Influence of materials recycling processes in the life cycle assessment of energies

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- Methodology for EoL modelling in Life Cycle Assessment
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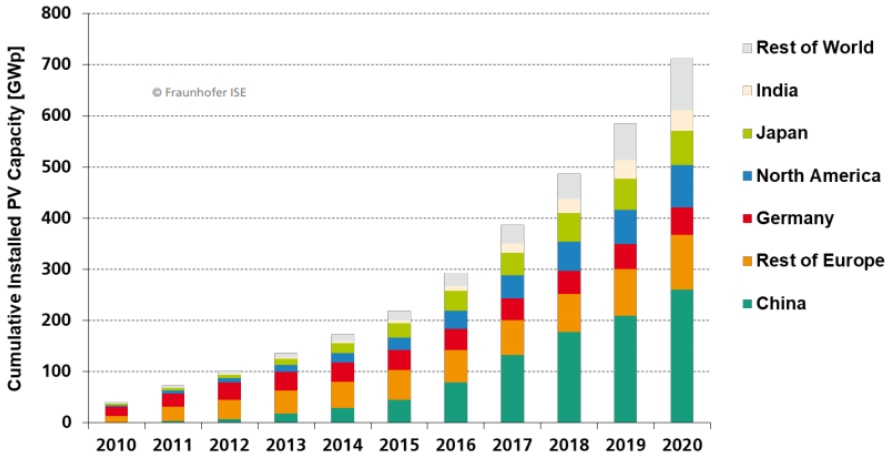
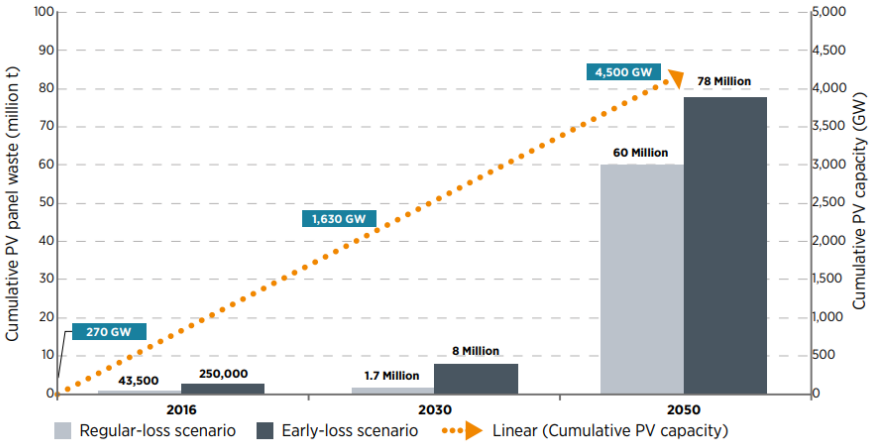
Assessment



Global cumulative PV Installation (Fraunhofer 2020)



Overview of global PV panel waste projection (IRENA 2016)

- Fast development of wind and photovoltaic energies
- Very high material intensity of these technologies
  → Large amount of waste to be treated in the future

Energy source	Load factor
Wind onshore	0.22/0.3
Wind offshore	0.35/0.4
Solar PV	0.13/0.2 depending on regions
Nuclear	0.7/0.8

Objectives

- Determine end of life impacts of photovoltaics (and wind turbine) energies

  → Refine the impact results of these electricity generation sources
  → Compare several recycling processes
  → Be more accurate in the energy mix modelling

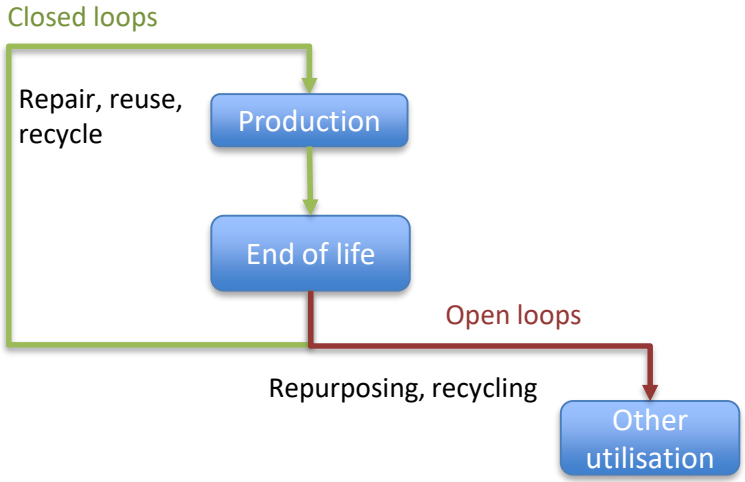
- Impacts are reported per kWh produced to be compared with other electricity production systems

$$Impact/kWh = \frac{Impact\ of\ the\ system\ over\ his\ whole\ life\ cycle}{Estimated\ electric\ production\ during\ his\ lifespan}$$

SimaPro

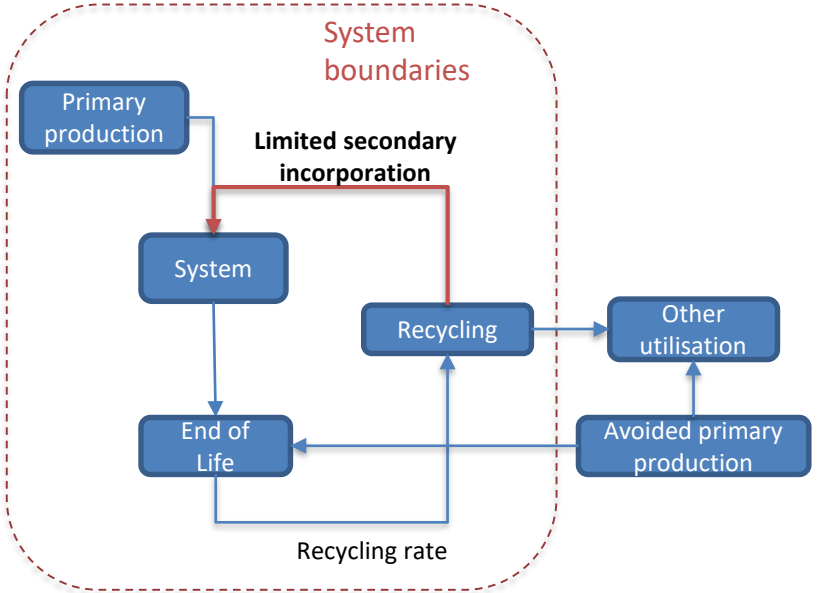
ISO 14044:2006 standard distinguishes 3 different recycling loops with 3 different methods:

- Closed loops
- Open loops
- **Open loops modelled as closed loop recycling.**

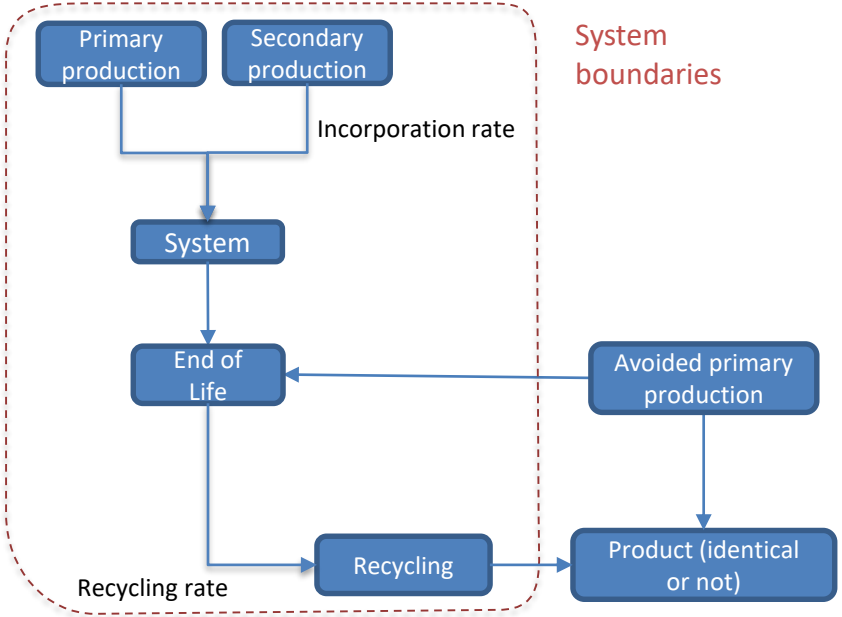


ISO 14044:2006 Environmental management — Life cycle assessment — Requirements and guidelines
ISO 14049:2012 Environmental management — Life cycle assessment — Illustrative examples on how to apply ISO 14044 to goal and scope definition and inventory analysis

ISO 14049 methodology



Methodology used

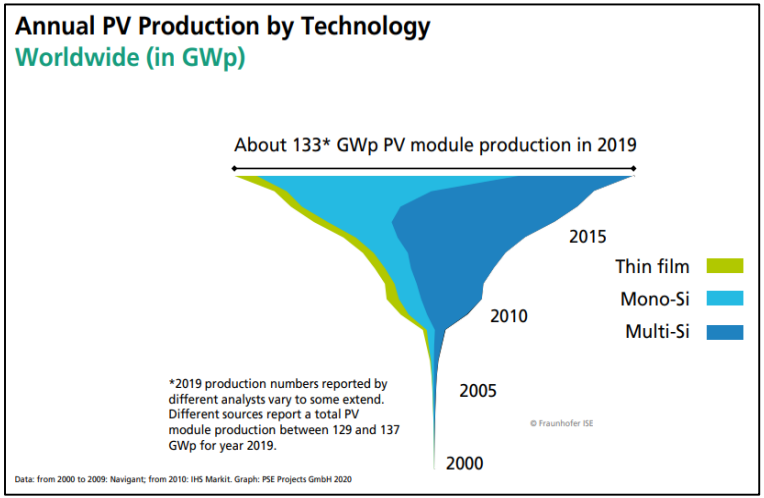


Recycling rate = collection rate * process efficiency

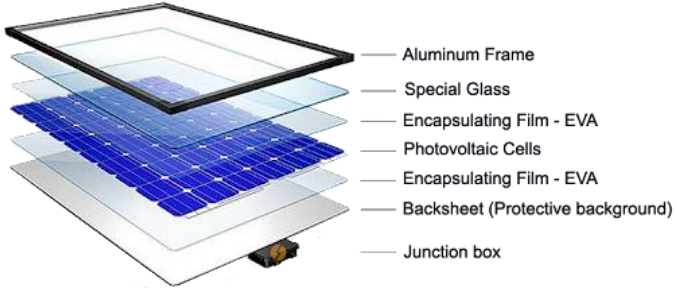
- ❖ Calculate the global impacts of the EoL step
- ❖ Take into account the different recycling loops **in the same way**

Application to photovoltaic

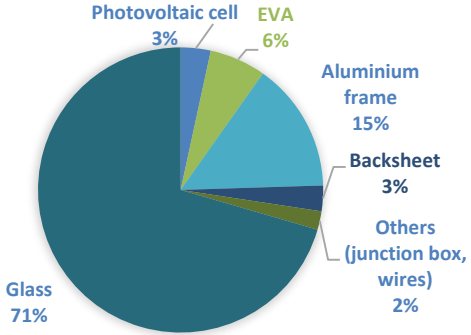
- The objective is to model the technologies reaching the end of life until 2050 -> launched on the market until 2020
- Crystalline silicon technology (c-Si): mono-crystalline and poly-crystalline.



Annual PV production by technology (Fraunhofer 2020)



Panel composition (Roofway.com)



Mass composition of a photovoltaic panel

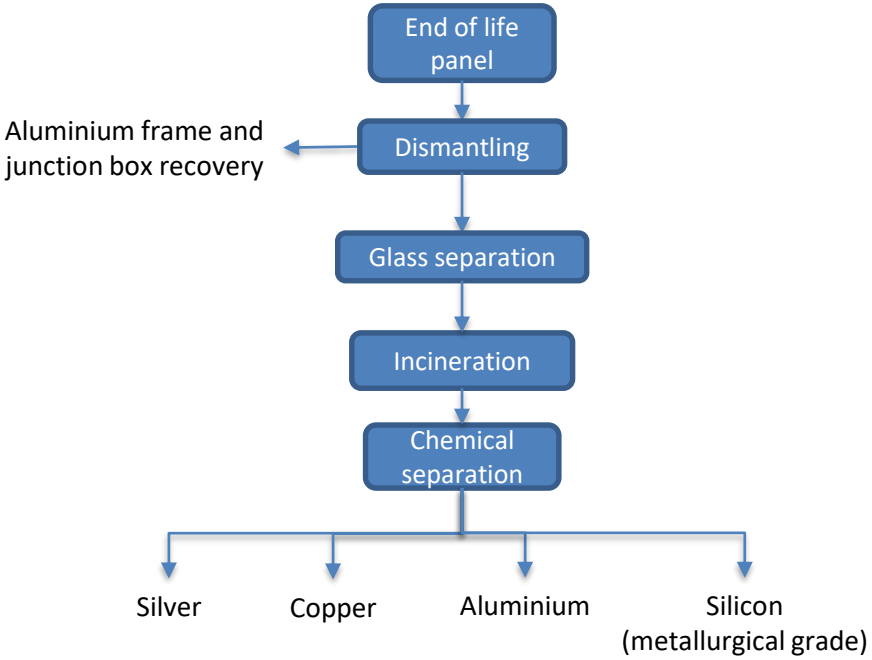
Recycling routes

- 3 steps :
  - Dismantling frame and junction box
  - Delamination
  - Cell processing

- Detailed process inventory given in the publication

Reference process

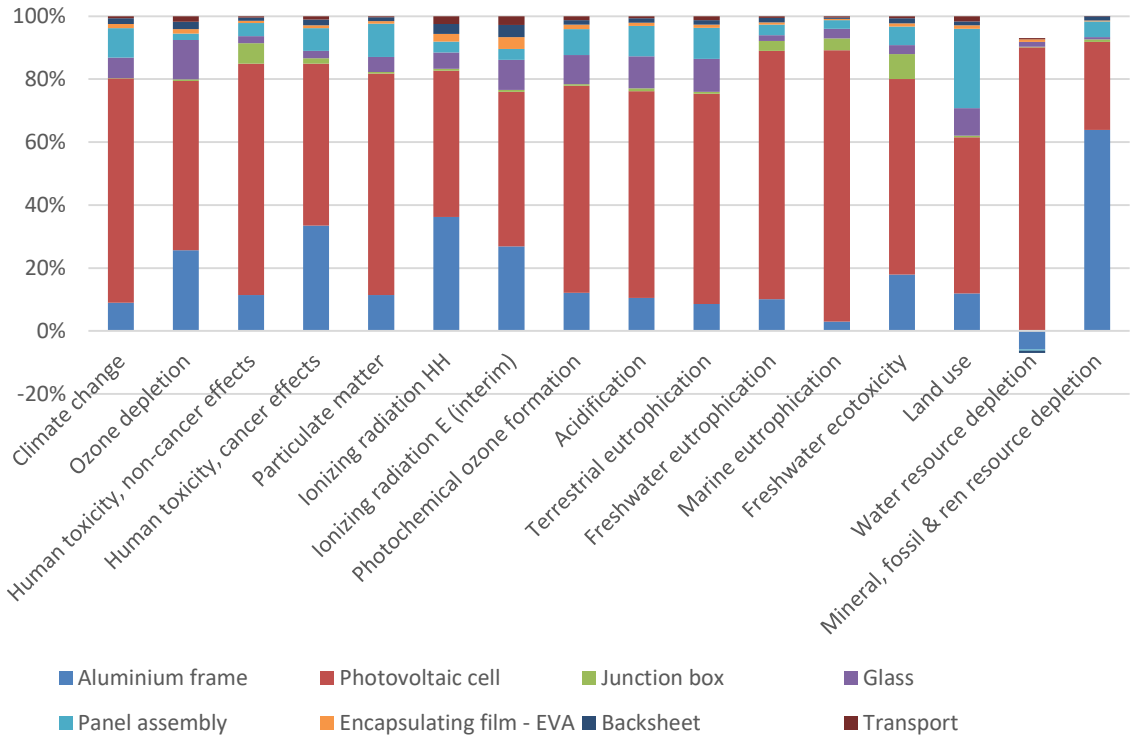
FRELP project (Latanussa 2016)



C. Latanussa, F. Ardente, G Blengini, L. Mancini "Life Cycle Assessment of an innovative recycling process for crystalline silicon photovoltaic panels" Solar Energy Materials & Solar Cells 156, 2016.

LCA of the production of a virgin mono-Si panel (IEA 2020)

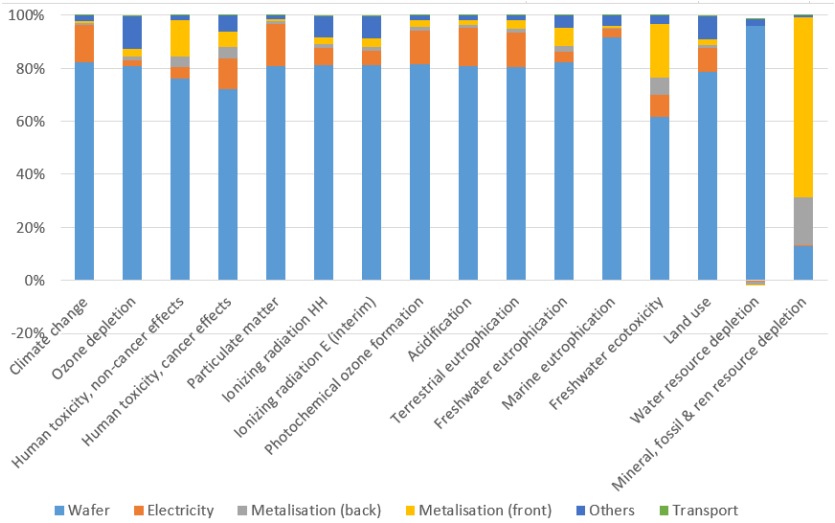
	Catégorie d'impact	Unité
1.	Climate change	kg CO2 eq
2.	Ozone depletion	kg CFC-11 eq
3.	Human toxicity, non-cancer effects	CTUh
4.	Human toxicity, cancer effects	CTUh
5.	Particulate matter	kg PM2.5 eq
6.	Ionizing radiation HH	kBq U235 eq
7.	Ionizing radiation E (interim)	CTUe
8.	Photochemical ozone formation	kg NMVOC eq
9.	Acidification	molc H+ eq
10.	Terrestrial eutrophication	molc N eq
11.	Freshwater eutrophication	kg P eq
12.	Marine eutrophication	kg N eq
13.	Freshwater ecotoxicity	CTUe
14.	Land use	kg C deficit
15.	Water resource depletion	m3 water eq
16.	Mineral, fossil & ren resource depletion	kg Sb eq

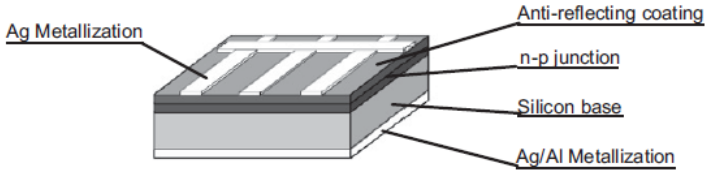


❖ Cell manufacturing has the highest impact for most indicators

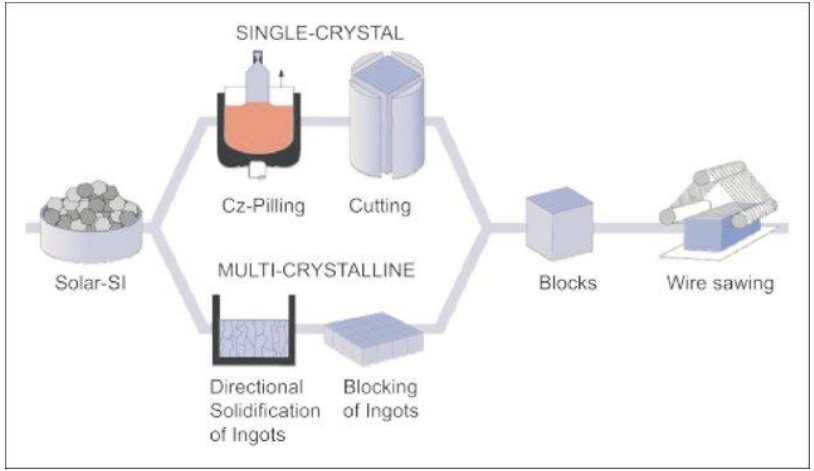
IEA : International Energy Agency

LCA of the production of a virgin mono-Si panel





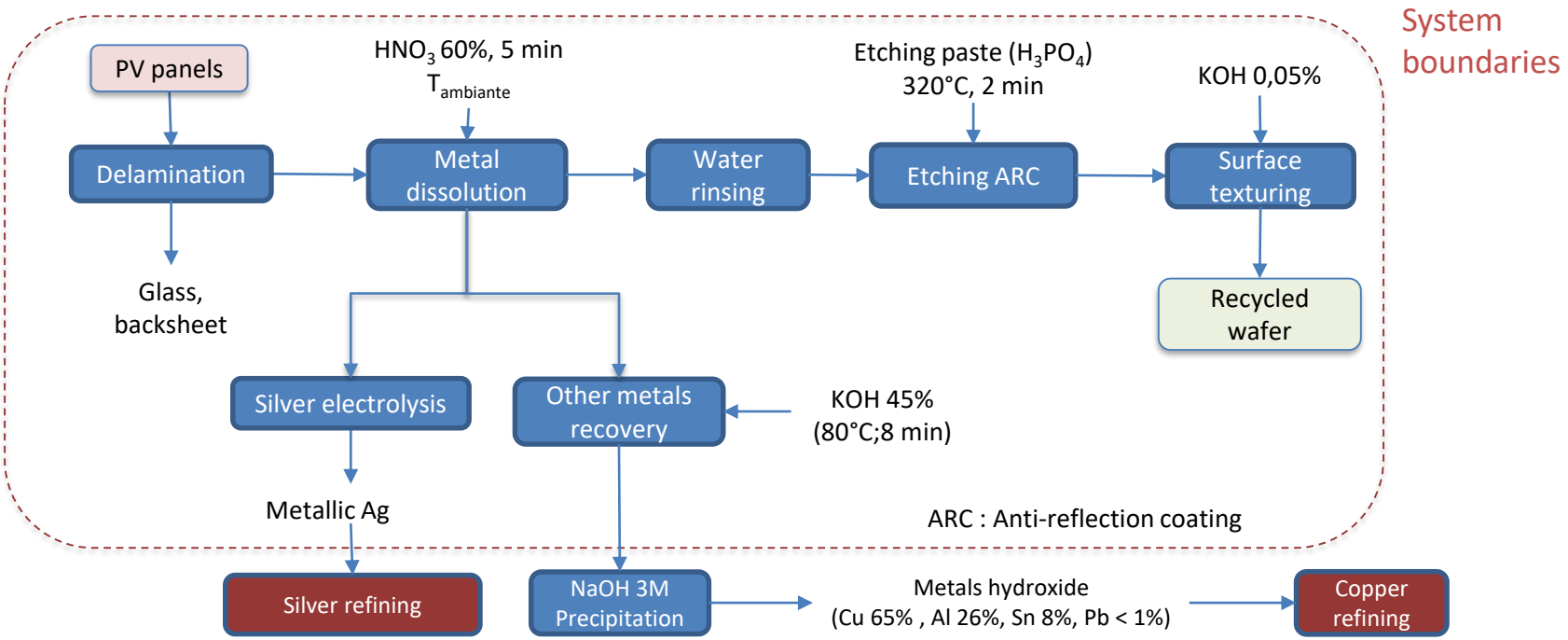
Photovoltaic cell composition (Radziemska 2010)



Single and multi-crystalline wafer production (Israil 2013)

- Important energy consumption (75.4 kWh/m² for single-Si and 53.4 kWh/m² for multi-Si)
- Significant research effort to reduce this value in recent years.

Etching of the cell



IEA : International Energy Agency

J. Shin, J. Park, N. Park "A method to recycle silicon wafer from end-of-life photovoltaic module and solar panels by using recycled silicon wafers" Solar Energy Materials & Solar Cells 162, 2017.

Resulting materials of both processes

	Latanussa		Alternative process	
Material	Recycling rate	Resulting material	Recycling rate	Resulting material
Aluminium frame	1	Aluminium	1	Aluminium
Copper	0.98	Copper	0.98	Copper
Photovoltaic glass	0.98	Ordinary glass	1	Ordinary glass
Silicon	0.95	Metallurgical grade silicon	1	Wafer mono-Si
Aluminium (cell)	0.5	Aluminium	0	Aluminium
Lead				
Silver	0.94	Silver	0.94	Silver
Tin				
EVA	Incineration	Energy		
Backsheet	Incineration	Energy		

Gain of the different processes

- **Panels only**, the whole installation is not considered (electric installation, inverter, panel support)

		Panel production (China)		Production (China) + recycling Latanussa (Europe)			Production (China) + alternative recycling (Europe)		
Indicators (ILCD)	Unit	Mono-Si	/ kWh	Total	/ kWh	Recycling gain	Total	/ kWh	Recycling gain
Climate change	kg CO2 eq	1,70E+02	2,85E-02	1,66E+02	2,78E-02	-2%	7,84E+01	1,31E-02	-54%
Ozone depletion	kg CFC-11 eq	9,90E-06	1,65E-09	5,80E-06	9,70E-10	-41%	1,10E-05	1,84E-09	11%
Human toxicity, non-cancer effects	CTUh	7,68E-05	1,28E-08	8,41E-05	1,41E-08	9%	4,94E-05	8,27E-09	-36%
Human toxicity, cancer effects	CTUh	1,08E-05	1,81E-09	1,22E-05	2,04E-09	13%	6,83E-06	1,14E-09	-37%
Particulate matter	kg PM2.5 eq	1,68E-01	2,80E-05	1,73E-01	2,89E-05	3%	7,40E-02	1,24E-05	-56%
Ionizing radiation HH	kBq U235 eq	9,65E+00	1,61E-03	2,41E+00	4,03E-04	-75%	1,64E+01	2,74E-03	70%
Ionizing radiation E (interim)	CTUe	2,77E-05	4,63E-09	1,85E-05	3,10E-09	-33%	3,41E-05	5,70E-09	23%
Photochemical ozone formation	kg NMVOC eq	6,03E-01	1,01E-04	6,24E-01	1,04E-04	3%	3,18E-01	5,31E-05	-47%
Acidification	molc H+ eq	1,11E+00	1,86E-04	1,15E+00	1,92E-04	3%	5,45E-01	9,11E-05	-51%
Terrestrial eutrophication	molc N eq	2,11E+00	3,54E-04	2,16E+00	3,61E-04	2%	1,07E+00	1,80E-04	-49%
Freshwater eutrophication	kg P eq	8,68E-02	1,45E-05	9,40E-02	1,57E-05	8%	3,20E-02	5,35E-06	-63%
Marine eutrophication	kg N eq	6,03E-01	1,01E-04	6,18E-01	1,03E-04	2%	1,66E-01	2,78E-05	-72%
Freshwater ecotoxicity	CTUe	1,45E+03	2,42E-01	1,68E+03	2,80E-01	16%	8,22E+02	1,37E-01	-43%
Land use	kg C deficit	2,36E+02	3,94E-02	2,00E+02	3,35E-02	-15%	2,05E+02	3,43E-02	-13%
Water resource depletion	m3 water eq	4,59E-01	7,67E-05	3,70E-01	6,19E-05	-19%	1,86E-01	3,11E-05	-59%
Mineral, fossil & ren resource depletion	kg Sb eq	5,98E-02	9,99E-06	9,95E-02	1,66E-05	66%	1,06E-02	1,77E-06	-82%

- Low gain for the Latanussa process (even increase on some indicators)
- Significant gain in alternative recycling (nearly 50% on average)

Conclusion

- Need to take recycling into account when measuring the environmental footprint of renewable energy (high material intensity): significant variation in environmental impacts, according to the chosen process.
  → Importance of **optimizing the recycling process, which is not yet mature**

- LCA can be used to focus research on different recycling processes and to compare the efficiency of existing processes: **eco-design of the whole process**.

- Our methodology related to EoL burdens allocation **needs to be challenged by LCA practitioners**.

Study	g CO2 eq /kWh	Source
Primary panel production (China)	28.5	IEA inventories
Production (China) + recycling Latanussa (Europe)	27.8	Latanussa
Production (China) + alternative recycling (Europe)	13.1	Shin

- There could be significative changes between energies ranking when considering the **energy transition,** depending on the effective recycling processes that will be finally implemented.