Calculation of energy payback time of PV and its determinants

Presentation at the Swiss Photonics Workshop

Dübendorf, October22th 2013

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The principle of Energy payback time calculation

$$EPBT[years] = \frac{Primary\ energy\ invested\ in\ PV\ system}{Primary\ energy\ substituted\ by\ PV\ system\ per\ year}$$

or

$$EPBT[years] = \frac{Electrical\ energy\ invested\ in\ PV\ system}{Electrical\ energy\ substituted\ by\ PV\ system\ per\ year}$$

The principle of Energy payback time calculation

$$EPBT[years] = \frac{Primary\ energy\ invested\ in\ PV\ system}{Primary\ energy\ substituted\ by\ PV\ system\ per\ year}$$

Definition of "primary energy"

- **Energy embodied in natural resources** prior to undergoing any human-made conversions or transformations.
- **Energy contained in raw fuels**, and other forms of energy received as input to a system.
- Can be **non-renewable or renewable**.

What is the “primary energy” of different sources?

- Fossil fuels: lower or upper heating value
- Natural Uranium: various methods
  - Substitution: how much primary fossil energy would be needed to produce the same amount of electricity?
  - Average thermal efficiency of nuclear power plant (ca. 32%)
  - Energy content in fissile isotope (considering remaining fissile isotopes in nuclear wast[…])
- Solar: various methods
  - Irradiation
  - Harvested (by PV (cell, module or system) or thermal collector)

Value choice introduces ambiguity.
Differences up to one order of magnitude!

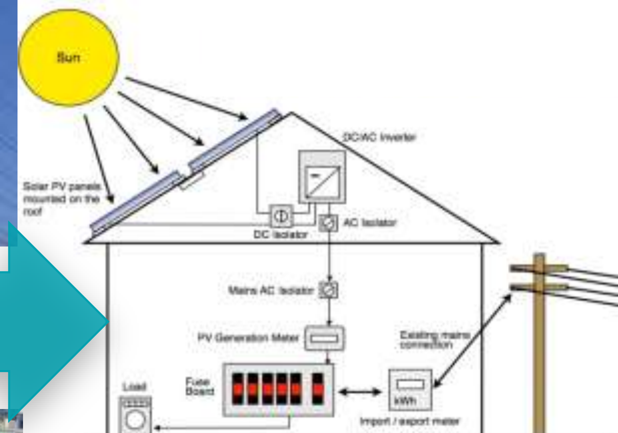
→ Important to choose consistent values for all energy sources!
→ Important to compare only EPBT values from different studies if they are consistent!

The principle of Energy payback time calculation

$$EPBT\,[years] = \frac{Primary\ energy\ invested\ in\ PV\ system^{1)}}{Primary\ energy\ substituted\ by\ PV\ system\ per\ year}$$

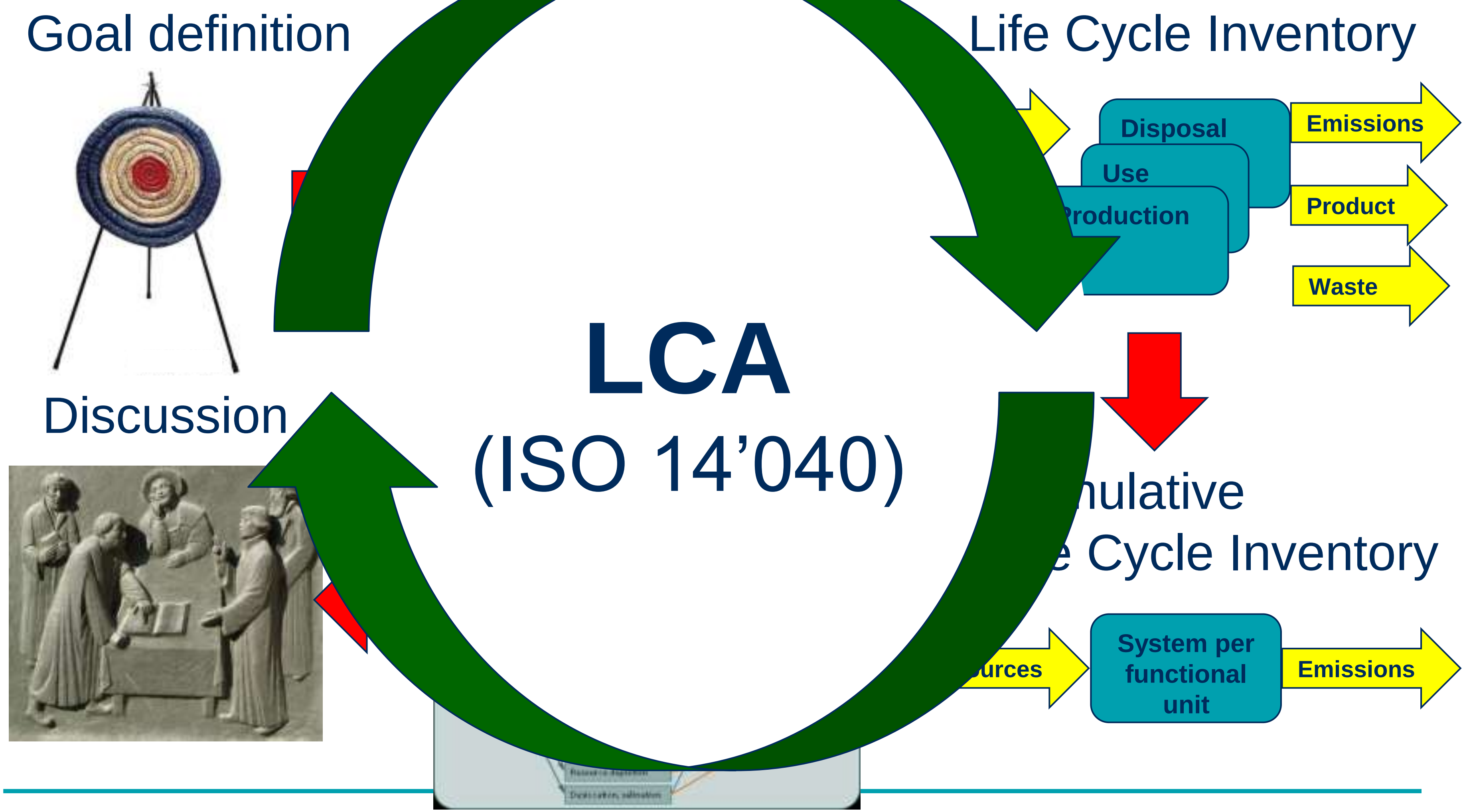
1) For production, use and end of life but without solar irradiation on PV modules during use phase

How to calculate primary energy invested in PV system?

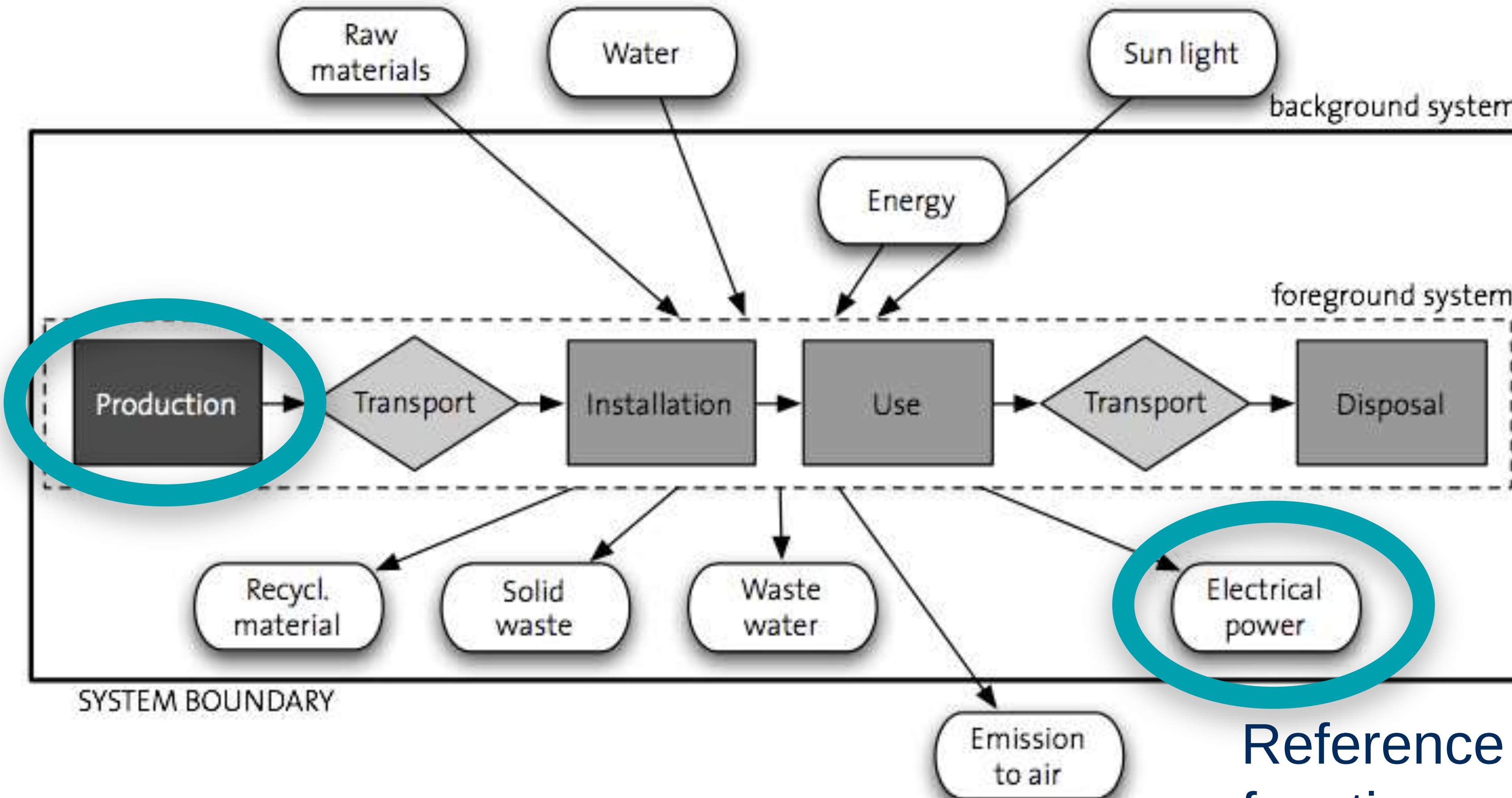


chain of production

How to do life cycle assessment?

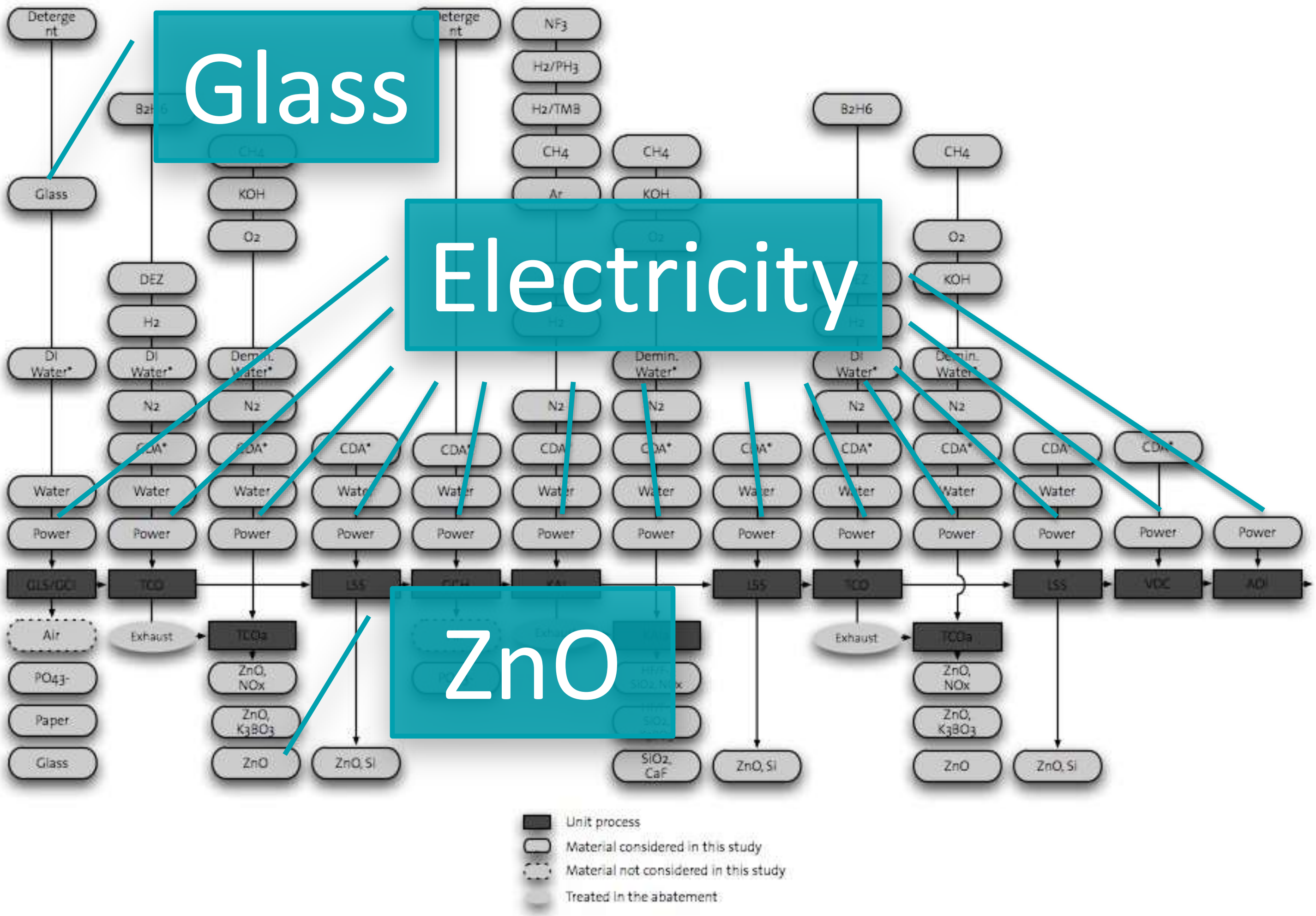


Model of the Product system of PV power generation

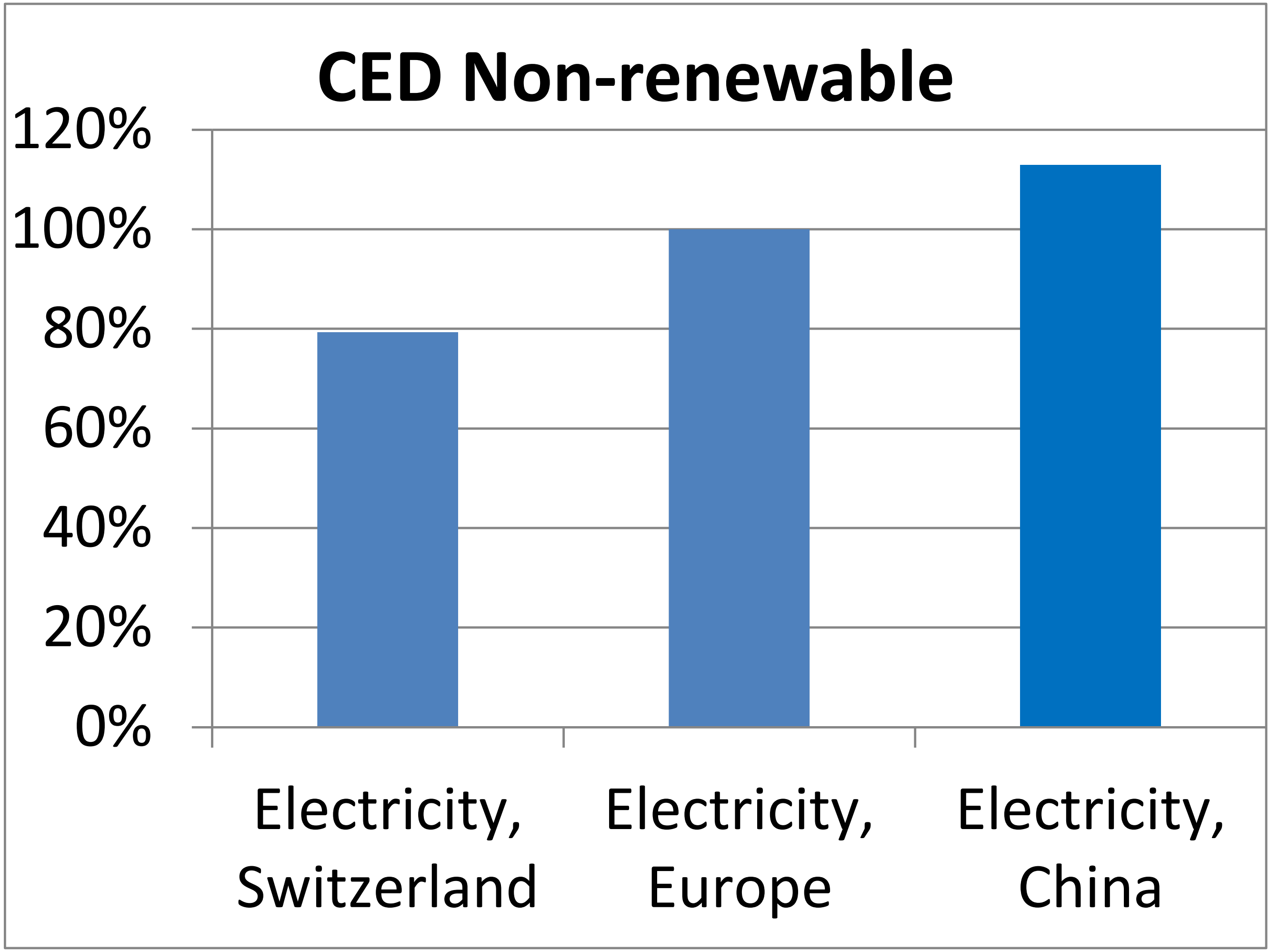


Reference function

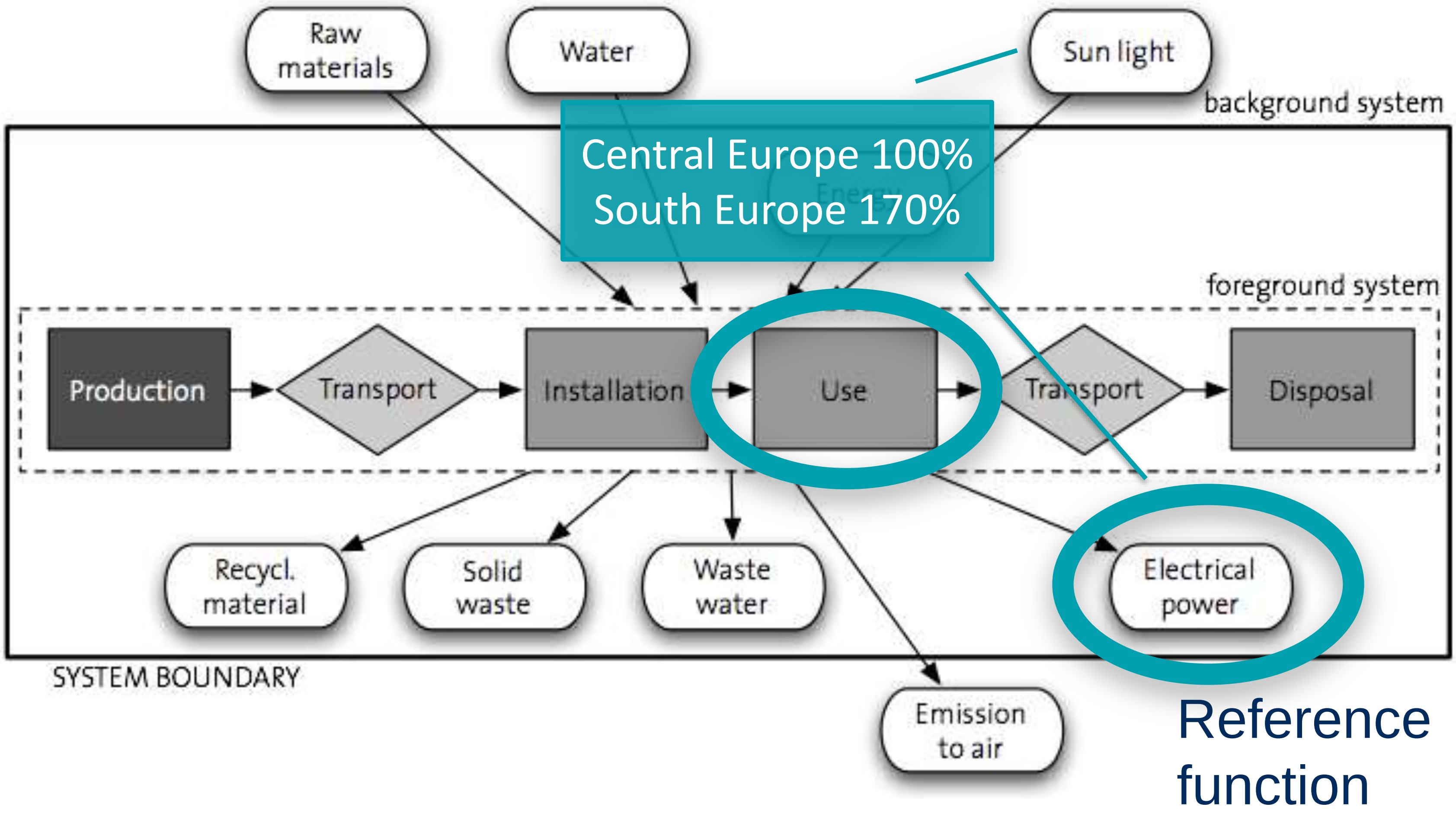
Production of PV cells (thin film Si)



Influence of production location



Product system of PV power generation



Ambiguities in LCA (of PV system)

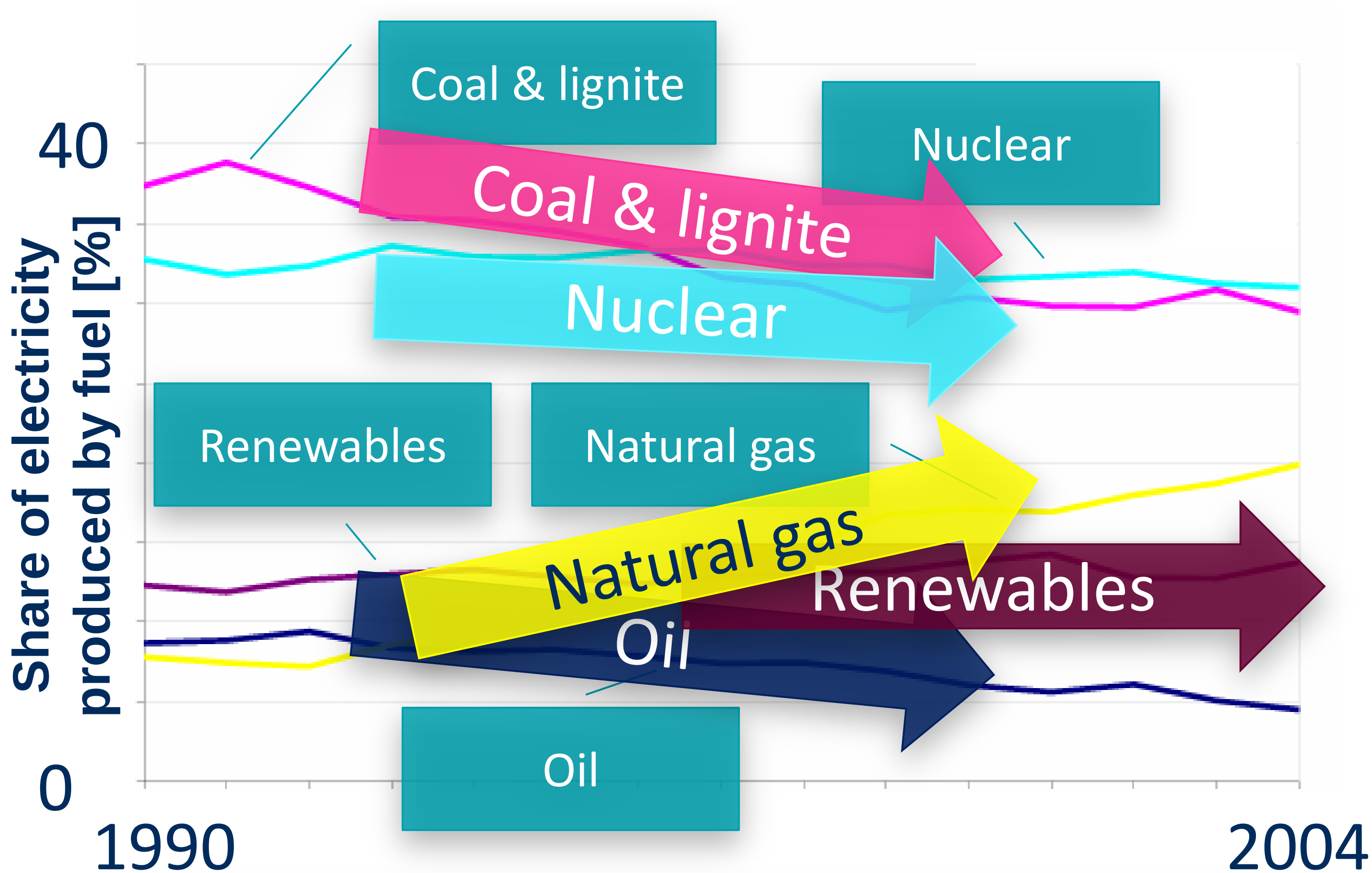
- System boundaries
  - Cut-off criteria
  - Inclusion of infrastructure
  - Inclusion of R&D
- Principles for modeling multi-functionality of systems
- Data sources
- Choice of background data

Energy payback time; principle

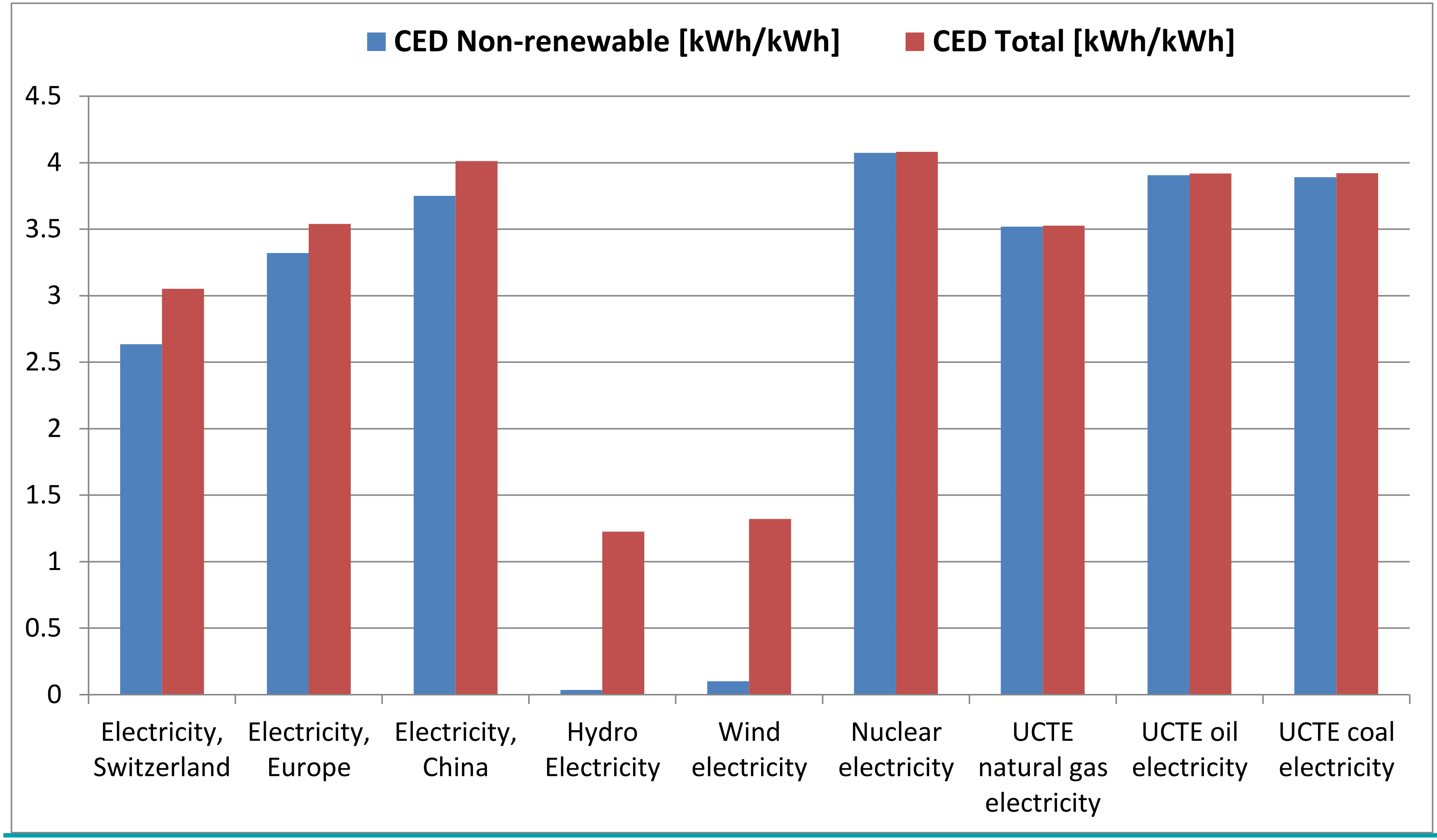
$$EPBT[years] = \frac{Primary\ energy\ invested\ in\ PV\ system^{1)}}{Primary\ energy\ substituted\ by\ PV\ system\ per\ year}$$

1) For production, use and end of life but without solar irradiation on PV modules during use phase

What energy is substituted by PV electricity?



What energy is substituted by PV electricity?



Examples

	CED System [MJ/m2]	electricity generated [kWh/m2]	
		Central Europe	South Europe
Crystalline Si	6500	3530	6000
mc-Si	5000	3295	5600
Ribbon-Si	3500	2940	5000
Cd-Te	1500	2235	4500
Amorpous Si	1900	2650	3800

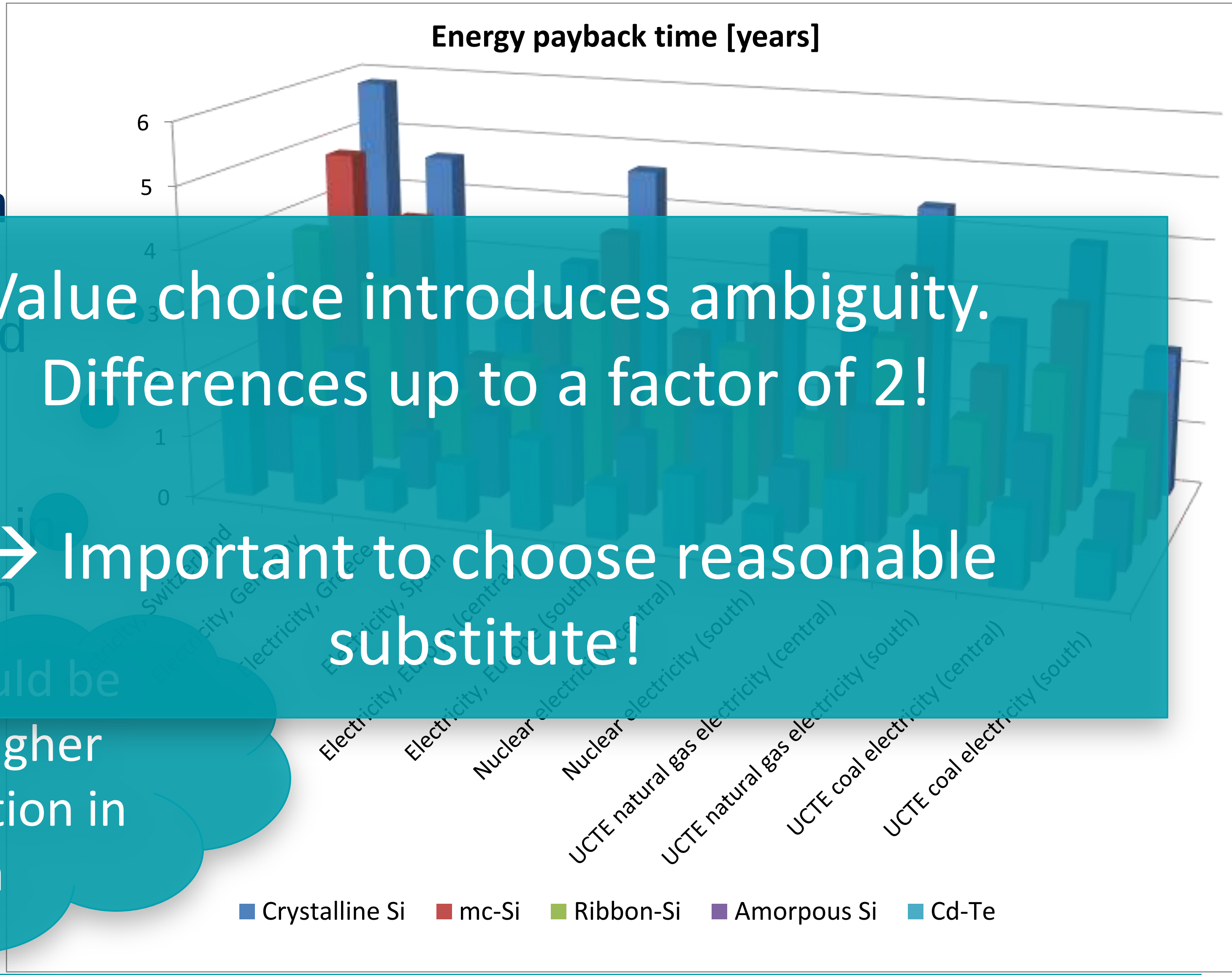
Values would be ca. 20% higher for production in China

Exemplary values in reasonable range for **PV system produced in Europe**.
CED of substituted electricity from ecoinvent v2.2

Examples

Differences in electricity generated and substituted.

No difference in PV production



Value choice introduces ambiguity. Differences up to a factor of 2!

→ Important to choose reasonable substitute!

Values would be ca. 20% higher for production in China

Quantis

A glimpse beyond energy

Payback of greenhouse gasses emitted

Examples

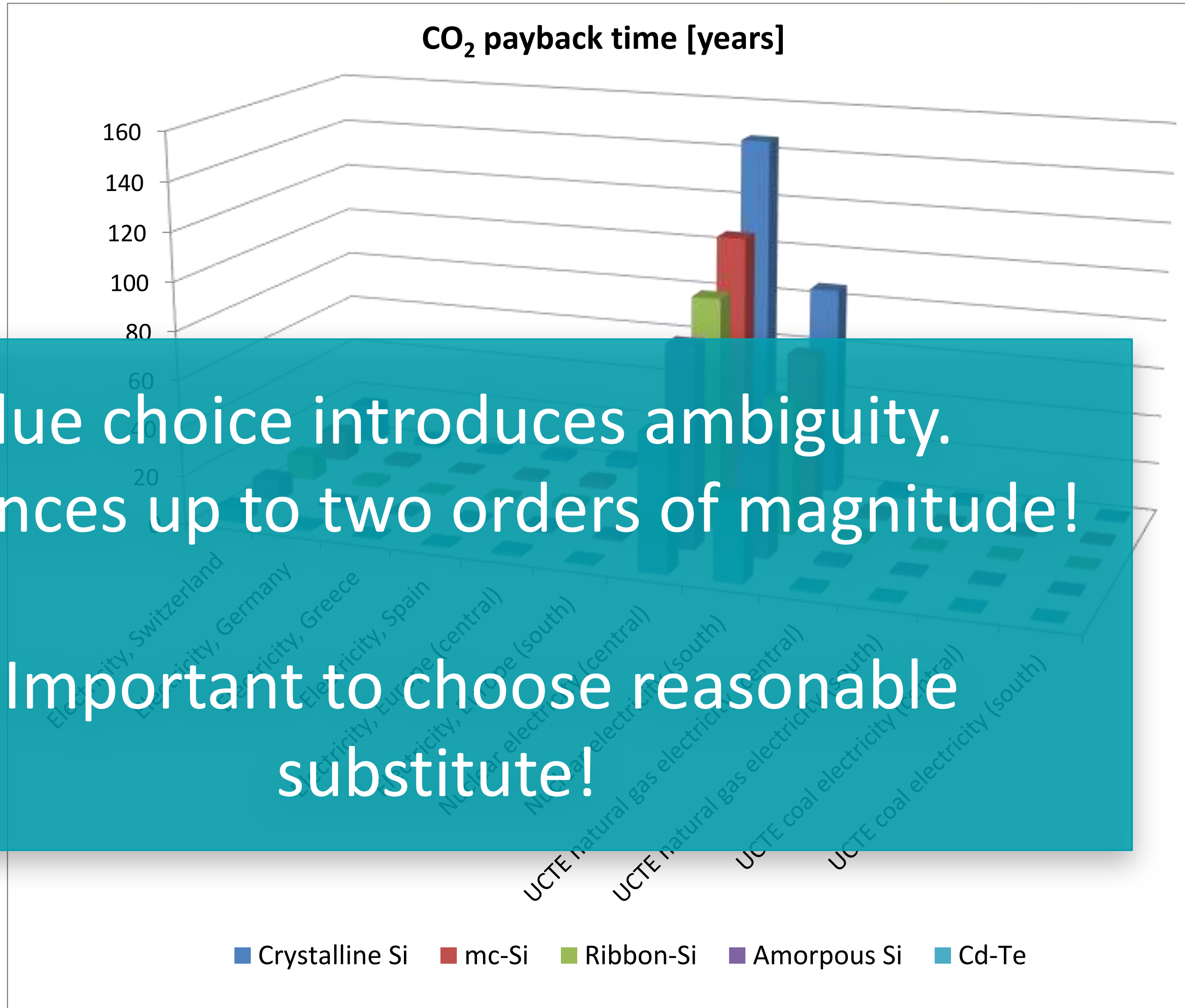
	GWP System (kg CO2-eq/m2)	electricity generated [kWh/m2]	
		Central Europe	South Europe
Crystalline Si	280	3530	6000
mc-Si	200	3295	5600
Ribbon-Si	150	2940	5000
Cd-Te	80	2235	4500
Amorpous Si	100	2650	3800

Exemplary values in reasonable range for **PV system produced in Europe**.
GWP of substituted electricity from ecoinvent v2.2

Examples

Differences in electricity generated and substituted.

No difference in PV production



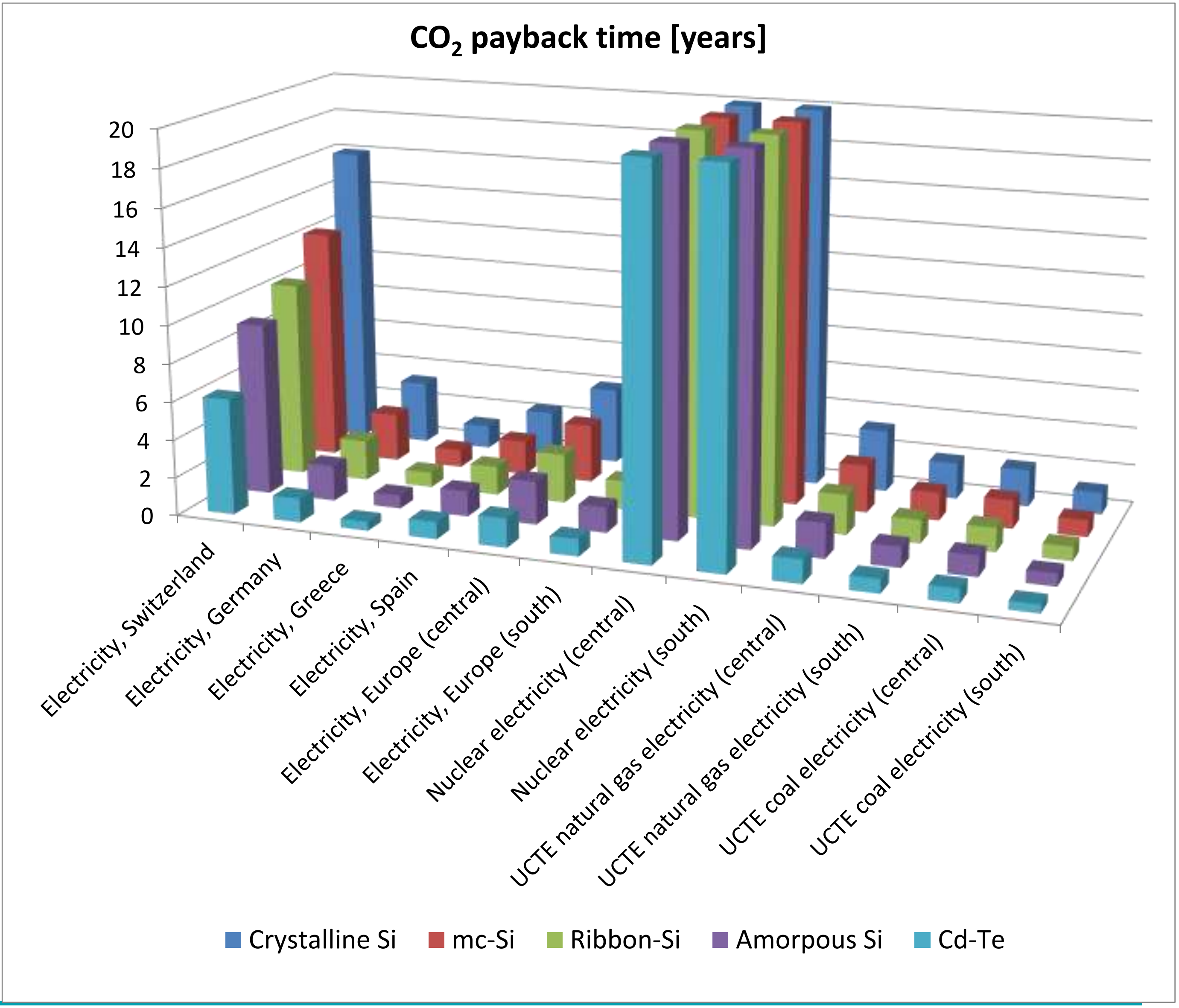
Value choice introduces ambiguity.
Differences up to two orders of magnitude!

→ Important to choose reasonable substitute!

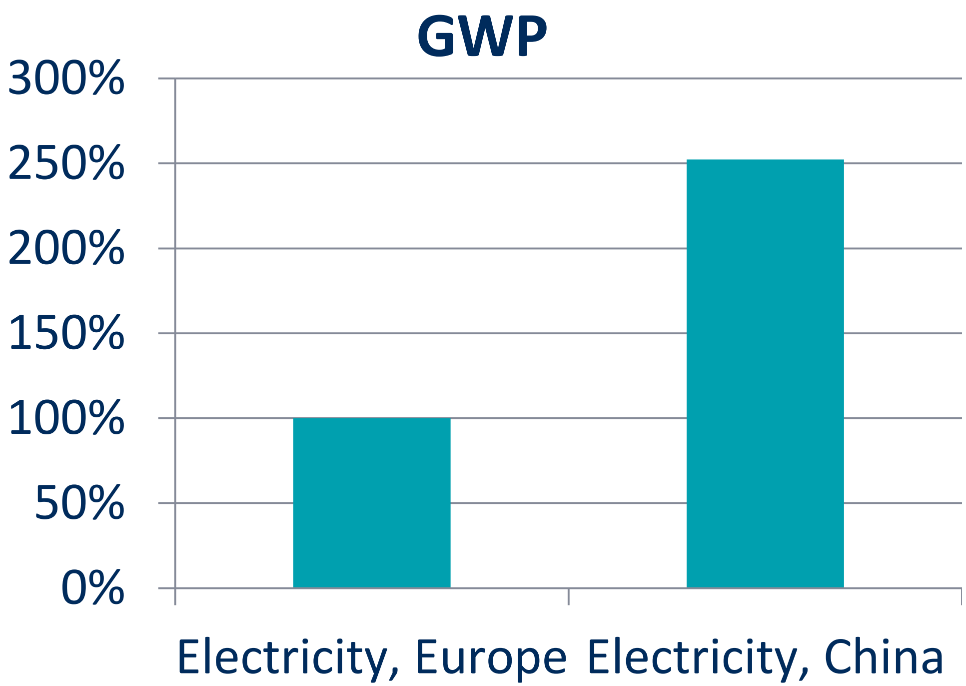
Examples

Differences in electricity generated and substituted.

No difference in PV production



Example: Influence of production location



Assumption:
GWP of PV system produced in China is 1.5 times the GWP of the same system produced in Europe.

Examples

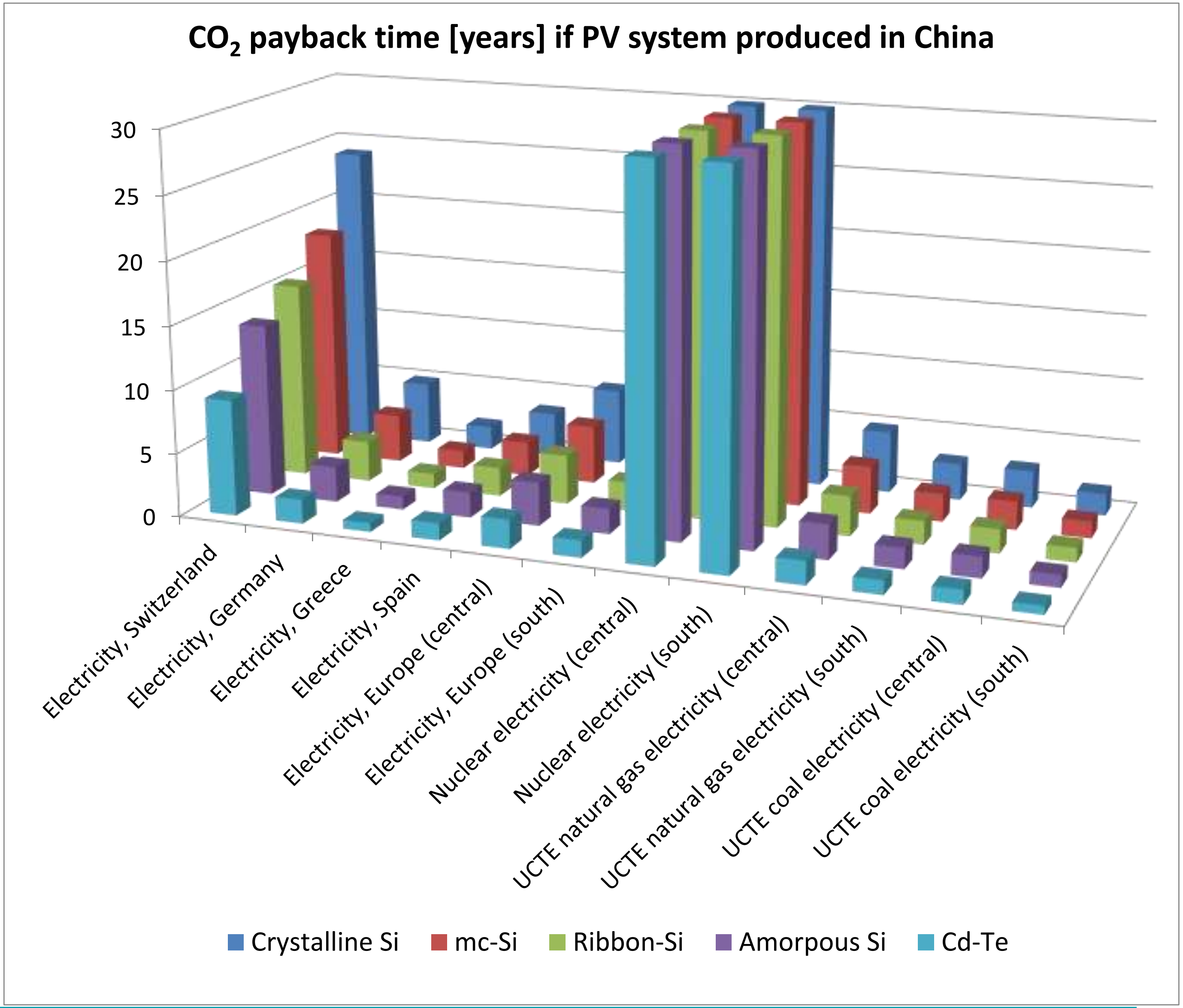
	GWP System (kg CO2-eq/m2)	electricity generated [kWh/m2]	
		Central Europe	South Europe
Crystalline Si	420	3530	6000
mc-Si	300	3295	5600
Ribbon-Si	225	2940	5000
Cd-Te	150	2235	4500
Amorpous Si	120	2650	3800

Exemplary values in reasonable range for **PV system produced in China**.
GWP of substituted electricity from ecoinvent v2.2

Examples

Differences in electricity generated and substituted.

No difference in PV production

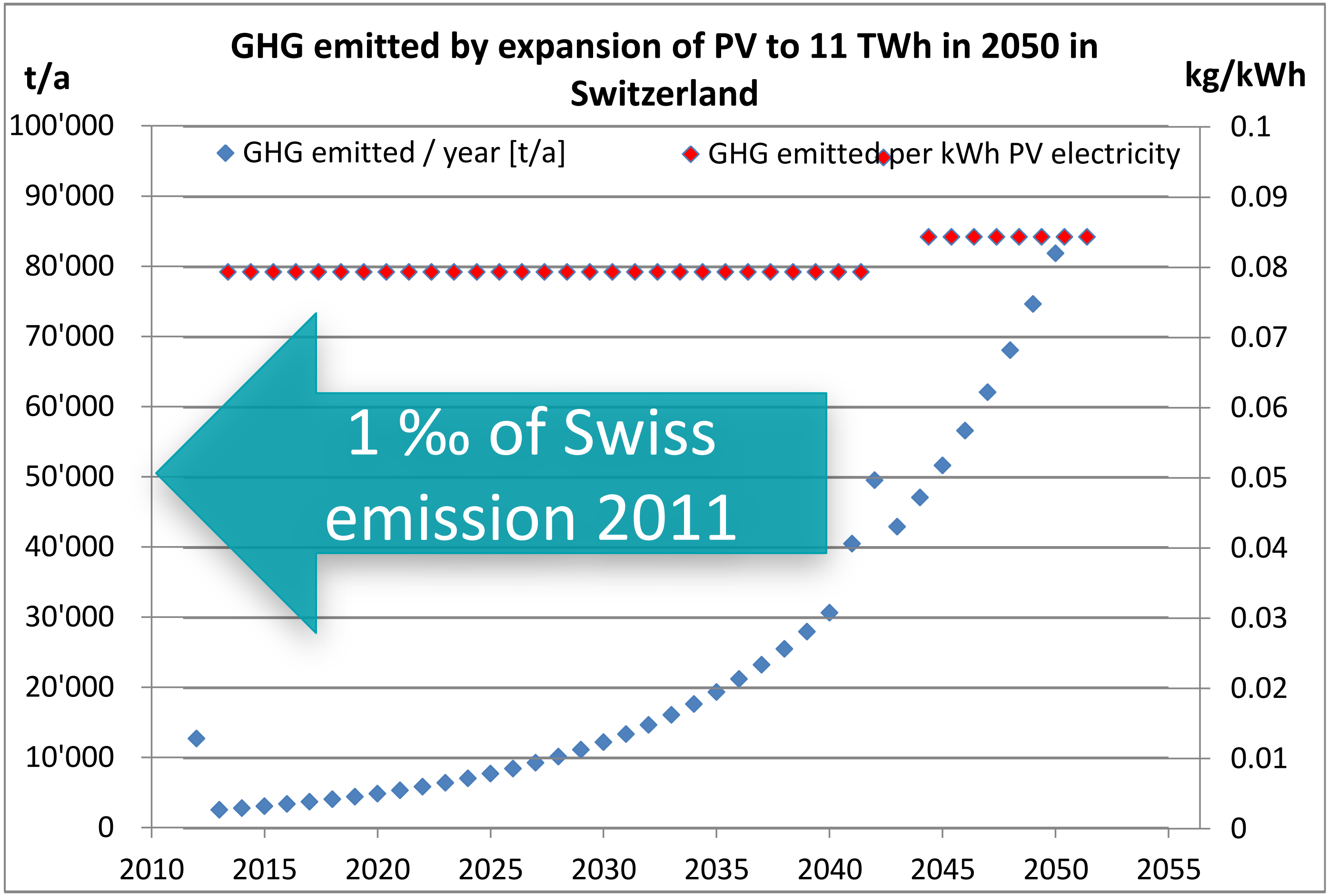


Emissions from scale up of PV

What happens if PV electricity generation in Switzerland is scaled from today 0.33 to 11 TWh in 2050?

Scale-up

Worst case Assumptions:
- C-Si
- Production in CN
- Constant properties (efficiency, GHG intensity)



Conclusions

Conclusions

- EPBT calculation is value based.
- Care has to be taken when comparing EPBT values of different studies.
- Influence of (arbitrary) choices can be larger then differences between PV technologies.

- GHG payback can be much longer then EPBT
- Influence of value choices on GHG payback is much bigger than on EPBT
- GHG emissions from transition towards high solar share in electricity generation are comparably small.

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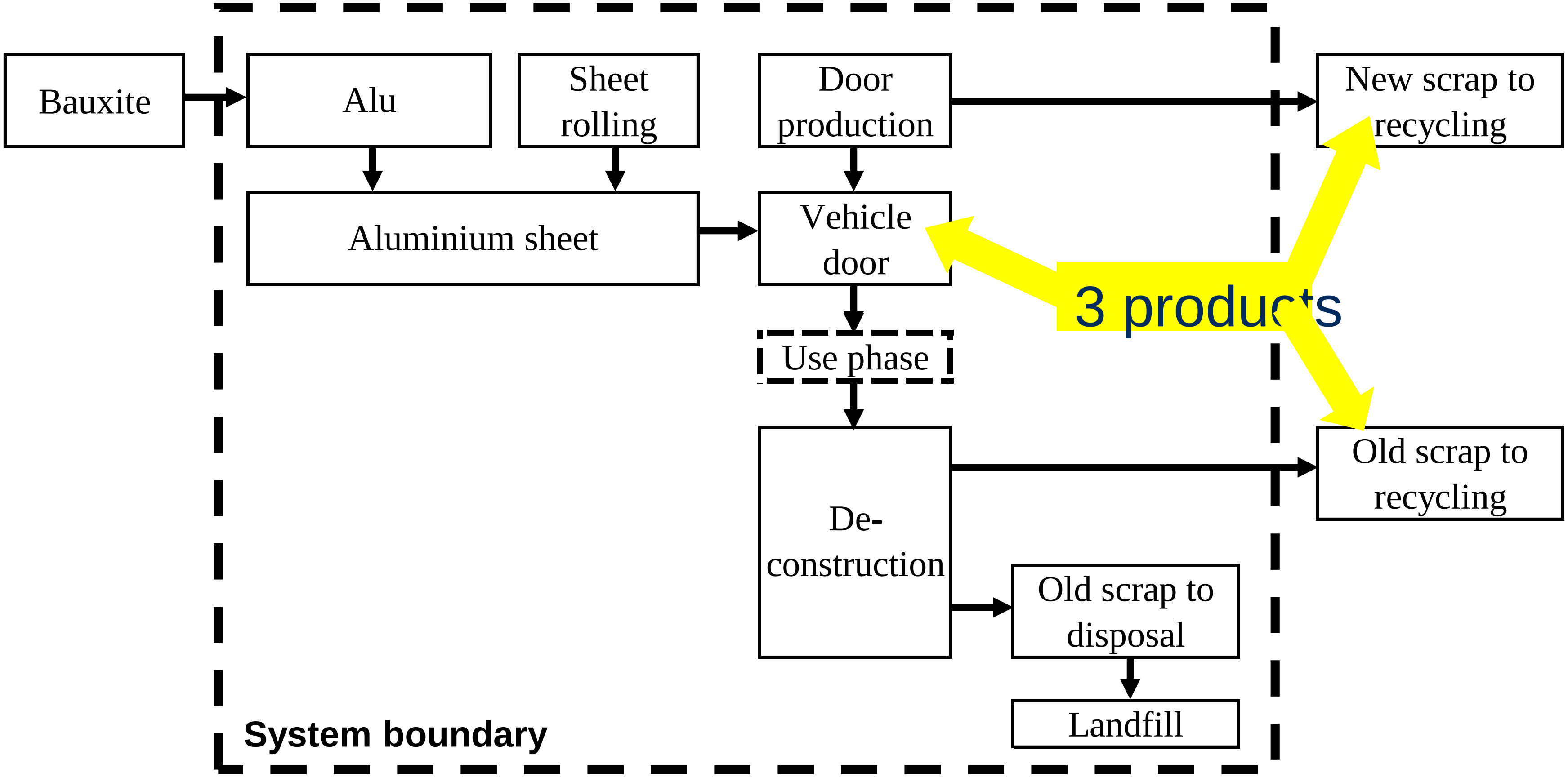
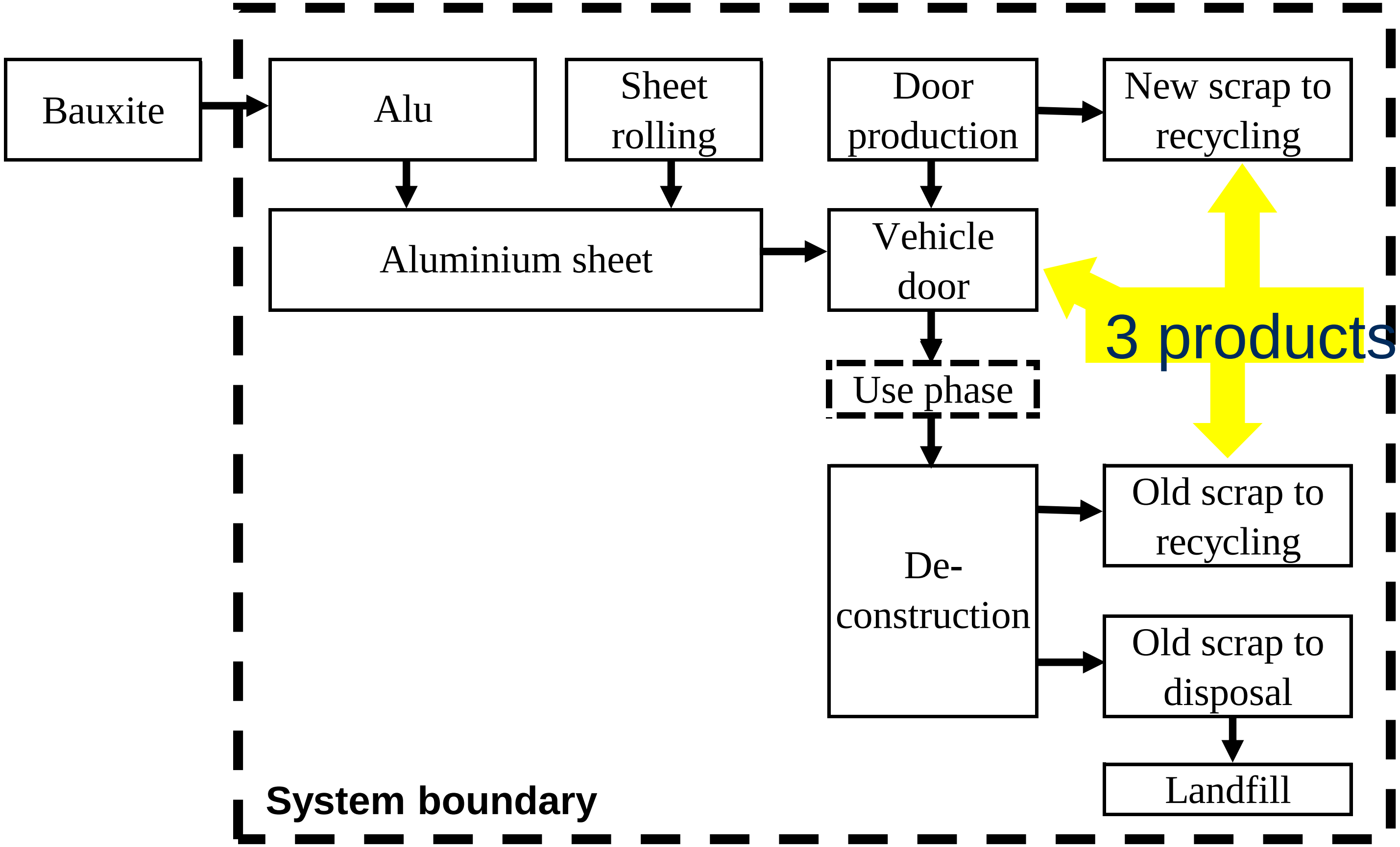
Allocation: cut off



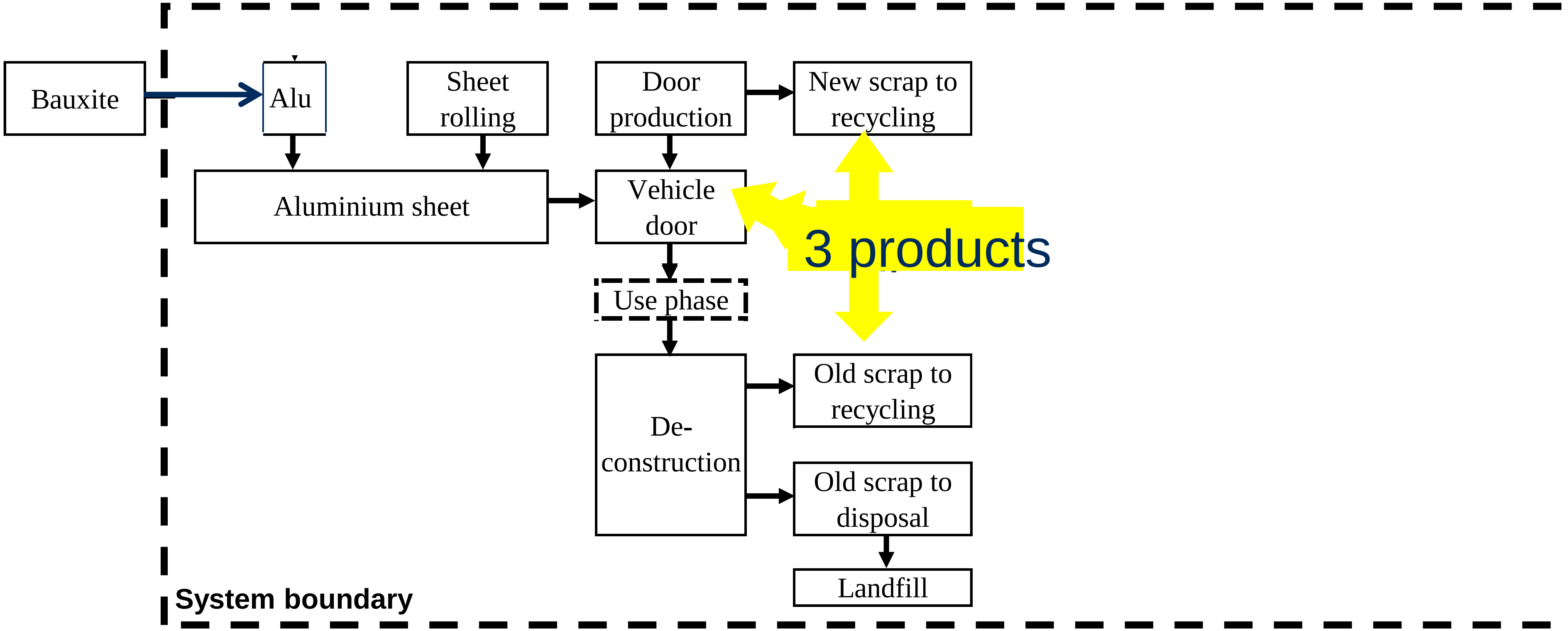
Allocation



Mass
- New scrap: 10%
- Car part: 0%
- Old scrap: 90%

Value
- New scrap: 3%
- Car part: 95%
- Old scrap: 2%

Avoided allocation



What energy is substituted by PV electricity?