Business Plan and Life Cycle Analysis of a solar charging integrated parasol for micro-charging of hand held electronic devices

Panagiotakopoulos Dimitrios
dimitris.panagiotakopoulos@ist.utl.pt
Instituto Superior Tecnico, European Institute of Innovation and Technology
Lisbon, Portugal

October 2014

Abstract

In February 2014 KIC - Innoenergy accepted and approved our business idea and my team and I got inducted in the Business Incubator Iberia in Barcelona. KIC – Innoenergy is a branch organisation of the European Institute of Innovation and Technology, which main objective is to bridge the gap between the academic world and the market. The mechanism employed is the creation of start-ups through a platform where technical and managerial education is engaged with investors and real world solutions. The aim of the present work is to initiate, contribute and accelerate the G-RooT start up. G-RooT is a start-up created by myself and co-founder Danish Rehman in order to integrate photovoltaics into daily life objects, raise awareness about solar energy by engaging opinion leaders and create a world where there is energy available for charging hand held devices where there are areas of products exposed to the sun. G-RooT's first product is G-SOLution, a solar charging parasol targeting the market of luxury hotels. The present document briefly explains the business plan, which is written according to the regulations and the formal template used by EIT Incubators across the European Union and focus on an initial Life Cycle Analysis that has been performed to the product. It aims to confirm the concept of green - forming G-SOL, which is interpreted by the author as producing objects that not only do not have carbon footprint but on the contrary saving the carbon footprint of the relevant regular ones. Therefore, the environmental impacts of G-SOL were examined in terms of sixteen impact categories with main focus to Global Warming Potential. This was achieved by performing an LCA study using the SimaPro software and ILCD 2011 Midpoint impact methodology. Further, different PV technologies were investigated and a sensitivity analysis was also performed in terms of waste treatment and disposal. The carbon footprint of G-SOL is -128 kg of CO_2 – eq. and our solution causes the most negative effect in the impact categories Mineral, Fossil and Renewable Resource Depletion followed by Ozone Depletion while the least to acidification. Aluminium is the material that contributes the most to the environmental load with 894 kg of CO_2-eq followed by the woven cotton fabric with 53.8 and the multi-Si module with 52.6 kg of CO_2-eq. Different cases-scenarios' results vary between -274 kg of CO_2 - eq. to 764 kg of CO_2 - eq., where negative value means that the product has a net effect of reducing greenhouse gas emissions.

Introduction

Smartphones and devices have become an integral part of our daily lives and with increasing communication services offered by companies, our reliance on these devices will further increase many folds. By the end of 2013 BI Intelligence, Business Insider paid research service, predicted to have 1.78 billion smart phones and tablets around the globe **[**1**]** Assuming an average energy consumption of 5Wh (iPhone), these devices require 3.25 TWh electricity every year, enough to electrify 0.8 million average European households. According to Moomaw et. al [2] CO_2 emissions associated with natural gas are 469g per kWh of energy produced which reflects annual emissions of $1.5x10^3$ tons of CO_2 for charging these devices. Take into account that a UK's one adult's household emits 3.6 ton of CO_2 annually[3]. Increased use of personal electronic devices certainly has a global impact on environment that can be reduced by charging using clean resources such as solar power.

The need

To have a feedback from smartphone users we employed an online survey to understand their daily dependence on smartphones and associated battery discharging problem. The survey consisted of 20 qualitative questions and response from 112 users was recorded. Online survey and associated results can be found at web address as mentioned in reference [3]. Gender distribution amongst participants from

26 different countries was 67% men and 33% women. 95% of the participants had earned a graduate degree or more. 92% of the users surveyed had faced the problem of running out of juice while out and 13% mentioned to encounter this problem every other day. 44% of the participants expressed their dependence on smartphones as their daily essential need while 39% mentioned the use just for practical purposes. When asked about the reaction of users to charge their devices using clean sources of energy, 85% mentioned that they will feel good for their contribution to the environment and 78% agreed to recommend it to their friends through social media. Another research conducted in USA, UK, Germany and UAE showed that 71% of the people using mobile phones would prefer longer lasting batteries[5]. Users are demanding more than the capabilities of technology mainly because their cell phones are an essential part of their life and secondly because they are not aware of the limits their mobiles have. Nomophobia is the fear of being out mobile phone contact. The term, an abbreviation for "no-mobile-phone phobia", was coined during a 2010 study by the UK Post Office who commissioned YouGov, a UK-based research organization to look at anxieties suffered by mobile phone users. The study found that nearly 53% of mobile phone users in Britain tend to be anxious when they "lose their mobile phone, run out of battery or credit, or have no network coverage". The study found that about 58% of men and 47% of women suffer from the phobia, and an additional 9% feel stressed when their mobile phones are off. The study compared stress levels induced by the average case of nomophobia to be on-pair with those of "wedding day jitters" and trips to the dentists. Ten per cent of those questioned said they needed to be contactable at all times because of work [6].

To further validate our idea and better determine the need we conducted a survey to hotel owners and managers in Mykonos island in Greece. A questionnaire was provided to them consisting of two sections, the qualitative and the quantitative. The first is related more to general understanding of their environmental techniques or measures they employ, the way they operate, decision making process and general understanding. On the other hand, the quantitative was more specific since we introduced them the concept and we were trying to further understand them in order to design and build our solution on them and according to their feedback. It was observed that all these hotels are looking for environmental actions mainly because it is a trend to be green. Secondly, an action that implemented by one is then copied by all. Almost everyone- hotel owners or managers- perceive sustainability as a burden to luxury hotels since for them the clients' comfort is the highest priority. However, they are struggling in being green and being luxury simultaneously. This was the reason why the majority of them were enthusiastic about our offer; It is green and it increase their costumers' satisfaction. Further, we found out that their clients are extensively (90%) using their electronic devices by the pool. Last but not least, everybody was enthusiastic about the CO^2 savings, which can be used as a marketing tool.

In conclusion, a strong need for enabling longlast outdoor usage of electronic devices such as smart phones, tablets and notebooks without running out of juice exists which can be served by providing charging platforms outdoors.

Industry analysis

Established rivals

Out of all available clean energy resources, solar energy has proven possibility of integration in everyday products. The advent of this Product Integrated Photovoltaic (PIPV) domain can be traced back to 1980 when the small solar powered pocket calculator was introduced in the market. Scaling up the concept and integrating solar technology in outdoor products having plenty of sunshine throughout the year, therefore offers another way to sustainable future. Our market research has shown that new start-ups and products for sustainable shading have been launched in recent years and market is still developing. Start-ups are USA and Canada based whereas some already established companies from China are producing a practical sunshade with possibility of charging electronic devices. Strawberry Energy is only Serbian company in European continent, which offers threat of adapting quickly and entering the market with similar products. The Key Value Proposition by these companies is mobile charging unit and therefore they offer leasing to events, conferences and open spaces along with the option of buying the solution. Solbrella is the most recent entrant in the market (2014) and their target market is quite similar to ours. Our strategy will be to differentiate from them by offering sustainability in product design rather than a mobile charging unit.

All the competitors can be segmentized according to the installed power and associated price. Hammacher Schlemer (HS) offers only 1W and requires 12 sunshine hours to fully charge the battery that will give almost 2 charges to the iPhone 4S. Powerbarr (PB) offers 40W requiring 4 sunshine hours to fully charge the accompanied battery that will then enable to have approximately 27 iPhone 4S charges. These two can be classified as small electronic device charging category. Next group encompasses Green SunRising (GSR), EnerFusion (EF) and SolGreen (SG). These shades can be utilized to charge devices, computers and partially e bikes. Solar tree from Strawberry Energy (SE) comes with 530W and storage capacity when fully charged provides almost load of a complete household.

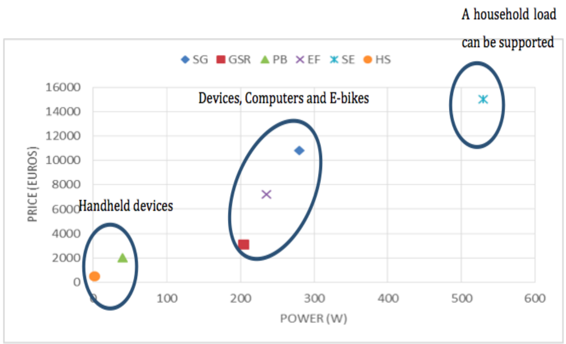


Fig. 1 competitors' price and power analysis

Product

Our solution to the well established problem of outdoor charging, G-SOLution, is a solar powered sunshade designed to produce enough electricity to charge personal gadgets by exploiting the available sun outdoors. It utilizes high performance solar cells to convert sunlight into electricity and stores in a built-in battery. The technical characteristics of the product are:

- High performance 20W solar cells module on the top of sunshade
- Damp proof fabric available in different colours
- 10Amph battery backup from Smart Battery for at least 10 iPhone charges
- 5 sunshine hours required to fully charge the battery
- 2 standard USB 2.0 outlets for charging devices
- Positive carbon footprint in the entire life cycle
- Wind resistance in loads of 6 Beaufort

Value Proposition

We are offering green differentiation to our costumers and increased satisfaction to their clients during their relaxing or working time outdoors. Being under the sun becomes more playful and comfortable than ever. Environmental techniques or measures usually taken by luxury hotels are decreasing the comfort they offer to their costumers while our offer increase their costumers' satisfaction and at the same time gives them the green differentiation they are seeking of. We define green differentiation as the combination of sustainability and quality.

Dual or multifunctional products, such as our solar charging shades are used for sun protection and harvesting of sun power simultaneously. The rapid growing technological development has set our mobile phones, tablets or laptops as integral part of our lives, depriving us many times of the outdoor environment because we need electricity. We transform, or greenform- as we like to call it- lifeless outdoor furniture to alive and elegant objects, which interact with the users by providing them free, clean and limitless energy. Our customers can work or play with their hand held electronic devices while out and away from grid tied sockets without caring of running out of juice. Nature employ its tools; the sun and gives solution to our modern problems.

Introduction to LCA

Background and relevance of the subject

A literature review was conducted based on two frameworks; the first one is the eco design and the second one the LCA of different materials, PV technologies and product integrated solar cells. Obviously, the goal of the study is to integrate eco thinking during the designing phase of G-RooT's product. The basic principle of eco-design is increasing eco-efficiency and reducing environmental loads. Literature highlights the importance of taking environmental considerations into account in the early stage of product design and development [6]. Specifically, Kathleen Donnelly et al. from Lucent Technologies describe a product-based environmental management system (PBEMS) where the leading idea is to incorporate sustainable principles during product design phase. In the PBEMS system, business and environmental processes are utilized together in order to integrate product strategy with Life Cycle Assessment (LCA). Another paper [7] from Conrad Luttropp and Lagerstedt have created a generic set of rules/good advice/checklists for the early phase of product development. The paper presents Luttropp's generic set of design rules and how they can be used as a base to make situation-specific guidelines and checklists, e.g. adapted for various design tasks, product types and persons. This set of 'rules' promotes more effective early compromises and specification negotiations.

There is no doubt that considering eco-design during the early stages of the product development is more beneficial than taking it into account after the product manufacturing. However, the vast majority of SMEs are underestimating, and in some cases ignoring, the benefits of eco-branding and subsequently eco-marketing. European Union is making a great effort towards this direction by conducting educative seminars on LCA and entrepreneurship as well as having its own eco-label [8]. The categories that eco-flower (EU eco-label) has formed till now are summarized in: beauty care, cleaning up, clothing, do it yourself, electronic equipment, coverings, furniture, gardening, household appliances, lubricants, other household items, paper products, holiday accommodation.

Each of these categories is further subdivided, however SOLution parasol do not stand in any of these subdivisions. It is truth that the eco-labelling is under development and that there is open to public call for new categories or subcategories proposals.

Besides the EU, there are many private entities or corporations that provide eco-labeling for almost any kind of product, like the carbon neutral company [10]. In any case, though, LCA is necessitated in order to further proceed. On the other hand, there is a significant number of Life Cycle Assessments made for photovoltaic systems, e.g. by Ftenakis and Kim [10] and other researchers all over the world. Their results differ quite a lot and in some cases the differences are in the range of 300-400%. More specifically, for multi-crystalline silicon the required energy ranges from 2400 – 7600 MJ/m^2 of PV panel and for mono-crystalline in the range of 5300 – 16500 MJ/m^2 of PV panel [12]. The differences were mainly allocated to the assumptions each researcher made and to allocation rules he employed. Dr. Alsema in his report [11] mentions that the energy requirements for multi – crystalline panel with 14% efficiency module in Southern European conditions is 4200 MJ/m^2 and for mono 5700 MJ/m^2.

Goal and Scope of LCA study of G-SOL

The primary goal of this study is to assess the environmental life cycle impacts of the proposed product G-SOL. Sixteen impact categories will be investigated with main focus to the GWP since the climate change is of paramount importance environmental issue. Furthermore, it is investigated the possibility of producing carbon neutral or near to neutral product. One of our main goals as a start up is to create carbon neutral or products that have net effect of reducing greenhouse gas emissions; as we like to call it green-form existing daily use objects into power sources.

The secondary objective is to perform a sensitivity analysis. By doing so, we will identify what are the main contributors to the environmental burden as well as how sensitive is our model to changes in a range of parameters' values of the model and to changes in the structure of the model, i.e. a focus will be on parameters and their values sensitivity. A series of simulations will be performed by varying parameters in a base case scenario to investigate how the changes affect the environmental performance of the proposed product. Five years of G-SOL use has been defined as the functional unit of the product system.

Finally, different end of life scenarios will be under research in order to evaluate the environmental performance and to come up with techniques to reduce the final carbon footprint. Both the results from the LCA and the sensitivity analysis will contribute to identify environmental issues and possible options on how these can be improved.

System Definition and Description

This life cycle assessment is covering the product's emissions of Green House Gases, measured in Global Warming Potential, during its whole life cycle. The system is analyzed from cradle to grave, i.e. from the 'birth' of the raw materials – or in other words the raw material extraction – till its 'death' – the final disposal or recycling. As it has been already mentioned we are interested to know initially whether our product can potentially be carbon neutral during its life cycle and secondary how big its total impact on the environment can be. Therefore, we tried to include as much as possible components in its life cycle. For this reason, we have identified the five most important components, leaving aside some like for instance screws. These are presented below:

1. Aluminium pole
2. Photovoltaic (PV) module
3. Battery
4. Printed Circuitry Board (PCB)
5. Textile

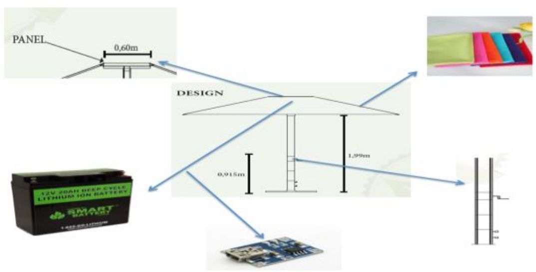


Fig. 2 Illustration of system components

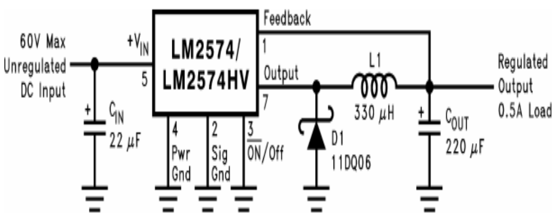
The system can be seen as a sum of different components of which it consists of. The aluminium pole has been designed to be two meters tall. More specifically, it is a tube with

1cm thickness. On the top of the parasol, there is the solar panel, which occupies an area of 0.2484 m^2. The rest of the cap consists of woven cotton textile. The battery is a lithium ion battery with weight of 1.7 kg. Furthermore, there is a PCB with weight of approximately 40 grams.
The usage stage of the system can be seen as a stage where electricity is generated from the solar module. All the electricity generated can be used for charging hand held devices. This energy is seen as replacing energy from the grid since the devices would have been charged aliquo modo.

Solar charger building up
The main element of the solar charger is the PCB. PCB is an electronic circuitry printed on cardboard, which is mainly made from glass fibre and phenol. The support that just described in addition with the components' housing (plastic and ceramics) account for 73 weight-% of the PCBs. Furthermore, a multitude of elements is present in varying concentrations. Metals account for about 27 weight-% of the PCB. Typical concentrations in PCBs are Fe 10%, Al 5%, Cu 5%, Pb 1%, Ni 1%, Sn 2%, Zn 1%, Mn 1%, Br 1%, and traces of many other hazardous and/or precious metals (Ag, Au, Pt, Pd) [13].
The components that are necessary for our solar charger Minimum Viable Product (MVP) are:

- two resistors of 49.7 KΩ and ¼ W;
- one resistor of 43 KΩ and ¼ W and one of 74.9 KΩ and ¼ W;
- one IC model LM2574 from Texas Instruments Ltd. which is functioning as step down voltage regulator to 0.5A;
- one diode 11DQ06;
- one inductor of 330 μH;
- one capacitor of 220 μF and one of 22 μF;
- USB port.

Figures 26 presents the circuitry of the IC regulator and the bridge, which is necessary for charging Apple devices. At this point, it is useful to mention that this bridge was designed through reverse engineering from a regular Apple charger.



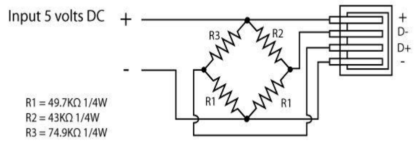


Fig. 3 Electricity circuitry for the voltage regulator (up) and the Apple bridge (down)

Assumptions and limitations
The initial and basic limitation is that the product under research is not a manufactured product. This by itself is setting some limitations in the degree of the analysis. In other words, there is lack of information about the manufacturing details. However, the main components, i.e. the materials used are well defined as well as the potential suppliers. In other words, transportation from the manufacturers of the different components has been taken into account. For the materials used in the production of the G-SOLution, LCA data from the ecoinvent3 library as well as the ELCD and the Swiss input output libraries have been used. Modifications have been made in some cases in order better to match the data of the proposed components, as for instance in the case of the PV module efficiency.
The usage phase is another stage where assumptions have been made, since the product has not been tested in real conditions. In the base case scenario, it has been assumed that the product will be used for 5 years and during this time no component will be replaced due to malfunctioning. We consider 5 years even though the life expectancy of all the sub components is higher due to the fact that luxury hotels usually renovate their decoration every five years.

Geographical
The system has been placed in Mykonos island and the transportation from our assembling facility till there has been taken into account. Besides that, solar irradiation and energy yield has been calculated on real data. About the suppliers and their geographical placement is presented below:

- Aluminium: Alumil with industrial facility in Kilkis, Greece
- PV module
  - Multi Si: Silcio solar technologies, Patra, Greece (base case scenario)
  - Mono Si: MunchenSolar, Germany
  - Amorphous Si: Global Solar, Shenzen China

- Battery: Smart Battery, Florida, United States
- PCB: Locally manufactured in Bulgaria
- Textiles: Sunbrella, mother company Dickson, France

For the avoided product 'electricity production from the grid', which is the electricity that would have been consumed in order to charge the devices charged from our product, background data from the ecoinvent3 library has been used. Specifically, the electricity mix of Greece has been used since the product has been placed in Greece.

Time
All the components of our parasol have quite high life expectancy. The data provided from the manufacturers is presented:

- Aluminium: 10 years warranty from Alumil [14]
- PV modules: 20-25 years life expectancy [17]
- Battery: 5,000 cycles or around 10 years [16]
- PCB: It has been assumed 5 years. There is no end of life for the PCB however the sub components of it like resistors or IC may break down during its usage.
- Fabric: 10 years warranty from Sunbrella [15]

Solar irradiation and energy yield
For the examined system, it has been assumed that all the solar energy produced throughout the year by the solar charger will charge the hand held devices of the users. In reality, some energy may be lost because of no demand for charging and/or a fully charged battery. However sizing and usage optimizing is another scientific topic, out of the scope of this study.
Solar calculations should be performed in order to find out the real solar energy yield. In the majority of the LCAs reports and papers generic values for solar irradiance, solar radiation and insolation have been used. Ftenakis et al [19] and Alsema et al [18] are using Southern European average insolation data with value 1700 KWh/m^2/yr, performance ratio of 0.8 and lifetime of the PV modules of 30 years. These values can be characterized quite optimistic; satisfactory though for the purposes of an LCA of PV paper. Furthermore, the calculation procedure is quite vague and it is not clear whether losses (for instance temperature losses) have been taken into account.
In our case, the solar calculations are precise and they are based on real data measured for the year 2012 [11].

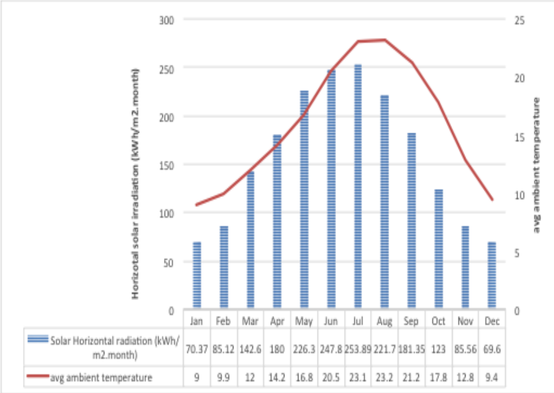


Fig. 4 Horizontal Solar Insolation and average ambient temperature for Mykonos island

Further, the effect of power losses due to the cell temperature increase is based on formula.

$$T_c = T_a + \frac{G * (NOCT - 20)}{800} \quad (1)$$

where Tc the cell temperature and Ta is the ambient temperature given. The temperature defined by STC, i.e. 25 °C was deducted from the cell temperature and for each degree was encountered 0.42% (this value is changing based on the PV manufacturer Silcio (base case) specifications and subsequently on the PV technology, multi-Si) reduction in the power of the module tested under STC (Standard Test Conditions). The new maximum power obtained was multiplied by the sun hours per month to compute the final energy output.

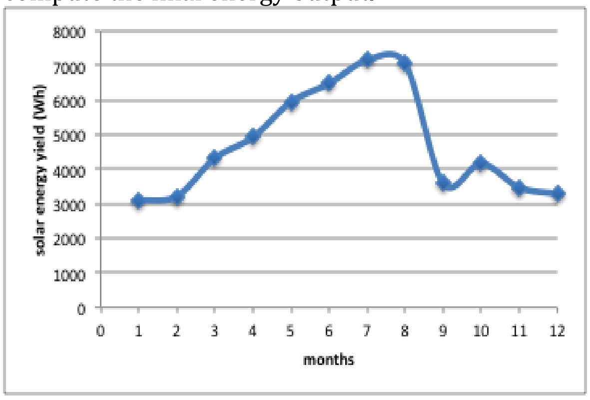


Fig. 5 Energy yield from multi-Si module in Mykonos

The total energy yield from our 20W nominal power solar module during a whole year is estimated at 56.6591 kWh. For simplicity reasons it will be from now on used the value of 56kWh. The calculations have been made using excel and analytically, the results can be found in the annex.

Results and Discussion

System Network
The system under analysis, i.e. the life cycle of our product named G-SOL is presented below. Fig. **6**, which follows, represents partially the

whole system. A cut off percentage of 0.7% has been applied and only the top part of the network is shown. The cut-off percentage indicates that processes that contribute less than 0.7% are not shown. It is useful to first briefly explain the network presented in Fig. **6**. As can be seen there are different boxes with different colours. The green colours represent materials, the olive oil colour energy usage, the blue assemblies, the yellow life cycle and the pink waste treatment. Further, next to each box there is a thermometer, which represents the environmental contribution to climate change. The thermometer is red when it is a negative effect and green when it is positive. Climate change is measured in kg of CO_2 – equivalent.
In the life cycle of G-SOL are included the raw material extraction, the manufacturing of the materials used for building up the product, the use phase and the disposal scenario. For the raw material extraction and the manufacturing of the materials used in the product, generic data from the libraries of SimaPro has been used. For the manufacturing of the aluminium pole literature data has been used [22]. Transportation from the industrial facilities of the suppliers have been considered and calculated based on approximately the real distances 11. Furthermore, transportation from our facility till Mykonos island has also been taken into account. For the use phase we have considered 5 years of usage. For this time period we calculated the solar energy yield in the previous chapter. The same amount of energy, produced though from the grid, was set as an avoided product during the use phase. By doing so, the positive environmental effect of using PV modules could be directly represented in the network. Finally, for the waste scenario the components of the parasol are disposed as follows:

- The aluminium pole is recycled;
- The battery is treated under hydrometallurgical treatment for batteries;
- Textiles and the PV module are sent to MSW, considering average landfill values for Greece, Spain, Portugal:
- The PCB is treated as scrap printed wiring board with shredding and separation.

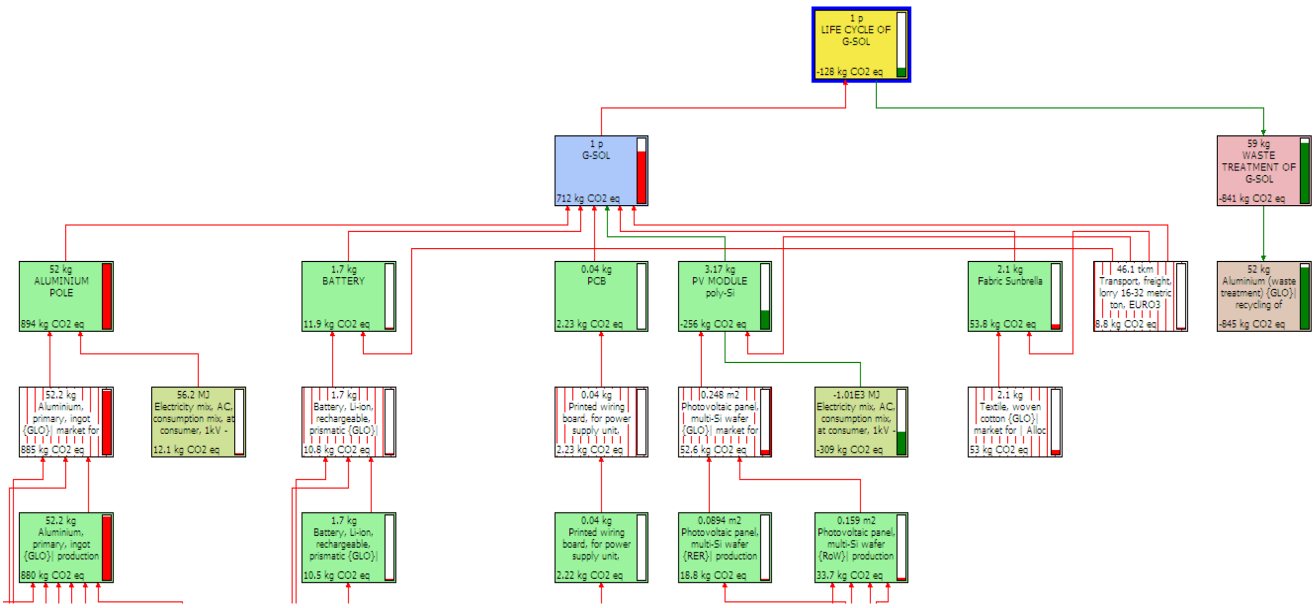


Fig. 6 Base case system network

As can be observed the highest contribution to climate change is from the production of the aluminium pole, specifically 894 kg of CO_2-eq. It is followed by the woven cotton fabric with 53.8 kg of CO_2-eq., the battery and last can be found the PCB. On the other hand, the PV module has a positive contribution of 256 kg of CO_2-eq. since it has been accounted that the amount of energy which produces, which would have otherwise been generated from the grid. More specifically, from the production of the multi – Si PV panel there is negative contribution of 52.6 kg of CO_2-eq. and from the avoided energy generation from the grid a positive contribution of 309 kg of CO_2-eq.,.
Besides the materials and processes that G-SOL consists of, the assembly is completed with the transportation. It can be observed that the transportation by freight trucks has 8.8 kg of CO_2-eq emissions while the transportation by ships is not essentially contributing to the final carbon footprint. Last but not least, the biggest

positive contribution stems from the waste treatment and especially from the aluminium recycling, which indicates the importance of recycling in the case of using aluminium as the basic production material.

Characterization results per group of processes

A quite useful and interesting representation of results is per group of processes. Four different phases were defined: use, transportation, waste (treatment) and top. The avoided energy from the grid was defined as use phase and in the transportation we solely included the transportation from and to our facility in Bulgaria. In other words, only the transportation, which is directly linked with our operations was accounted for. Finally, "top" groups all the other processes.

Fig. **7**presents the results per group. It can be seen that the role of transportation is not significant. Its contribution is limited in 5-6 categories while in the category climate change it is even indiscernible. On the other hand, the use phase positively influence the environmental load, in particular the categories acidification, particulate matter and climate change.

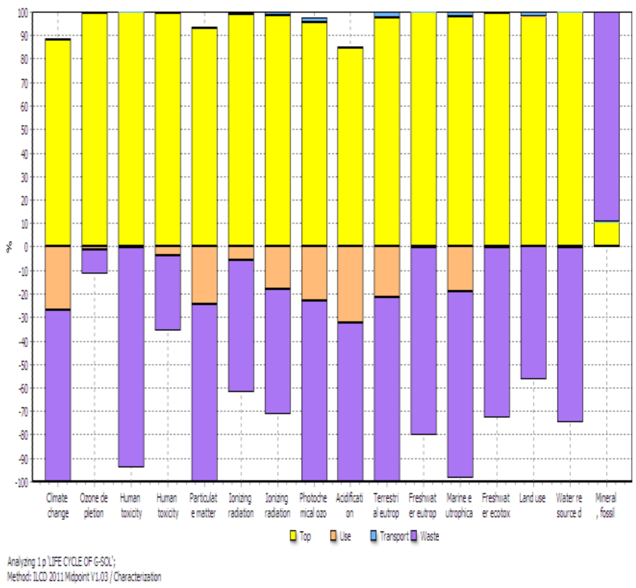


Fig. 7 Results analysis per group of processes

Comparative analysis

In this section the three different PV module suppliers/technologies are examined: poly-crystalline silicon (which is the base case scenario), mono-crystalline and amorphous silicon.

System parameters

Using different modules sequence that some parameters are changing.

Table 1: System parameters based on the photovoltaic technology

PV technology	Supplier	Location (for transportation calculations)	PV module area (m^2)	PV module weight (kg)	Fabric weight (kg)
poly-Si	Silcio Solar technologies	Patra, Greece	0.2484	3.17	2.1
mono-Si	Munchen Solar	Munich, Germany	0.19	2.47	2.12
a-Si	Global Solar	Shenzhen, China	0.4138	1.44	2.05

The table above indicates that by changing solar module, other parameters are also changing. This is a result of different solar module efficiencies, which is translated into change in the module area. Subsequently, it changes the area that the fabric occupies on the cap of our parasol. It has to be stated that besides the weight of the photovoltaic and the fabric, it is also altered the final weight of the product. These changes even though are small in the range of one to two kilograms.

Results

We took into account the parameters' alterations described previously and we followed the same procedure as in the base case scenario in order to create assemblies and life cycles into SimaPro. By doing so, we ended up with Fig. **8**.

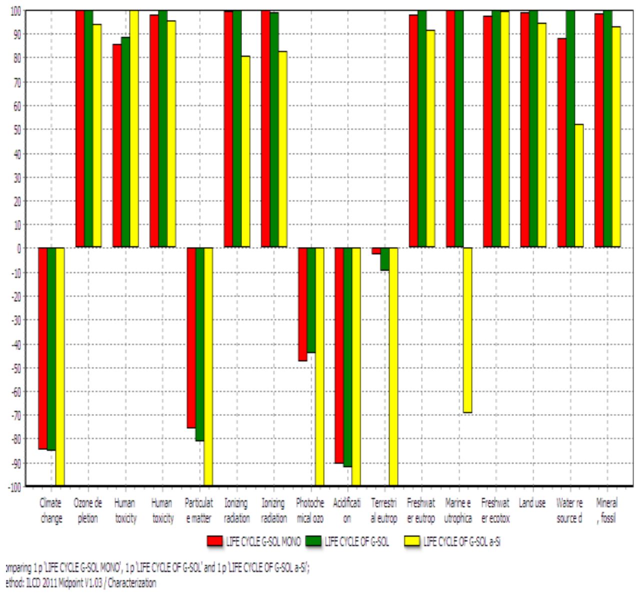


Fig. 8 Comparative LCA based on different PV technologies

It can be observed, initially, that the scenario, which uses amorphous silicon as the PV technology results in a better performance in terms of life cycle assessment. More specifically,

in the category climate change, which is our main concern, there is around 16% less environmental burden. In six out of sixteen categories, the technology a-Si is positively contributing to the environment. In climate change, particulate matter, photochemical ozone formation, acidification and terrestrial eutrophication all the three technologies have positive contribution while in marine eutrophication two out of three, i.e. mono-crystalline and poly-crystalline have negative environmental influence. Last, only in two categories – human toxicity and fresh water eco-toxicity – has higher environmental load compared to the other two.
Finally, it is presented a table where the carbon footprint of the product and the product life cycle is illustrated based on the tree different modules

Table 2 Carbon footprint of G-SOL

Carbon Footprint	Multi-Si	Mono-Si	a-Si
G-SOL life cycle	-128 kg of CO_2-eq.	-128 kg of CO_2-eq.	-151 kg of CO_2-eq.
G-SOL (life cycle without end of life scenario)	712 kg of CO_2-eq.	713 kg of CO_2-eq.	691 kg of CO_2-eq.

The difference in terms of carbon footprint in between the product having as its solar module supplier Silcio Solar in Greece (multi-crystalline Si) or Munchen Solar in Germany (mono crystalline Si) is negligible. However, the Global Solar PV module illustrate a much better performance basically due to the use of amorphous silicon as PV material. The transportation from China, where the company is located, does not seem to affect essentially the positive result.

Waste treatment scenarios

In this chapter two different waste treatment scenarios will be presented and analyzed in terms of life cycle assessment.

Scenario case 4: MSW disposal of G-SOL

The base case scenario has been developed on the assumption that the aluminium pole will be recycled. What if, though, the product owner simply dispose all the components of the product into a landfill? In this scenario, we analyze the potential impacts of such an action. This is quite possible to happen due to lack of awareness or maybe incentives. In the vast majority of the cases, people prefer ease and convenience instead of putting additional effort. Therefore, it is important to observe the results of such a common action.

The Fig. **9** presents the top processes and assemblies of that scenario network. A cut off rule of 2.1% has been applied.

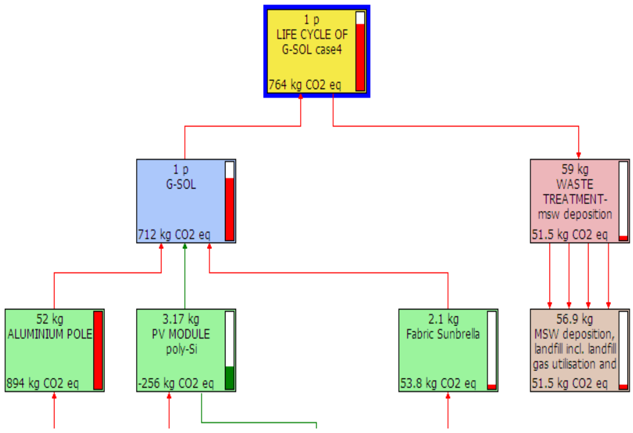


Fig. 9 MSW deposition of G-SOL

As it can be seen, the life cycle of such a scenario results in 764 kg of CO_2-eq.. More specifically, the assembly G-SOL contributes with 712 kg of CO_2-eq. and the waste treatment with 59 kg of CO_2-eq, which is an increase of around 12%. The assembly of our product has been kept the same as in the base case scenario. The difference in the final result is stemming from the disposal of it. It is clear the importance of a proper end of life treatment in order to minimize the final carbon footprint.

Scenario case 5: Solar charger for developing country

In this chapter a reusing scenario of the solar charger has been set (for the functional unit: five years of operation). In detail, it was decided to investigate the possibility of sending the solar charger, part of our product, to Pakistan through a local donation organization. In many developing countries there is absence of grid electricity or there are electricity shortages. On the other hand, mobiles are becoming, if not yet be, an essential part of people's lives in these countries (for instance paying bills or microloans through their phones). By providing these people with our solar charger, we spread awareness in these areas, providing solution to their problem, helping ourselves reduce our carbon footprint and motivating our clients to contribute for a better world.

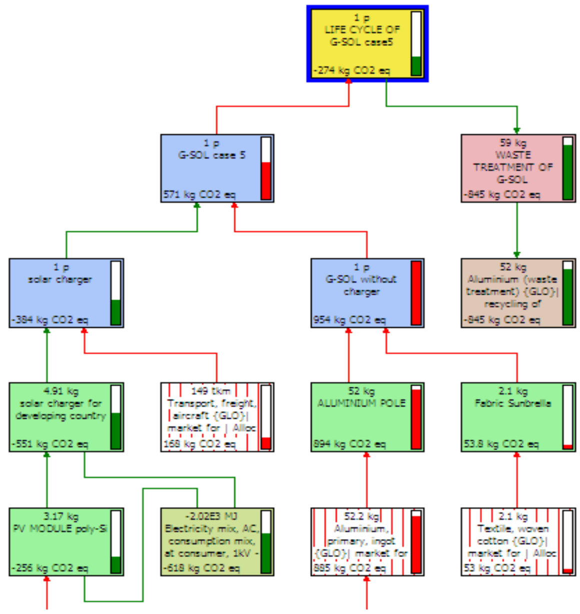


Fig. 10 Case 5 system network

The product was split into two assemblies: one is the G-SOL without the charger and the solar charger. The solar charger has its own life cycle and after five years of usage it is not disposed; on the contrary is sent through air transportation to Pakistan. The rest of the product is sent in the waste treatment already applied in the base case scenario as well. During these five years of extra life for the charger no subcomponent is replaced since their lifetime exceeds this time frame of ten years. Further, no disposal has been accounted for the charger.

The solar charger is positively contributing with 618 kg of CO_2-eq. savings during its use phase. Finally, the product solar charger has a positive contribution of 384 kg of CO_2-eq. This reduction is caused due to the PV module manufacturing and the transportation through airplane to Pakistan. On the other hand the life cycle of our product has increased its carbon saving to 274 kg of CO_2-eq., more than double of the base case scenario.

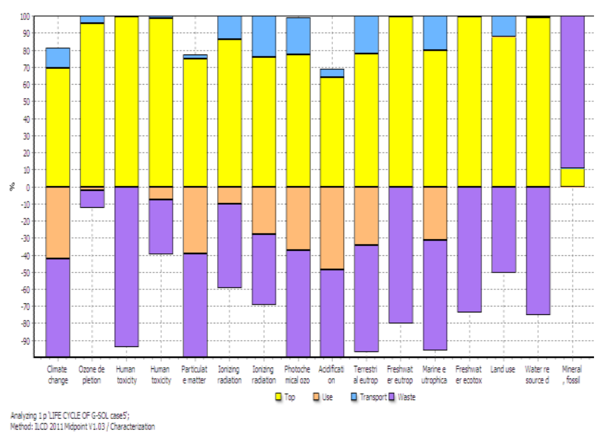


Fig. 11 Case 5: groups impact assessment

In Fig. **11** three groups have defined, i.e. use phase, transportation and waste and top includes the rest of the processes. Transportation increases the environmental impacts with its maximum value of approximately 24% in the category ionizing radiation. In the climate change it contributes around 12%. The use phase meets its highest value in acidification of 50% and climate change of 41%. It is interesting that the use phase contribution becomes comparable with the waste treatment in terms of positive effects; however the proper waste treatment for one more time is of paramount importance.

Conclusion

The initial hypothesis of green-forming G-SOL under the specific system boundaries is confirmed. G-SOL can be a parasol-micro energy charging station-which contributes positively to the environment by decreasing the total environmental burden that conventional products create. Mineral, Fossil and Renewable Resource Depletion is the impact category with the highest negative effect caused by our solution followed by Ozone Depletion while acidification with the lowest. The carbon footprint of G-SOL using Global Solar module was -151 kg of CO_2-eq. (even though its factory facility is located in China) compared to -128 kg of CO_2-eq. from the crystalline Silicon suppliers, taking into account the net effect of reducing greenhouse gas emissions from the solar electricity generation during the use phase. Furthermore, it was clarified the importance of proper waste treatment. Aluminium is the material that contributes the most to the environmental load with 894 kg of CO_2-eq followed by the woven cotton fabric with 53.8 and the multi-Si module with 52.6 kg of CO_2-eq; however recycling it at the end of the product's lifetime can lead to a positive environmental contribution reducing its carbon footprint to 49 kg of CO_2-eq. This has to be taken into consideration by the team in order to design a recycling scheme for G-RooT's products. Finally, the sensitivity analysis on the waste treatment revealed that a potential reusing of the solar charger (not by the client but by a household in the developing world) could further increase the positive carbon footprint by 36%. The latter not only improves the environmental performance of our product but also providing solution to people in developing countries and gives additional motivation to our clients to use G-SOL instead of the conventional products.

References

[1]. Business Insider Intelligence estimates, Gartner, Strategy Analytics, Company filings, World Bank 2013

[2]. Moomaw, W., P. Burgherr, G. Heath, M. Lenzen, J. Nyboer, A. Verbruggen, 2011: Annex II: Methodology. In IPCC: Special Report on Renewable Energy Sources and Climate Change Mitigation

[3]. '*UK Households' Carbon Footprint: A Comparison of the Association between Household Characteristics and Emissions from Home Energy, Transport and Other Goods and Services'*, Milena Busch, IZA DP No. 7204

[4]. Online Survey, Understanding Your Need of Technology, available as https://docs.google.com/forms/d/1rpOUSgvG50eXlnfYgRxo7FZ7uWl0305LmAf8Nsmg8Sk/viewform

[5]. http://www.prnewswire.com/news-releases/new-research-reveals-mobile-users-want-phones-to-be-more-resilient-with-longer-battery-life-233725021.html

[6]. http://www.dailymail.co.uk/news/article-550610/Nomophobia-fear-mobile-phone-contact--plague-24-7-age.html

[7]. "*Eco-Design Implemented Through a Product-Based Environmental Management System*", Kathleen Donnelly, Zoe Beckett-Furnell, Siegfried Traeger, Thomas Okrasinski and Susan Holman

[8]. *EcoDesign and the TEN GOLDEN RULES: Generic advice for merging environmental aspects into product development.*", Luttropp and Lagerstedt

[9]. ec.europa.eu/environment/ecolabel

[10]. www.carbonneutral.com

[11]. Alsema E., "*Energy pay back time and CO2 emissions of PV systems."* Progress in Photovoltaics: Research and applications", 2005, p. 17-25

[12]. Aulich H. A., Schulze F., "crystalline silicon feedstock for solar cells." Progress in Photovoltaics: Research and applications", 2005, p. 141-147

[13]. A.J.D. Lambert, "*Life Cycle Analysis including recycling",* Sarkis 2001, Greener Manufacturing and Operations, Sheffield: Greenleaf publishing, Ch.2, p. 36-55

[14]. www.alumil.com

[15]. www.sunbrella.com

[16]. www.lithiumion-batteries.com

[17]. www.enfsolar.com

[18]. Ftenakis V., Alsema E., 2006, *"Photovoltaics anergy payback time, greenhouse gas emissions and external costs: 2004 – early 2005 status"*, Progress in Photovoltaics: Research and applications 14, 275-280

[19]. Ftenakis V.M., 2004. Overview of potential hazards. In: Markvart T., Gastaner L. (Eds.), *Practical handbook of Photovoltaics: Fundamentals and applications*. Elsevier

[20]. Viorel Badescu, *"Time dependent model of a complex PV water pumping system",* DOI: 10.1026/S0960-1481(02)00069-1, Elsevier

[21]. www.solargis.info

[22]. www.apostaseis.gr

[23]. Fraunhofer Institute for Systems and Innovation Research, "*Methodology for the free allocation of emission allowances in the EU ETS post 2012 – Sector report for the aluminium industry",* November 2009