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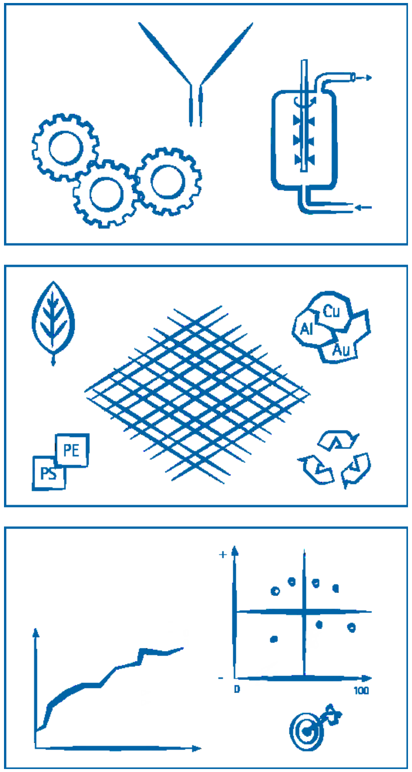
PV Life Cycle Analysis



Karsten Wambach

June 19, 2017

Technology. Materials. Strategies.

Standards/Guidelines and Working Groups

- DIN EN ISO 14040/44
- ILCD Handbook (Data)
- IEA-PVPS Task 12, LCA Guidelines for PV Systems
- EU Product Environmental Footprint (PEF)
- EU Ecolabel
- IEA PVPS task 12 (LCA, EHS)
- IEA PVPS task 15 (Environmental assessment)
- IEC PT 62994-1 (EHS Risk assessment in manufacturing)
- NSF PV Module Sustainability Leadership Standard
- Solar Power Europe Taskforces Environmental Footprint & Ecodesign
- SVTC Scorecard

Legal Background

Europe:

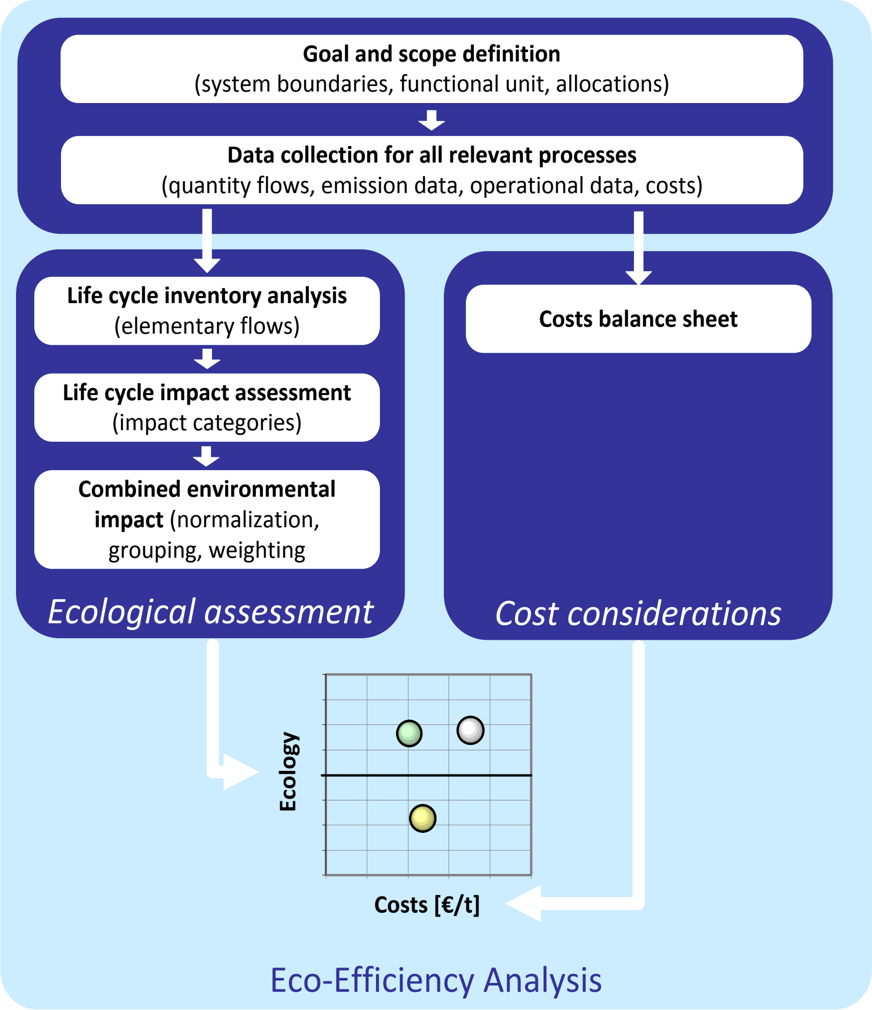
- **Waste Framework Directive** 2008/98/EC, Commission Regulation (EU) No 1357/2014 on Annex III
- **Hazardous Waste Directive** 91/689/EEC
- **List of Wastes** Decision 2000/532/EC, Commission Decision (EU) No 2014/955/EU
- **ROHS** Directive 2011/65/EU
- **WEEE** Directive 2012/19/EU

- CENELEC CLC/TC111, Mandate M/518, EN50574, EN50625-2-4/TS50625-3-5

Germany:

- Draft: EEE Treatment Ordinance
- Draft: LAGA M31A and B
- VDI 2343

LCA and Eco Efficiency Analysis



- Functional unit
- System boundary
- Data collection
- Calculation of input and output balance

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Guidance Document

Process description for LCA data collection

Contents:

See also http://www.iea-pvps.org/index.php?id=434

LCA and Eco Efficiency Analysis

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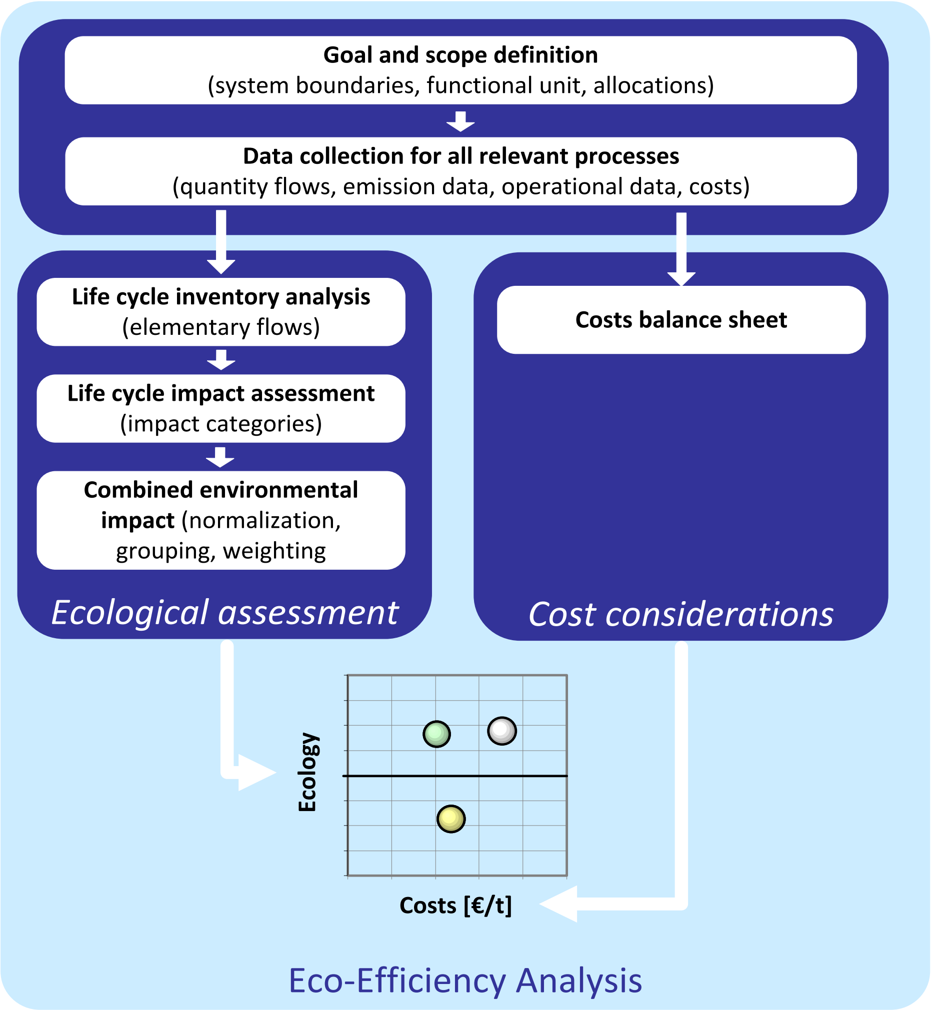
Input	Quantity [9]	Unit	Data quality and comments [10]
Energy sources [11]			
Electricity	68,2	kWh	
Natural gas	70,5	MJ	
Raw and starting materials [12]			
Argon (liquid)	1,0	kg	Protection gas for growing
Ceramic tiles	0,18	kg	Quartz crucible for melting the silicon
Silicon	0,82	kg	Production mix for photovoltaics
Hydrogen fluoride	0,01	kg	For etching
Nitric acid (50% in H_2O)	0,068	kg	For etching
Operating material [13]			
Lime (hydrated)	0,022	kg	Waste water treatment
sodium hydroxide (50% in H_2O)	0,041	kg	Waste gas neutralization
Deionised water	4,01	kg	
Cooling water	5,1	m³	
Process			
Process name [1]	**PV Modul Production**		
Process step / description [2]	**Czochralski process (Single crystal growth)**		
Site location [3]	Munich, Bavaria		
Data reference and unit [4]	**1 kg ingot (CZ single crystalline silicon)**		
Reference period [5]	2008 till 2011		
Flow chart [6]	not available		
Contact person [7]	René Peche		
Adress	Am Mittleren Moos 46		
Phone number	+49 821 7000 186		
E-Mail	rpeche@bifa.de		
Creation date [8]	03.08.2016		
Output			
Products [14]			
CZ single crystalline silicon	**1**	**kg**	
Emissions to air [15]			
No direct emissions			
Emissions to water [16]			
BOD5 - Biological Oxygen Demand	130	g	
COD - Chemical Oxygen Demand	132	g	
Hydroxide	368	g	
Nitrate	85,5	g	
Nitrogen oxides	31,7	g	
Wastes / disposal route [17]			
Inorganic waste	0,168	kg	current type of disposal: residual material landfill
By-products [18]			
Non			
Transports [19]			
Transport goods [20]	**Simple distance or location** [21]		**Means of transport** [22] **and comments** [10]
Ceramic tiles	Hangzhou (CN)		Mix of trucks and cargo vessel
Silicon	Munich (DE)		Truck (24 t)
Inorganic waste	100 km single way		Truck (7,5 t)

General Information	done
(9) Quantity As a general rule data should be entered by mass [kg]. Liquids should be specified in liters [l] – please use the comment column for density information. Gases should be specified by mass, volume specifications only are allowed in standard cubic meters [Nm³].	❐
(10) Data quality and comments Data source: e.g. operating statistics, measured, calculated or estimated value	❐
(11) Energy sources e.g. power, gas, c	❐
(12) Raw and sta e.g. chemicals, pl	
(13) Operating m e.g. water (proce	

General Information	done
(1) Process name Please enter the short name of the process to be accounted.	❐
(2) Process step / description Please enter a short description of the process or process step.	❐
(3) Site location Location where the process takes place	❐
(4) Data reference and unit Please enter the reference value and reference unit to which the data applies.	❐
(5) Reference period Reference period which	
(6) Flow chart The process flow chart i which are necessary for	
(7) Contact person Contact person in the ca	
(8) Creation date Creation date of the dat	

General Information	done
(14) Products All process outputs specifically created in the production process	❐
(15) Emissions to air e.g. CO_2, CO, SO_2, NMVOC, NO_x, N_2O, CH_4, halogenated hydrocarbons, heavy metals, particles, etc.	❐
(16) Emissions to water e.g. analytical values for COD, BOD, heavy metals, inorganic and organic compounds, etc.	❐
(17) Wastes / disposal route Please also enter the waste treatment option: recycling, incineration, disposal.	❐
(18) By-products All process outputs not specifically targeted on in the production process	❐
(19) Transports Please enter the transport information for all material inputs and wastes. Small amounts of municipal waste could be neglected.	❐
(20) Transport goods Please enter all material inputs from (13) and (14) delivered by subcontractors.	❐
(21) Simple distance or location Distance between subcontractor/disposal company and production site in km	❐
(22) Means of transport e.g. truck (incl. gross vehicle weight), train, inland marine transport, etc.	❐

LCA and Eco Efficiency Analysis



Results for each category indicator

- Assignment of results from inventory analysis (e.g. CO_2, CH_4, N_2O) to category indicators (e.g. global warming potential)
- Discussion of the results with respect to goal and scope of the LCA
- Merging with analysis of the costs within the scope of an eco-efficiency analysis

Levelized cost of energy (LCOE)

for Solar PV Installations depends on

- performance
- system costs
- ongoing operations & maintenance
- over the lifetime of a system

Eco-efficiency analysis of PV Modules (bifa 2013)

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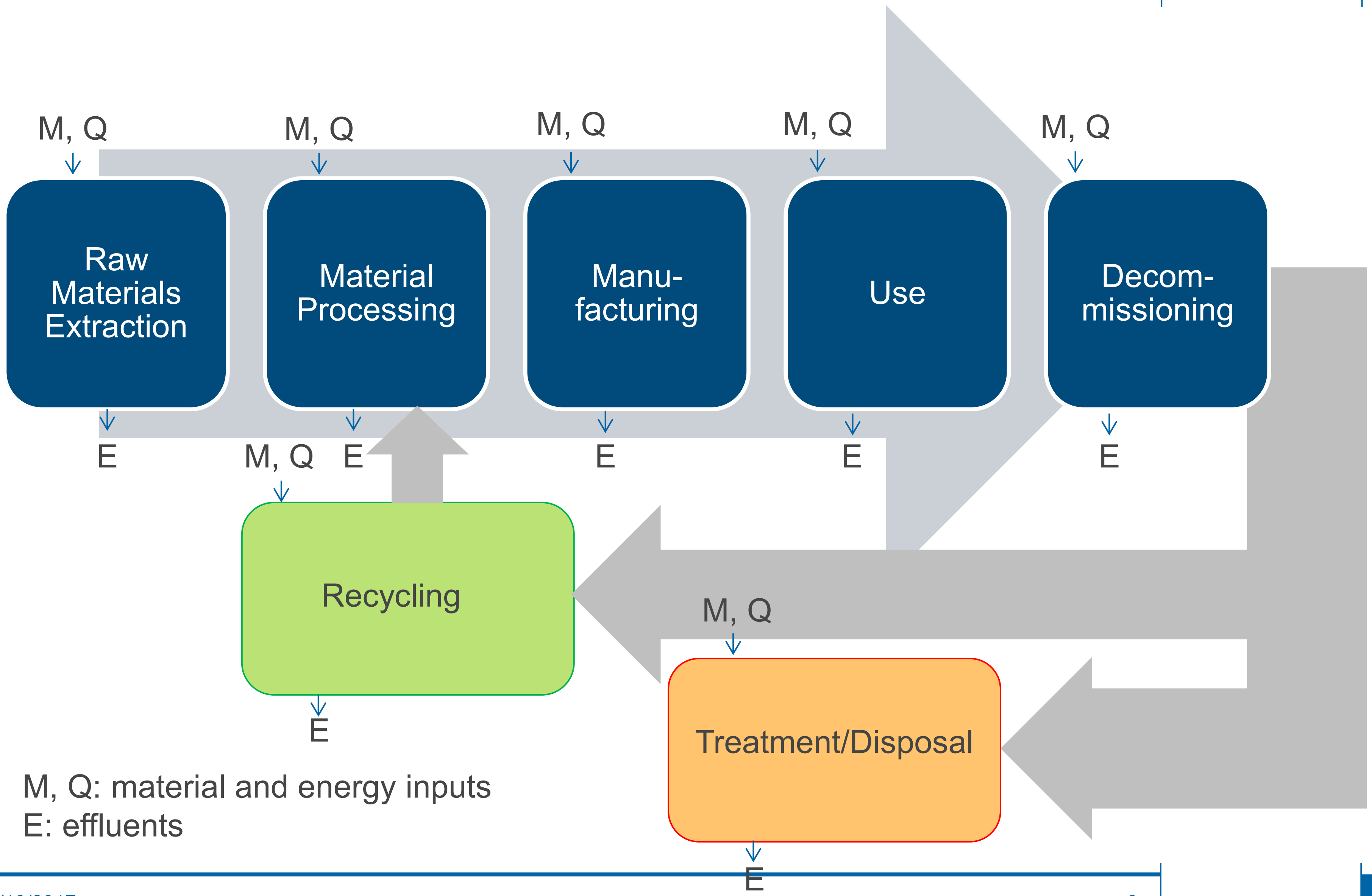

M, Q: material and energy inputs
E: effluents

Eco-efficiency analysis of PV Modules (bifa 2013)

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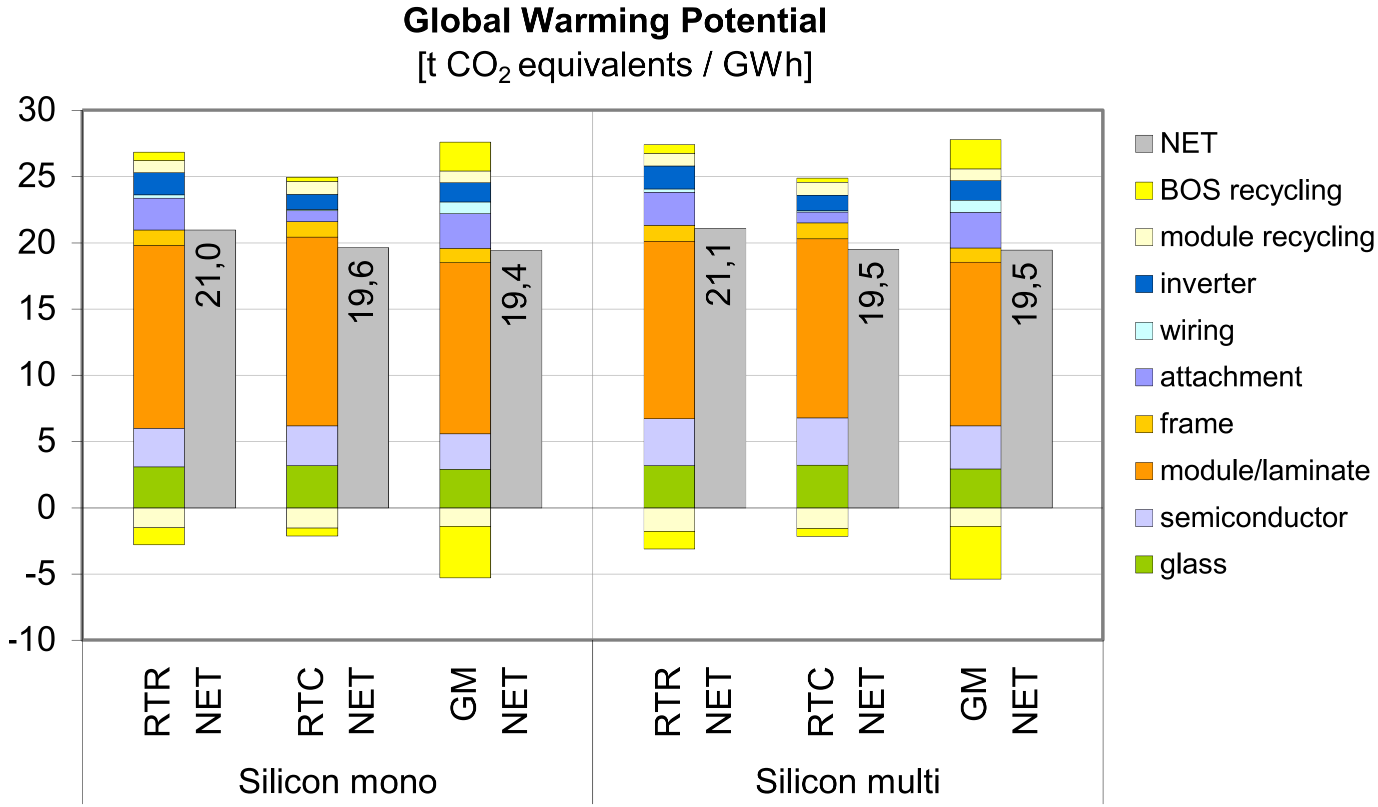
- Lifecycle: starting from 2012 with status quo recycling option in 2042
- Application cases: rooftop residential (RTR), rooftop industrial (RTC), ground-mounted system (GM)
- Silicon Module



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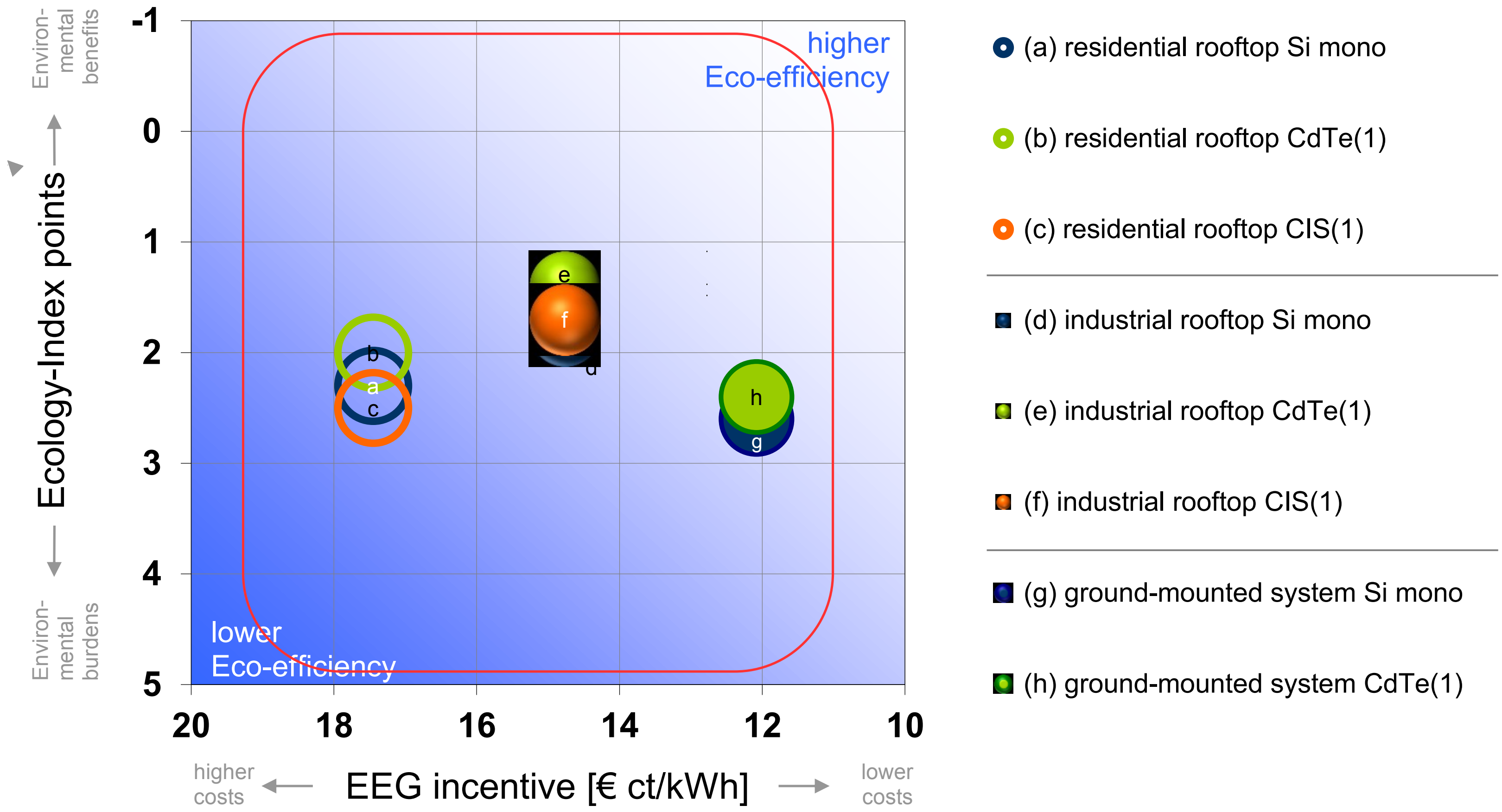
Scenario: high-quality recycling (optimal)
Module types: Si-mono, CdTe and CIS



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H2020 Project:

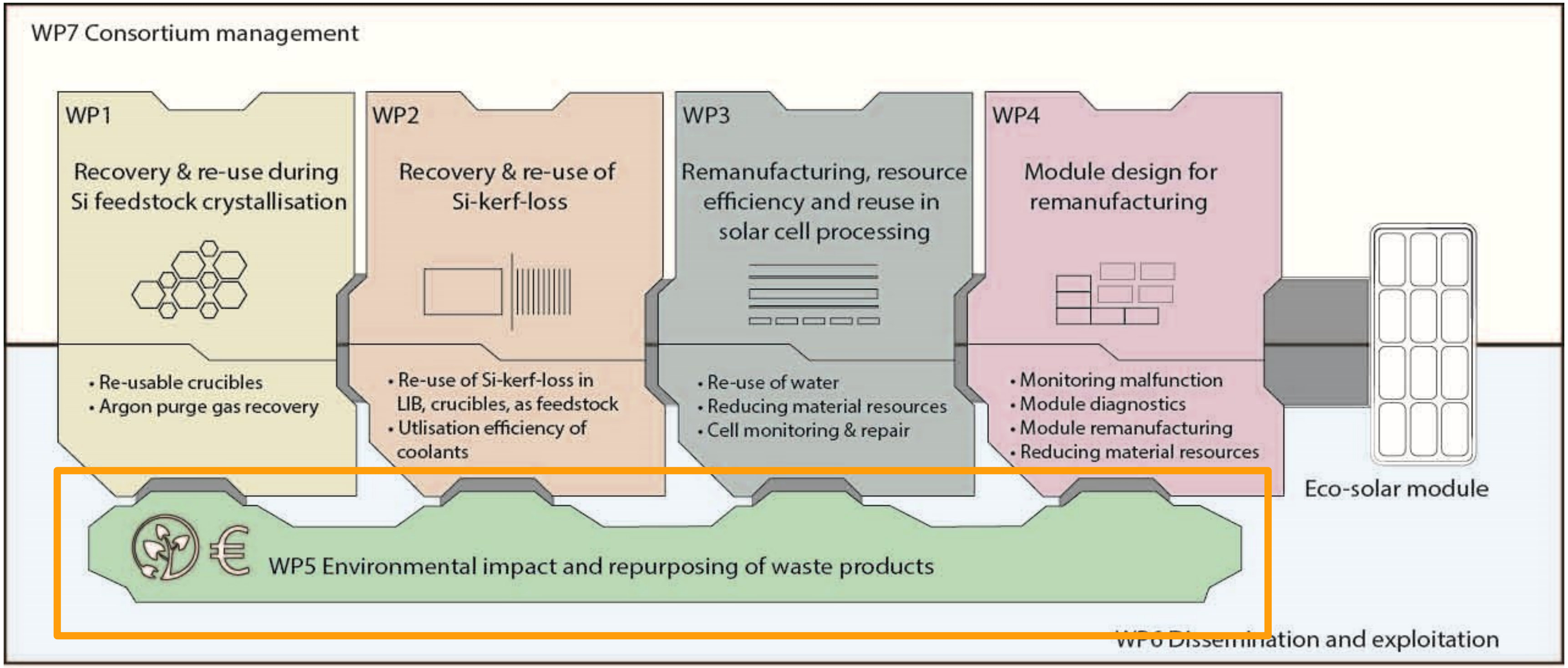
Eco-Solar Factory: 40%plus eco-efficiency gains in the photovoltaic value chain with minimised resource and energy consumption by closed loop systems

Target: Development of an integrated value chain to manufacture and implement solar panels in the most ecologic way by

- maximising resource efficiency,
- taking into account reuse of materials during production and
- repurposing solar panel components at end of life stage.

Duration: 01.10.2015 – 30.09.3018

Example: Eco-Solar Factory



Baseline: standard EVA laminated module (60 6-inch solar cells, about 270Wp) with front glass and polymer back sheet including aluminium framing

Evaluated project developments by work package:

- **WP1 “recovery & reuse during feedstock crystallisation”:**
  - Argon gas recovery
- **WP2 “recovery & reuse of Si-kerf-loss”:**
  - New wire sawing process with thinner diamond wire
  - New silicon kerf recovery process from sawing machines coolant
- **WP3 “remanufacturing, resource efficiency and reuse in solar cell processing”:**
  - New cell process
- **WP 4: “module design for remanufacturing”:**
  - Usage of a EVA-free glass/glass frameless NICE module

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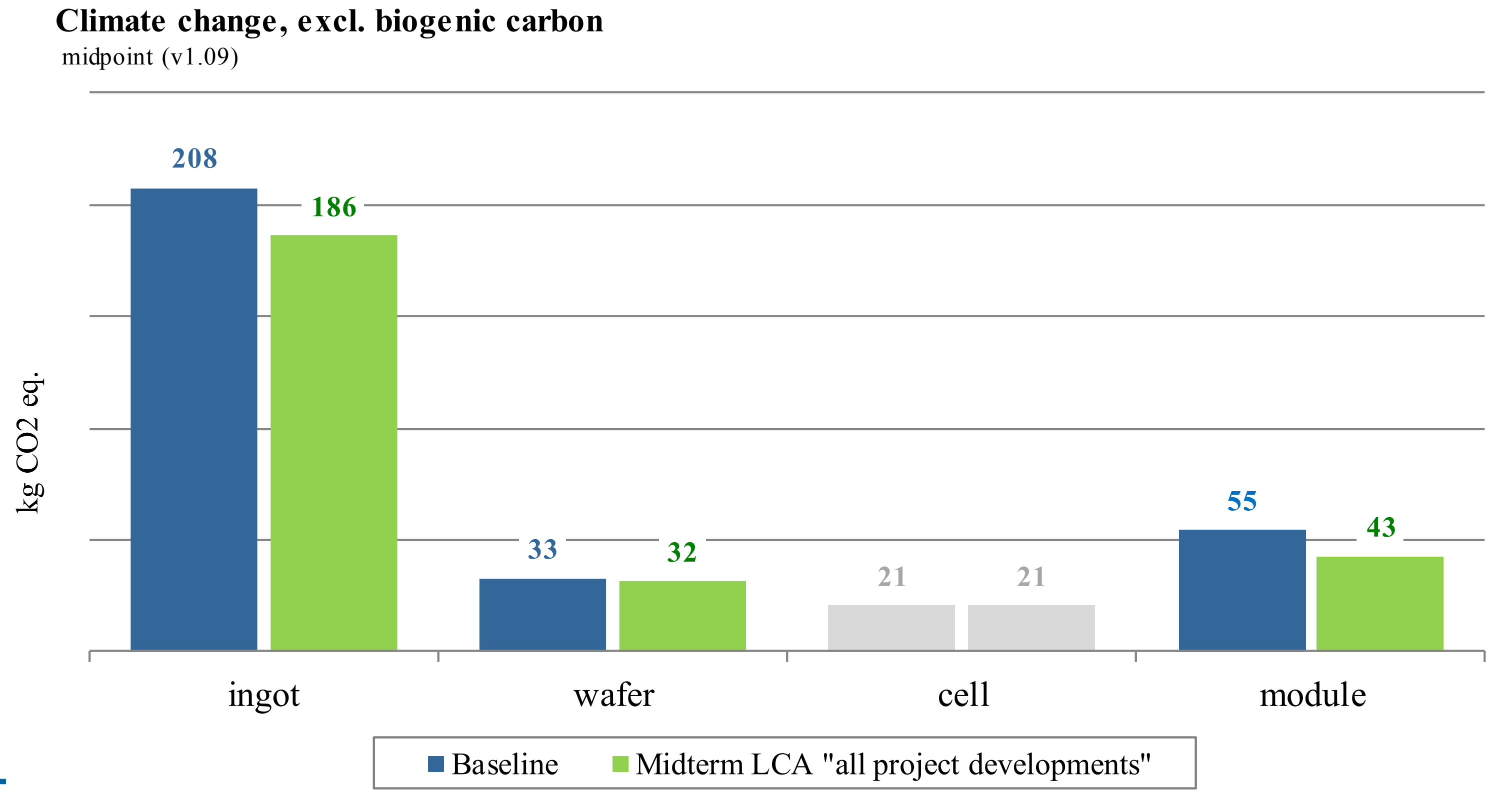
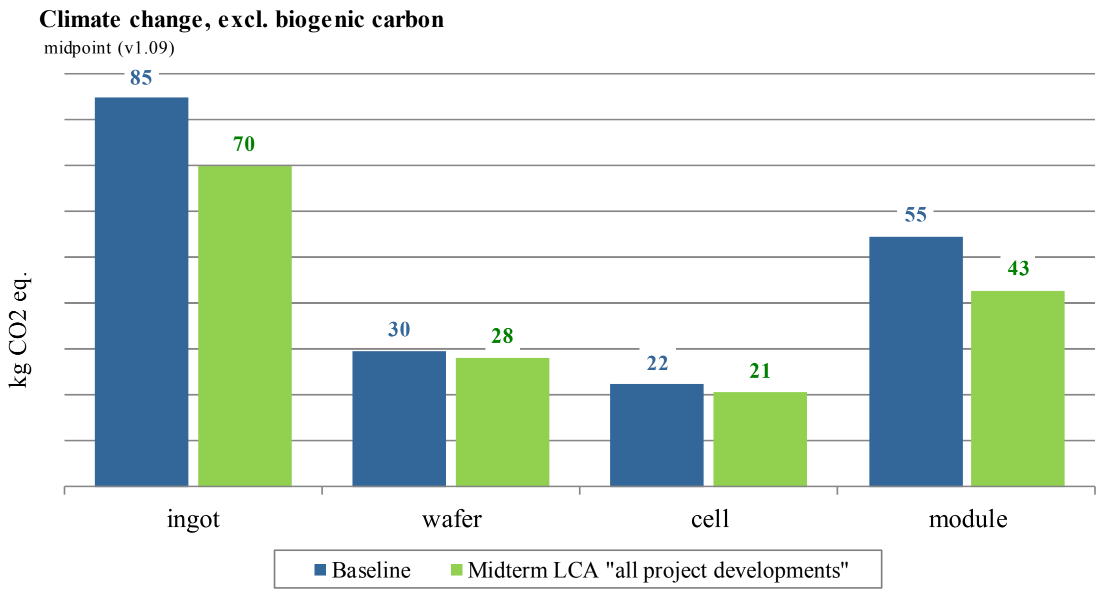
First exemplary results for mono-Si based PV module

- Project developments: argon gas recovery, new wire sawing process, usage of an EVA-free glass/glass frameless NICE module
- First exemplary results: For all examined impact categories environmental advantages exist amounting to 6.6 % for ozone depletion and more than 56 % for depletion of mineral, fossil and renewable resources.



Example: Eco-Solar Factory

- First exemplary results for **multi**-Si based PV module
  - Project developments: argon gas recovery, new wire sawing process, new silicon kerf recovery process, new cell process, usage of an EVA-free glass/glass frameless NICE module
  - First exemplary results: For all examined impact categories environmental advantages exist amounting to 1.2 % for photochemical ozone formation and almost 51 % for depletion of mineral, fossil and renewable resources.



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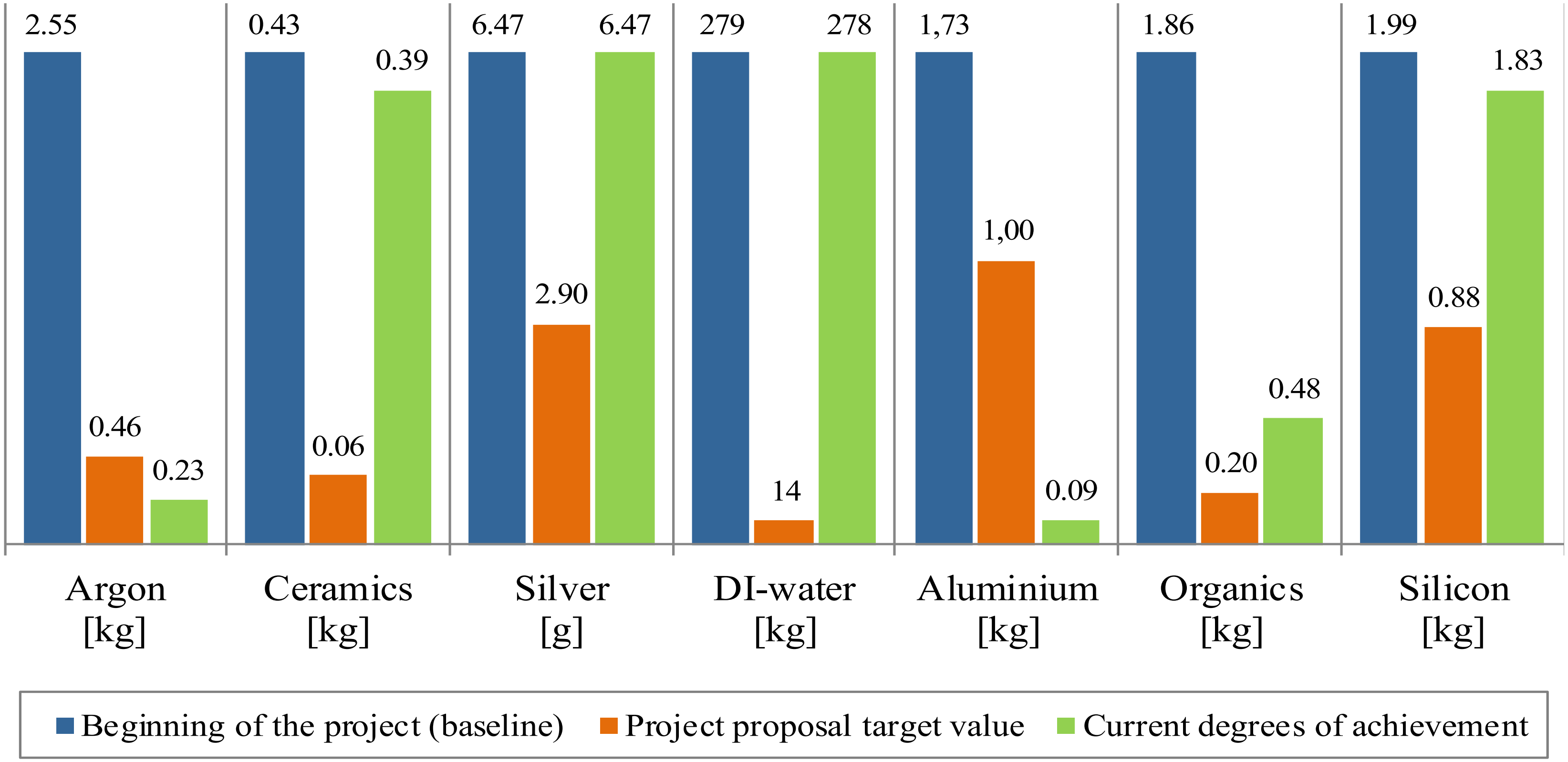
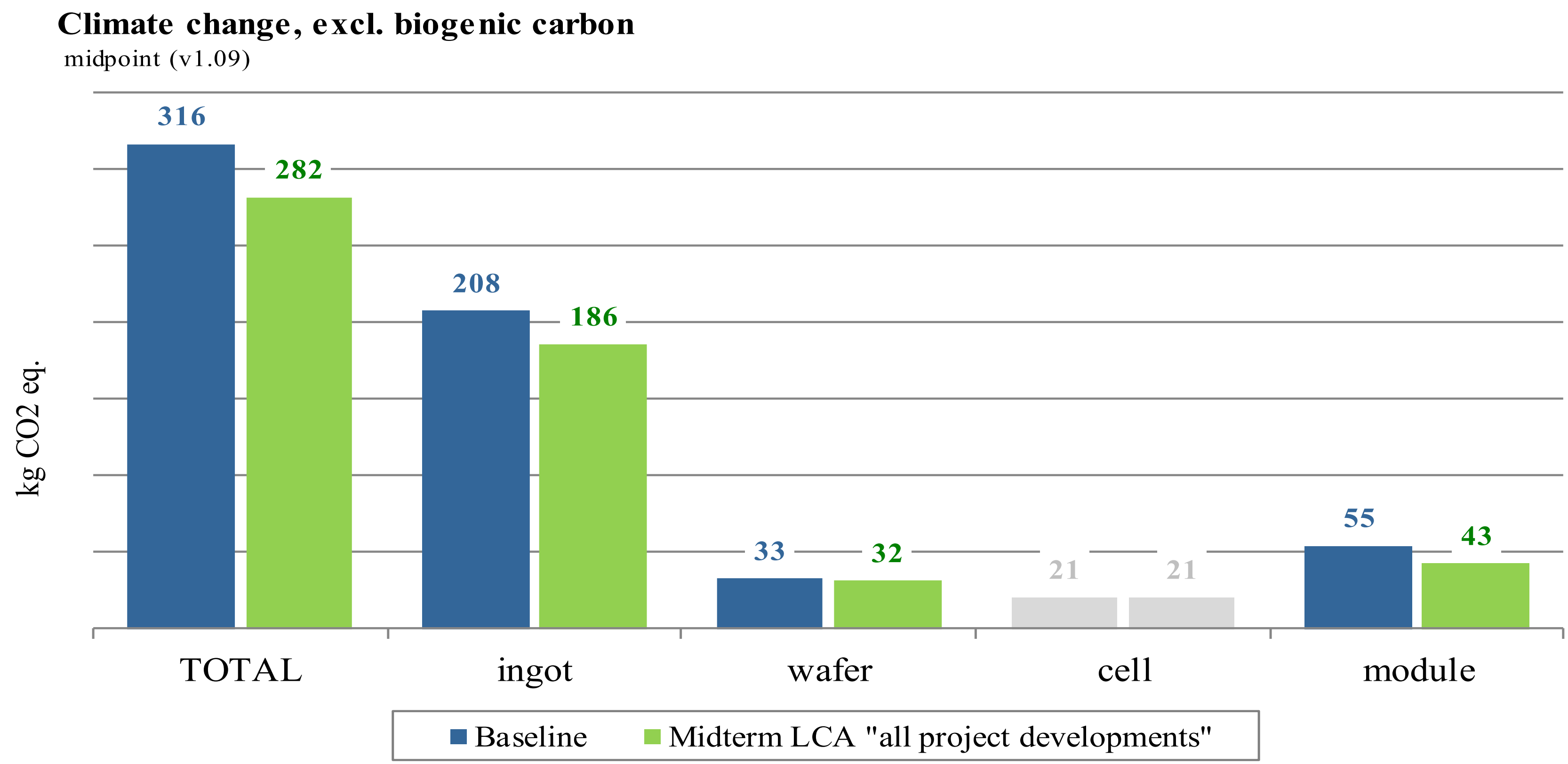


Reduction of waste and resource consumption per production unit for mono-Si based PV-module (60 6-inch solar cells) envisaged at the beginning of the project and current degrees of achievement

WP5: Midterm LCA



beginning of the project and after implementing all project developments
production of 1 mono-Si based PV-module (60 6-inch solar cells)

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Achievements

- Data base updates, continuous integration of new data
- Updating of the material and energy flow model.
- Reduction of the raw materials & consumables (Ar, ceramics, Al, silver, DI-water and silicon).

Benefits

LCA provides the basis for adjustments and optimization in both cradle to grave and cradle to cradle approaches.

- Optimisation of Environmental Footprints
- Eco-efficiencies to support investment decisions by inclusion of economic data
- Environmental Reporting (ISO14001, EMAS, CDP etc.)

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