Espace-PV: Key Sensitive Parameters for Environmental Impacts of Grid-Connected PV Systems With LCA

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ESPACE-PV: KEY SENSITIVE PARAMETERS FOR ENVIRONMENTAL IMPACTS OF GRID-CONNECTED PV SYSTEMS WITH LCA

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ABSTRACT: The study of sensitive parameters for the life cycle analysis (LCA) of PV system showed that irradiation intensity will bring the biggest variation on environmental impact when considering regions with large difference in solar irradiation level. For example, in France a system installed in the northern region will produce electricity with more than a 100% of the impact of a southern system. Other important factors are the lifetime of the system and the associated electricity use for the different components needed for the PV system. They can bring up to 35% of variation in the production of CO_2 gas and primary non-renewable energy use. This study has been developed within Espace-PV project and results have been analyzed and compared with the EcoInvent database. These results are provided for a 3 kW_p multicrystalline grid connected system integrated in a slanted roof with near optimal inclination.
Keywords: Environmental effect, LCA, PV system & irradiation intensity

1 INTRODUCTION

With the high increase in PV system production and solar energy use for many countries in Europe the question of reliable environmental impact assessment needs to be address quickly. LCA allow to assess these environmental impacts by covering the whole life cycle including its production phase, its use phase and its end of life. Among different international initiatives, the EcoInvent database is reporting extensive solar system inventories [1,2]. This database has been created within the Crystal Clear project [3] . In this database, many aspects are considered such as the type of technology used for solar cells, the type of solar panels, the type of installation or the system power level. However, most of the EcoInvent PV inventory results are site specific and a new project has been launched by our team (ESPACE-PV) to investigate and to identify key design parameters for an optimal PV system in terms of technical production/options and location. The Espace-PV model analyzes the variations a system would undergo if it was built in France and was producing electricity on the French territory. It will also assess the impact of variation of a change in the lifetime length. The lifetime length will be based on an acceptable guaranties range offered by PV companies. To start the analysis we will consider global warming (g. of CO_2 eq./kWh) and non-renewable energy (MJ/kWh) indicators as key LCA outputs. To evaluate the level of variation on environmental impacts we will compare the results of the Espace-PV model with values from the EcoInvent database (EcoInvent model) using Simapro 7.1. The results will underline key issues where industry should focus to lower environmental impacts of grid-connected PV systems.

To explain how we did the LCA for the Espace-PV model we will first present a list of characteristics (scope of study) and hypothesis made to create the model. Then an analysis of the computation results will underline the most important aspect of the system to minimize the environmental impacts.

2 SYSTEM AND HYPOTHESIS

2.1 Scope of Espace-PV study

The LCA is done for the production of electricity with an integrated PV multicrystalline installation of 3 kW_p on a slanted roof. The total surface of the system is 23.47 m² and it uses 1 inverter of 2500 W at a time which is considered to have a lifetime of 5 years. The installation is considered to be optimized by having a roof facing the southern direction at an inclination angle of 45°. Energy production performance of the PV system is assumed to be 13.2 %. From this information and solar irradiation data [4], electricity production during the entire lifetime of the PV system has been assessed. Lifetimes of 20, 25 and 30 years have been considered.

The reference system to be compared with Espace-PV model is issued from process network (EcoInvent model) is based on a system of comparable installation characteristics producing electricity in Switzerland for 30 years. The different production processes of this model are used as a basis for creating the Espace-PV model processes network. Figure 1 present the simplified network used for our model.

2.2 Hypothesis

The EcoInvent process network is based on assumptions defining the LCA validity. First, the MG (Metallurgic Grade) silicon values are taken from the Norway production with electricity production mainly based on hydroelectricity. Second, the solar grade process is based on one type of production scheme where, the values are averaged. The solar cell production values are for a typical fabrication process which might not represent the impacts of all the new possible techniques used today on the market.

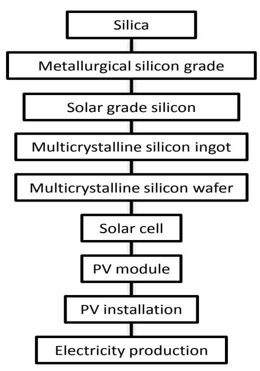

Figure 1: Simplified Process Network used for the Espace-PV model.

All the data references for the previous process are based on numbers compiled in 2005. However, the cell productions is not inducing significant variation for the CO_2 production and non-renewable energy use which are the two impacts that we analyze. Finally, the PV installation of the EcoInvent database is using 2.4 inverters over the 30 years lifetime which means that the lifetime of one inverter is averaged to 12.5 years. Within Espace-PV model we decided to base our calculation on an average of 1 inverter every 5 years which relates to current market guaranties.

At this time, Espace-PV changes made in the EcoInvent inventories input data and energy sources are based on partial data or average from simple calculation (irradiation level). The important changes in Espace-PV model are the source of electricity for each of the steps between multicrystalline silicon ingot process and electricity production process. The EcoInvent model uses Swiss electricity mix values and the Espace-PV model uses the French electricity mix values. Also, the silicon grade process is changed from the use of hydroelectricity combined with gas cogeneration to the French high voltage electricity mix. We should also say that the EcoInvent network uses 3 different sources of silicon (EG (15%), EG off grade (5%) and solar grade (80%)), where we decided for the Espace-PV model to only use solar grade silicon as it will probably represents the coming situation in Europe where plants dedicated to solar grade silicon are currently being built.

3 RESULTS AND ANALYSIS

3.1 Environmental impacts

When considering the site of solar energy production the variation of irradiation in France can vary the impacts by more than a 100%. Figure 2 presents the results for both the CO_2 production and non-renewable primary energy over the whole life cycle with a lifetime of 25 years.

The values of irradiation were computed from a model taking the horizontal irradiation level as an input. The calculations were made using SoDa platform [4]. When comparing the values of horizontal and inclined irradiation it became clear that an installation that is not optimized will also vary the energy production.

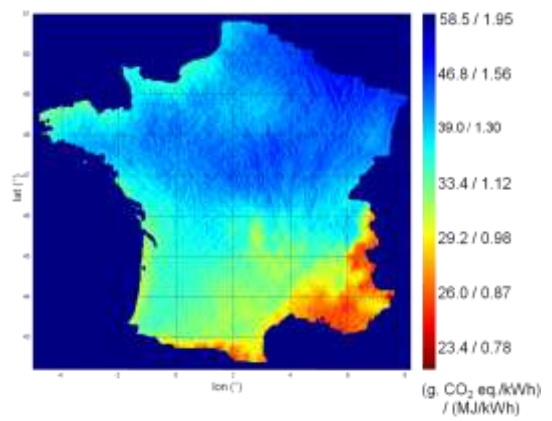

Figure 2: CO_2 production (g. CO_2 eq./kWh) and non-renewable primary energy use (MJ/kWh) for solar energy production depending on the level of irradiation over the French territory. (45° inclination + 25 years lifetime)

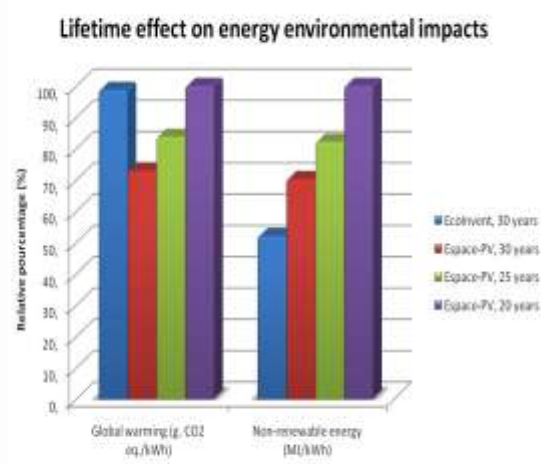

Figure 3: Lifetime effect comparison between the Espace-PV model and EcoInvent model (version 2.0).

The level of change was evaluated to be of a 35% average. So it is not only important to place the system in the best region possible but it is also important to find the optimal inclination in order to lower the environmental impacts.

Figure 3 presents the effect of lifetime over the environmental impacts. From this figure a change between a system with a lifetime of 20 years and 30 years will see a 30% increase on average.

Finally, an analysis of the contribution of each process on both the CO_2 production and non-renewable primary energy usage was made to identify the process with the biggest impact. Figure 4 presents the result of this analysis and the most important process is clearly the production of solar grade silicon whatever model we consider. On the other hand, the global warming impact is not so important within the Espace-PV model for the silicon production. This is probably due to the high contribution of nuclear energy in the French electricity mix. Also the importance of the inverter is becoming higher in the Espace-PV model since it uses 5 inverters instead of 2.4 for the EcoInvent model over a 30 years lifetime.

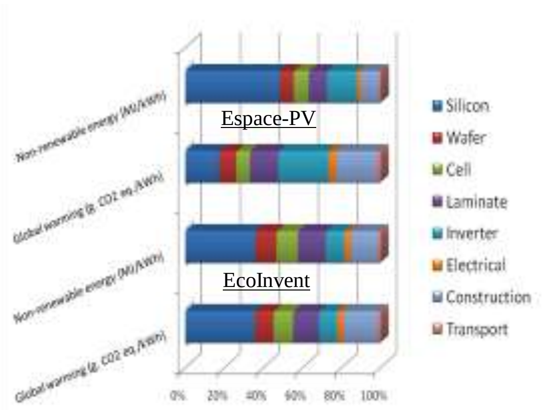

Figure 4: Process importance for non-renewable energy and global warming environmental impacts. Results from Espace-PV model and EcoInvent model over a 30 years lifetime.

3.2 Comparison

In order to gain more insight we have compared the results obtained for the Espace-PV model with values for other type of energy source and electricity mix for relevant countries. Table 1 presents these values. The non-renewable primary energy impact is higher for the Espace-PV model and this is still explained by the amount of nuclear energy used for the solar laminate fabrication. Results show that producing electricity with solar energy is always a good option in France (compared with the French electricity mix). On the other hand, production of solar energy in Switzerland would increase the environmental impact of the electricity mix if there is no way to improve the system efficiency (13.2%).

Table I: Comparison values

Energy sources	GW (g. CO_2 eq./kWh)	NREU (MJ/kWh)
Coal (EI models)‡	1090.0	12.5
Hydro (EI models) ‡	3.5	0.04
Nuclear (EI models) ‡	9.3	13.4
Solar (EI model - Multicrysalline)	54.4	0.97
Solar (Espace-PV model multicrystalline)*	23 to 59	0.78 to 1.95
French electricity mix (EI model)	89.7	11.9
Swiss electricity mix (EI model)	21.3	5.7
Cogeneration burner (EI model)	534.0	9.9

* Over irradiation range in France
‡ Average values
EI = EcoInvent models (version 2.0)

4 DISCUSSION

4.1 Comparing energy sources

The reason why the Espace-PV model brings lower level for the global warming impact is mostly due to the source of electricity for the solar grade silicon process. In the EcoInvent multicrystalline laminate fabrication process, the combination of hydroelectricity and cogeneration creates an electricity mix that generates more CO_2 equivalent than the French electricity mix. In all other process, the level of impact of the Swiss electricity mix is lower than the French electricity mix as can be seen in Table 1.

4.2 Important design parameters

According to the sensitivity studies performed through this study, it is now possible to rank some key design parameters for a French integrated multicrystalline PV systems.

1. Irradiation level dependant on the system position on the French territory affects the environmental impact by more than a 100%.
2. Installation orientation could vary on average by 35% the level of received irradiation and thus, the level of impact as much.
3. A lifetime of 20 years will carry a 30% increase on environmental impact when compared to a lifetime of 30 years
4. The Espace-PV model electricity source (French electricity mix) delivers a lower global warming impact by as much as 16% when compared to the EcoInvent electricity model for fabrication of multicrystalline laminate fabrication (combination of the Swiss electricity mix, hydroelectricity and cogeneration)
5. The Espace-PV model electricity source will increase the non-renewable primary energy by about 35% referring to the EcoInvent electricity model because of the high use of nuclear energy in the French electricity mix.

This parameters sensitivity study highlights the irradiation level to be the most important parameter to lower the environmental impact of a PV system. Then, the silicon production site should have access to the electricity mix with the lowest environmental cost and focus on the optimization of the solar grade silicon production. Finally aiming at a longer lasting system would always improve the environmental performances of a PV system.

5 CONCLUSION

The results of this LCA with regards to the sensitive parameters can guide future development of the PV industry and market to lower its environmental impact. Governmental policies should, at the very least, focus the construction of system in high irradiation environments with optimal orientation installation. Then, higher quality system with longer lifetime should be favored. The last and most delicate aspect to consider is the electricity use associated with the fabrication of all the components needed in a solar system.

To enhance the complete LCA of solar energy system it will be necessary to fully consider the effect of recycling of the system in future research. It might not be a good idea to promote solar energy for certain region or countries until the production methods are able to produce system with lower CO_2 emissions.

6 ACKNOWLEDGMENT

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