ENVIRONMENTAL PROFILE OF PV MASS PRODUCTION: GLOBALIZATION

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ABSTRACT: The globalization of the production of PV requires an analysis of the environmental impact which takes country specific production processes into account. The country electricity mix influences the primary energy needed and CO_2-equivalents emitted per kWh produced. The electricity mix used for the production of poly-silicon is often different from the country mix but also considered confidential in many cases. For the production of poly-silicon several manufacturers use hydropower or Combined Heat&Power (CHP)/Cogeneration but exact data are missing. As a result energy payback time and carbon footprint for equal factories differ based on electricity mix used. In addition to this difference due to production location the irradiation on the solar panel depends on installation location.

For commercial roof-top flat plate PV systems, the energy payback time and carbon footprint vary considerably for silicon based modules based on the actual country mix, with the low end of the range with poly-Si from hydropower and wafer/cell/module from UCTE electricity. The energy payback time and carbon footprint of CdTe thin film PV technology is less sensitive to country energy mix due to the lower electricity consumption of CdTe PV module production compared to other PV technologies For this analysis, all systems were assumed to be installed in Southern Europe (1700 kWh/m^2.year). For commercial roof-top flat plate PV systems with poly-Si from hydropower and wafer/cell/module from UCTE electricity, installed in Southern Europe (1700 kWh/m^2.year):

- Energy payback time ~0.8-1.7 years,
- Carbon footprint ~19-34 g CO_2-eq/kWh.

Concentrator PV modules use a different part of the irradiation compared to flat-plat PV modules and can only be compared for a certain installation location. Two commercial CPV systems assumed to be installed in Catania (Sicily) have energy payback times of 0.7 and 1.5 years at DNI of 1794 kWh/m^2.year (Catania, Sicily) on a 2-axis tracker. The global irradiation on optimally-inclined flate plate module on this location is 1925 kWh/m^2.year.
Keywords: environmental effect, sustainable, energy payback time, carbon footprint

1 INTRODUCTION

Economic, social and environmental sustainability are key factors for successful application of photovoltaics. The current **globalization** trend is that production of PV modules and its components is shifting to Asia (Figure 1). To compare the environmental impacts of the various commercial PV technologies we have used the same electricity mix for all of them, i.e. hydropower for the production of solar grade silicon and a European (UCTE) electricity mix for the production of wafers, cells and modules. However to calculate actual environmental impacts the actual electricity mix need to be used. This paper will show results of a technology comparison and also the impact of geography on the energy payback time and carbon footprint of commercial PV modules.

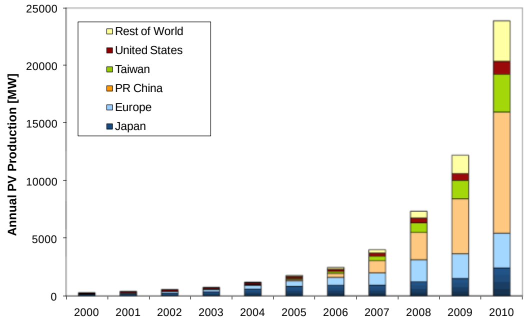

Figure 1: Global PV production [1]

2 METHODOLOGY

2.1 Life Cycle Assessment

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 in this analysis is Simapro 7.3 with the ecoinvent 2.2 database. Since the ecoinvent database is used, the ecoinvent methodology is also used for internal consistency.

2.2 Energy payback time

The energy payback time is the time needed for the PV system to generate the amount of electric energy that substitutes the amount of primary energy that was needed to produce it. The energy payback time = Primary energy input / Substituted primary energy related to the electric energy output per year.

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 1.08 method is used as implemented in Simapro. The efficiency of the substituted UCTE electricity mix is 11.4 MJprim/kWh.

2.3 Carbon footprint

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 are described in [2].

3 DATA COLLECTION

3.1 PV system production

Data were collected for recent commercial production of crystalline silicon, micromorphous silicon, CdTe and CIGS PV modules. The data for glass/glass micromorphous (µm) silicon PV modules are estimates for a production plant which will begin production in 2012. The results for the 20 MWp CIGS PV module production are comparable with the 30 MWp production shown in [3]. Older data for which no updates could be obtained are excluded. Data for roof-top Balance-of-Systems are taken from [4]. See table I for data sources and key parameters for the production of the PV system. Values for module degradation rate and performance ratio are taken from [5]

Table I: Data sources and key parameters for the production of the PV system
Schottler 2009 [6]

	mono	multi	µm-Si	CdTe	CIS
DATA SOURCES					
poly-silicon	1	1			
ingot/wafer	1	3			
cell	Schottler2009	2 + Schottler2009			
module	same as multi	2	Oerlikon Solar THINFAB	First Solar DE, US, MY	DE
mounting	1	1	1	1	1
inverter	ecoinvent 2.2	ecoinvent 2.2	ecoinvent 2.2	ecoinvent 2.2	ecoinvent 2.2
KEY PARAMETERS					
wafer thickness	180 µm	180 µm			
cell size	156 mm x 156 mm	156 mm x 156 mm			
module size	6 x 10 cells	6 x 10 cells			
glass	single	single	double	double	double
EVA or PVB	EVA	EVA	EVA	EVA	PVB
frame	yes	yes	no	no	yes
mounting on -roof	Schletter	Schletter	fiX	Schletter (cSi)	Schletter (cSi)
inverter	2.5 kW	2.5 kW	2.5 kW	2.5 kW	2.5 kW
module recycling	via glass recycler	via glass recycler		excl. filtercake recycling	same as CdTe
average total module eff	14.4%	14.1%	10.0%	11.3%	11.0%
degradation (%/year)	0.67	0.67	0.67	0.67	0.67
performance ratio	0.75	0.75	0.75	0.75	0.75

3.2 Production location

Top production locations for poly-silicon, wafers, cells and modules are given in figures 2 and 3 [7, 8].

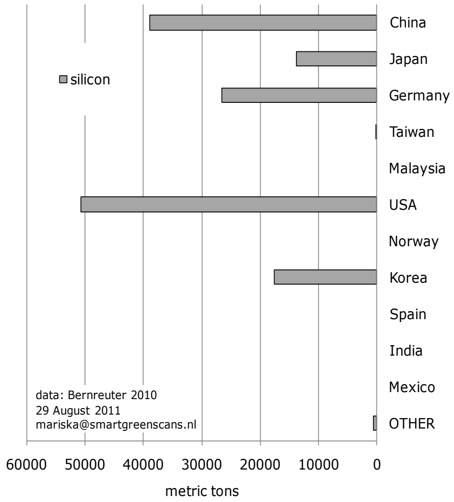

Figure 2: Poly-silicon production 2010 estimates [7]

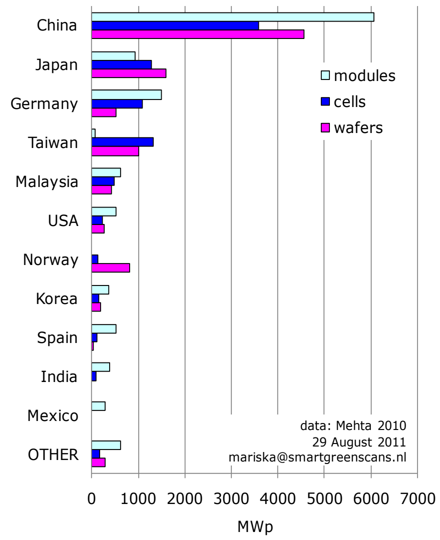

Figure 3: Wafer (2009), cell (2009) and module production (2010 estimates) [8]

3.3 Electricity mixes

For the actual production locations we used ecoinvent 2.2 medium voltage electricity generation (2005) for European countries. For other countries electricity generation was estimated by using the country electricity mixes from IEA [9]. Since the actual efficiencies of power generation and transport losses are unknown the uncertainty of the environmental impacts per kWh produced like MJprim/kWh and CO_2-eq/kWh is high.

For the production of poly-silicon several manufacturers use hydropower (REC Silicon, Wacker in Burghausen) or Combined Heat&Power (CHP)/Cogeneration (Tokuyama, Wacker in Burghausen) but exact data are missing. Besides country electricity generation we also calculated the environmental impacts with hydropower for the production of poly-silicon.

4 ENERGY PAYBACK TIME

Energy payback times for commercial Concentrator Photovoltaics (CPV) assumed to be installed in Catania (Sicily) are shown in figure 4 which is an update of [10]. The energy payback time of CPV systems cannot be compared with flat-plate PV systems because for one value of Direct Normal Irradiation (DNI) on 2-axis tracker there is a broad range of Global Irradiation on optimized plane of the flat-plate module [10].

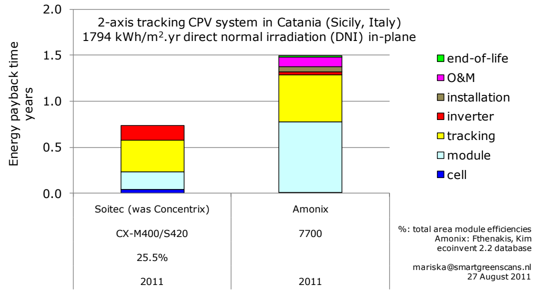

Figure 4: Energy payback time of commercial CPV systems installed at DNI of 1794 kWh/m^2.year (Catania, Sicily) on a 2-axis tracker. The global irradiation on optimally-inclined flate plate module on this location is 1925 kWh/m^2.year

Energy payback times for commercial roof-top PV systems with flat-plate modules are shown in figure 5. It was assumed that the poly-silicon is produced with hydropower and the wafers, cells and modules with UCTE electricity mix. The micromorphous silicon PV modules indicated here are expected to be produced in 2012. The module technologies shown have different scale of production. In general larger scale production decreases factory energy consumption and increases yields.

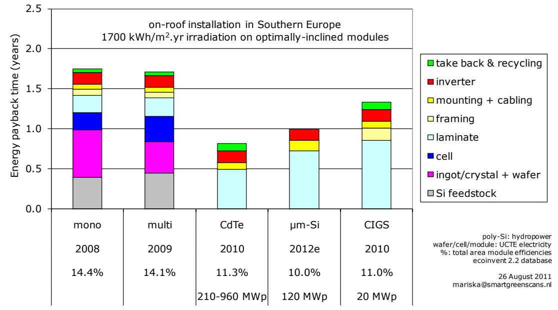

Figure 5: Energy payback time of commercial PV systems installed on roof-top at irradiation of 1700 kWh/m^2.year on optimally-inclined modules. The data for micromorphous silicon PV modules are estimates.

Because of the globalization of PV module production energy payback times are also calculated with 1) hydropower for poly-silicon and country electricity mix for wafers, cells and modules, 2) country electricity mix for poly-silicon and country electricity mix for wafers, cells and modules. These results are shown in figure 6. For the calculations with country mix the production locations from [7] and [8] are taken.

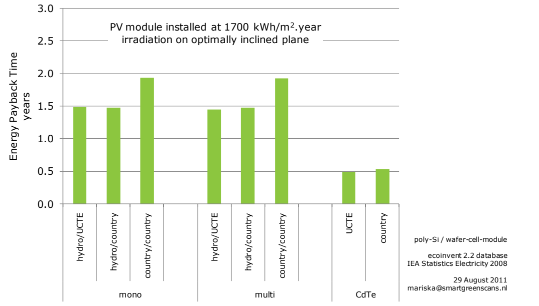

Figure 6: Energy payback time of commercial PV modules installed on roof-top at irradiation of 1700 kWh/m^2.year on optimally-inclined modules. Poly-silicon produced with hydropower or country electricity mix. Wafer/cells/modules produced with UCTE or country electricity mix.

5 CARBON FOOTPRINT

Results for carbon footprint are shown in figure 7. A module degradation rate of 20% in 30 years is taken from [5] which may be too high because many module power guarantees are 20% after 25 years and it is expected that modules will perform much better than the guaranteed values.

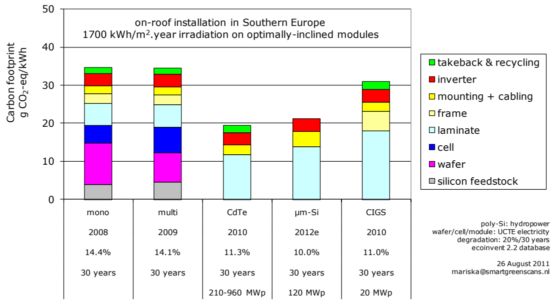

Figure 7: Carbon footprint of commercial PV systems installed on roof-top at irradiation of 1700 kWh/m^2.year on optimally-inclined modules. Module degradation is 20% in 30 years. The data for micromorphous (µm) silicon PV modules are estimates.

Carbon footprint results with global production of the modules are shown in figure 8.

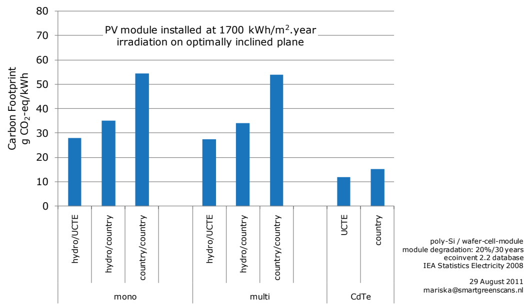

Figure 8: Carbon footprint of commercial PV modules installed on roof-top at irradiation of 1700 kWh/m^2.year on optimally-inclined modules. Poly-silicon produced with hydropower or country electricity mix. Wafer/cells/modules produced with UCTE or country electricity mix.

Carbon footprint results for coal-based electricity generation with carbon capture and storage, wind energy, nuclear energy including waste disposal and multicrystalline silicon PV are shown in figure 9.

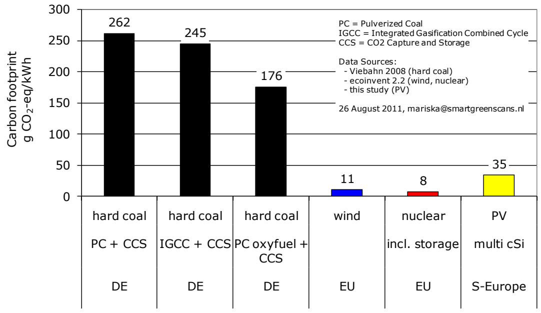

Figure 9: Carbon footprint of electricity generation.

6 CONCLUSIONS

The globalization of the production of PV requires an analysis of the environmental impact which takes country specific production processes into account. The country electricity mix influences the primary energy needed and CO_2-equivalents emitted per kWh produced. The electricity mix used for the production of poly-silicon is often different from the country mix but also considered confidential in many cases. For the production of poly-silicon several manufacturers use hydropower or Combined Heat&Power (CHP)/Cogeneration but exact data are missing. As a result energy payback time and carbon footprint for equal factories differ based on electricity mix used. In addition to this difference due to production location the irradiation on the solar panel depends on installation location.

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8 REFERENCES

[1] A. Jaeger-Waldau, to be published in PV Status report 2011

[2] SETAC Europe LCA Steering Committee (2008) Standardisation efforts to measure greenhouse gases and ‘carbon footprinting’ for products. International Journal of Life Cycle Assessment 13/2 p. 87-88

[3] A. Lozanovski, M. Held (2010) Update of the environmental indicators and energy payback time (EPBT) of CIS modules in Europe and scenario analysis of solar cell printing, 25th European Solar Energy Conference, 6-10 September 2010, Valencia, Spain

[4] M.J. de Wild-Scholten, E.A. Alsema, E.W. ter Horst, M. Bächler, V.M. Fthenakis (2006) A cost and environmental impact comparison of grid-connected rooftop and ground-based PV systems, 21st European Photovoltaic Solar Energy Conference, Dresden, 4-8 September 2006

[5] E. Alsema, D. Fraile, R. Frischknecht, V. Fthenakis, M. Held, H.C.Kim, W. Pölz, M. Raugei, and M.J. de Wild Scholten (2009) Methodology Guidelines on Life Cycle Assessment of Photovoltaic Electricity, Subtask 20 "LCA", IEA PVPS Task 12

[6] M. Schottler, M. Schmidt, H. Hottenroth (2009) Technologien und Konzepte zur Minderung von Treibhausgas-emissionen bei der Herstellung von Halbleiter-Bauelementen und Solarzellen, report M+W Zander FE GmbH, Stuttgart Germany

[7] J. Bernreuter, F. Haugwitz (2010) The Who's Who of Solar Silicon Production: Companies, Technologies, Cost, Capacities - Global Perspectives Through 2012, Bernreuter Research, http://www.bernreuter.com/en/shop/solar-silicon-report.html

[8] S. Mehta (2010) PV Technology, Production, and Cost Outlook: 2010-2015, GTM Research, http://www.gtmresearch.com/report/pv-technology-production-and-cost-outlook-2010-2015

[9] IEA Electricity/Heat Statistics 2008 (2011) http://www.iea.org/stats/prodresult.asp?PRODUCT=Electricity/Heat

[10] M.J de Wild - Scholten, M. Sturm, M.A. Butturi, M. Noack, K. Heasman, G. Timo (2010) Environmental sustainability of concentrator PV systems: Preliminary LCA results of the Apollon project, 25th European Photovoltaic Solar Energy Conference and Exhibition Valencia, Spain, 6-10 September 2010