

Using Life Cycle Assessment to Determine the Environmental Impacts Caused by Solar Photovoltaic Systems

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Abstract. The paper presents research that investigated the Life Cycle Assessment of multi-crystalline photovoltaic (PV) panels, by considering environmental impacts of the entire life cycle for any solar PV systems. The overall manufacturing process of a solar PV panel ranging from silica extraction, crystalline silicon ingot growth, wafering to module fabrication and packing of the solar PV panel. The results from this research showed that the module assembly and cell processing of the manufacturing process contributed towards the main environmental impacts of the life cycle of solar PV systems.

1 Introduction

The initial concept of Life Cycle Assessment (LCA) began in 1960's with concerns over energy resources and raw materials of a products life and finding ways to minimise the energy use [1]. In 1963, Harold Smith reported his initial calculations at the World Energy Conference for calculation of cumulative energy requirements for the manufacturing of chemical intermediates and products [1].

LCA is a tool for environmental management, which is not applicable to all decision-making process, to solve a problem. It considers environmental; problems such as resource consumption, human health, ecological environment and does not consider, social or economic effects such as costs, public image, quality, performance etc. Hence, the decision-making process should involve another type of assessments and information. LCA methodology does not consider environmental law and regulations, which is an important aspect for any organisation dealing with environmental policy and decision-making process [2].

LCA analysis is a method that calculates the environmental inputs and outputs of a process or product from which the results are extensively used in energy technologies to evaluate the research and development funding and in formulating energy policies. The European community publication [3], was used by decision makers and reflects when compared to any other technology, PV have higher environmental impact e.g., Greenhouse gas (GHG) emissions of 180g carbon dioxide/kWh in Germany, 10 times higher GHG emissions of nuclear fuel cycle and 45% of combined cycle (CC) natural gas power generation [4]. This indicates that fossil fuel consumed during the production of material used for the manufacturing of multi-crystalline solar PV. The data used in this study was outdated and few assumptions were invalid and the LCA

methodology is used to calculate the environmental impact of multi-crystalline PV technology based on the latest data. Since 1970 major research has taken place in the field of solar PV with few instances where the amount of energy required in the production of solar cells to the finished products is calculated [5].

Technically, LCA is not a scientific methodology as it considers both subjective and objective components. The subjective components include assumption, choice and value 18 judgements such as the selection of data sources, the selecting of environmental damage types, system boundaries, the selection of calculation procedures, evaluation process etc. Circulatory effects are the common problem in the boundary definition. It means one must know the complete LCA of all the components of related material and process to analyse the LCA for any material or process, which is next to impossible. The subjective components consist of trade-offs, hypothesis and value judgments. Therefore, LCA results in consists of detailed explanations of the assumption made, information obtained and scientific methods behind the subjective judgements. Time and geographic location also play an important role in LCA results. Environment data might change with different geographic scope and time, so the calculated results are limited to a specific location and time-period.

2 Methodology

This research which is related to Life Cycle Assessment (LCA) of solar PV systems and will be conducted covering the following points:

- Determination of system boundaries (goal and scope).
- SimaPro software will be used to analyse the data to conduct LCA on solar PV systems.
- Interpreting the results obtained from the SimaPro Software.

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Life Cycle Assessment (LCA) is a highly recognised method to evaluate environmental impacts of a system or product [6]. The structure of the LCA methodology has been well established by the International Standard 14040 (ISO 2006b) [7]. The LCA framework as shown in

Figure 1 is done in four phases, which are:

- Goal and Scope Definition
- Inventory Analysis
- Impact Assessment
- Interpretation

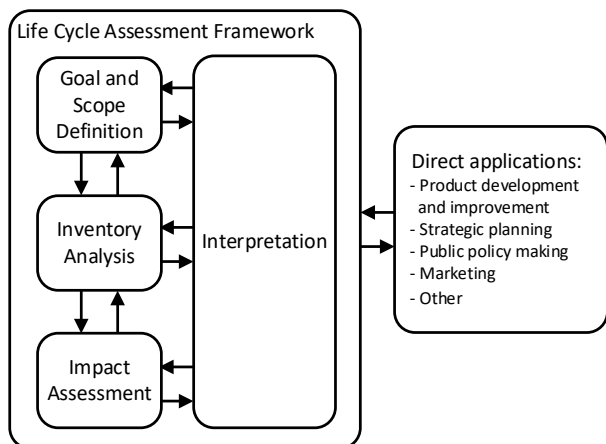


Fig. 1. Framework of Life Cycle Assessment

2.1 Goal and Scope

The most important step in LCA is to determine the goals, scope, and functional unit, which provides a basis to decide the relevant global, regional, or local environmental metrics. Wherever needed researchers must determine assumptions and requirements of data before setting the boundaries.

The goal choices for LCA experts need to be determined based on the intended viewers, application, and study scope. The functional unit is a key element of LCA which must be clearly defined. The functional unit is a measure of the function of the studied system and it provides a reference to which the inputs and outputs can be related.

2.2 Inventory Analysis

Life Cycle Inventory (LCI) is the collection of study data pertaining to the flow of material and energy. It is the process of quantifying the raw material requirement, energy, solid waste, atmospheric and waterborne emissions and other releases for the whole life cycle of a process, product or activity. This data is obtained from the available literature, general databases, LCI databases, or a combination of these sources.

2.3 Impact Assessment

This phase evaluates the environmental and potential human health impacts of the environmental resource. It addresses the resource depletion, ecological and human

health effects. It attempts to create a relation between the process or product and its potential environmental impacts.

Also in this phase, interpretation of inventory and impact assessment is drawn to recommendations and conclusions. For this, sensitivity, uncertainty analysis and peer review would be performed as recommended by the International Organisation Standard ISO 14040.

So, system boundaries were defined as follows:

- Quartz mining
- Metallurgical smelting
- Silicon purification
- Polycrystalline ingot
- Wafer slicing
- Cell processing
- Module assembly

These are shown in Figure 2 along with the inputs and outputs.

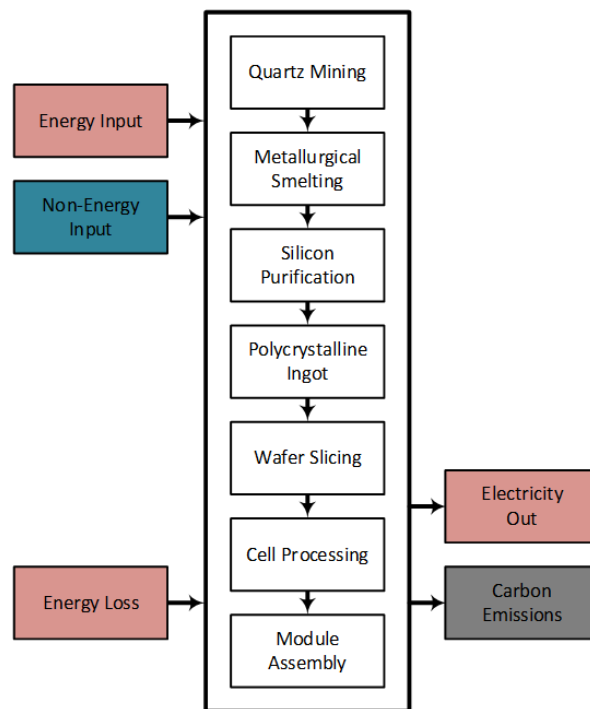


Fig. 2. System Boundaries for solar PV module

To analyse the LCA it was necessary to create a material flow structure for the solar PV module as shown in Figure 3. The material flow was divided into four stages from beginning to the end process such as (a) metal extraction, (b) pre-manufacturing, (c) manufacturing and (d) module assembly.

3 Results

Once the material flow was fixed, materials were set up in the SimaPro software to perform the analysis. The flows as shown in Figure 3 between all the constituents of the solar panel, a small cut-off was made to have a better overview of the most important process and material flows.

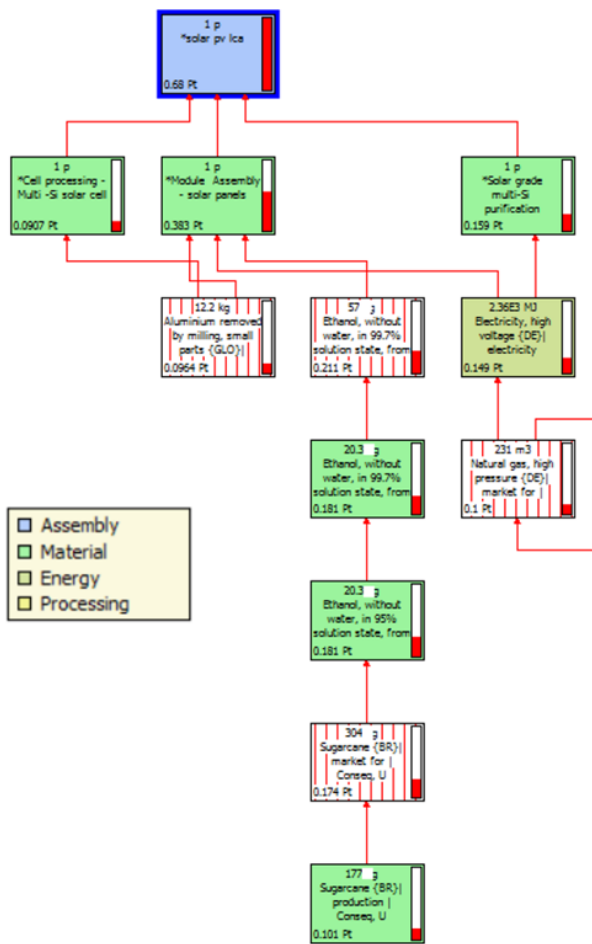


Fig. 3. A scheme of LCA for multi-crystalline solar cell

This scheme determines all the material used in the manufacturing process of solar PV from cradle to grave. All the materials used in the process are fed into the software to calculate the environmental effects. The impact assessment method IMPACT 2000+ was used for this analysis where the impacts are generally categorized by damage to human health, ecosystem quality and resources. It is an end damage assessment method and easily understandable to all through its various impact categories. The major part of the environmental impacts

during the whole lifecycle of a solar module is expected to stem from the production and processing of the different components. A categorization of these components obtained from SimaPro, according to their individual contribution to the environmental impact is shown in Figures 4, 5 and 6.

The results obtained in Figure 4, shows human health, resources and climate change have highest impact coming from the cell processing and module assembly. However, category ecosystem quality has the least impact on the environment.

The results in Figure 5 shows that the module assembly and cell processing have the highest impact on human health, ecosystem quality, climate change and resources. However, ingot casting, metallurgical silicon smelting and wafer slicing have considerably less impact on the environment.

The results in Figure 6 shows, emissions that are harmful to human health, such as carcinogens and respiratory inorganic, Aluminium constitutes the highest contribution. This can be explained by the aggressive emissions (SO₂, carbon dioxide, and PFC, PAH etc.) related to each stage of Aluminium production starting from extraction to processing. Health risks related to module assembly and cell processing, however, from using different chemicals as toluene, hydrochloric acid, methyl chloroform at various production stages as shown in Figure 6. It was found, electricity consumption during solar grad Poly-Si production was one of the factors that had the most effect on the primary energy demand, Acidification Potential and Eutrophication Potential, followed by electricity consumption during cells

processing, steam consumption during solar grad Poly-Si production, aluminium and glass consumption during modules assembly. Electricity consumption during solar grad Poly-Si production was also the factor that had the most influence on the Global Warming Potential and Photochemical Ozone Creation Potential, followed by electricity consumption during cells processing, aluminium consumption during modules assembly, steam

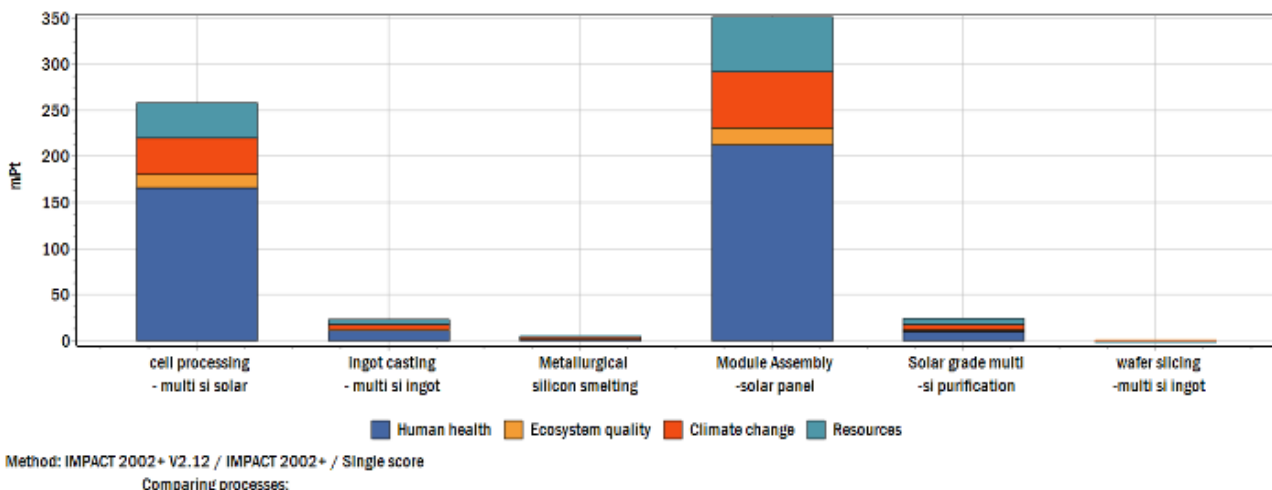


Fig. 4. Single score graph comparing processes

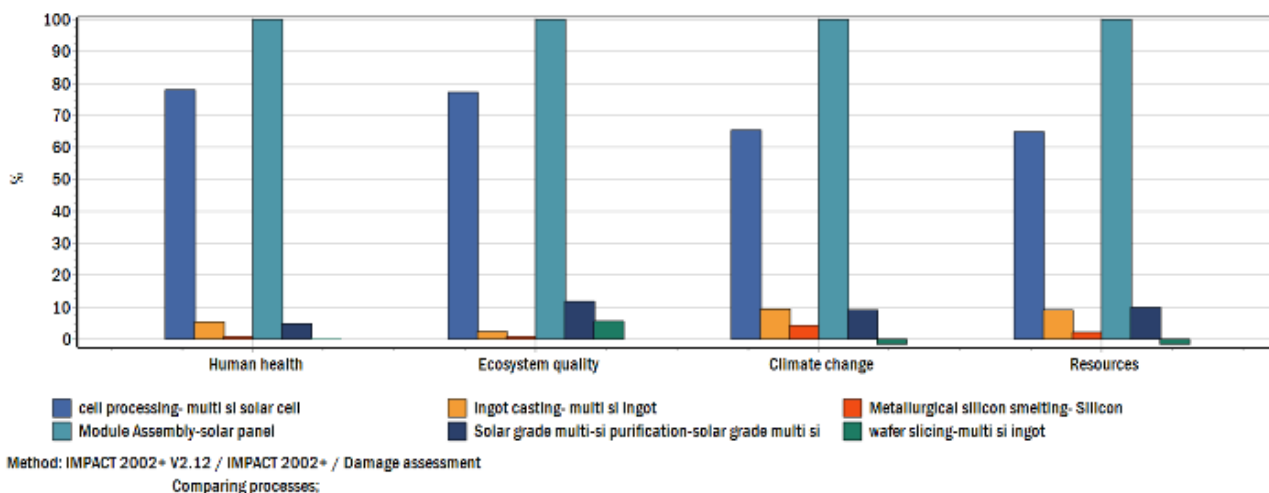


Fig. 5. Damage assessment for solar module life-cycle

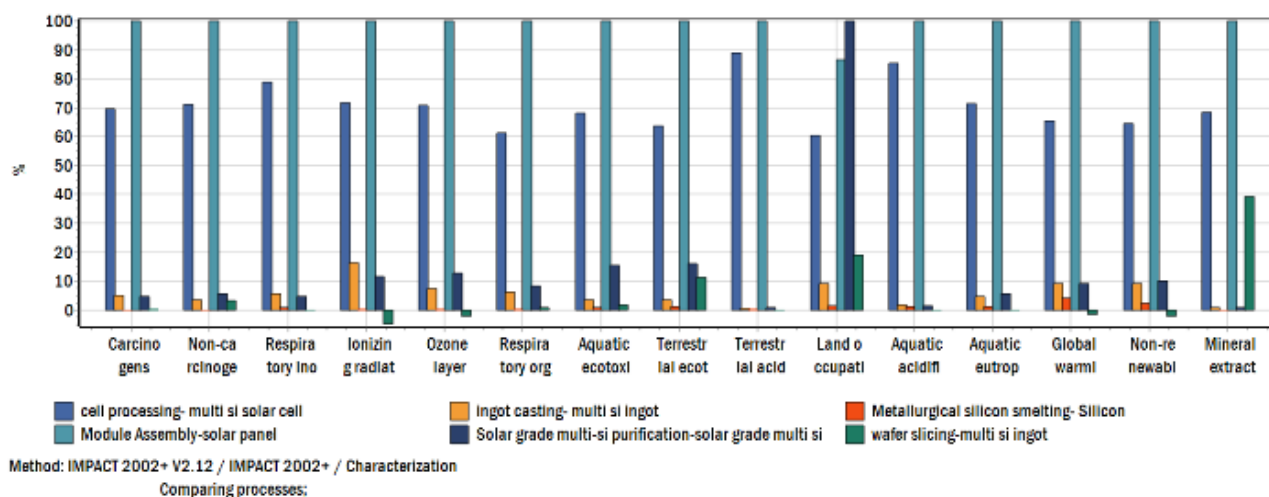


Fig. 6. The individual contribution to the environmental impact of the production of different components of a solar cell

consumption during solar grad Poly-Si production, and glass consumption during modules assembly.

3 Conclusion

Using SimaPro software, the environmental impacts and energy demand were compared with other forms of energy generating systems as per kWh of electricity generated. It was found that the environmental impacts and primary energy demand were far less when compared with coal-fired electricity production. Therefore, using coal-fired plants with PV plants will improve the primary energy demand tremendously. PV technology has improved in terms of efficiency and cost in last few decades, so with the help of subsidies and government incentives, implementation of PV technology in conjunction with other energy production systems is more feasible. Most of the impacts come from the production and the processing of its different components. The LCA showed that the module assembly and cell processing constitute the major contribution to most of the impact categories. It also showed the obvious correlation between energy consumption and environmental impacts from the fact that the most energy consuming processes were also those with the highest

negative impacts both to the environment and human health. The module assembly and cell processing were identified as the most energy consuming processes. To reduce the energy required for solar cell production, the efforts should therefore mainly be concentrated on making improvements in these two processes.

4 References

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