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Environmental impact of PV cell waste scenario

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A B S T R A C T

Rapid growth of the volume of waste from PV cells is expected in the following years. The problem of its utilization seems to be the most important issue for future waste management systems. The environmental impacts of the PV recycling scenario are presented in the manuscript. The analysis is based on the LCA approach and the average data available in specialized databases for silicon standard PV cell is used. The functional unit includes parameters like: efficiency, composition, surface area. The discussion on the environmental impact change due to the location of the PV production and waste processing plants is presented in the manuscript. Additionally, the discussion on the environmental effect of substituting different energy resources with PV cells is presented in the manuscript.

The analysis of the PV cell life cycle scenario presented in the article was performed using the SIMA PRO software and data from Ecoinvent 3.0 database together with additional data obtained from other sources.

1. Introduction

The policy of introducing renewable sources of energy, apart from positive environmental impacts, will lead to the increase of a waste stream from, among others, solar power plants. Forecasts prepared for the entire EU show that in the next 20 years the waste stream from PV cells may reach 3 million tonnes per year (Klugmann-Radziemska et al., 2010). It may cause a severe environmental problems.

The waste stream of this type might be significantly higher if one takes into account technological progress and the increase of PV cells efficiency associated with it. This in turn will result in pressure to replace old cells with new ones more quickly. Moreover, the loss of cell's efficiency during its life cycle should be taken into account as well. That is why, the subject of recycling of waste from PV cells becomes highly relevant. Based on past experience it cannot be clearly said whether particular waste will be suitable for processing or if processing will be economically and environmentally justified.

The reliability analysis of the environmental effects of the use of photovoltaic panel should be complete and comprehensive. This means that the assessment should be based on the LCA approach and contain all the elements relevant to the different phases of the life cycle: production, use and disposal of waste. Due to a rapid development the PV panel technology, the recycling options can change significantly as well. The model of environmental impact assessment for PV cells is presented in the manuscript. The scenario includes all unit processes together with energy and material flows. This is the basis for evaluation of environmental loads related to the consumption of all materials used in the production and utilization of modules and it should be included in the analysis.

The sensitivity analysis should be carried out together with the environmental evaluation. It shows the influence of unit processes and environmental impact on emission in different phases of the LCA. On this basis, the weighting of environmental effect linked to a particular element should be described and finally the selection of elements of major importance should be made.

2. Tools and methods

Life cycle assessment (LCA) is a multi-step procedure for calculating the lifetime environmental impact of a product or service. The complete process of LCA includes goal and scope definition, inventory analysis, impact assessment, and interpretation.

LCI is the life cycle inventory, which is the data collection portion of LCA. LCI is the laid out and aggregate collection of every element included in the system. It consists of detailed tracking of all the flows in and out of the product system, including raw resources or materials, energy by type, water, and emissions to air, water and land by specific substance. The analysis should be extremely

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complex and should involve all processes and all inputs of individual unit processes in LCA. There are many methodologies based on LCA approach. One of them is ReCiPe, which was chosen for calculations presented in this manuscript.

2.1. ReCiPe

ReCiPe is a methodology which connects the midpoint and the endpoint of the environmental analysis by using many categories of impact which are divided into groups. The method has been given the name ReCiPe as it provides a 'recipe' to calculate life cycle impact category indicators. The most important feature of ReCiPe is its ability to transform a long list of LCI results into a limited number of indicators. These indicators represent a relative impact on natural environment. There are two levels of indicators in ReCiPe methodology. They are divided into eighteen midpoint and three endpoint indicators.

The eighteen midpoints are fairly accurate but hard to interpret. Three easy to understand but more general end categories are: Human Health, Ecosystems and Resources.

The method allows to choose between types of indicators and facilitates the process of correct interpretation. The advantage of this method is the ability to deliver one environmental indicator based on implementing midpoint indicators. Individual weights for particular categories are implemented in the software which is used as an analytic tool, e.g. SimaPro. Weights can be modified if the importance of particular categories of environmental impact changes. Weighting is transforming the value of indicators into numeric parameters by assigning a certain amount of points to each category of impact. A unifying unit is the midpoint (Pt). It is the measure of environmental impact that one European has within one year.

2.2. Goal and scope

The aim of this analysis is to study the environmental impact of the full life cycle of a PV cell and to determine the importance of recycling processes for overall environmental impact. An additional element is the assessment of an environmental relief related to substituting electric energy produced in a standard energy mix with energy produced in the PV panel. Production process data with division to unit processes were derived from literature (Stoppatto, 2008). Transportation, usage and recycling data is authors' own elaboration based on various literature and database sources (Stoppatto, 2008; Alsema, 2000; Varun and Ravi Prakash, 2009; Mroziński, 2010).

The environmental effect of recycling processes is defined as a benefit resulting from the decrease in primary raw materials consumption. It is the environmental relief equal in size to environmental impact related to the acquisition of raw materials recovered in recycling processes. Environmental costs related to energy consumption of processes of preparing waste and their recycling are of no significance and are omitted. The analysis is divided for 4 stages: production, transport, use and waste scenario. The LCA analysis concerns of 1 example PV module included assumptions:

- work for 28 years,
- daily average insolation of 1000 W/m^{2,}
- production of 3200 kWh,
- transport PV panel 12,000 km by sea and 1000 km by land,
- material recycling for some of material was established.

The evaluation presented in this article includes production and transport stage, and a waste scenario based on recycling. There is no negative environmental impact of the cell's operation during its life cycle. But within this period, electrical energy is produced and it substitutes the energy produced in power plants specific to a given energy mix. The negative environmental impact that would have been created if the energy produced in PV cells had been produced in these power plants is treated as the environmental relief. For the purpose of this analysis it is assumed that the total amount of the substituted electrical energy comes from Poland, France and Norwegian. Data for this types of power plant was taken from Eco-invent database. The recycling process are different for different substances. The analysis presented in this manuscript shows the maximum level of possible environmental relief gained due to recycling process. This was done according to the assumption that all substances used to produce PV panel from virgin material will be replaced with recycled ones. It means that environmental relief due to recycling equals the environmental impact of obtaining raw materials used for PV cell production. It should be underlined that is represents the maximum level of environmental relief data could be gained. The results are ideal for feasibility studies of recycling of PV panels and shows the ideal level of reduction of environmental impact due to recycling.

3. Results and discussion

The final result of the environmental analysis depends on a great number of input for particular stages of a life cycle. The general outline adopted in this research paper is shown in Fig. 1. The LCA analysis of 1 PV module is closely related to the assumptions presented in Section 3.1.

3.1. LCI

Aggregated data for photovoltaic panel production are presented in Table 1. A functional unit that all the data is converted into is 1 module and it contains 36 single wafers with the size of 12 cm × 12 cm × 12 cm^2. The surface of the module is 0.65 m^2 and its assumed efficiency is 16%. It is assumed that the module will work for 28 years with the daily average insolation of 1000 W/m^2. It amounts to production of 3200 kWh during the full life cycle of the panel. Fig. 3 illustrates the environmental impact of producing the same amount of energy in hard-coal fired power plant. It is assumed for the recycling stage that only copper, solar glass, aluminium and silicon are recovered. The possible level of recovery is assumed from literature and it is respectively 90% for copper, solar glass and silicon, and 100% for aluminium (Appleyard, 2010). It is assumed for the transportation stage that the length of the transportation route is 12,000 km by sea and 1000 km by land. Data for this calculation was taken from Eco-invent database.

3.2. Midpoint results

The analysis of the production process itself of 1 photovoltaic module with adopted parameters has been made and the results are presented in Fig. 2. They contain unit loads of individual components of the analysis in 18 categories of impact. The biggest environmental load are aggregated emissions from the production process. In as many as four categories of impact: Climate Change, Terrestrial Acidification, Photochemical Oxidant Formation and Particulate Matter Formation, the emission constitutes over 60% of the load in a given category. Electricity is another element with a significant impact. For the purpose of the analysis it is assumed, based on the database, that it is electricity produced from hard coal. It stems from the fact that the production of most of the panels is carried out in China, where the majority of energy comes from this source. Apart from the Climate Change category, the high

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