Future Environmental Impact Assessment Experience Curves, LCI updating, or both?

Atse Louwen, Utrecht University

REFLEX Expert Workshop

Karlsruhe, 8th November 2017

Universiteit Utrecht

Agenda

13:30 Atse Louwen (UU)
Experience curves for future environmental impact assessment

14:00 Mary Fuss & Lei Xu (KIT-ITAS)
Environmental impact assessment using LCI updating

14:30 Coffee break

14:45 Open Discussion

Universiteit Utrecht

Introduction

- In previous presentation, one example was shown of the application of experience curve for environmental impact assessment
  - Describing historical developments in env. impacts
  - Establishing experience curve, calculating integral and using this to assess net, cumulative env. impact and benefits
- Within in REFLEX, we investigate the environmental impact of future energy systems

How can experience curves be applied for future environmental impact assessment?

Recap, what is the experience curve

- Experience curve is a theoretical model that describes
  - the cost decrease of a product
  - As a function of the cumulative production of this product

- Developed in this form by Boston Consulting Group

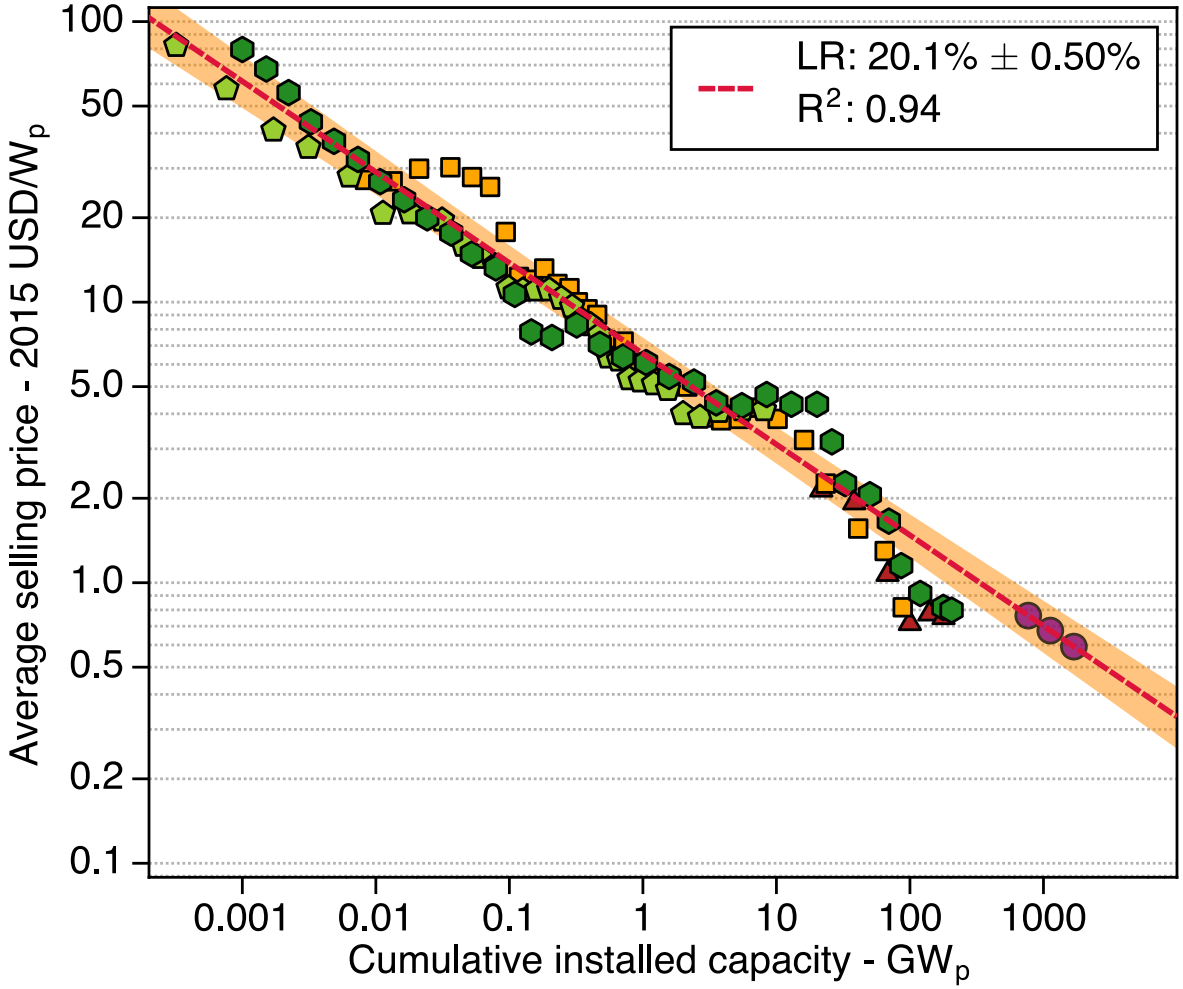
- Equation: $C(n) = C_0 \times n^{\log_2(1-l)}$
  - Every doubling of cumulative produced units n,
  - Cost per unit C drops with l
  - C_0 is the cost of the first

Recap, what is the experience curve

- Normally the experience curve is applied to describe cost decrease
- It can also be applied to other metrics, e.g.
  - CED and GHG emissions per unit of product
  - Specific Energy Consumption of products and processes
  - Efficiency of products or processes

Universiteit Utrecht

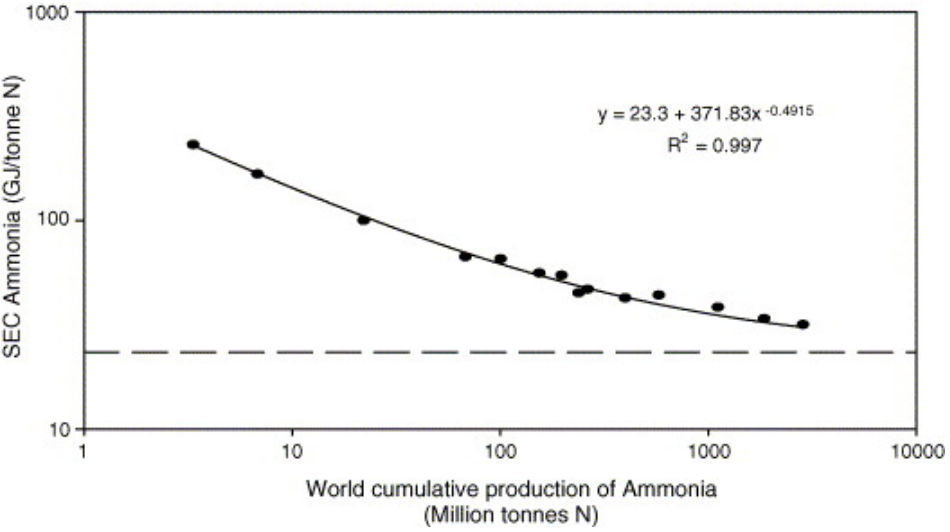
Experience Curve - Cost

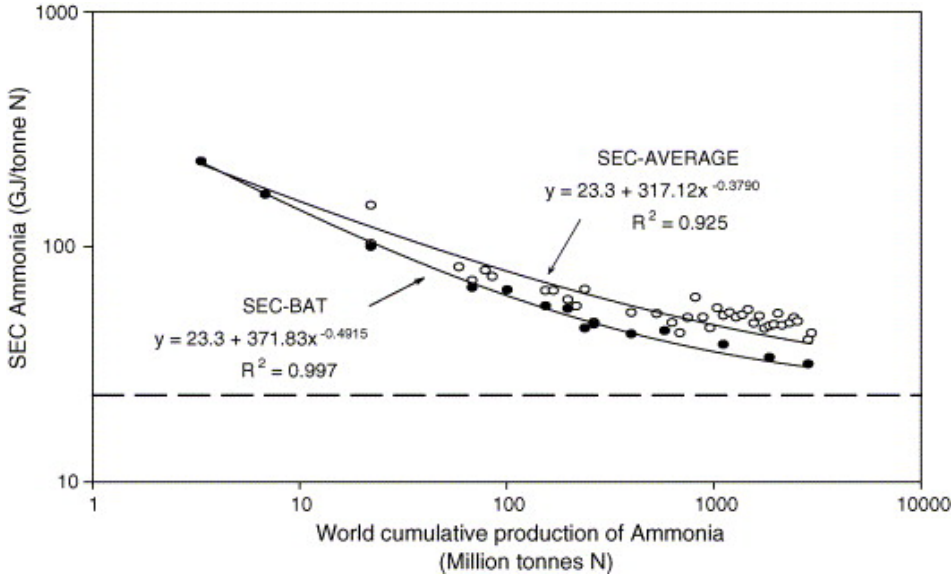


Universiteit Utrecht

Experience Curves – SEC (product)

- SEC of ammonia production
- EC amended to include theoretical minimum SEC
- On the right: BAT vs Average



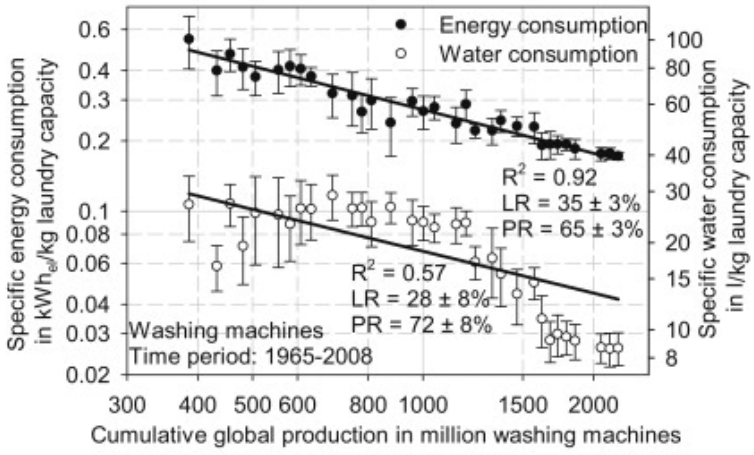


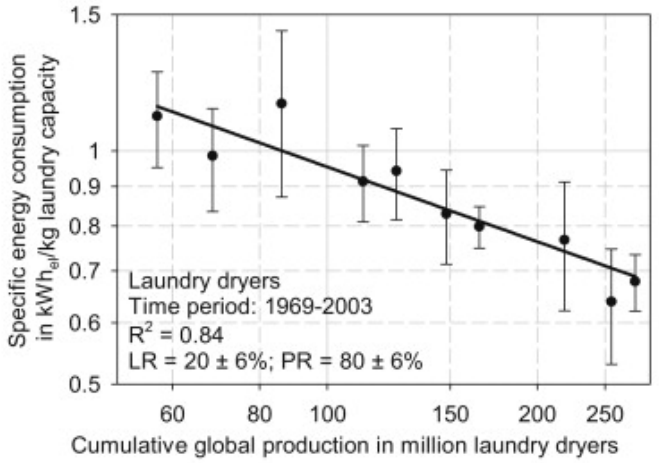
Ramírez & Worrell, 2006 (10.1016/j.resconrec.2005.06.004)

Universiteit Utrecht

Experience Curves – SEC (process)

- Washing machines, laundry dryers
- Describing the improvement of appliances
- Cf. left: clear trend for energy, not for water use



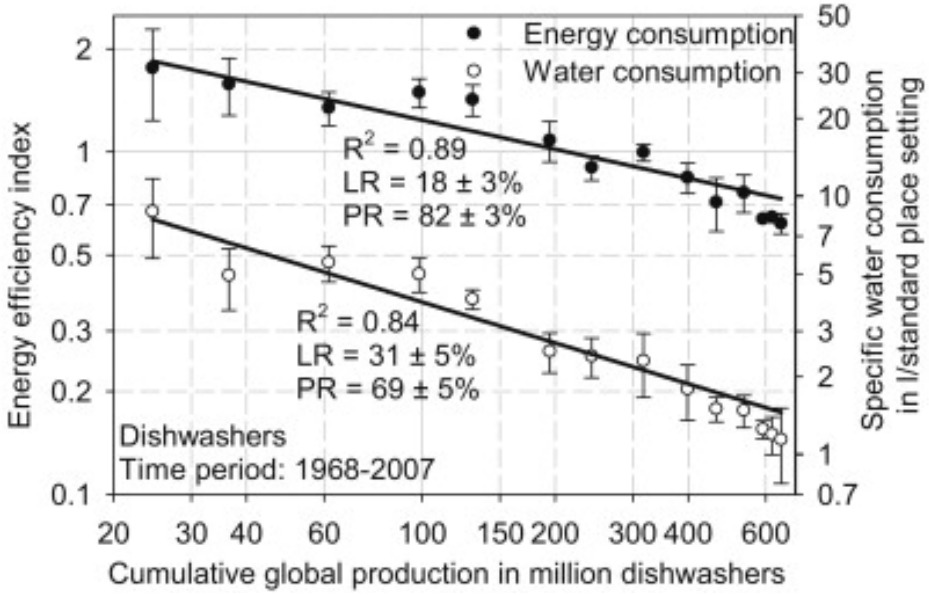


Weiss et al, 2010 (10.1016/j.enpol.2009.10.022)

Universiteit Utrecht

Experience Curves – Efficiency (process)

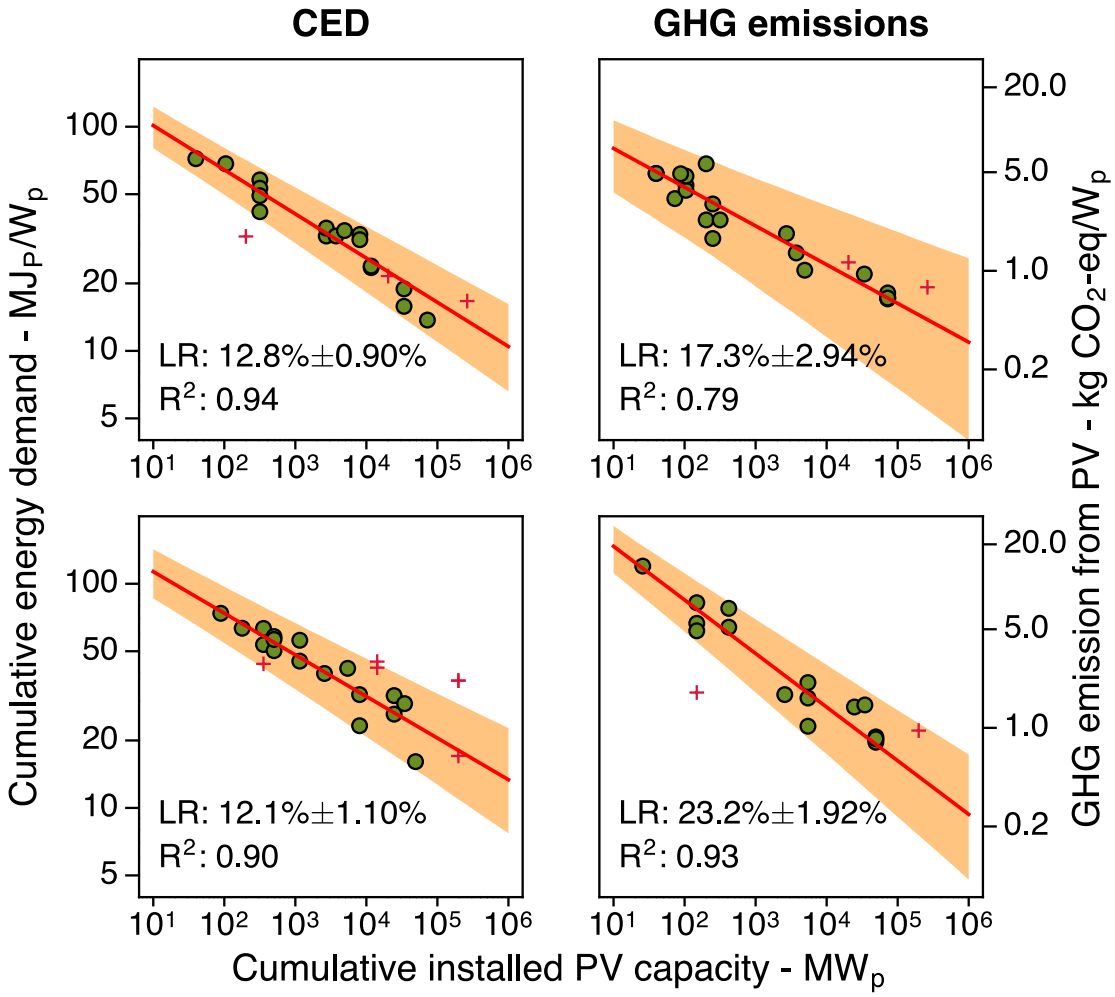
- Energy efficiency, water consumption of dishwashers



Weiss et al, 2010 (10.1016/j.enpol.2009.10.022)

Universiteit Utrecht

Experience curves – CED and GHG



Application to environmental assessment

- Take-away: experience curves have been established for a variety of EIA related parameters
- This model allows to show historical development in mathematical way, and project this into future
- So, what are possible applications?

Universiteit Utrecht

Application to environmental assessment

So, what are possible applications?

1. Annual, cumulative and net environmental impact from whole industry (this morning)
2. Estimation of future environmental impact (projecting EC into the future)
3. Cumulative impact from process/product in future scenarios
4. Projection of LCI parameters into future
5. Other applications?

Universiteit Utrecht

Application 2. Example
Estimations of future environmental impact

Aim: analyse future CED of PV systems

- Example for PV:

$$CED(cap) = CED_0 \cdot cap^{\log_2(1-l)}$$

$CED_0 = 235\ \mathrm{MJ/W_p}, l = 12.1\%$

- In 2050, estimate of 4600 GW of PV capacity (IEA)
- Resulting CED = 13.6 MJ/W_p, now = 22-23 MJ/W_p

Year	2013	2017	2050
Capacity (GW)	160	300	4600
CED (MJ/W_p)	25.34	22.54	13.57
EPBT (NL)	2.22	1.97	1.19
EPBT (S-Eur)	1.45	1.29	0.78

Universiteit Utrecht

Application 2. Example
Estimations of future environmental impact

By extrapolating historical trend vs. cumulative production, future environmental impact can be determined (estimated)

- Likely more accurate than time-based extrapolation
- Requires limited assumptions on technology change (top down)
- Requires projections of capacity development
- Possibly does not account for radical technology innovations/shifts
- Without addition of parameters, does not have minimum impact (e.g. is unware of physical, technical constraints)

Universiteit Utrecht

Application 3. Example
Cumulative impact assessment - GHG

Aim: establish total cumulative emissions from renewables implementation between certain years

- Example for PV:

$$GHG(cap) = GHG_0 \cdot cap^{\log_2(1-l)}$$

$GHG_0 = 1135\ \mathrm{kgCO_2eq/W_p}, l = 23\%$

- Cumulative total: integrate experience curve

$$\int GHG_0 \cdot cap^{\log_2(1-l)} \mathrm{d}cap = \frac{GHG_0}{\log_2(1-l)} cap^{\log_2(1-l)}$$

Universiteit Utrecht

Application 3.
Cumulative impact assessment - GHG

- Cumulative total: integrate experience curve

$$\int GHG_0 \cdot cap^{\log_2(1-l)} \mathrm{d}cap = \frac{GHG_0}{\log_2(1-l)+1} cap^{\log_2(1-l)+1}$$

- Total emissions between now and 2050:

$$\frac{GHG_0}{\log_2(1-l)+1}(4600\mathrm{GW})^{\log_2(1-l)+1} - \frac{GHG_0}{\log_2(1-l)+1}(300\mathrm{GW})^{\log_2(1-l)+1}$$

- Comes out to 21.06 Gt of CO_2-eq (60% of current annual global emissions)
- Average of 4.90 kg/W_p (compared to 9.8 for current)

Universiteit Utrecht

Application 3.
Cumulative impact assessment - GHG

By taking integral and extrapolating experience curve, cumulative impact can be determined

- Likely more accurate than time-based extrapolation
- Requires limited assumptions on technology change (top down)
- Does not need time-series data (only endpoint)
- Quantifies total environmental impact from products, processes, etc. e.g. for scenario studies
- Requires projections of capacity development
- Possibly does not account for radical technology innovations/shifts
- Without addition of parameters, does not have minimum impact (e.g. is unware of physical, technical constraints)

Universiteit Utrecht

General con's of these experience curves

- No insight into development of products/processes (e.g. material/cost breakdown)
- Not aware of technical/physical constraints, e.g.
  - Theoretical minima of environmental impact
  - Minimum amounts of materials required

Universiteit Utrecht

General con's of these experience curves

- Compared to e.g. LCA:
  - Historical data not necessarily reflects changes in all LCI parameters
  - If input electricity mix is constant in the historical data, future changes in the mix are not reflected in projected results…

- Therefore, we want to investigate a combined approach!

Universiteit Utrecht

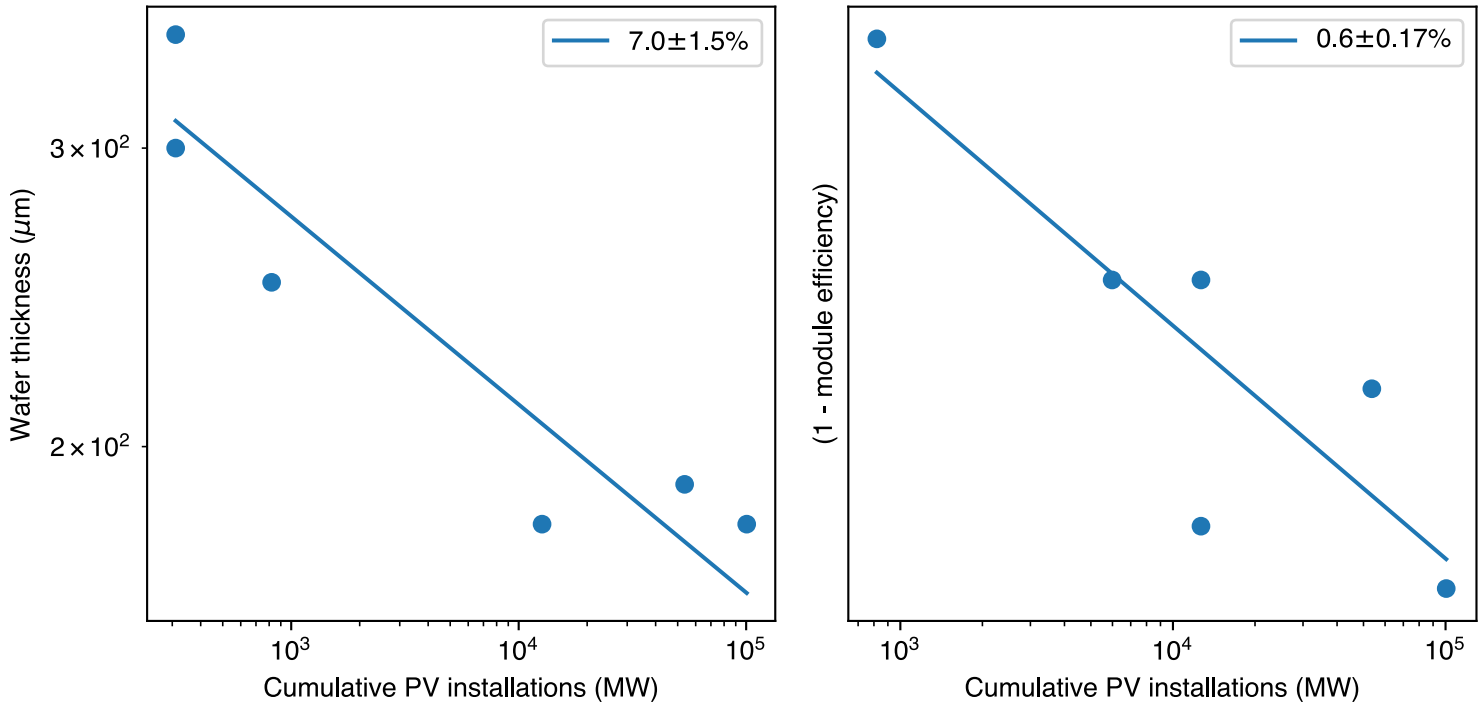
Application 4.
Scaling of LCI parameters

- As the examples earlier have shown, we can establish experience curves for many parameters
- Looking at prospective LCA, we see that it can be hard to update LCI components
- Possible (partial) solution/contribution: apply experience curves to project LCI components

Universiteit Utrecht

Application 4.
Scaling of LCI parameters

- Example, PV (again, sorry….)
- Learning for wafer thickness (-7%) and efficiency (+0.6%)



Universiteit Utrecht

Application 4.
Scaling of LCI parameters

- Limited preliminary analysis shows a possibility of using experience curves for estimating future LCI components
- Downsides are that you need LCI data for a specific technology over ”long” time-horizon
  - Often not readily available in papers

Thank you!

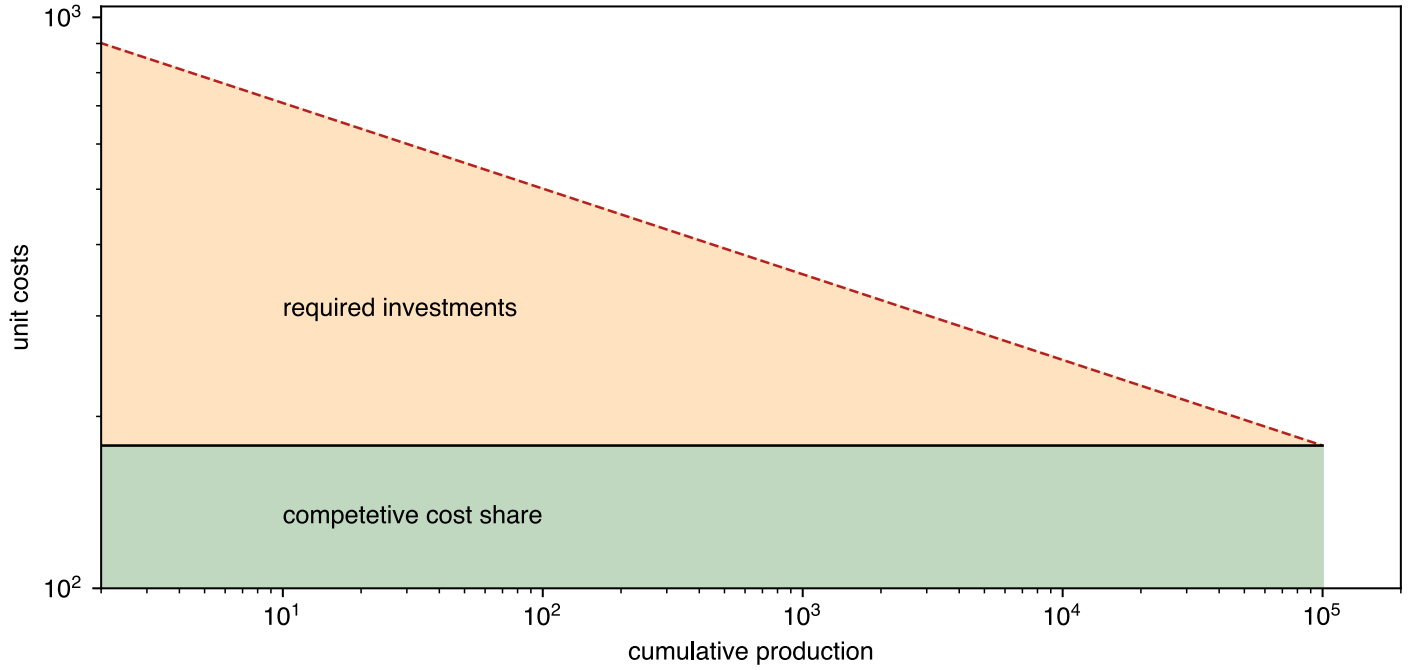
Your thoughts?

Back up slides

Universiteit Utrecht

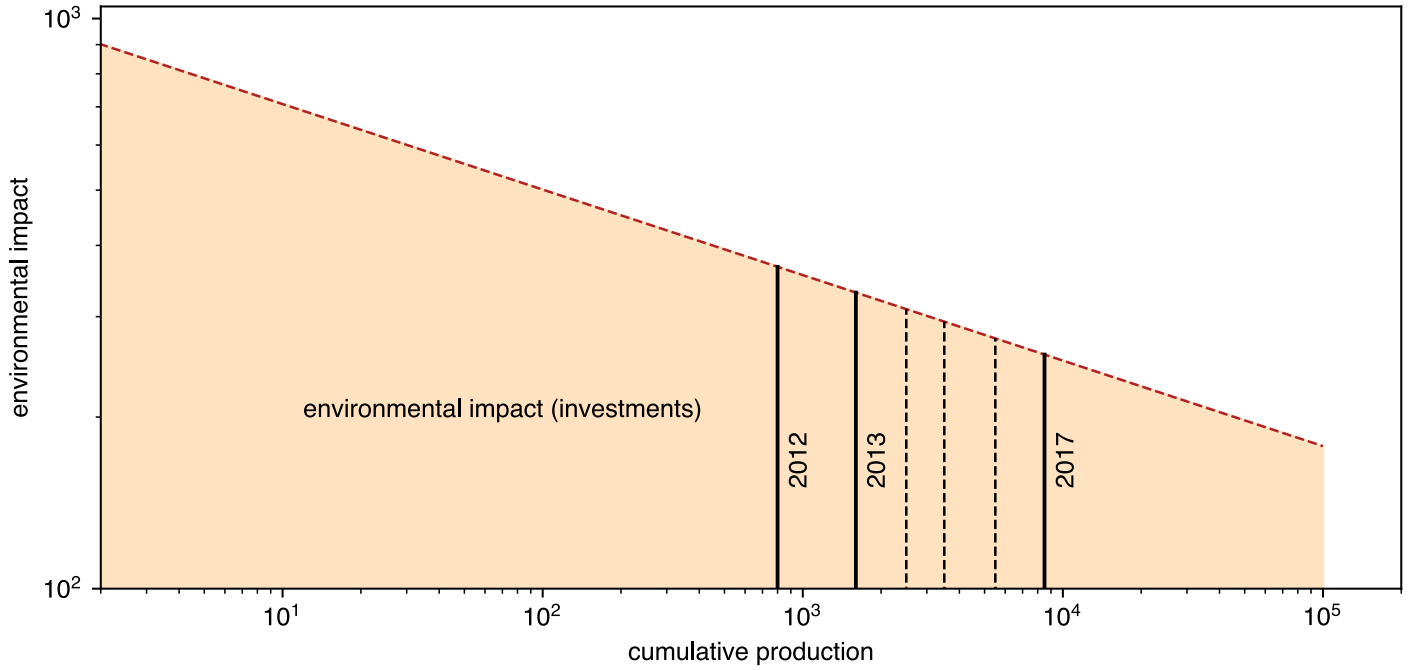
Integral of experience curves gives the cumulated costs

- E.g. compared to an incumbent technology



Universiteit Utrecht

Here, we use the integral to calculate cumulative and net Energy + GHG emissions



Universiteit Utrecht

Net contributions - Energy

$$E_{\text{net}} = \sum_{y=1975}^{n} \left[E_{\text{produced}}(y) - E_{\text{consumed}}(y) \right]$$

$$E_{\text{produced}}(y) = \sum_{l} cap(y,l) \times PR(y) \times \text{insolation}(l)$$

$$E_{\text{consumed}}(y) = \left(\frac{CED}{\text{cap}} \right)(y) \times f_{CED}(l) \times \text{capgrowth}(y,l)$$

from experience curve

Universiteit Utrecht

Net contributions - GHG emissions

$$GHG_{\text{net}} = \sum_{y=1975}^{n} [GHG_{\text{avoided}}(y) - GHG_{\text{emitted}}(y)]$$

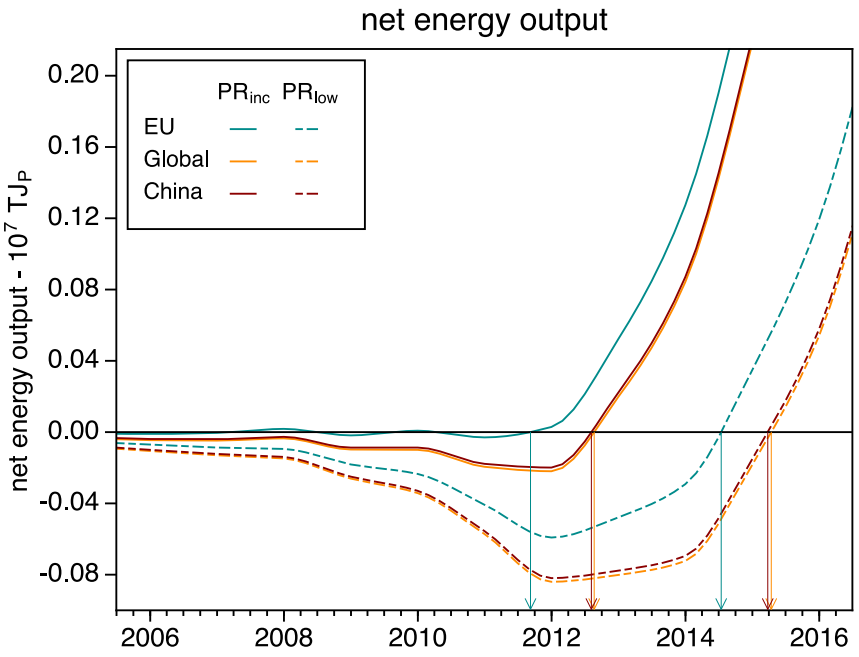
$$GHG_{\text{avoided}}(y) = \sum_{l} cap(y,l) \times PR(y) \times \text{insolation}(y,l) \times GHG_{\text{grid}}(y)$$

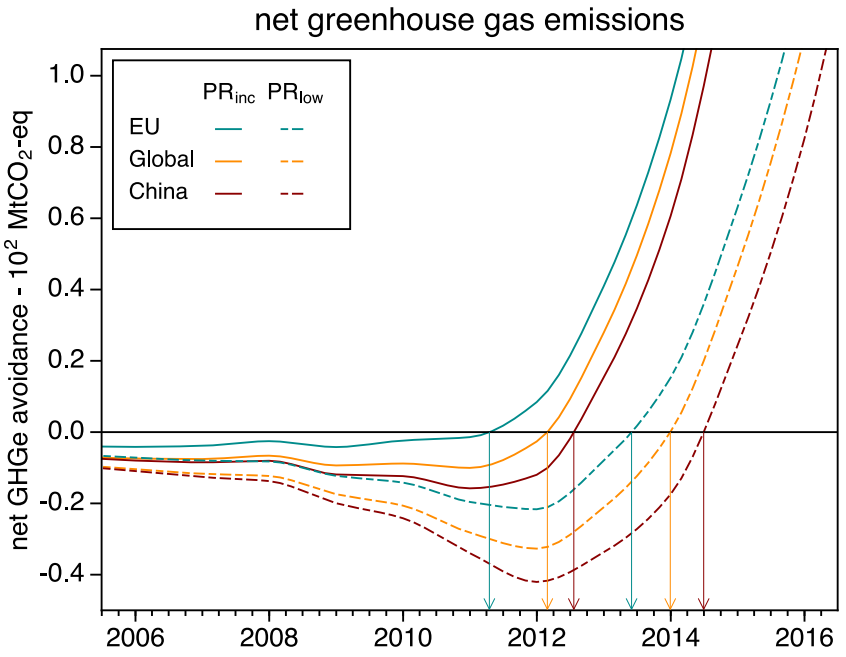
$$GHG_{\text{emitted}}(y) = \sum_{l} \left(\frac{GHG}{cap}\right)(y) \times f_{GHGgrid}(l) \times \text{capgrowth}(y)$$

from experience curve

Universiteit Utrecht

Results – multiple scenarios





Universiteit Utrecht

Uncertainty – one scenario