PEARLPV

Environmental impact assessment for PV modules and systems

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Introduction

- One of the main advantages of PV is the reduced environmental impact compared to conventional fossil fuels and some other renewable technologies
- However, it is important to quantify and then minimise the impact
- In this presentation, we will consider how we model environmental impact, some of the assumptions we need to make and the link to the modelling of PV system performance

Boundary conditions

- In general, we wish to assess the environmental impact for the whole of the life cycle (termed cradle-to-grave or, if we can recycle/reuse most of the materials, cradle-to-cradle)
- This involves quantifying all inputs and outputs and then determining their impact
- The life cycle starts when the raw materials are extracted from the earth, followed by manufacturing, transport and use, and ends with recycling or final disposal

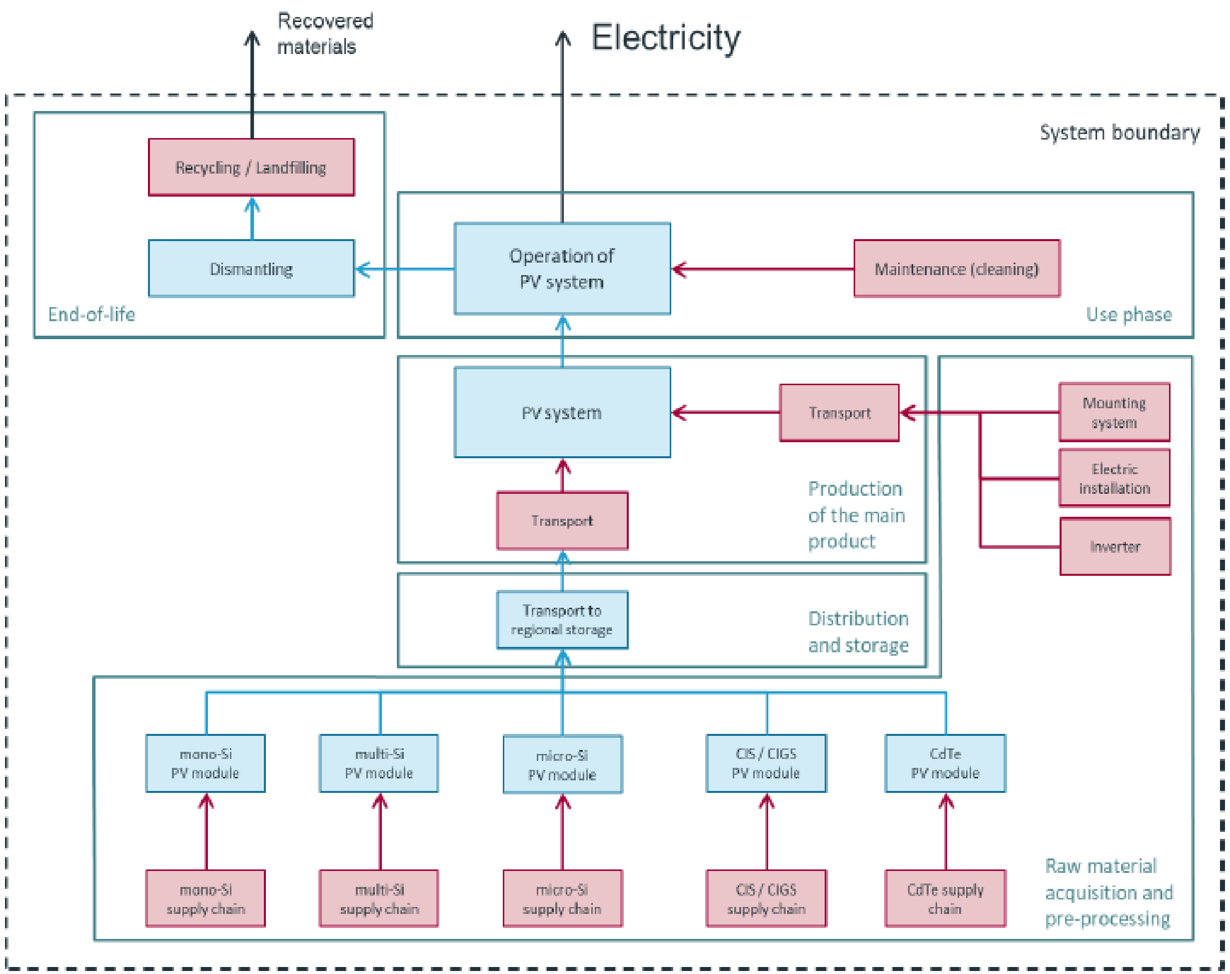


Figure 1: Product system of PV electricity production, adapted from [1]

Diagram from IEA PVPS T12-19:2020

Environmental Life Cycle Analysis (LCA)

- An LCA study consists of four main step:
  - Defining the goal and scope of the study
  - Making a model of the product life cycle with all the environmental inflows and outflows – this is usually referred to as the life cycle inventory (LCI)
  - Understanding the environmental relevance of all the inflows and outflows – this is called the life cycle impact assessment (LCIA) phase
  - The interpretation of the study
- The LCI stage is usually undertaken by those with expertise of the product manufacture and use
- The LCIA stage requires relevant software which can determine the impacts of the LCI in a consistent manner

The Life Cycle Inventory

- The usual approach is to divide the life cycle into several steps, e.g. mining and refining, transport of materials to manufacturing sites, manufacture of products, usage, decommissioning and disposal
- All material and energy requirements must be identified and quantified
- Where appropriate, process yields are defined
- Waste products and their treatment are included in the inventory
- Examples of inventories for a range of PV module types and other PV system components are given in the IEA PVPS Task 12 report T12-19:2020, Life Cycle Inventories and Life Cycle Assessments of Photovoltaic Systems

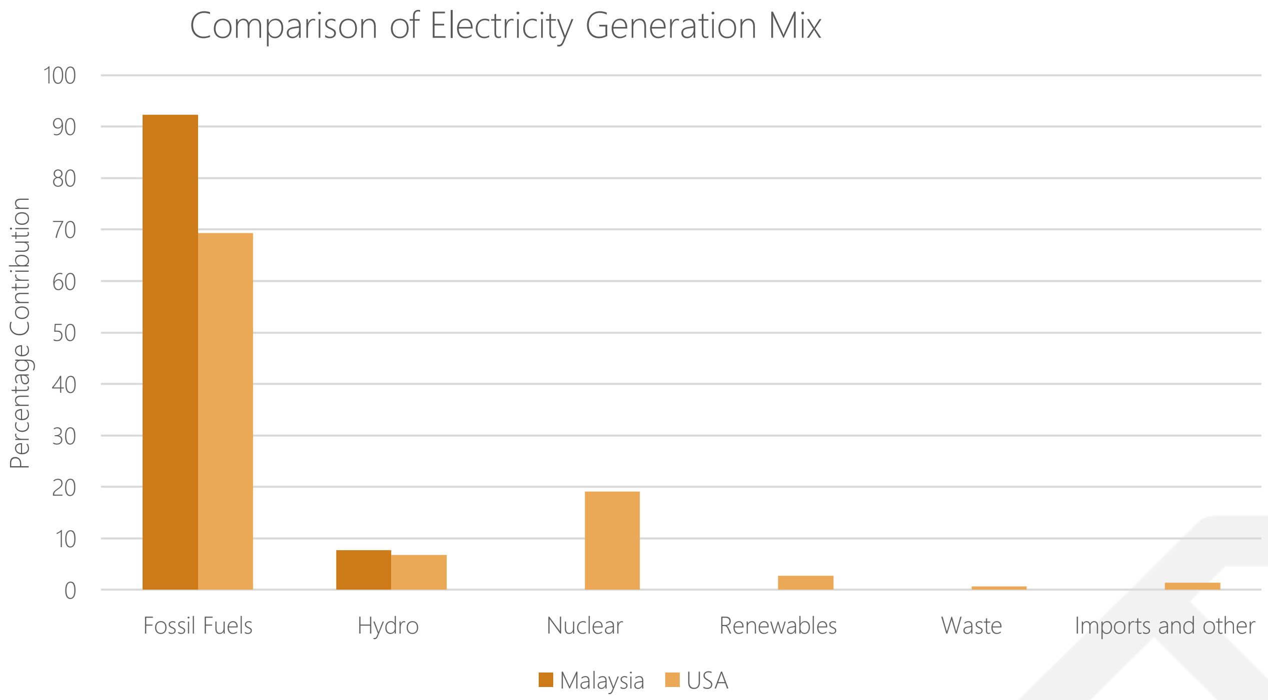
LCI Example from Task 12 Report

Table 26b: Unit process LCI data for cadmium-telluride photovoltaic panels at the European regional storage

	Name	Location	InfrastructureProcess	Unit	photovoltaic laminate, CdTe, mix, at regional storage	UncertaintyType	StandardDeviation 95%	GeneralComment
	Location				RER			
	InfrastructureProcess				1			
	Unit				m2			
product	photovoltaic laminate, CdTe, mix, at regional storage	RER	1	m2	1			
materials	photovoltaic laminate, CdTe, First Solar Series 4, at plant	MY	1	m2	7.52E-1	1	3.00	(1,1,1,1,1,3); CdTe module import from Malaysia
	photovoltaic laminate, CdTe, First Solar Series 4, at plant	US	1	m2	5.44E-2	1	3.00	(1,1,1,1,1,3); CdTe module import from US
	photovoltaic laminate, CdTe, First Solar Series 6, at plant	MY	1	m2	1.19E-1	1	3.00	(1,1,1,1,1,3); CdTe module import from Malaysia
	photovoltaic laminate, CdTe, First Solar Series 6, at plant	US	1	m2	7.51E-2	1	3.00	(1,1,1,1,1,3); CdTe module import from US
transport	transport, transoceanic freight ship	OCE	0	tkm	2.18E+2	1	2.09	(4,5,na,na,na,na); Import of modules from the US 6469 km, from Malaysia 14783 km
	transport, freight, lorry, fleet average	RER	0	tkm	1.56E+1	1	2.09	(4,5,na,na,na,na); Average transport distance from Rotterdam to Europe is 943 km

Electricity Mix at Manufacturing Site

- Because the mix of fossil fuels, renewable technologies and nuclear energy for the generation of electricity varies between countries we need to take this into account in the impact assessment



Data from IEA PVPS T12-19:2020
Year: 2013

Recommendations for PV LCA

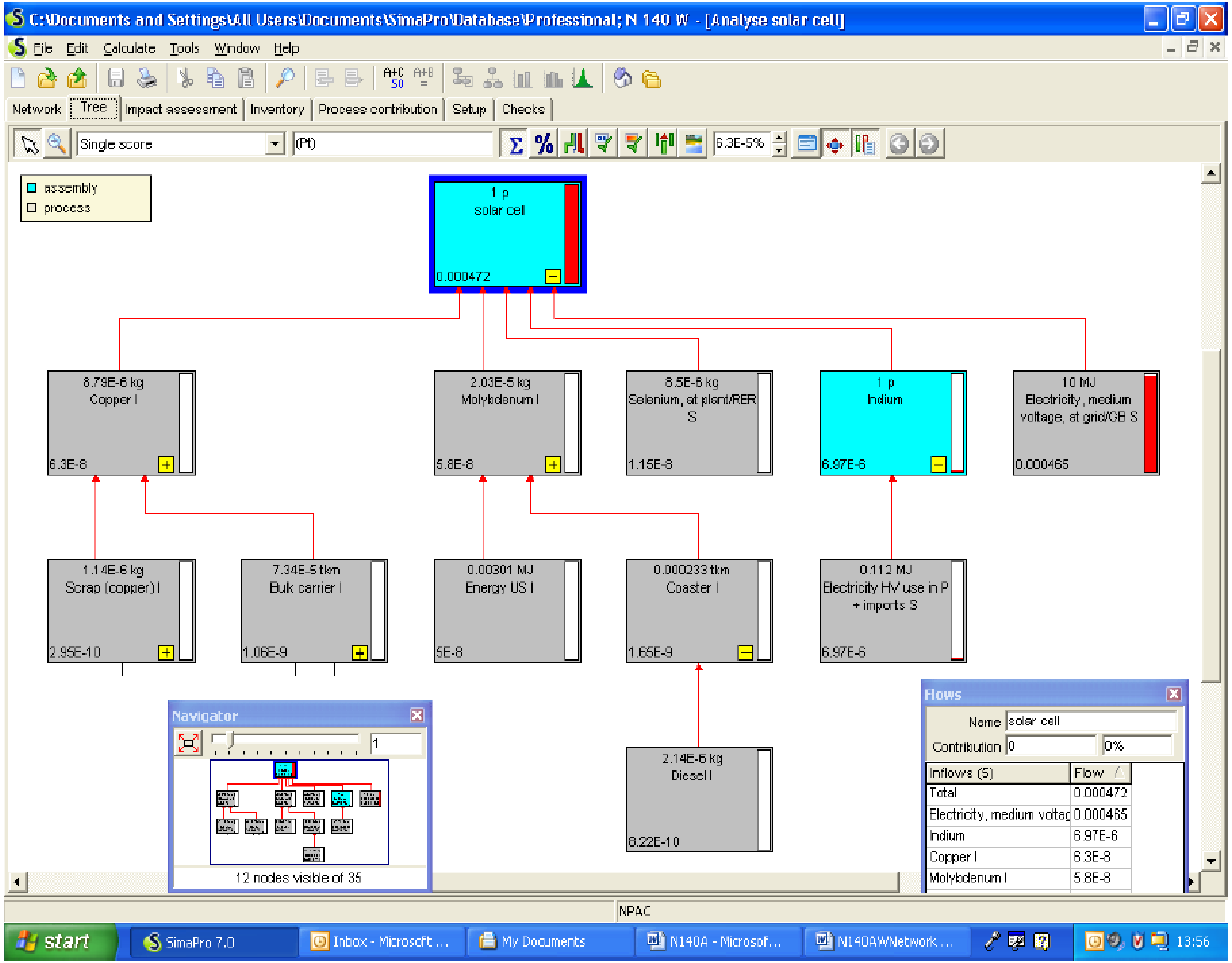
- The recommendations for PV LCA in this presentation are taken from IEA PVPS Task 12 T12-18:2020 Methodology Guidelines on Life Cycle Assessment of Photovoltaics, unless otherwise stated
- The guidelines divide the overall life cycle into 4 stages with the following inputs:
  - Product Stage: raw material and energy supply, manufacture of the panels, mounting system, cabling, inverters and all other components required for the production of electricity and supply to the grid
  - Construction Stage: transport to plant site, construction and installation
  - User Stage: auxiliary electricity demand, cleaning, maintenance, repair and replacement
  - End of Life Stage: deconstruction, dismantling, transport, waste processing, recycling and reuse, disposal

Life Cycle Impact Assessment

- Once the inventory is complete, the impact of all inputs and outputs can be assessed, depending on a definition of their use and treatment
- For example, we might say a certain amount of diesel is used to transport a defined amount of material from the processing plant to the manufacturing plant and we can assign an average particulates emission to that diesel use
- In theory, it is possible to do this stage completely “by hand” but the number of calculations and the range of impacts assessed make it very tedious and time consuming
- A number of specialised LCIA software packages are available – SimaPro and GaBi are the two most used in the PV community
- The LCA software includes access to an inventory of relevant materials and energy data, such as the electricity mixes already discussed (ecoinvent for SimaPro) – this makes comparison between analyses possible, although care is still required

LCA Software Example - SimaPro

- SimaPro is one of the packages extensively used in the PV and other communities
- The ecoinvent database is a default option, but there are also optional inventories on agriculture, food and from specific countries
- It is widely used in education and research institutions, because it allows you to define inputs at the process level and explore different assumptions - although one of the problems from a research viewpoint is whether the latest materials are included in the database
- It is also quite expensive so is only really sensible for researchers doing a lot of analysis



Example of process step LCA with Simapro 7

Deposition of $CuInSe_2$

Need to define a functional unit
For PV, this is a piece (module). power (W or kW) or area (m^2) at the process analysis level

Interpretation of the LCA

- Most software packages performing the LCIA offer quantification of a range of environmental impacts, including greenhouse gas emissions (GHGs), heavy metals, acidification potential, eutrophication potential etc.
- The guidelines list the following impact assessment categories/indicators for PV LCA:
  Global Warming Potential, Ozone Depletion Potential, Comparative Toxic Unit (for humans, cancer and non-cancer), impact on human health of particulates, human exposure to ionising radiation, tropospheric ozone concentration increase, acidification, eutrophication (terrestrial, freshwater, marine), ecotoxicity (freshwater), land use (including biodiversity loss), **water use**, resource use (minerals and metals, fossils), **cumulative energy demand** (renewable and non-renewable), nuclear waste

Interpretation of the LCA (2)

- If we want to compare impacts for different technologies, we must define a unit product for which to express the impact – for PV, we can use power rating (W or kW), unit area (m^2) or electricity output (kWh).
- The impact/kWh is the most useful to compare different PV systems and to compare PV with other energy technologies
- In order to calculate this, we need to utilise the predicted lifetime output of the system and that requires us to make some assumptions about operating conditions and lifetimes – this provides a direct link with the modelling of system output

System assumptions – life expectancy

- 30 years for mature module technologies
- 15 years for inverters in small plants, 30 years with 10% part replacement every 10 years for large plants
- 30 years for transformers
- 30 years for mounting structures for building attached arrays, 30-60 years for building integration and ground mounted installations on metal supports
- 30 years for cabling
- Manufacturing plant variable depending on development of the technology

System assumptions – solar irradiation

- The current guidelines do not actually provide a value to use
- They suggest to assume optimal orientation for ground mounted systems and actual average orientation for a group of systems connected to the grid
- Further, for BIPV and bifacial systems, they suggest using annual irradiation values determined from state-of-the-art modelling software (although this is not specified)
- Whilst this approach allows the impact of a specific system (or set of systems) to be determined, it poses some problems for comparisons
- In the literature, it is common to use a value of 1700 $kWh/m^2/year$ for comparing module technologies, for example

System assumptions – other parameters

- Site-specific performance ratio or a default value of 0.75 for roof top installations and 0.80 for ground mounted systems – these values allow for degradation of PR over time
- For BIPV and bifacial systems, use site-specific PR values
- Linear degradation of -0.7% per year, unless verified long-term test data indicates a different value – this is for mature module technologies
- Curtailment of output, either at the inverter or at the grid connection, should be included in the output estimate if it occurs
- Back-up systems, such as batteries or alternative generation included in hybrid systems, is considered outside the scope

Energy Payback Time

- The calculation of cumulative energy demand allows the calculation of energy payback time (EPBT) – this is the period of time taken to compensate for the primary energy used in the life cycle by the energy generated by the system (using a conversion factor related to the primary energy equivalent based on the relevant electricity conversion efficiency)
- There is a related parameter, the non-renewable energy payback time (NREPBT), which considers the compensation of non-renewable energy inputs only

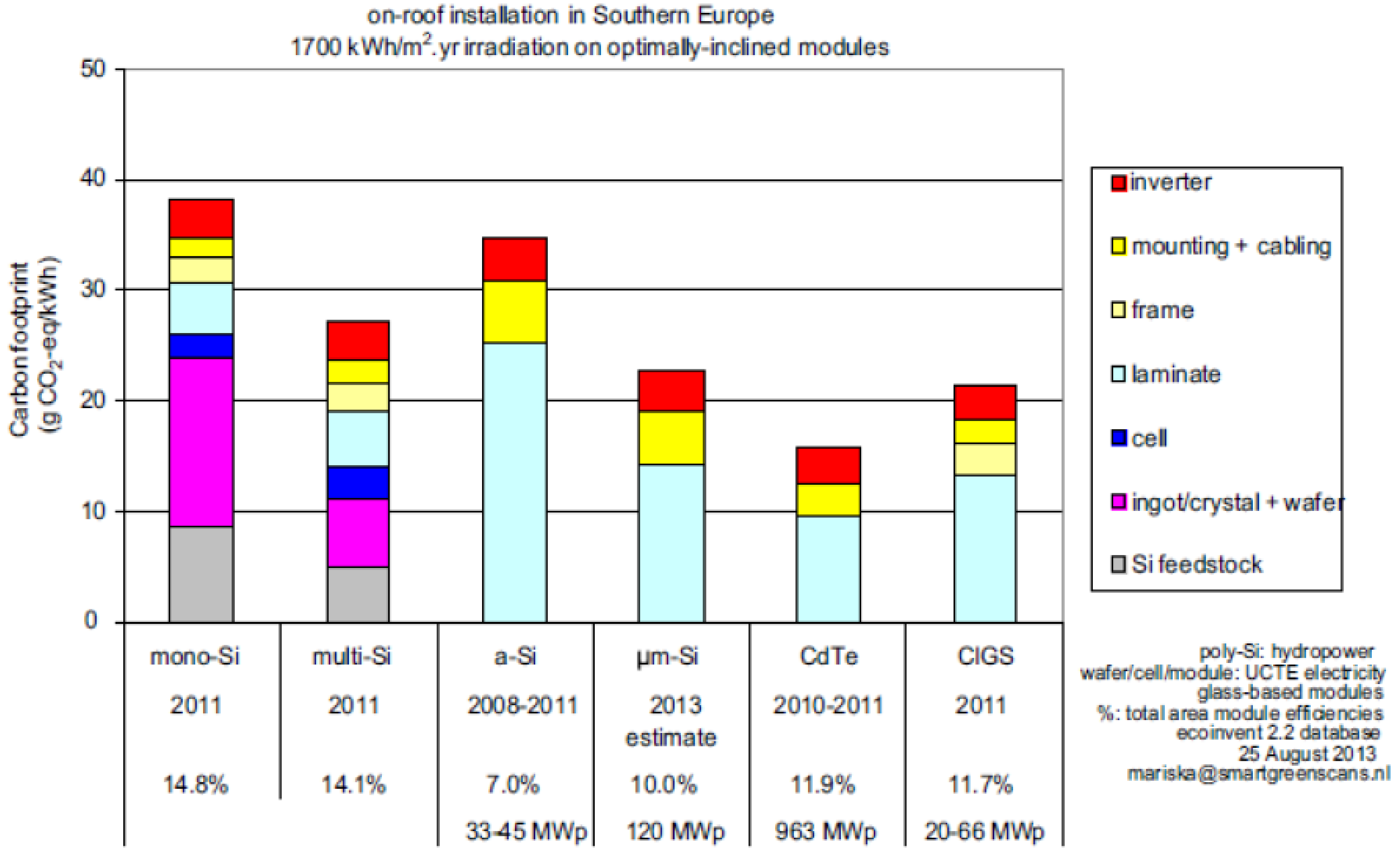


Fig. 3. Carbon footprint of commercial PV systems, irradiation 1700 kWh/m^2 year.

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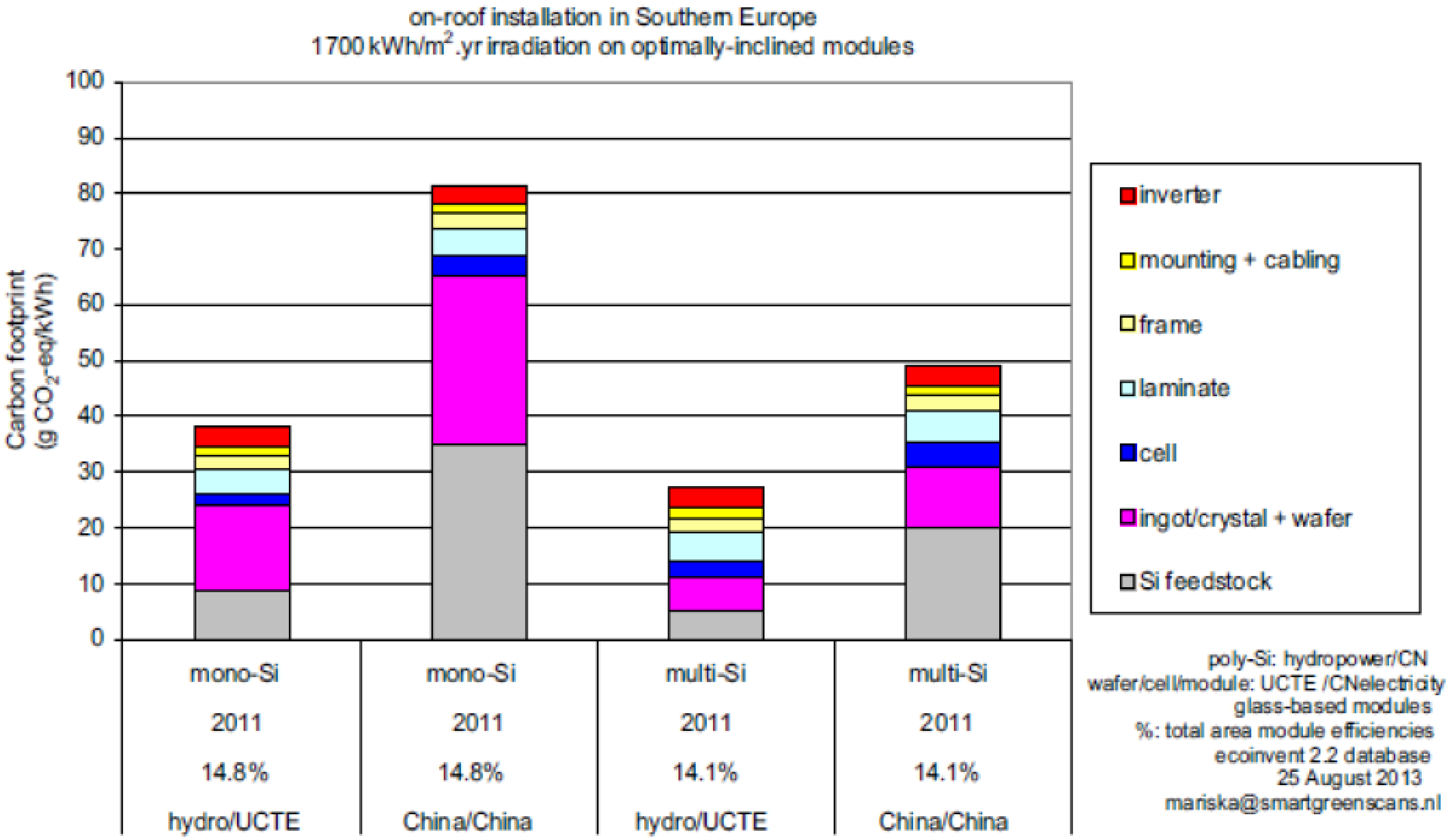

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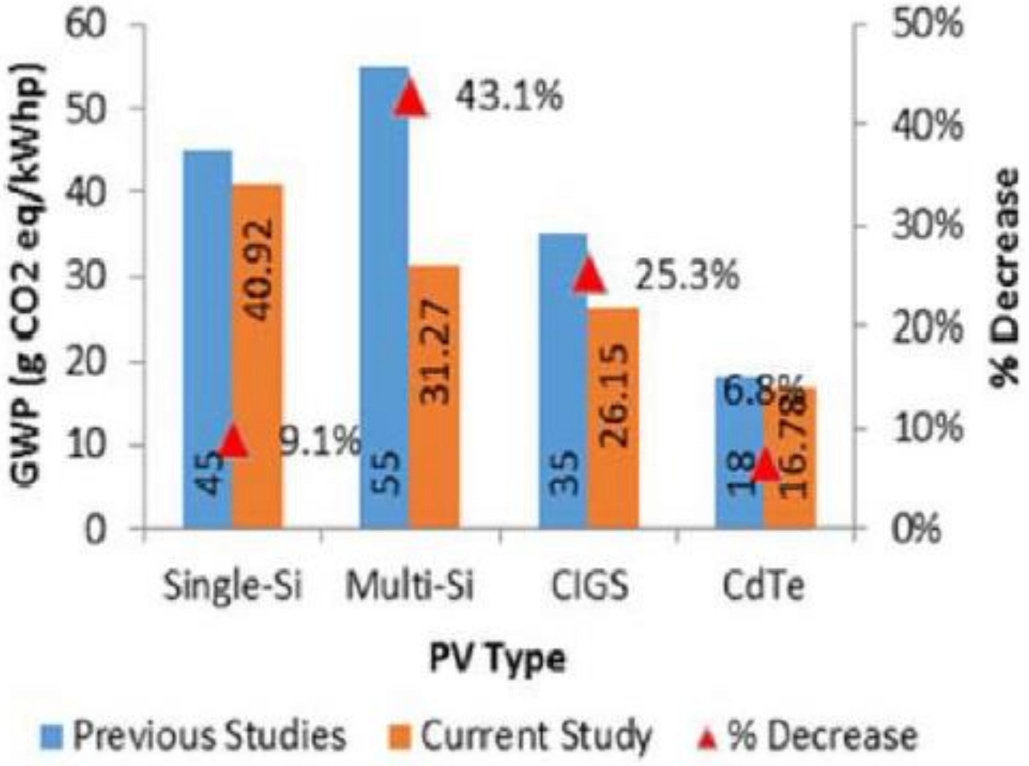
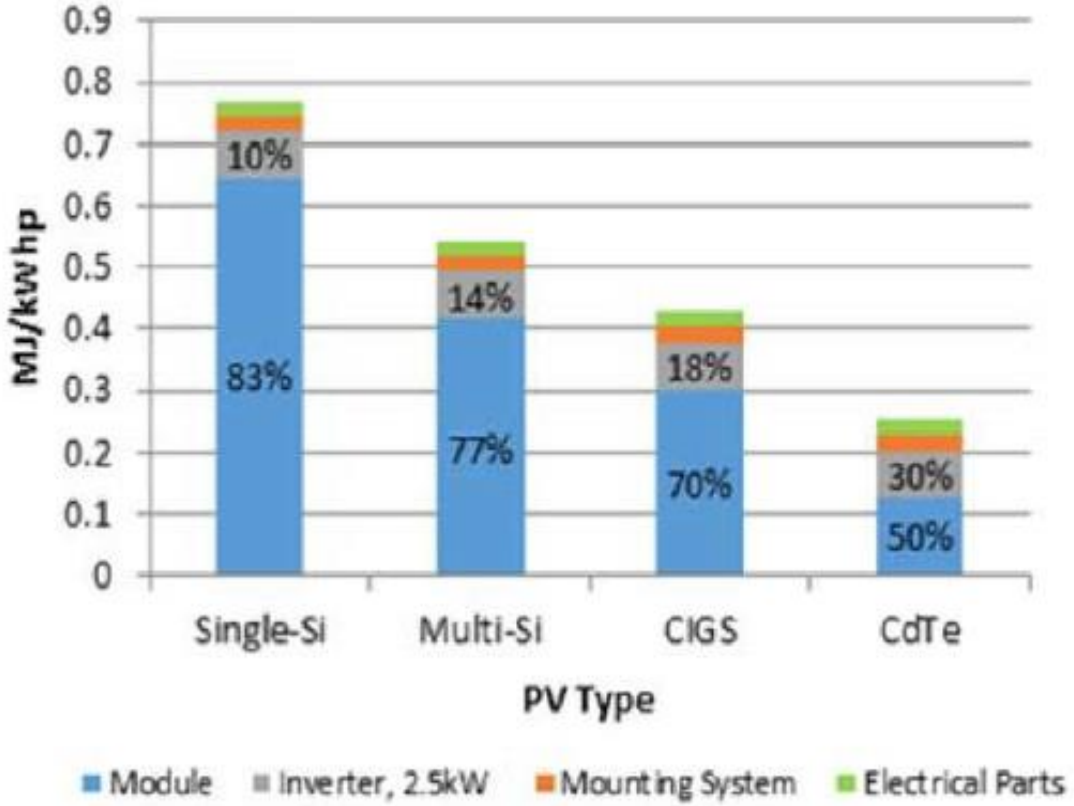
Fig. 5. Carbon footprint of commercial crystalline silicon PV systems showing sensitivity to electricity mix, irradiation 1700 kWh/m^2 year.



Dahiya and Vogt, 32nd EUPVSEC, 2016



Summary

- We have taken a look at the procedures for assessing environmental impact of PV systems
- The IEA PVPS Task 12 reports provide a lot of information relating to the performance of a life cycle analysis
- Most analyses are done on established production lines
- The environmental impacts, particularly cumulative energy demand, has reduced over recent years and it is starting to become important to consider all the system elements