

# Prospective LCA

A systematic approach to assess the environmental impact of emerging technologies

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# Emerging technologies

- High uncertainty and degrees of freedom
- Scarce data, but lower lock-in
- Using lab/pilot/early stage data likely leads to skewed results compared to mature technologies
  - Developments
  - Diverse scaling
  - learning

# LCA for emerging technologies

- History
- Many approaches
- Even more recommendations

**METHODS, TOOLS, AND SOFTWARE**

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## A systematic approach to assess the environmental impact of emerging technologies

A case study for the GHG footprint of CIGS solar photovoltaic laminate

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**Abstract**

Estimating the environmental impact of emerging technologies is uncertain but necessary to guide investment decisions. We propose a systematic procedure to assess the future environmental impact of emerging technology development stage (technology readiness level < 9), the recommended experience mechanisms to support the technology development process, including (a) size scaling effects, and (c) process synergies. The procedure includes (b) process analysis and quantification of the environmental impact, (d) process analysis, including (i) process analysis, (ii) process analysis, (iii) process analysis, (iv) process analysis, (v) process analysis, (vi) process analysis, (vii) process analysis, (viii) process analysis, (ix) process analysis, (x) process analysis, (xi) process analysis, (xii) process analysis, (xiii) process analysis, (xiv) process analysis, (xv) process analysis, (xvi) process analysis, (xvii) process analysis, (xviii) process analysis, (xix) process analysis, (xx) process analysis, (xxi) process analysis, (xxii) process analysis, (xxiii) process analysis, (xxiv) process analysis, (xxv) process analysis, (xxvi) process analysis, (xxvii) process analysis, (xxviii) process analysis, (xxix) process analysis, (xxx) process analysis. The applicability of our approach to the industrial development phase, including (i) process analysis, (ii) process analysis, (iii) process analysis, (iv) process analysis, (v) process analysis, (vi) process analysis, (vii) process analysis, (viii) process analysis, (ix) process analysis, (x) process analysis, (xi) process analysis, (xii) process analysis, (xiii) process analysis, (xiv) process analysis, (xv) process analysis, (xvi) process analysis, (xvii) process analysis, (xviii) process analysis, (xix) process analysis, (xx) process analysis, (xxi) process analysis, (xxii) process analysis, (xxiii) process analysis, (xxiv) process analysis, (xxv) process analysis, (xxvi) process analysis, (xxvii) process analysis, (xxviii) process analysis, (xxix) process analysis, (xxx) process analysis. We found that the GHG footprint per kilowatt peak of produced CIGS laminate is expected to decrease as the technology matures, with the largest decrease being for copper indium gallium selenide (CIGS) photovoltaic laminate. We found that the GHG footprint per kilowatt peak of produced CIGS laminate is expected to decrease as the technology matures, with the largest decrease being for copper indium gallium selenide (CIGS) photovoltaic laminate. We found that the GHG footprint per kilowatt peak of produced CIGS laminate is expected to decrease as the technology matures, with the largest decrease being for copper indium gallium selenide (CIGS) photovoltaic laminate. We found that the GHG footprint per kilowatt peak of produced CIGS laminate is expected to decrease as the technology matures, with the largest decrease being for copper indium gallium selenide (CIGS) photovoltaic laminate.



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# Prospective LCA

“an LCA is prospective when the (emerging) technology studied is in an early phase of development (e.g. small-scale production), but the technology is modeled at a future, more-developed phase (e.g. large-scale production).”

- Also called ex-ante, ...

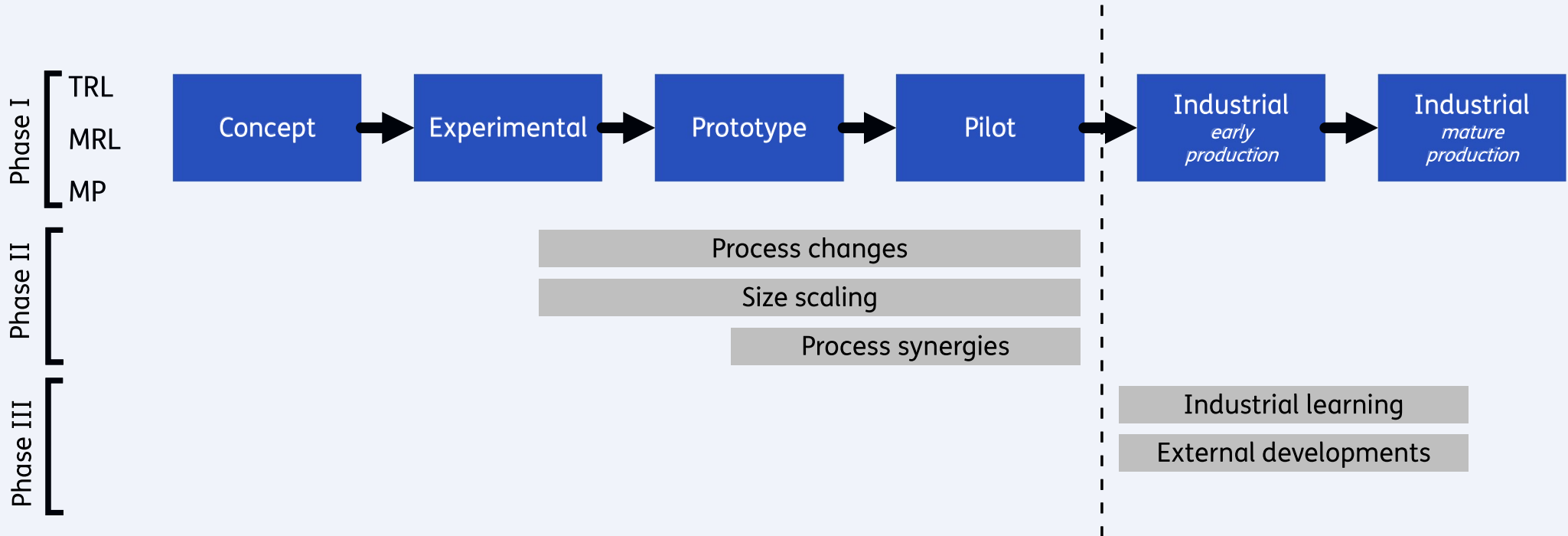
# PROSPECTIVE LCA

foreground

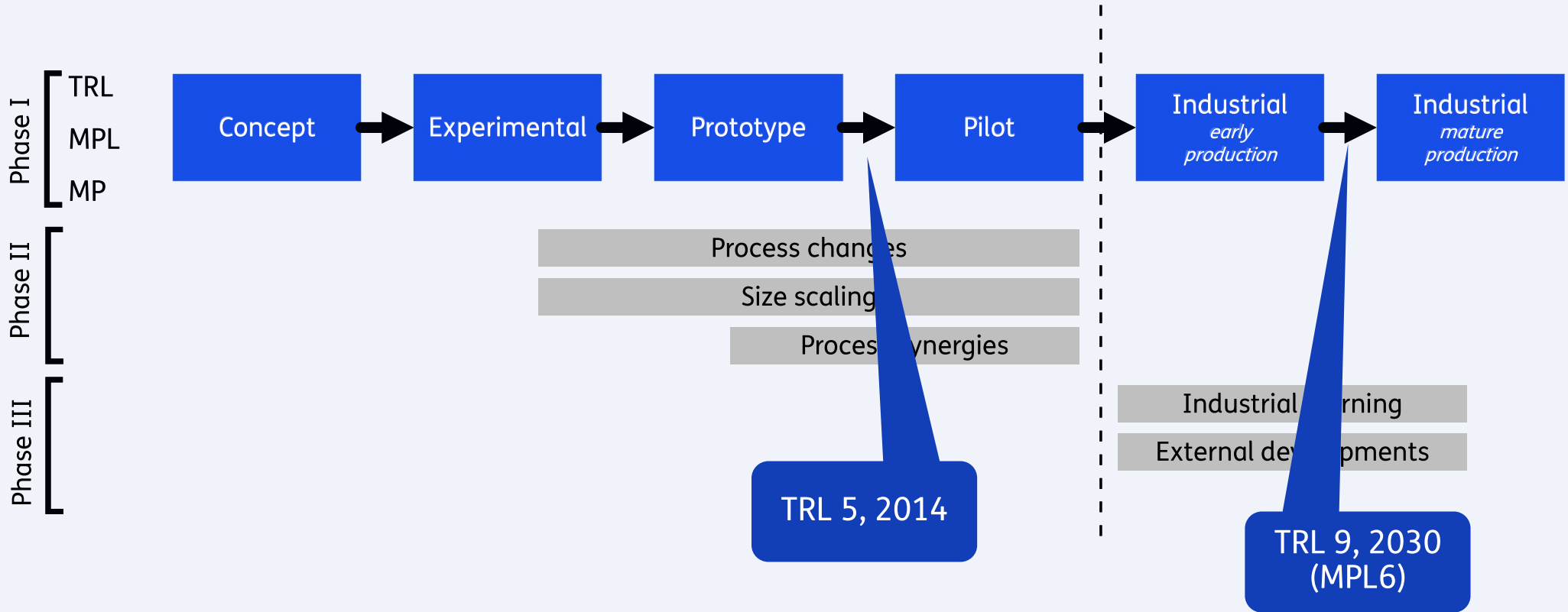
- Technology changes
  - Engineering calculations, process modelling, simulation
- Alternatives might change
- Economy changes (e.g., energy transition)
  - IAM based scenarios
- Iterative and communicative

background

# Stepwise approach



# Example 1kWp CIGS laminate



# Process Changes

Replacement of materials, equipment or processing methods for alternatives

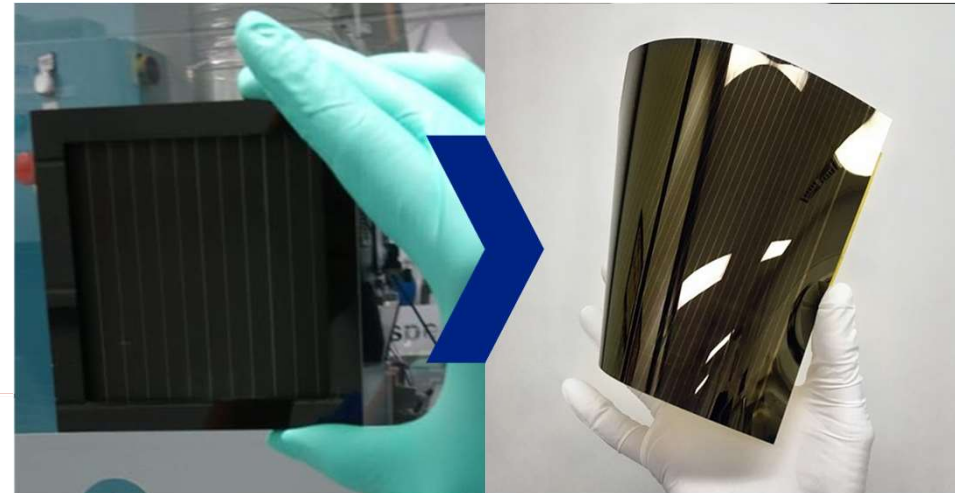
- Physical limitations
- Improve performance
- Cheaper production
- Safer production

Modeling approaches:

- Deduce from existing industrial process with similar function
- Consult technology experts

## Case study example

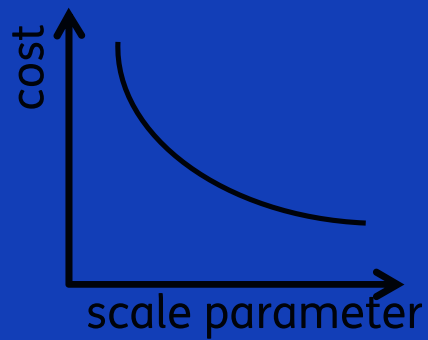
- 1) Processing method: sheet-to-sheet → roll-to-roll
- 2) Buffer material: Cd(S) → Zn(O,S)
- 3) Transparent conductive oxide : i-ZnO/AZO → i-ZnO/ITO





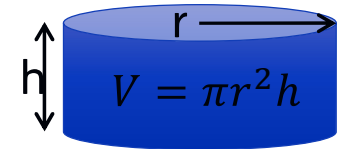
# Size Scaling

- Product scaling
- Equipment scaling



Modeling approaches:

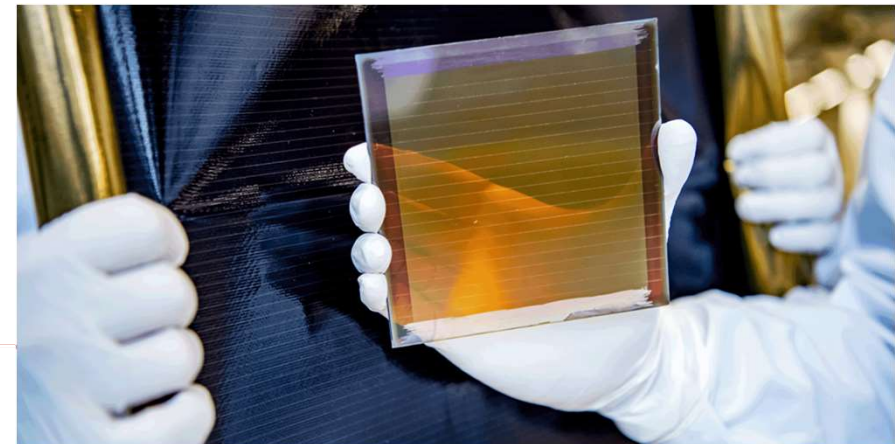
- Scaling curves
- Geometry calculations



Case study example

30x30 cm<sup>2</sup> → 60x120 cm<sup>2</sup>

→ electricity demand

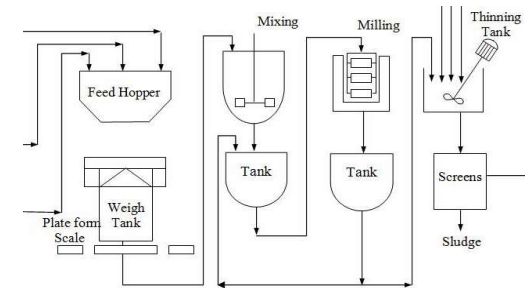


# Process Synergies

- Recycling of unutilized inputs
- Waste valorization
- Heat recovery

## Modeling approaches:

- Deduce from plant flow chart of existing industrial process
- Consult technology expert



## Case study

Indium from spent ITO sputtering targets is recycled



# Industrial Learning

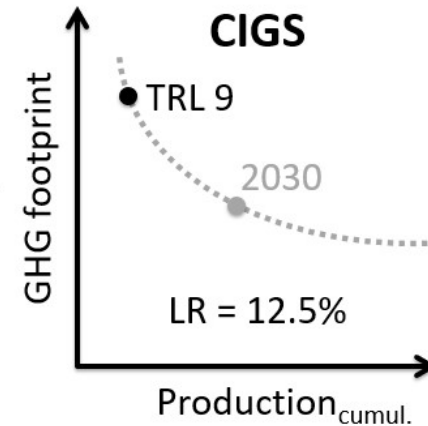
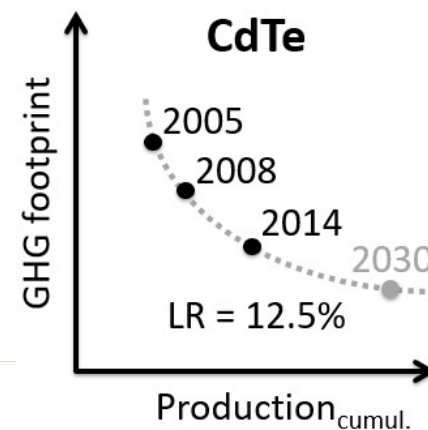
- Learning-by-doing
- Learning-by-(re)searching
- Learning-by-interaction
- Entangled economies of scale
- *Forgetting*

## Modeling approaches:

- Extrapolation of learning curves
- Roadmaps

## Case study example

CdTe curves and projections on cumulative production



## External Developments

- Decarbonization of the energy sector
- Material/energy efficiency improvements
- Land use intensification

### Modeling approaches:

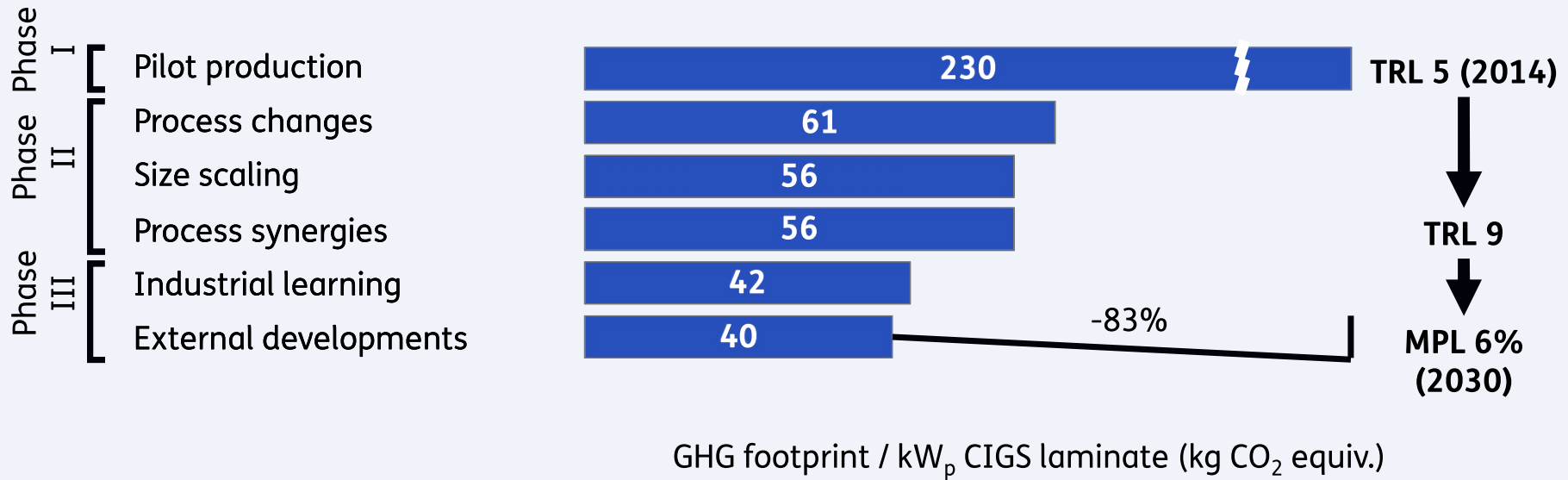
- Adjusting **LCI databases** with projections from **IAMs**

### Case study example

Updated grid mix of the electricity used in the foreground process, based on projections from an IAM



# Example: results



# Plastic waste treatment



Fig. 4. Process contribution analyses of GHG footprints for treatment of 1 kg in year 2030. Numerical values are provided in Supporting Materials 2. Net GHG footprints for each scenario are indicated with grey/white squares. Emission saving potentials are indicated with grey bars. The GHG savings from avoided fossil CO<sub>2</sub> emissions at HVC end-of-life are marked with a dashed border. These savings are to be subtracted from the results in case one assumes a use and end-of-life scenario for the HVCs or products derived in which incineration is not the end-of-life fate. GHG: greenhouse gas; BL: baseline scenario; RCP: representative concentration pathway 4.5 W/m<sup>2</sup> by 2100 scenario; EB: electric boiler; BB: biogas boiler; CO<sub>2</sub>: carbon dioxide; HVC: high value chemical.

# Lessons for LCA PV Harmonization Discussion

- Foreground inventory changes can learn from each other
  - Some generalisable, e.g. process changes (roll-to-roll) and synergies (TCO) to expect
  - Joint database?
- Yes, background matters
  - E.g. for which SSPs to present results for new PV technologies?

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