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UPDATE PHOTOVOLTAICS IN VIEW OF ECOINVENT DATA V2.0

Schlussbericht

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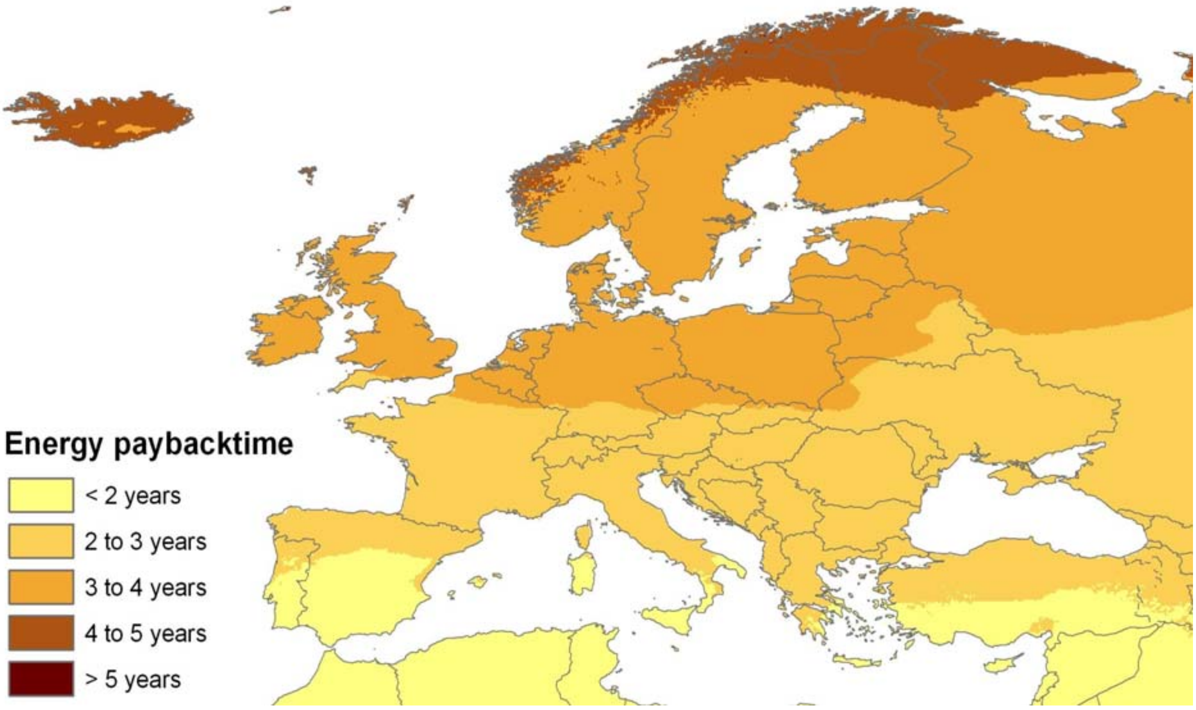

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Energy pay back time of 3 kWp slanted-roof multicrystalline panels operated in Europe in relation to the UCTE electricity mix

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Zusammenfassung

Im Rahmen des Projektes ecoinvent 2000 wurden die Sachbilanzdaten für mono- und polykristalline Photovoltaikanlagen grundlegend überarbeitet. Dabei wurde der Produktionsstatus für das Jahr 2000 betrachtet. Diese Daten sind bereits fünf Jahre später veraltet, da die Produktionstechnologien verbessert wurden und sich das Wissen um die Umweltbelastungen aus der Herstellung erweitert hat.

In diesem Projekt wurden die Sachbilanzdaten so erhoben und dokumentiert, dass eine Integration in den Datenbestand v2.0 der ecoinvent Datenbank ohne Probleme möglich ist und die Daten somit einer breiten Öffentlichkeit zur Verfügung stehen.

Neben der Aufdatierung werden auch erstmals Daten für die Herstellung und den Betrieb von Dünnschichtmodulen (ribbon-Si, CIS und CdTe) und amorphem Silizium erhoben. Ausserdem werden die Stromerträge für eine Reihe von Europäischen Ländern bestimmt.

Der bisherige ecoinvent Bericht zum Thema Photovoltaik wurde vom Deutschen ins Englische übersetzt. Damit wird die Art der Dokumentation an die Anforderungen des ecoinvent Zentrums gerecht und der weltweite Kundenstamm für diese Datenbank besser bedient.

Abstract

In this project, the data for photovoltaics in the ecoinvent database have been updated on behalf of the European Photovoltaics Industry Association and the Swiss Federal Authority for Energy. Data have been collected in this project directly from manufacturers and were provided by other research projects. LCA studies from different authors are considered for the assessment. The information is used to elaborate a life cycle inventory from cradle to grave for the PV electricity production in grid-connected 3kWp plants in the year 2005.

The inventories cover mono- and polycrystalline cells, amorphous and ribbon-silicon, CdTe and CIS thin film cells. Environmental impacts due to the infrastructure for all production stages and the effluents from wafer production are also considered. The ecoinvent data v2.0 is used as background database.

The report investigates the life cycle inventories of photovoltaics, comparing different types of cells

used in Switzerland and analysing also the electricity production in a range of different countries. It is also discussed how the environmental impacts of photovoltaics have been reduced over the last 15 years, using the CED indicator. The consistent and coherent LCI datasets for basic processes make it easier to perform LCA studies, and increase the credibility and acceptance of the life cycle results. The content of the PV LCI datasets is publicly available via the website www.ecoinvent.org for ecoinvent members.

Ausführliche Zusammenfassung

Ziel der erstellten Sachbilanzen ist die Erfassung der Stoff- and Energieströme für die Produktion von Elektrizität mit netzgebundenen Photovoltaikanlagen in der Schweiz und in vielen weiteren Ländern. Für die Aufdatierung der Ökobilanz wurden alle Prozessschritte von der Silizium Produktion bis zum Betrieb der Anlagen mit den zur Verfügung stehenden aktuellen Informationen überarbeitet. Dabei wird die Marktsituation im Jahr 2005 abgebildet.

Für die MG-Silizium Produktion haben sich im Vergleich zur letzten Auflage nur geringe Änderungen bei der Bilanz ergeben.

Die Herstellung von gereinigtem Silizium (Halbleiterqualität oder solar-grade Silizium aus modifiziertem Siemensverfahren), CZ-sc-Silizium (Einkristall Silizium aus dem Czochralski-Tiegelziehverfahren), das Blockgiessen und die Waferfertigung wird in getrennten Teilschritten bilanziert. Für die Bereitstellung von gereinigtem Silicon werden die Marktverhältnisse im Jahr 2005 betrachtet. Dafür wurden für die Herstellung von SoG-Si (*solar*-grade) aktuelle Daten erhoben.

Für die Waferfertigung wird von einer teilweisen Recyclingmöglichkeit für Sägeabfälle ausgegangen. Berücksichtigt werden detailliertere Angaben zum Wasserverbrauch und zur Emission von Wasserschadstoffen bei der Waferfertigung. Erstmals wurden dabei auch Daten zu amorphem Silizium erhoben.

Für die *Solarzellen* Fertigung (und alle anderen Produktionsschritte) wird auch die Infrastruktur mit berücksichtigt. Neu werden in dieser Studie auch sogenannte Dünnschichtzellen bilanziert. Dabei werden sowohl CdTe als auch CIS Zellen betrachtet. Erstmals wird eine Bilanz für ribbon-Silizium Zellen erstellt. Dabei wird der multikristalline Silizium Wafer direkt aus der flüssigen Siliziumschmelze gezogen und so eine höhere Materialeffizienz erreicht. Alle sechs Typen von Solarzellen werden separat bilanziert. Durch die separate Bilanzierung der Zellen kann eine beliebige Kleinanlage aus den Grundlagendaten kombiniert werden.

In diesem Projekt werden die Paneel- und die Laminat-Bauweise bilanziert. Die Paneels haben eine eigene tragende Struktur und können an der Gebäudehülle aufgesetzt werden; Laminat-Konstruktionen müssen in das Gebäude integriert sein. In der Bilanz der Panelfertigung werden aktuelle Daten zur Effizienz von *Solarzellen* verwendet.

Im Bereich der Stromproduktion ab Photovoltaikanlage werden verschiedene gebäudeintegrierte Kleinanlagen (3 kW_p) bilanziert. Modular aufgebaute Anlagen der mittleren Leistungsklasse können als Vielfaches der 3 kW_p-Kleinanlage berechnet werden.

Für den Anlagenbetrieb wurden aktuelle Daten (Zeitreihen) zum Stromertrag von Schweizerischen Photovoltaikanlagen ausgewertet. Dabei wird ein durchschnittlicher Standort in der Schweiz mit einem Jahresertrag von 820 kWh pro Jahr und installiertem kW-Peak (kW_p) zugrundegelegt. Für alle Schräg- und Flachdachanlagen wird ein Wert von 920kWh/kW_p. verwendet Der berechnete Ertrag für Fassadenanlagen liegt bei 620 kWh/kW_p. Eine Durchschnittsbilanz für die Stromerzeugung mit PV Anlagen wird auch für eine Reihe weiterer Länder auf Grundlage veröffentlichter Ertragszahlen erstellt.

Die Resultate für die Bilanz einer gesamten Photovoltaik-Anlage zeigen, dass der Hauptteil des Ressourcenverbrauchs und viele Emissionen aus dem Stromverbrauch für die Fertigung der Solarzellen und der Paneels stammt. Damit kommt dem Standort der Produktionsanlagen eine besondere Bedeutung zu. Die Analyse zeigt auch, dass relevante Umweltbelastungen in allen Stufen der Produktion anfallen. Aufgrund der inzwischen verbesserten Produktion für Solarzellen, steigt die Bedeutung der übrigen Komponenten einer PV-Anlage weiter an. Zu diesen Komponenten gehört das Befestigungssystem, der Wechselrichter und die elektrische Installation. Insbesondere bei Solarzellen mit geringer Effizienz kommt dem Befestigungssystem inzwischen eine relevante Bedeutung zu.

Eine Reihe von Schadstoffen wird dabei unabhängig vom Energieverbrauch emittiert. Eine Energiebilanz alleine reicht somit zur Beurteilung dieses Energiesystems und zum Vergleich mit anderen Systemen nicht aus.

Für alle relevanten Produktionsschritte konnten die bisherigen Daten aktualisiert und ergänzt werden. Die Bilanzen wurden teilweise aus Einzelbetrachtungen verschiedener Hersteller kombiniert. Im Vergleich zu den ersten Schweizer Ökobilanzen für Photovoltaik ist der kumulierte Energiebedarf pro Stromertrag um den Faktor 3 zurückgegangen.

Auf Grund des raschen technologischen Fortschritts in der Produktion von PV-Anlagen stellt auch diese Ökobilanz keinen Endpunkt in der Betrachtung dar. Vielmehr ist eine Aufdatierung nach einiger Zeit wünschenswert. Hierfür wären insbesondere vollständige und aktuelle Angaben von Herstellern aus verschiedenen Stufen des Produktionszyklus sehr erwünscht.

Die aktualisierten und ergänzten Sachbilanzdaten können als Grundlage für die ökologische Beurteilung von Photovoltaikanlagen in der Schweiz und in vielen weiteren Ländern herangezogen werden. Die hier erhobenen Ökobilanzdaten ermöglichen auch den Vergleich der Umweltbelastungen mit anderen Technologien für die Bereitstellung von Elektrizität. Zu beachten ist dabei aber, dass für andere Elektrizitätssysteme die Herstellung der notwendigen Infrastruktur evtl. nicht in ähnlich grosser Detailtiefe wie für Photovoltaikanlagen erfolgte.

1. Introduction

Life cycle assessment (LCA) has proved to be a powerful tool for the environmental improvement of production processes in the energy sector. However, the increased use of the LCA method to analyse systems is hindered by the lack of agreement on the use of methods and by the limited availability of life cycle inventory (LCI) data. The data for photovoltaics in the ecoinvent database have been updated in this project on behalf of the European Photovoltaics Industry Association and the Swiss Federal Authority for Energy ([1]).

In the past years the PV sector developed rapidly. Ongoing projects such as *CrystalClear*[1] have investigated the up-to-date life cycle inventory data of the multi- and singlecrystalline technologies ([2]). Updated LCI data of single- and multicrystalline PV technologies were investigated within the framework of the CrystalClear project based on questionnaires sent to different involved industries. The data investigated with 11 European and US photovoltaic companies for the reference year 2005 are now implemented in the ecoinvent database v2.0 and documented according to the ecoinvent requirements ([1]). The following unit process raw data have been investigated and updated:

- multicrystalline SoG-silicon, Siemens process (new solar-grade process)
- multicrystalline-Si wafer (mc-Si or multi-Si)
- singlecrystalline-Si wafer (sc-Si or single-Si)
- ribbon Si wafer (so far not covered by ecoinvent data v1.3)
- ribbon-, multi- or single-Si cell (156 mm x156 mm)
- modules, ribbon-Si (new) and other module types
- silica carbide (SiC)
- PV-electricity mix Switzerland and in other countries
- recycling of sawing slurry and provision of SiC and glycol
- front metallization paste and back side metallization paste of solar cells
- inverter including electronic components

New thin film cells technologies like CIS or CdTe are entering the market. For the first time also thin film photovoltaics (CIS, CdTe and amorphous silicon) are investigated for the ecoinvent data based on literature information.

The yield per kW_p is one important factor for the comparison of PV with other types of electricity pro-

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1 See www.ipcrystalclear.info for detailed information.

duction. For ecoinvent data v1.3 only the situation in Switzerland had been investigated [3]. For the ecoinvent data v2.0 we investigated the PV technology mixes for several European countries using the specific electricity yields in each country based on published irradiation levels ([4]). Also yields in selected non-European countries (e.g. in Asia, Australia and North-America) were considered for a rough extrapolation of the European PV model to PV installations in those countries. However, different electricity/energy mixes for the manufacturing upstream chains have not been modelled for different country-specific cases but only the average European chain was investigated in detail.

2. System Boundaries

Sixteen different, grid-connected photovoltaic systems were studied. These are different small-scale plants of 3 kW_p capacity and operational in the year 2005 in Switzerland (see Tab. 1).

The plants differ according to the cell type (single- and multicrystalline silicon, ribbon-silicon, thin film cells with CdTe and CIS), and the place of installation (slanted roof, flat roof and façade). Slanted roof and façade systems are further distinguished according to the kind of installation (building integrated i.e. frameless laminate, or mounted i.e. framed panel).

Tab. 1: Overview of the types of photovoltaic 3 kWp systems investigated for an installation in Switzerland

Installation	Cell type	Panel type 1)
Slanted roof	sc-Si	Panel
	mc-Si	Panel
	a-Si	Panel
	ribbon-Si	Panel
	CdTe	Panel
	CIS	Panel
	sc-Si	Laminate
	mc-Si	Laminate
	a-Si	Laminate
	ribbon-Si	Laminate
Flat roof	sc-Si	Panel
	mc-Si	Panel
Façade	sc-Si	Panel
	mc-Si	Panel
	sc-Si	Laminate
	mc-Si	Laminate

1) Panel = mounted; Laminate = integrated in the roof construction, sc-Si = singlecrystalline silicon, mc-Si = multicrystalline silicon.

All subsystems shown in Fig. 1 are included as individual datasets within the system boundaries for silicon based PV power plants. The process data include quartz reduction, silicon purification, wafer, panel and laminate production, manufacturing of inverter, mounting, cabling, infrastructure, assuming 30 years operational lifetime for the plant. The basic assumptions for each of these unit processes are described in the report. We considered the following items for each production stages as far as data were available:

- energy consumption,
- air- and waterborne process-specific pollutants at all production stages,
- materials, auxiliary chemicals, etc.
- transport of materials, of energy carriers, of semi-finished products and of the complete power plant,
- waste treatment processes for production wastes,
- dismantling of all components,
- infrastructure for all production facilities with its land use.

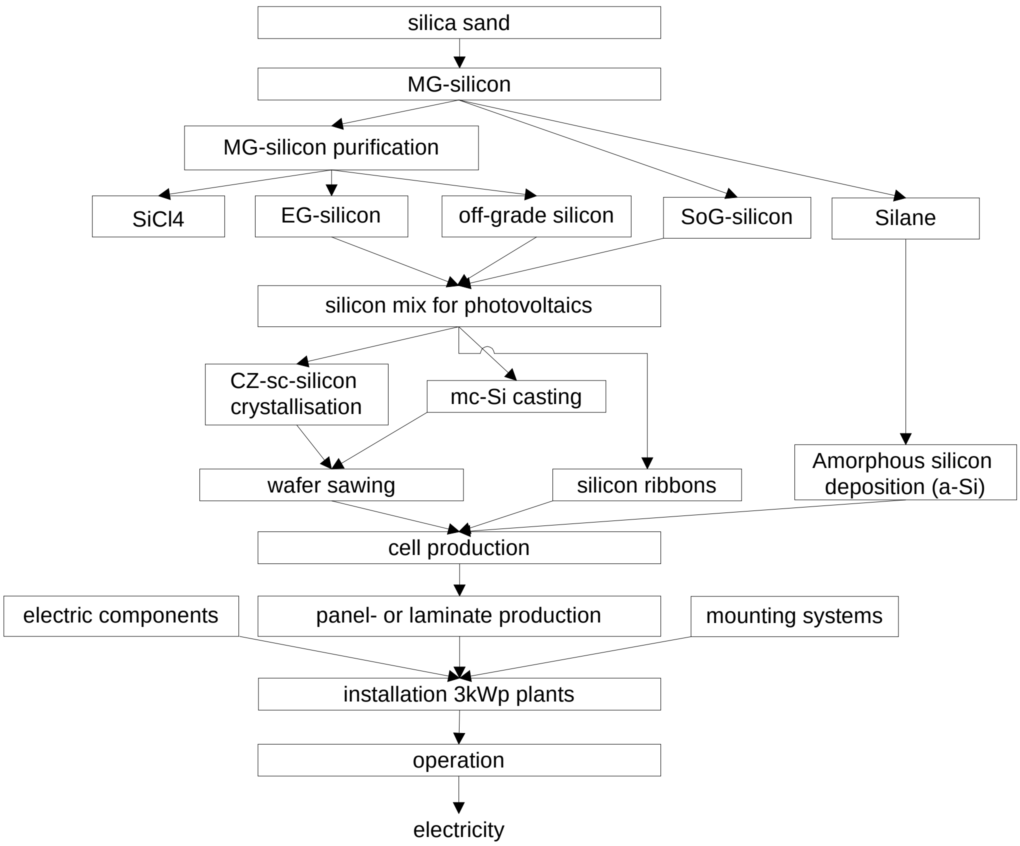

Fig. 1: Different sub systems investigated for the production chain of silicon cells based photovoltaic power plants installed in Switzerland. MG-silicon: metallurgical grade silicon, EG-silicon: e-lectronic grade silicon, SoG-silicon: solar-grade silicon, a-Si: amorphous silicon

All subsystems shown in **Fig. 2** are included within the system boundaries for thin film PV power plants. All inputs (semiconductor metals, panel materials and auxiliary materials) for the production of thin film cells, laminates and panels are investigated in other reports of the ecoinvent project ([5]). Thus, in the specific report for PV we only described the process stages starting from the laminate and panel production.

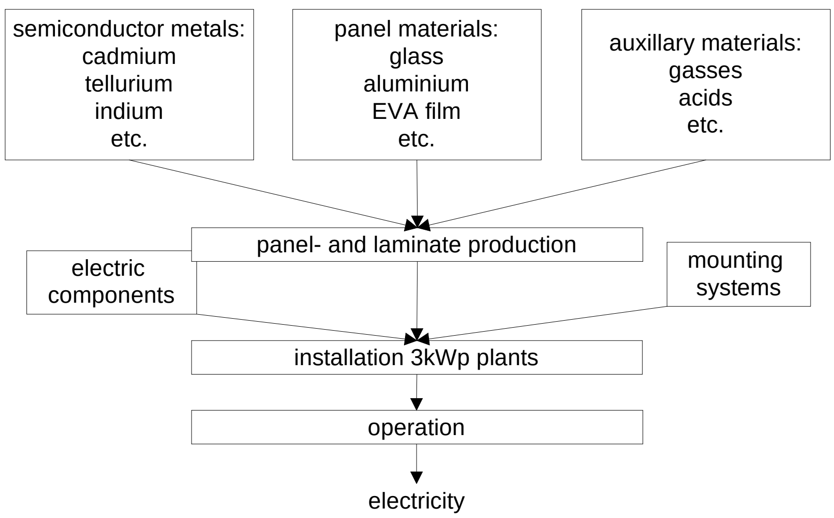

Fig. 2: Different sub systems investigated for thin film (CIS and CdTe) photovoltaic power plants installed in Switzerland

The average PV electricity mix in Switzerland considers the actual performance of the installed plants ([6]), while data for specific types of PV plants (e.g. laminate and panel, single- or multicrystalline) can be used for comparisons of different technologies. The calculations in ([4]) are performed for PV plants located in Berne with an annual yield of 922 and 620 kWh/kW$_p$ for roof-top and façade installations, respectively. This yield is calculated with an irradiation of 1117 kWh per m^2 and a performance ratio of 0.75. These results have been used for our technology specific assessments (e.g. in **Fig. 4**).

The actual PV electricity mixes in 2005 with different types of PV power plants in several countries are also modelled. The yield data for PV electricity mixes in other countries are based on a publication for optimum installations ([4]) and a correction factor which takes into account an actually lower yield of average installations in Switzerland compared to this optimum installation ([1]).

3. Key parameters for life cycle inventories

All life cycle inventory data are documented in an English report [1]. Parts of this project have been executed on behalf of the PSI Villingen (Review), the EMPA Dübendorf (life cycle inventories of thin-film materials [5]) and ETH Zürich (special chemicals [7]).

Tab. 2 shows the key parameters of the life cycle inventory in ecoinvent Data v2.0 [1]. Main changes in comparison to older Swiss inventories are the update of the energy use in silicon purification, the location specific consideration of power consumption throughout the production chain, and the inclusion of many additional process specific emissions.

Tab. 2: Key parameters of the life cycle inventory for photovoltaic power production of sc-Si and mc-Si and comparison with previous Swiss studies [3, 8, 9]

		sc-Si	**sc-Si**	**sc-Si**	**sc-Si**	**mc-Si**	**mc-Si**	**mc-Si**	**mc-Si**
	unit	1996	2000	2003	2007	1996	2000	2003	2007
silicon purification (EG-Si or SoG-Si)									
electricity use, DE, plant specific	kWh/kg			103	44			103	44
electricity use, modified Siemens	kWh/kg				110				110
CZ-silicon production									
electricity use, UCTE-mix	kWh/kg		100	123	86			-	-
sc-Si and mc-Si wafer									
thickness, wafer	µm	300	300	300	270	300	300	300	240
sawing gap	µm	200	200	200	191	200	200	200	249
wafer area	cm^2	98	98	100	243	107	107	100	243
weight	g	7.11	6.85	6.99	15	7.76	7.48	6.99	14
cell power	Wp	1.62	1.62	1.65	3.73	1.5	1.5	1.48	3.50
cell efficiency	%	16.5%	15.8%	16.5%	15.3%	14.0%	13.4%	14.8%	14.4%
use of MG-silicon	g/Wafer	66.7	17.6	19.0	33.5	129.4	17.3	19.2	37.9
EG-silicon use per wafer	g/Wafer	12.2	12.7	11.2	26.2	23.8	13.8	11.2	27.7
electricity use	kWh/Wafer	1.57	1.4	0.3	0.19	1.56	1.6	0.3	0.19
sc-Si and mc-Si cells									
electricity use	kWh/cell	1.3	0.27	0.2	0.74	1.28	0.27	0.2	0.74
panel/ laminate, sc-Si/ mc-Si									
number of cells	cells/panel	36	36	112.5	37.6	36	36	112.5	37.6
panel area	cm^2	4290	4290	12529	10000	4400	4400	12529	10000
active area	cm^2	3528	3528	11250	9141	3856	3856	11250	9141
panel power	Wp	58	55.5	185	140	54	51.7	166	132
efficiency production	%	99%	99%	97%	98%	99%	99%	97%	98%
use of cells sc-Si/ mc-Si	cells/kW$_p$	627	649	608	268	673.4	696	677	285
process energy use	MJ/kW$_p$	0.75	0.75	0.23	0.16	3.23	0.75	0.26	0.17
3kWp-plant									
panel area	m^2/3kW$_p$	22.2	27.8	18.2	19.6	24.4	24.4	20.3	20.8
operation									
yield, slope-roof + flat roof	kWh/kW$_p$	860	886	885	922	860	886	885	922
yield, facade	kWh/kW$_p$	860		626	620	860		626	620
yield, CH PV electricity mix	kWh/kW$_p$	860		819	820	860		819	820

sc-Si = singlecrystalline silicon, mc-Si = multicrystalline silicon.

4. Results

4.1 Selected Results For Process Stages

Here we make an evaluation of elementary flows over the life cycle.[2] Therefore emissions and resource uses are added up for all stages in the life cycle. Results are presented for one kWh of electricity. **Fig. 3** shows the shares of different production stages for some selected elementary flows of a

[2] Elementary flows describe the input of resources (e.g. crude oil) and emissions to nature (e.g. carbon dioxide). About 1000 different elementary flows are recorded in the ecoinvent data v2.0.

slanted-roof installation with a multicrystalline silicon panel. As an example BOD (Biological Oxygen Demand) is caused in high share due to the finishing of wafer surfaces. The analysis shows that each production stage might be important for certain elementary flows.

Compared to earlier investigations of PV, now the inverter and mounting systems get more importance. For most indicators these so called balance of system (BOS) elements have a share of 30% to 50%. This is due to the improvements, which could be observed for the production chain until the photovoltaic cell and the more detailed investigation of these additional elements, which for example includes now also electronic components of the inverter.

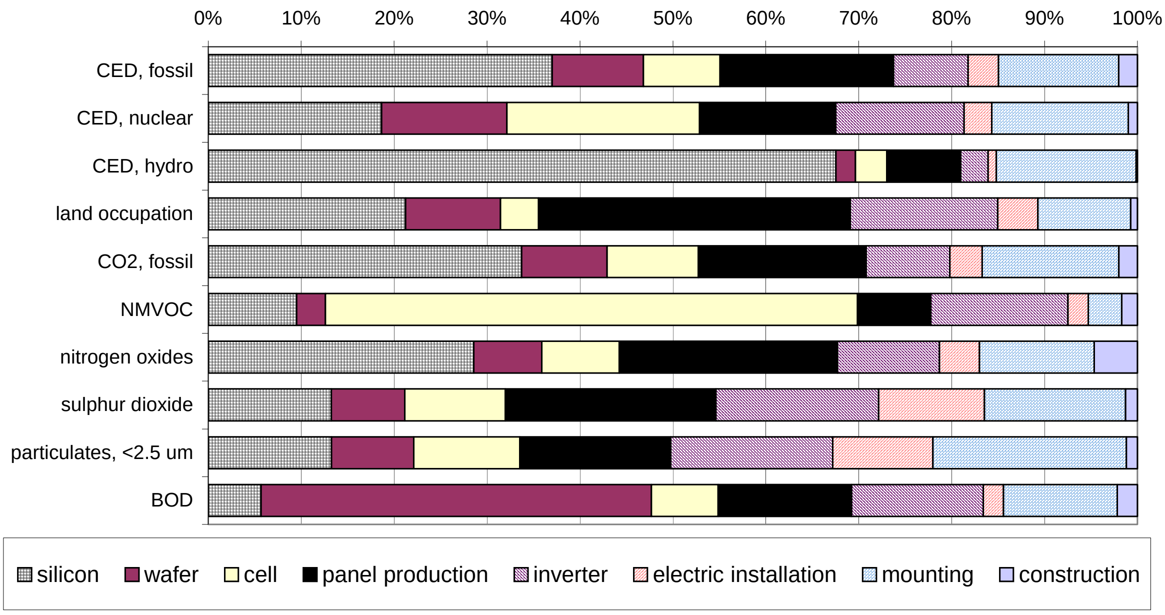

Fig. 3: Share of process stages for a Swiss grid-connected, 3kWp slanted-roof installation with a multicrystalline silicon panel for selected elementary flows of the inventory. CED = Cumulative Energy Demand

4.2 Pay-Back Time

An important yardstick for the assessment of renewable energy systems is the estimation of the energy and/or environmental pay back time. The outcome of such a comparison is influenced by the choice of the reference system on the one hand and the indicator on the other. Here we consider the UCTE electricity mix in year 2004 ([10]) as the reference system. Fig. 4 shows the pay-back-time for the non-renewable cumulative energy demand for PV power plants operated in Switzerland. This time is between 2.5 and 4.9 years for the different types of PV plants. Thus, it is 5 to 10 times shorter than the expected lifetime of the photovoltaic power plants. Different characteristics like type of installation, type of cells, type of panel (mounted, on Fig. 4) or laminates (integrated) are the key factors for determining the relative differences in results illustrated in this figure.

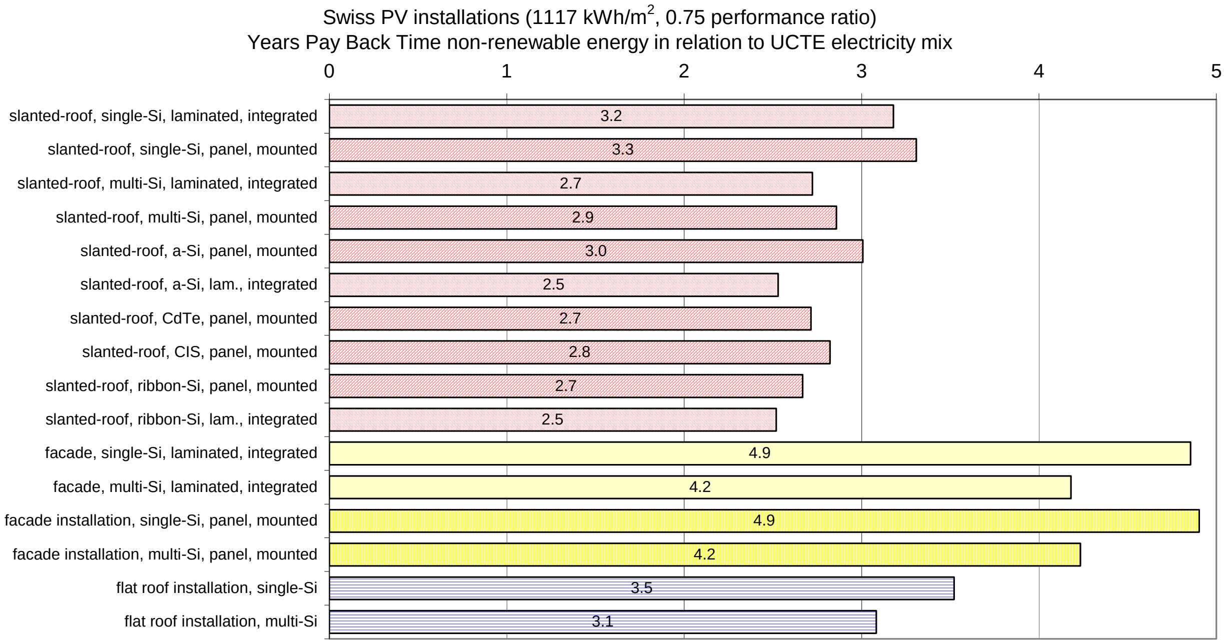

Fig. 4: Energy pay back time of 3 kWp photovoltaic power plants operated in Switzerland in relation to the UCTE electricity mix (results with ecoinvent data v2.0). red for slanted roof, yellow for façade, blue for flat roof

The energy pay back time is quite dependent on the irradiation at the area were the PV plant is operated. Here we calculate an example of energy pay-back times for different locations in Europe for multicrystalline panels installed on slanted roofs. The calculation is based on the yearly sum of global irradiation on horizontal surface (kWh/m^2) in the period 1981-1990 [11] and the non-renewable cumulative energy demand investigated for the 3kW$_p$ plant and the average European electricity mix. Fig. 5 shows the results of this calculation. The evaluation highlights the large differences of electricity yields depending on the region of installation. Pay-back times lower than two years can be achieved in the South of Spain, Italy, Turkey and in Northern Africa. Pay-back times in the North of Europe might be 2 to 3 times higher.

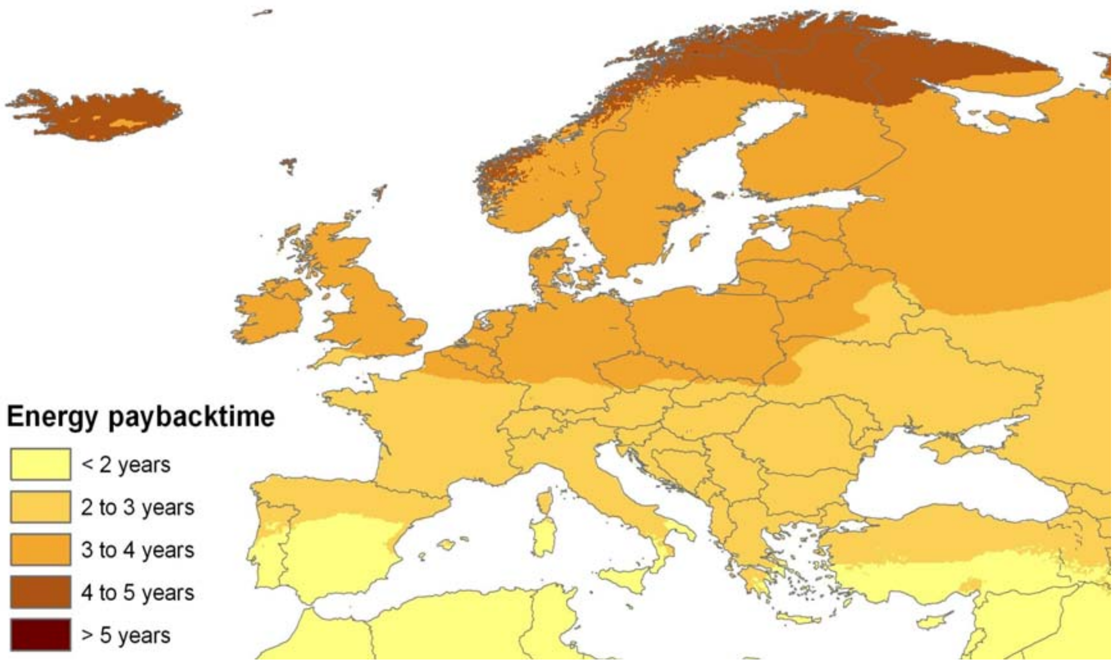

Fig. 5: Energy pay back time of 3 kWp slanted-roof multicrystalline panels operated in Europe in relation to the UCTE electricity mix (own calculation with [11])

4.3 Potential For CO_2 Mitigation

In order to identify the most promising regions for PV installations it is necessary to consider the irradiation as demonstrated in **Fig. 5**. A further factor is the actual impacts of the electricity supply replaced by the PV installations. Gaiddon & Jedliczka have defined a so-called potential for CO_2 mitigation [4]. This is defined as the amount of CO_2 emissions, which would be caused if electricity were supplied over the lifetime of the PV plant by the national grid mix minus the amount of CO_2 emissions caused by the production of the PV plant. In **Fig. 6** we take the national supply mixes including imports and exports of electricity as the reference system [10]. The calculation of electricity yields is based again on European irradiation data [11]. The highest CO_2-mitigation potentials can be achieved in countries with high PV electricity yields and high CO_2 emissions in the national supply mix. From this perspective Poland, Spain, Italy and Greece are the most promising regions for PV installations.

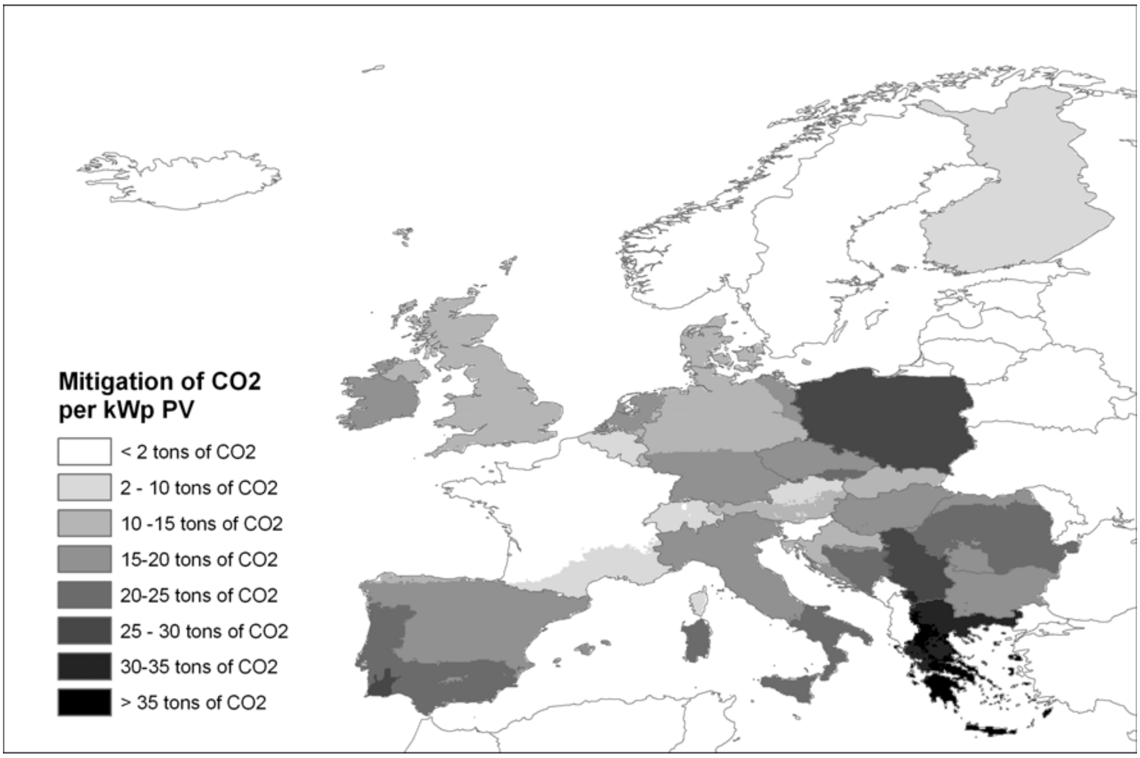

Fig. 6 Potential for CO_2 mitigation of multicrystalline slanted-roof PV plants compared to the national electricity supply mixes (t CO_2-eq per kW_p)

4.4 DEVELOPMENT OF LCA RESULTS

Fig. 7 shows the development of results for the cumulative energy demand of photovoltaic electricity in this study compared to previous Swiss studies. The figure shows also the increase in installed capacity in Switzerland. This evaluation shows that the cumulative energy demand has been decreased by a factor of 3 or more since the first studies on PV systems made in the early nineties.

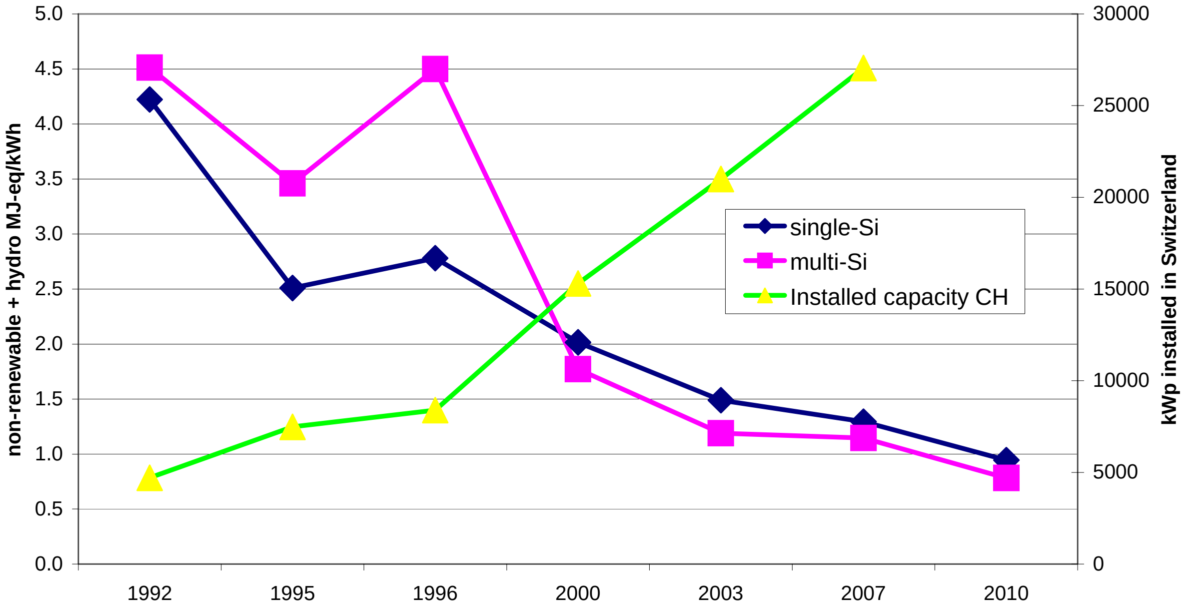

Fig. 7 Cumulative energy demand of the life cycle inventory for photovoltaic power production in this study (2005) and comparison with previous Swiss studies. Data for 2010 are forecasted in 2003 ([3, 8, 9, 12]) (results with ecoinvent data v2.0)

4.5 COMPARISON OF DIFFERENT COUNTRIES

Fig. 8 shows the global warming potential (100a) for photovoltaic power plants operated in different countries. The comparison shows that there might be considerable differences between different countries depending on the irradiation and thus on the actual yield per kW_p installed. CO_2-equivalent emission per kWh might be as low as 50 grams per kWh to the grid in the average case investigated for Spain. They will be even lower if optimum installations with best performance ratios are taken into account.

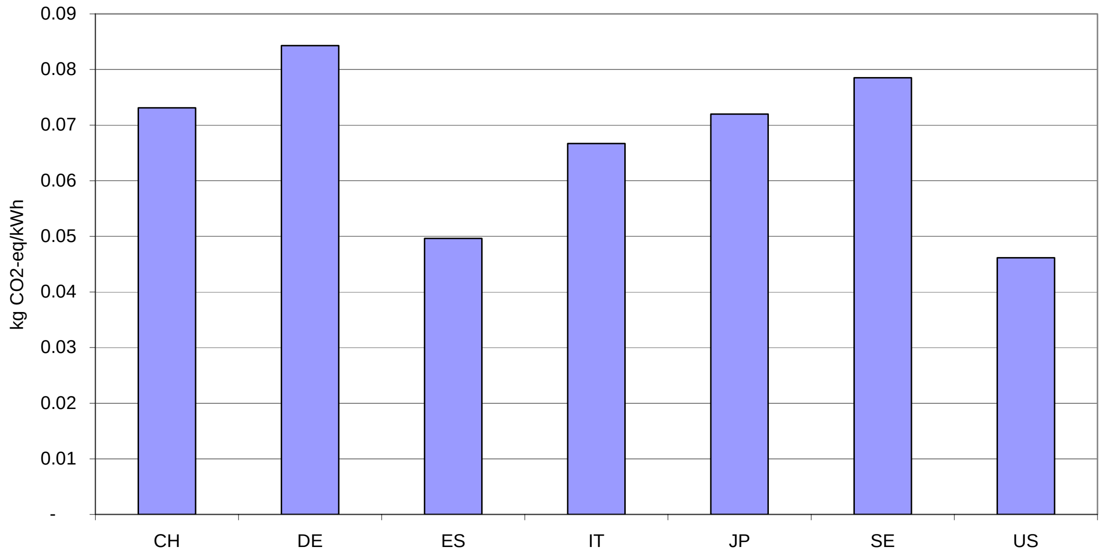

Fig. 8 Global warming potential in kg CO_2-eq per kWh for the average photovoltaic electricity mixes in different countries (results with ecoinvent data v2.0)

6. Conclusion and Outlook

The life cycle inventories of photovoltaic power plants performed for the ecoinvent data v2.0 can be assumed to be representative for photovoltaic plants and for the average photovoltaic mix in Switzerland and in other European countries in the year 2005. The analysis of the results shows that it is quite important to take the real market situation (raw material supply, electricity, etc.) into account.

Differences for the situation in other European countries in comparison to the data modelled for Switzerland are mainly due to different solar irradiation accounted for and the performance ratio. These factors must also be taken into account along with the technology development level for comparisons with other types of electricity generation. Other factors like differences in the shares of imports from different PV producing regions or types of PV cells have not been modelled. It should be considered that the inventory may not be valid for wafers and panels produced outside of Europe or the US, because production technologies and power mix for production processes are generally not the same. The datasets on PV electricity in non-European countries should thus be revised as soon as data are available for production patterns in more producing countries e.g. Japan.

For the modelling of a specific power plant or of power plant mixes not addressed in this study it is necessary to consider at least the annual yield (kWh/kW_p) and if possible also the actual size of the plant in square metres. Furthermore it is necessary to clearly define if average, plant-specific or optimum performance ratios are taken into account.

The analysis in this report is focused on the today production patterns and operation results. For the comparison of energy technologies, it is advisable to take into account also future development potentials. Several studies are available for PV technologies, which take into account also possible future improvements in the production chain.

The analysis of the environmental impacts with different LCIA methods shows that it is quite important to include process specific emissions of the production chain. Many, but not all possible emissions are investigated in this study. It is necessary to evaluate all types of environmental impacts with different LCIA methodologies if photovoltaic power plants shall be compared with other energy systems.

Compared to earlier investigations of PV, today the inverter and mounting systems get more and more importance. For most indicators these so called balance of system (BOS) elements have a share of 30% to 50%. On the one side, this is due to the improvements, which could be observed for the production chain until the photovoltaic cell. On the other side, now a more detailed investigation of these additional elements is available, which for example includes also electronic components of the inverter.

All data are public available for members of ecoinvent data v2.0. They have been published in November 2007 (www.ecoinvent.org). A CD ROM with the background reports will be provided to the customers in early 2008 [13].

Results of this project have been presented during two conferences [14, 15]. An article for Prog. Photovolt. Res. Appl. is in preparation [16].

7. Recommendation and Perspective

The whole production chain for photovoltaics is subject to rapid changes. An example is the supply situation for the silicon feedstock, which totally changed during the last four years.

Some emission data in the inventory are based only on single information source, some are from one specific producer only. Thus, they should be verified with data from other production companies and factories to the extent possible. In cases where several information sources were available, they showed partly a large variation. A general problem is that data had to be mixed from different sources with possibly different assumptions and boundaries.

The projected lifetime is a key parameter for the assessment, but operational experience with the new technologies is not yet sufficient to derive reliable conclusions. Many production processes, especially for photovoltaic power, are still under development. Thus, future updates of the LCI should verify key assumptions on energy and material uses as well as emissions, which are important for the LCIA.

The ecoinvent database provides detailed and transparent background data for a range of materials and services used in the production chain of photovoltaics. These data can also be used to assess the environmental impacts for the production of photovoltaic power plants in other countries or to investigate other technologies.

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