ENVIRONMENTAL SUSTAINABILITY OF CONCENTRATOR PV SYSTEMS: PRELIMINARY LCA RESULTS OF THE APOLLON PROJECT

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ABSTRACT: Energy payback time and carbon footprint have been calculated for 2 commercially available and 3 new CPV systems by life cycle assessment. Calculations have been carried out for the location of Catania, Sicily (Italy). The energy payback time varies from between 0.8 and 1.9 years. The carbon footprint varies from between 18 and 45 grams of CO_2-eq/kWh produced. The CPV systems are at varying stages of development, with different sizes and scale of production. Further development, increased size and scale of production are expected to bring a further decrease in the impacts. The largest contribution to the payback time and carbon footprint is from the tracking and module materials. Achieving high efficiencies and increasing the lifetime of the components is important to increase the kWh produced by the CPV system.
Keywords: environmental effects, concentrators

1 INTRODUCTION

Economic, social and environmental sustainability are key factors for successful application of photovoltaics. In this work the environmental sustainability of Concentrator PV (CPV) systems is investigated and compared with flat plat PV systems.

Within the Apollon collaborative EU Project (1 July 2008 – 30 June 2013) the following CPV technologies are developed [1]:

1) Point focus systems from SolarTec International based on a Fresnel lens which concentrated the light on III-V solar cells.

2) Dense array systems from CPower based on mirrors which concentrate the light on monocrystalline silicon and III-V solar cells (mirror based spectrum splitting system).

Three different technology pathways are followed comprising a starting, optimized and second generation technology. Prototype systems with the optimized and second generation modules will be installed and tested at ENEL in Catania (Sicily, Italy).

While the number of studies about the environmental impacts of flat plate PV systems is large, investigations about concentrator PV systems are scarce (Concentrix Solar [2-3], Amonix [4-6], SolFocus [7]). Results will be presented about the energy payback time and carbon footprint of the starting and optimized Apollon CPV systems plus two point focus commercial systems: (1) the Concentrix Solar Flatcon CX-7 point focus system and (2) the Amonix 7700 point focus system. The results will be given for an irradiation at the location of ENEL (Catania, Sicily, Italy). A comparison will be made with flat-plate PV systems and other electricity generation options.

2 METHODOLOGY

A Life Cycle Assessment (LCA) evaluates the environmental impact of a product or service from cradle to grave/cradle. The international standard ISO14040 describes the principles and framework for LCA. The software used is Simapro 7.2.4 with the ecoinvent 2.2 database.

The energy payback time is the time needed for the PV system to generate the energy which was needed to produce it. The energy payback time = energy input / energy output per year. Note that lifetime of PV system not included. The energy input is calculated using the "Cumulative Energy Demand" (CED) method which is the total life cycle primary energy consumption. In this study the CED 1.07 method is used as implemented in Simapro. The efficiency of the electricity supply used in the calculation is 11.4 MJprim/kWh (UCTE electricity mix).

The carbon footprint is a life cycle assessment with the analysis limited to emissions that have an effect on climate change. It is quantified using the indicator Global Warming Potential (GWP). The Intergovernmental Panel on Climate Change (IPCC) has defined the GWP100a as the relative effect of a greenhouse gas in terms of climate change considering a fixed time period of 100 years. It is expressed as carbon dioxide equivalents. In this study the IPCC2007 GWP100a method version 1.02 is used as implemented in Simapro. Standardization efforts for carbon footprinting is described in [8].

3 APOLLON TECHNOLOGIES

3.1 III-V solar cells

In the Apollon project the III-V solar cells (Figure 1) are produced by ENE using VB-Tec germanium wafers and they provided the data for this analysis.

Energy consumption for the production of germanium metal is taken from [9].

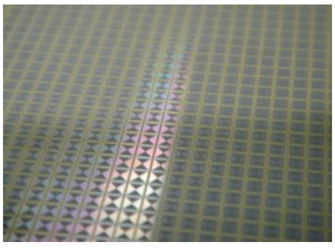

Figure 1: III-V solar cells from ENE

3.2 Monocrystalline silicon solar cells

In the Apollon project the high efficiency monocrystalline Laser Grooved Burried Contact (LGBC) solar cells (Figure 2) for the CPower modules are produced by Narec.

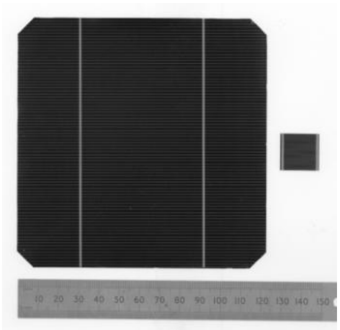

Figure 2: Optimized LGBC silicon solar cells (right) compared with a standard monocrystalline silicon solar cell of size 125 mm x 125 mm (left)

3.3. Apollon Point focus CPV systems

In the Apollon project the Point Focus systems are produced by SolarTec International. For the optimized module (Figure 3) aperture area and total module efficiencies have been obtained of 25.3% (Figure 4) and 22.0% respectively and further improvements are expected. The total module area of the system is 9 m^2.

Figure 3: Solartec optimized module

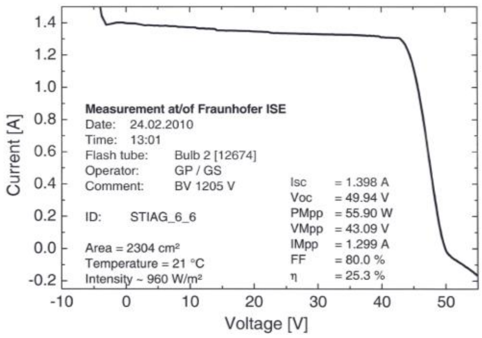

Figure 4: Solartec optimized module IV curve. Active area 0.23 m^2, total area 0.26 m^2

3.4. Apollon Dense array CPV system

In the Apollon project the Dense Array system is produced by CPower (Italy). The optimized module (Figure 5) efficiency has not been measured yet but the total area module efficiency is expected to be 21.8%. The total module area of the system is 9 m^2.

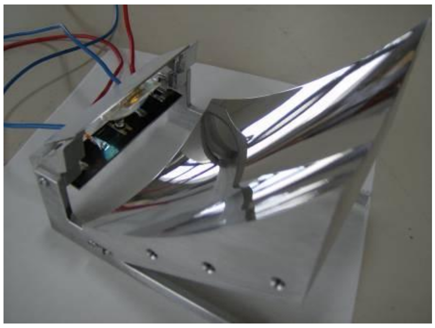

Figure 5: CPower optimized module

Figure 6: Solartec optimized tracker

4 CONCENTRIX SOLAR CPV SYSTEMS

The Concentrix Solar Flatcon CX-75 CPV system (Figure 7) is in commercial production. New confidential data for this analysis were provided by Concentrix Solar. The total module are of the system is 34 m^2.

Figure 7: Concentrix Solar Flatcon CX-75 CPV system

5 AMONIX CPV SYSTEMS

The Amonix 7700 CPV system (Figure 8) is in commercial production. Data for this analysis are taken from [6]. The total module area of the system is 328 m^2.

Figure 8: Amonix 7700 CPV system

6 PERFORMANCE OF CPV SYSTEMS

The electricity produced per year by the PV system depends on the irradiation level at the installation site and the performance efficiency of the system.

Concentrator and flat plat PV system use different parts of the solar irradiation. CPV systems can only utilize irradiation which is shining perpendicular to the module surface, the so-called Direct Normal Irradiation (DNI). This means CPV systems are typically based on some sort of sun tracking. Flat plate module however can in addition use diffuse light, called Global Irradiation (GI). In order to compare CPV systems with flat plate systems we need the correlation DNI and GI for the installation site. A plot of the correlation of DNI on a 2-axis tracker versus GI on a south-facing optimized angle (latitude tilt) non-tracking plane is given in Fig. 9. The correlation is not completely linear. Higher irradiation levels have higher ratio of DNI versus GI. This means that when going to higher irradiation locations the relative improvement in environmental performance of the CPV systems are larger than the flat plate systems. In this analysis the location of Catania (Sicily, Italy) is chosen because this is the place where the Apollon CPV systems will be installed (DNI = 1794 kWh/m^2.year, GI = 1925 kWh/m^2.year).

The performance of two commercial systems is given in Table I.

Table I: Energy generated by Concentrator PV systems (kWh/kWp.year) divided by Direct Normal Irradiation on a 2-axis tracker (kWh/m^2.year)

	(kWh/kWp.year) / (kWh/m^2.year)
Amonix 7700	1.03 [6]
Concentrix Solar Flatcon	1.04 [10]
Apollon	results expected in July 2012

7 ENERGY PAYBACK TIME

See figure 10 and table II for results.

Table II: Energy payback time of PV systems installed in Catania (Sicily, Italy). Flat plate roof-top data from [11].

	Energy payback time
Concentrix Solar Flatcon	0.6 years
CdTe	0.6 years
Si thin film	1.1 years
CIGS	1.2 years
CPower optimized	1.5 years
Amonix 7700	1.5 years
Crystalline Si	1.5 years
Solartec optimized	1.7 years

8 CARBON FOOTPRINT

See Figure 11 and Table III for results. An operational lifetime of 30 years was assumed. The design lifetime of the Amonix systems is 40 years.

Table III: Carbon footprint of PV systems installed in Catania (Sicily, Italy). Flat plate roof-top data from [11].

	Carbon footprint
CdTe	15 g CO_2-eq/kWh
Concentrix Solar Flatcon	18 g CO_2-eq/kWh
Si thin film	20 g CO_2-eq/kWh
CIGS	21 g CO_2-eq/kWh
Crystalline Si	26 g CO_2-eq/kWh
Amonix 7700	30 g CO_2-eq/kWh
CPower optimized	35 g CO_2-eq/kWh
Solartec optimized	42 g CO_2-eq/kWh

9 CONCLUSIONS

For the Apollon optimized, Concentrix Solar Flatcon CX-75, Amonix 7700 CPV systems and roof-top flat plate PV systems, assumed to be installed in Catania (Italy), the energy payback time varies from between 0.8 and 1.9 years and the carbon footprint varies from between 18 and 45 grams of CO_2-eq/kWh produced. This carbon footprint is comparable with wind and nuclear energy (11 and 8 grams of CO_2-eq/kWh produced [12]). The systems analyzed are at varying stages of development, have different sizes and scale of production. Further development, increased size and scale of production are expected further reduce energy payback time and carbon footprint.

The largest contribution to the life-cycle environmental impacts is from the tracking and module materials. With ecodesign the environmental profile of the system can be further improved. Achieving high efficiencies and increasing the lifetime of the components is important to increase the kWh produced by the CPV system.

10 ACKNOWLEDGEMENTS

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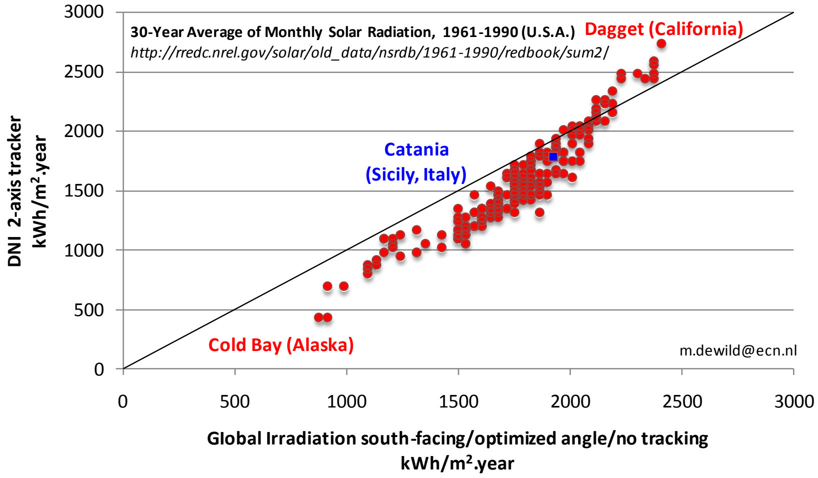

Figure 9: Direct Normal Irradiation on a 2-axis tracker versus Global Irradiation on south-facing optimized angle (latitude tilt) without tracking. Catania: 1925 kWh/m^2.year Global Irradiation, 1794 kWh/m^2.year Direct Normal Irradiation

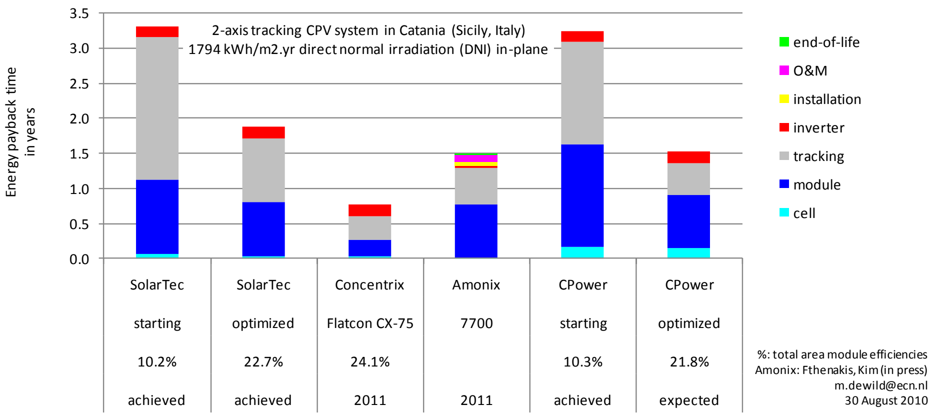

Figure 10: Energy payback time of Concentrator PV systems installed in Catania (Sicily, Italy)

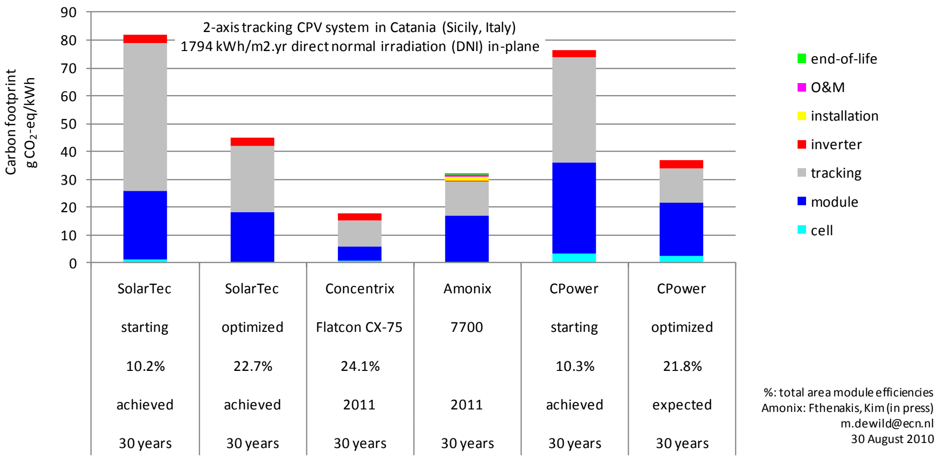

Figure 11 Carbon footprint of Concentrator PV systems installed in Catania (Sicily, Italy)