbon Footprint and Total Environmental Impact of the production phase of the OV and Sun King SHS.*

The Sun King has less capacity and is designed to run 4 lamps instead of a TV. The TV is by far responsible for the highest impact (roughly 70 %) in the production phase, followed by the solar panel in case of the OV and the cables in case of the Sun King. The LCD TV screen is built from a number of rare earth metals, which require an intensive extraction procedure and several process steps (e.g. cleaning) up to the final product.

## 2.3. Transport Phase

The 19'-TV pack is produced in China, and therefore has to be transported to Kakamega by container ship and lorry. In both impact methods (IPCC and ILCD), the lorry transport is responsible for roughly 90% of the emissions. The Sun King is produced in Kenya, and due to its lower weight and shorter transport distance, the environmental impact is much smaller than in case of the OV (see Figure 5). Included in the total transport activities are the transports of the spare parts required over the life-time of 20 years.

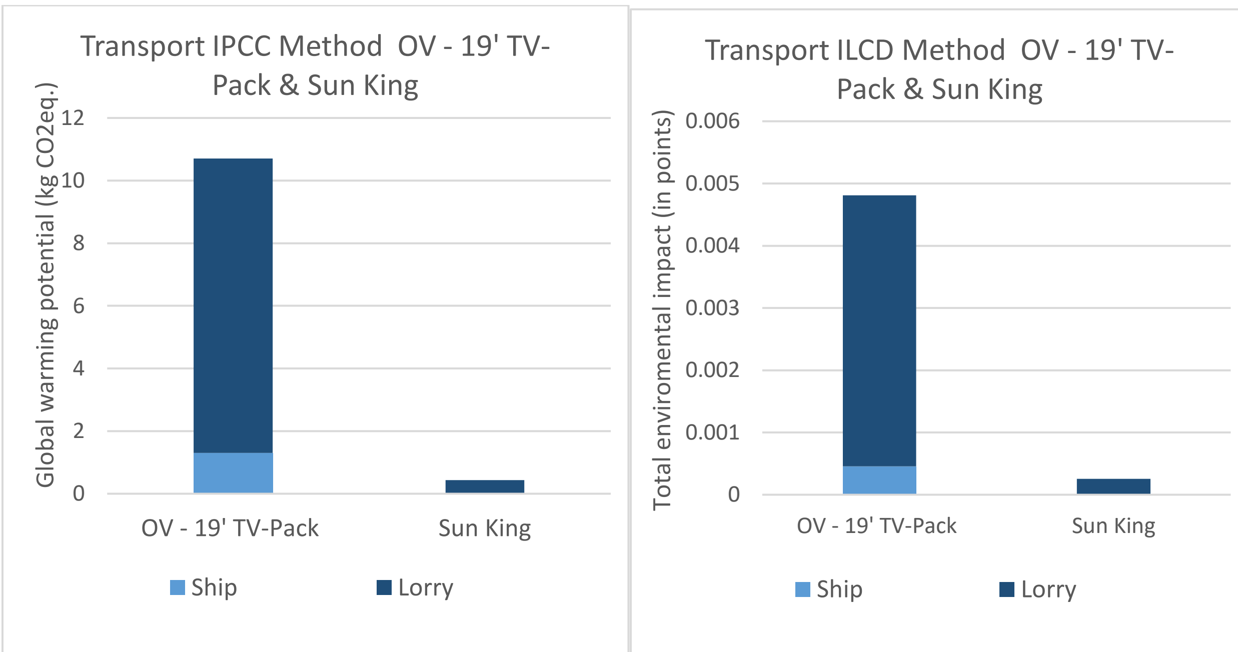



*Figure 5: Carbon Footprint and Total Environmental Impact of the transport phase of the OV and Sun King SHS.*

## 2.4. Use-Phase

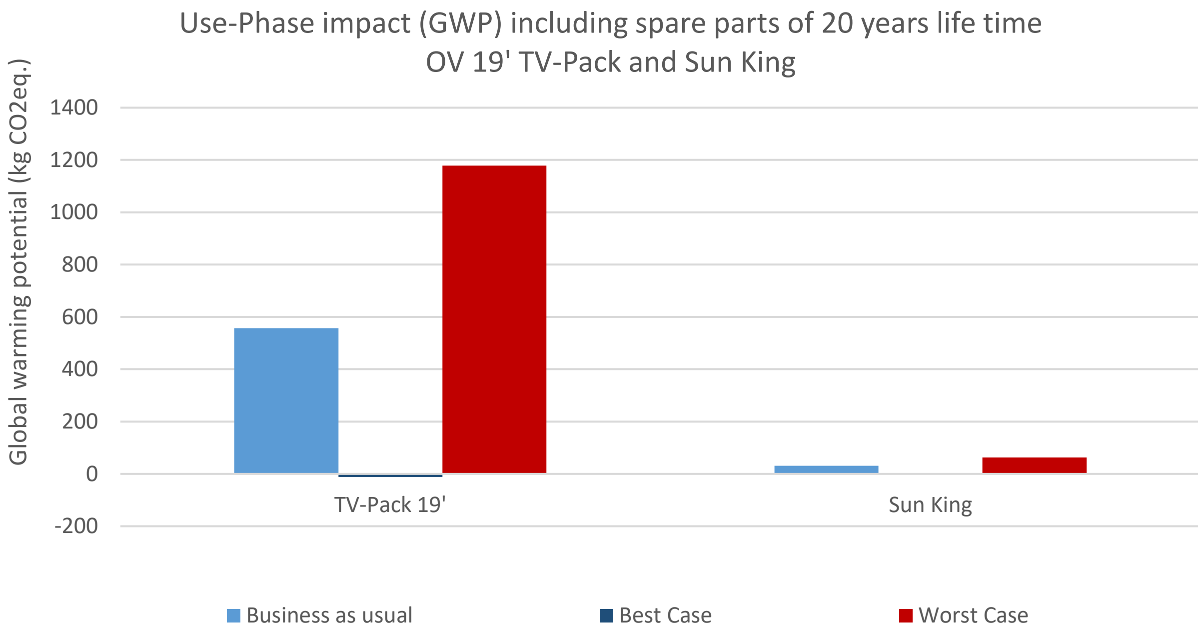
The Use-Phase of the two SHS is described by three scenario calculations, namely the "Business as usual", the "Best case" and the "Worst case" scenario. For this matter, the different components of the SHS have been critically assessed to determine how many of them are used per life-time of a SHS (see Table 2). In case of the "Business as usual" scenario, we assumed that 4 batteries are in use over a life-time of 20 years. This goes up to 5 pieces of battery in the "Worst case scenario", and drops to 2 pieces for the "Best case" scenario. To mention another example, we expect 1 TV to last for 20 years in the "Best case scenario", 2 TVs in the "Business as usual" scenario and 3 TVs in the "Worst case" scenario.

The amount of components in use over the life-time has an immediate impact on the resulting emissions. Figure 6 as well as Figure 1 and 2 clearly express that the use-phase has a determining role in the sustainability discussion of the SHS, be it in Kenya or anywhere else in the world.

*Table 2: Use-phase scenarios for Sun King and OV TV – Business as usual, Best and Worst case*

| Use-Phase Sun King | One production (kg $CO_2$e) | Business as usual (factor) | Best case (factor) | Worst case (factor) |
|---|---|---|---|---|
| **Battery** | 3.76 | 4 | 2 | 5 |
| **Keypad** | 1.68 | 4 | 1 | 4 |
| **Cable** | 10.89 | 2 | 1 | 3 |
| **Bulb (3x)** | 7.13 | 1 | 1 | 2 |
| **Mobile Phone Charger** | 0.52 | 6 | 2 | 7 |
| **Packaging** | 0.66 | 2 | 1 | 2 |
| **Solar Panel** | 11.80 | 1 | 1 | 2 |
| **Small parts** | 0.09 | 2 | 1 | 3 |
| **Transport Lorry** | 0.43 | 2 | 1 | 2 |
| **Warranty card and battery clamp** | 0.12 | 1 | 1 | 1 |
| **Total (kg $CO_2$e)** | **37.1** | **67.6** | **38.4** | **100.4** |

| Use-Phase OV TV 19'' | One production (kg $CO_2$e) | Business as usual (factor) | Best case (factor) | Worst case (factor) |
|---|---|---|---|---|
| **Battery** | 20.40 | 4.0 | 2.0 | 5.0 |
| **Keypad** | 8.41 | 4.0 | 1.0 | 5.0 |
| **Cable** | 18.23 | 2.0 | 1.0 | 3.0 |
| **Bulb (3x)** | 9.80 | 1.0 | 1.0 | 1.5 |
| **Mobile Phone Charger** | 0.71 | 6.0 | 2.0 | 7.0 |
| **Packaging** | 0.93 | 1.5 | 1.0 | 2.0 |
| **Solar Panel** | 133.57 | 1.0 | 0.75 | 2.0 |
| **Small parts** | 9.28 | 2-3 | 1.0 | 3.0 |
| **Transport Lorry** | 9.40 | 1.5 | 1.0 | 2.0 |
| **Transport Ship** | 1.30 | 1.5 | 1.0 | 2.0 |
| **TV** | 434.82 | 2.0 | 1.0 | 3.0 |
| **Total (kg $CO_2$e)** | **646.86** | **1203.4** | **634.6** | **1825.8** |



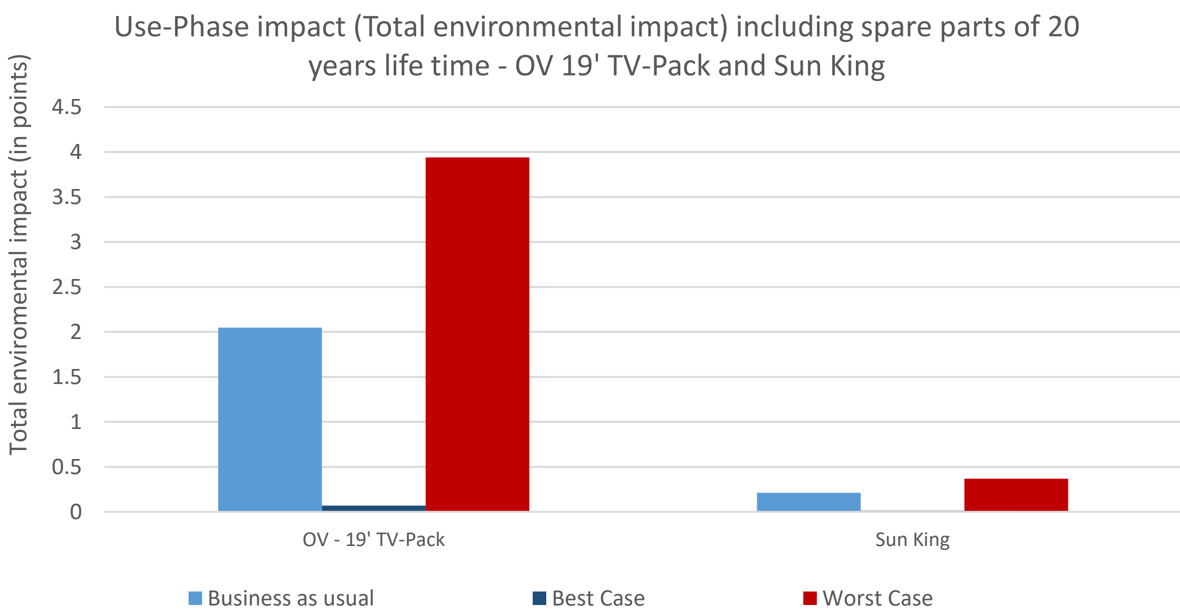
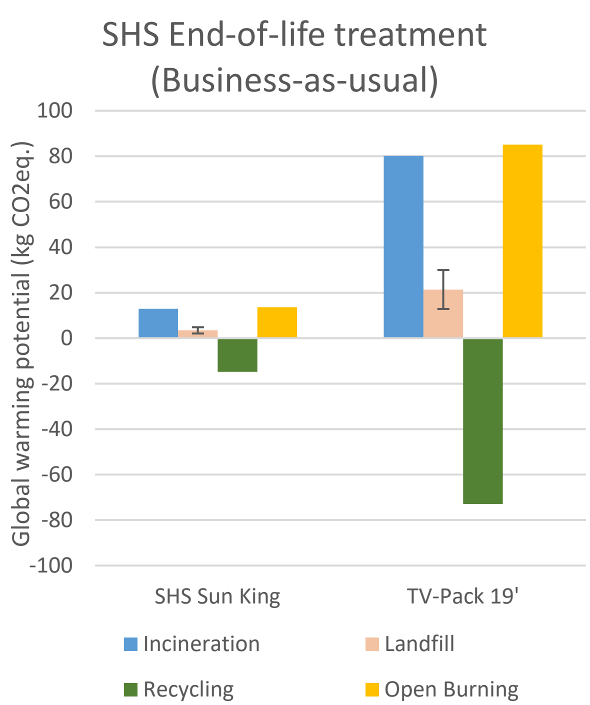




*Figure 6: Carbon Footprint and Total Environmental Impact of the use-phase of the OV and Sun King SHS according to the three scenarios “Business as usual”, “Best case” and “Worst case”.*

## 2.5. End-of-Life Phase

The last life-cycle phase of a product, the "End-of-Life" phase, has different impacts on different indicators, depending on the end-of-life process looked at. Open burning or landfill can have severe (long-term) impacts on health and environment. As landfill (open dump) impacts of electronic equipment are still not very specified and a challenge to measure, this life-cycle stage should be looked at in more details. The Swiss ecoinvent database 3.5 provides a number of end-of-life processes that are applicable for these SHS scenarios, like "treatment of lead smelter slag in material landfill" for parts of the battery or "treatment of municipal solid waste in open dump". Still, the processes for open dumping of SHS components used in this study are rough approximations with high uncertainties, indicated by black bars in Figure 7.



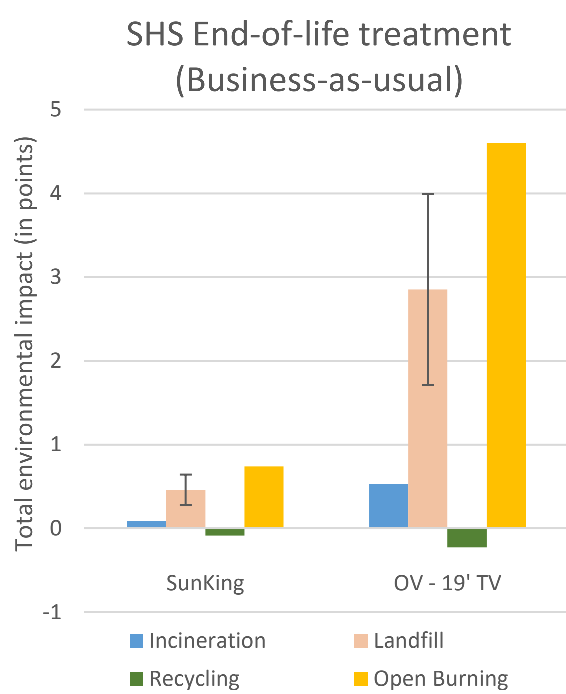




*Figure 7: Carbon Footprint and Total Environmental Impact of the end-of-life phase of the OV and Sun King SHS for the options "Incineration", "Landfill", "Recycling", and "Open Burning". ". Please notice that accurate end-of-life models especially for landfill options for electronic equipment are yet to be established and verified. The assumptions here are based on rough estimates by myclimate.*

As Figure 7 points out, incineration and especially open burning of SHS components are worse than landfill regarding carbon emissions. Landfill however has a relatively high impact on the other compartments like soil and water, which makes the result chart look different in the right-hand chart of Figure 7 showing the Total Environmental Impact.

Life Cycle Assessment methods normally calculate environmental impacts for a time-frame of 100 years, in which especially plastic materials are relatively stable and also other components are normally only dissolved after hundreds of years. It is currently hard to tell what will happen to the disposed Waste Electric and Electronic Equipment (WEEE) after a few hundred years. However, it is expected that over a time span of several centuries, the process of open dumping can have severe consequences on soil quality, river and ground water and through that on the health of humans, animals and plants.

It can be stated that recycling activities, if properly operated, lead to an environmental benefit, as valuable secondary resources are recovered. This is true for various metals (like aluminium, steel, copper), but also for a number of plastics (like PP, PE etc.).

# 3. Best/Worst Practices for SHS based on Environmental Analysis

Based on the environmental assessment discussed in Chapter 2, and based on available favourable operation modes, the best practices over the entire life-cycle of SHS can be established. At the same time, the worst practices should be avoided as much as possible. Chapters 3.1 and 3.2 describe best and worst practices over the life-cycle phases of the SHS.

## 3.1. Best Practices for SHS from an Environmental Point of View

From an environmental point of view, the optimal SHS case in each life-cycle phase can be described as follows:

*Production*:

- Eco-design: as little material input as possible, as little composite-material as possible
- Raw materials from sustainable extraction methods
- Raw materials from regional suppliers
- Production in a factory with an excellent power-mix (renewable energy)

*Transport*:

- Regional production with short transport distances
- Light products
- Technically high-standard transportation vehicles

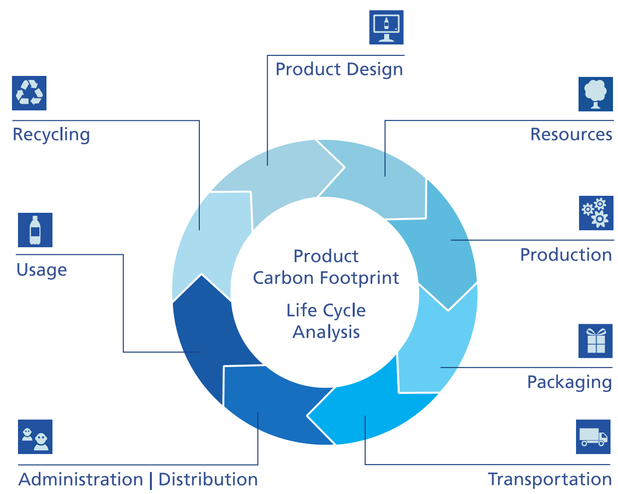
*Use-Phase*:

- Well working servicing system

- Regular maintenance
- Component-based repair system to avoid waste
- Skilled and motivated users and technicians
- Extended life-span of batteries, panels and other SHS components

*End-of-life* (compare also SRI publication 2017, "From Worst to Good Practices in Secondary Metals Recovery, FACT SHEET"):

- Proper depollution and dismantling of End-of-life products
- Taking care of problem fractions such as batteries
- Reuse and/or recycling of SHS through best-practice recycling processes and collection systems (e.g. FRELP "Full Recovery End Life Photovoltaic, compare Bhavesh Uppal et al. 2017, Sustainable recycling technologies for Solar PV off-grid system)
- Avoidance of open dumping of SHS components
- Avoidance of unsound smelting and open burning practices




## 3.2. Worst Practices for SHS from an Environmental Point of View

The worst practices for SHS in each life-cycle phase can be described as follows:

*Production*:

- Production with heavy material input
- Raw materials from unsustainable extraction methods
- Raw materials from remote suppliers
- Production in a factory with very CO2-intensive power-mix (based on fossil energy)

*Transport*:

- Products manufactured in far-away countries
- Heavy weights
- Bad load factors on ships and trucks

*Use-Phase*:

- Badly working servicing system
- Irregular or non-existent maintenance

- Unskilled and unmotivated users and/or technicians
- Short battery life, short life of panels and other SHS components
- "Throw-away mentality" to cause tons of untreated (hazardous) waste

*End-of-life*:

- Uncontrolled dumping of SHS, disposal in landfills
- Burning of components/cables in open fires
- Loss of valuable resources/metals
- Heavy environmental impact, health issues

It can be concluded that best practices for SHS should be implemented before trading and selling takes place; best practices should be carried out at a nation-wide level, covering all aspects over the entire life-cycle of SHS. If not, all the good intentions of giving people in remote areas access to information and education will have a bad aftertaste.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