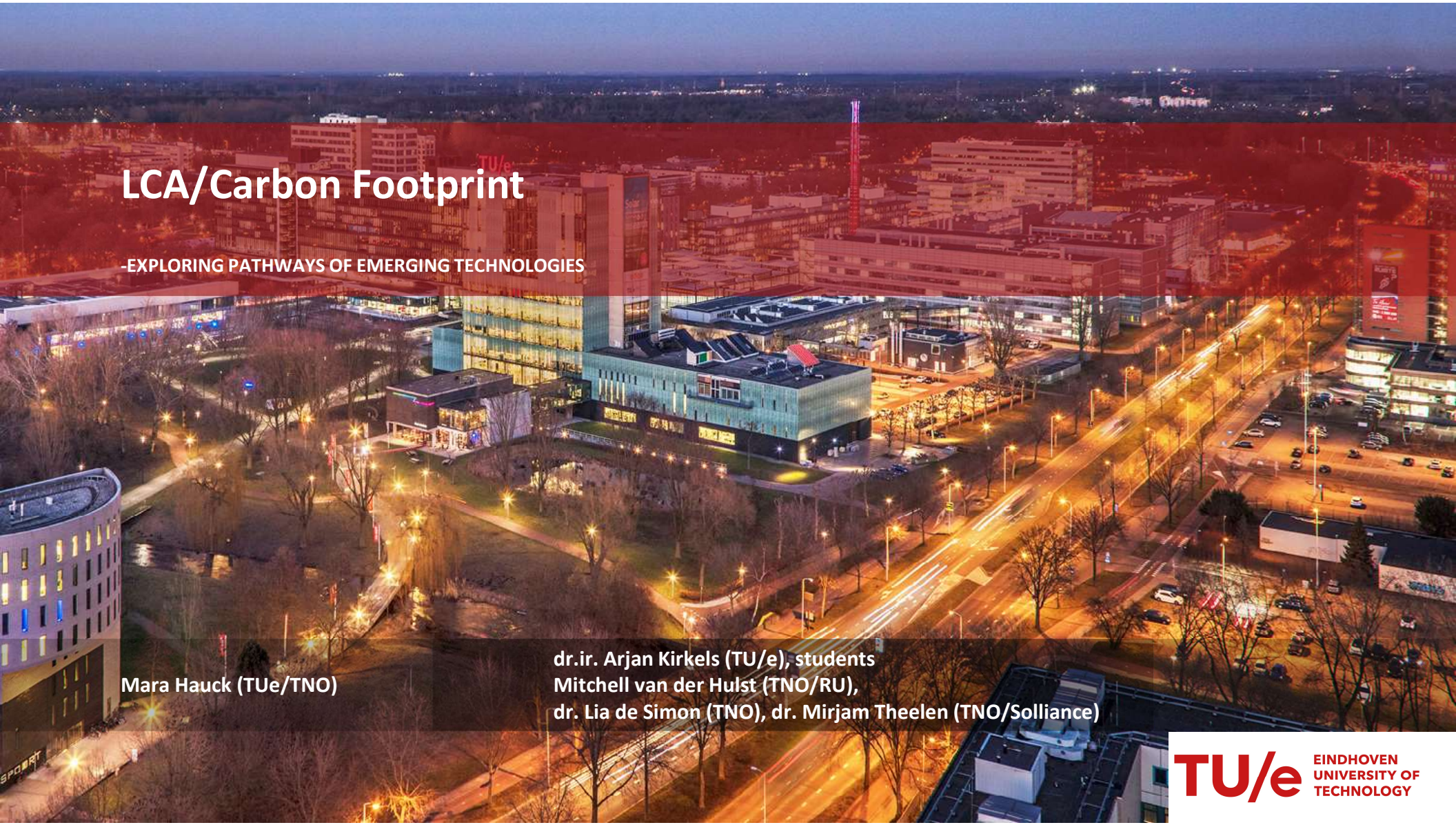


LCA/Carbon Footprint

-EXPLORING PATHWAYS OF EMERGING TECHNOLOGIES

Mara Hauck (TUe/TNO)

dr.ir. Arjan Kirkels (TU/e), students
Mitchell van der Hulst (TNO/RU),
dr. Lia de Simon (TNO), dr. Mirjam Theelen (TNO/Solliance)

TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY

Acknowlegdments

TNO innovation for life

SOLLIANCE SOLAR RESEARCH

Radboud University

METHODS, TOOLS, AND SOFTWARE

INDUSTRIAL ECOLOGY WILEY

A systematic approach to assess the environmental impact of emerging technologies

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

Mitchell K. van der Hulst[1,2] | Mark A. J. Huijbregts[1] | Niels van Loon[3] | Mirjam Theelen[3] | Lucinda Kootstra[2] | Joseph D. Bergesen[4] | Mara Hauck[2]

ELSEVIER

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Environmental benefits of reduced electricity use exceed impacts from lead use for perovskite based tandem solar cell

Mara Hauck*, Tom Ligthart, Martijn Schaap, Elise Boukris, Derk Brouwer [1]

TNO, Dutch Institute for Applied Research, Postbus 80015, 3508 TA Utrecht, The Netherlands

TU/e

TIS, EIRES

EMERGING TECHNOLOGIES

SOCIO-TECHNICAL SYSTEM

SUSTAINABILITY

transitions

ENERGY

FEASIBILITY

innovation science

ENERGY COMMUNITIES

WESTERN AND DEVELOPING COUNTRIES

ENGAGEMENT

ENERGY TRANSITION

LEARNING

ASSESSMI

SIMULATION

TECHNOLOGY TRANSFER

LCA

RESPONSIBLE INNOVATION

STAKEHOLDERS

Accelerating Climate transition

- Applied Physics – fundamental research new solar cells
- Architecture and building – building integration, performance, architecture
- Industrial engineering (ITEM) – sustainable business models

TU/e

CONTENTS

Intro:

- life cycle assessment
- developments

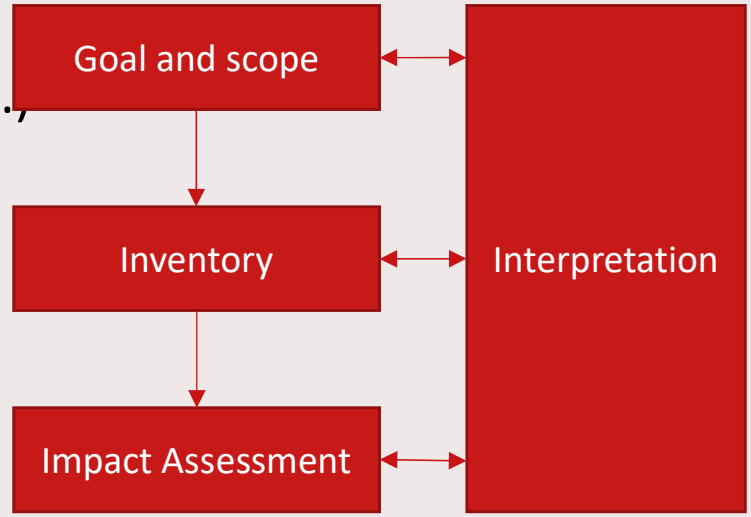
Examples own work

- Prospective LCA CIGS
- BIPV scenarios
- TIS students and topics

Future challenges

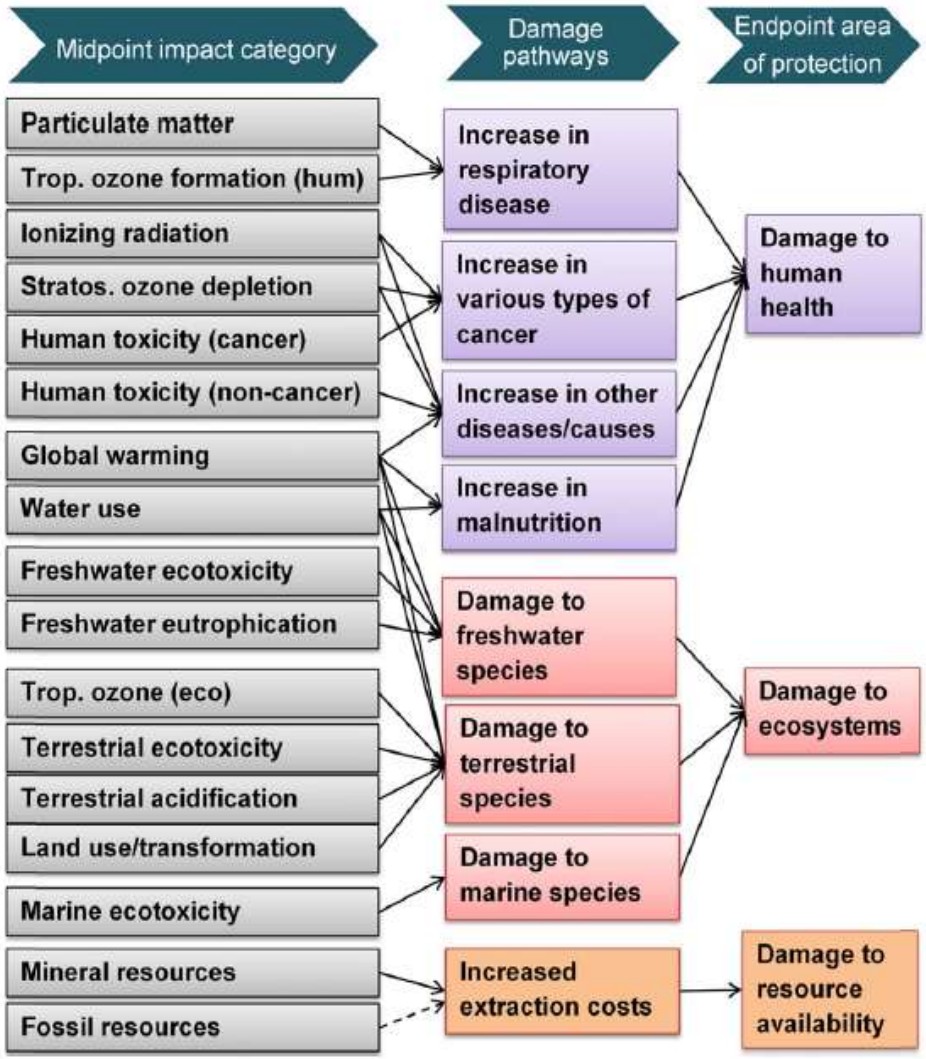
LIFE CYCLE ASSESSMENT AND CARBON FOOTPRINT

- Environmental LCA <-> LCC, SLCA,..
- 4 stages
  - Functional unit
- Life-cycle: resources to waste (cradle to grave,…)
- Optional: normalization and weighting



LIFE CYCLE ASSESSMENT

- Comparative tool
  - Products
  - Production technologies
  - Specific processes within chain
  - Throughout life cycle (hotspots)
- Prevent trade-offs between
  - Life cycle stages
  - Environmental problem areas
    - <-> carbon footprint



Source: Huijbregts et al., 2017

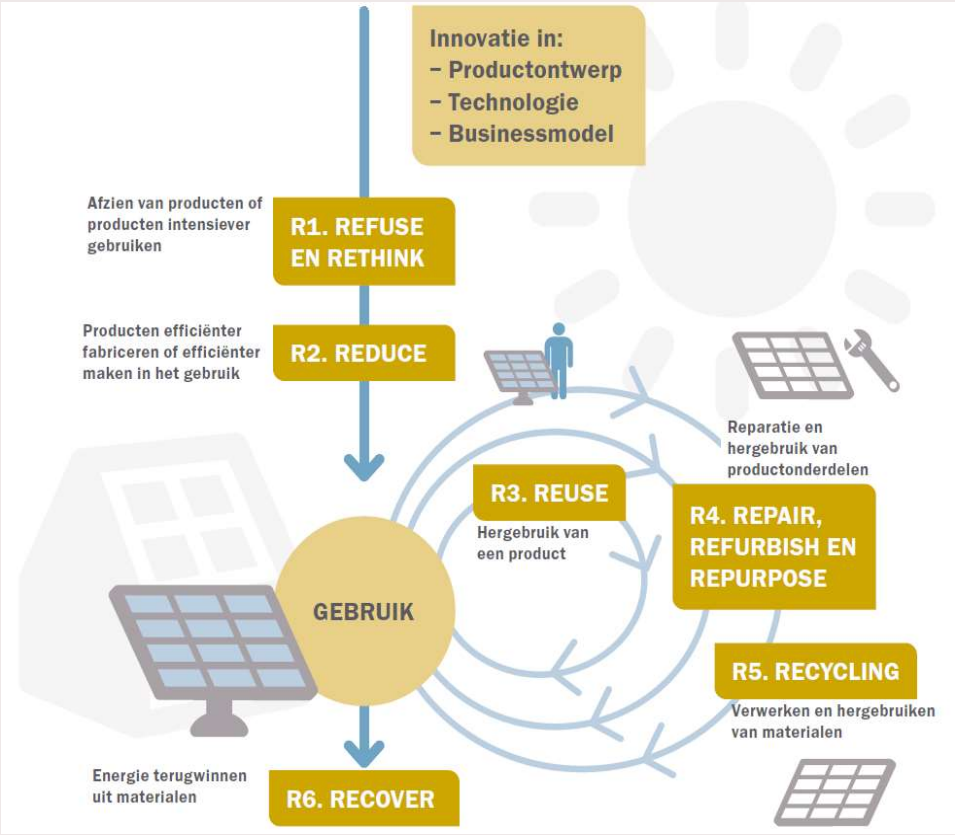
CARBON FOOTPRINT (CF) – 'RULES OF THUMB'

- The higher the lifetime electricity generation the lower the CF
  - Lifetime
  - Efficiency
  - Stability
- The less material the lower the CF
  - Production method and regions matter
- CF highly influenced by energy mix
  - Not only energy demand

CIRCULARITY

Also rules of thumb:

- Material/function



Theelen et al., 2021

LCA OF PV

Topics

- Often carbon footprint/energy demand and related
- Often cradle to gate or cradle to end-of-life
- Often cel/module level, BA ground-mounted
- Emerging technologies screening

Topics

- More impact categories -> scarcity, toxicity
- End of life and enhanced circularity
- Integration
- Prospective studies, including energy transition

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)." (Arvidsson et al., 2017), also called ex-ante LCA

Work by PhD candidate Mitchell van der Hulst

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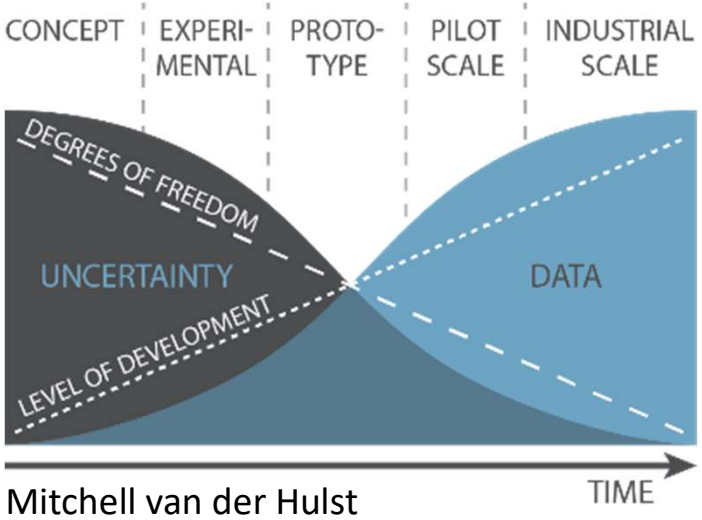
PROSPECTIVE LCA

- Technology under development: high uncertainty and degrees of freedom
- Data scarcity and results likely skewed, but lower lock-in

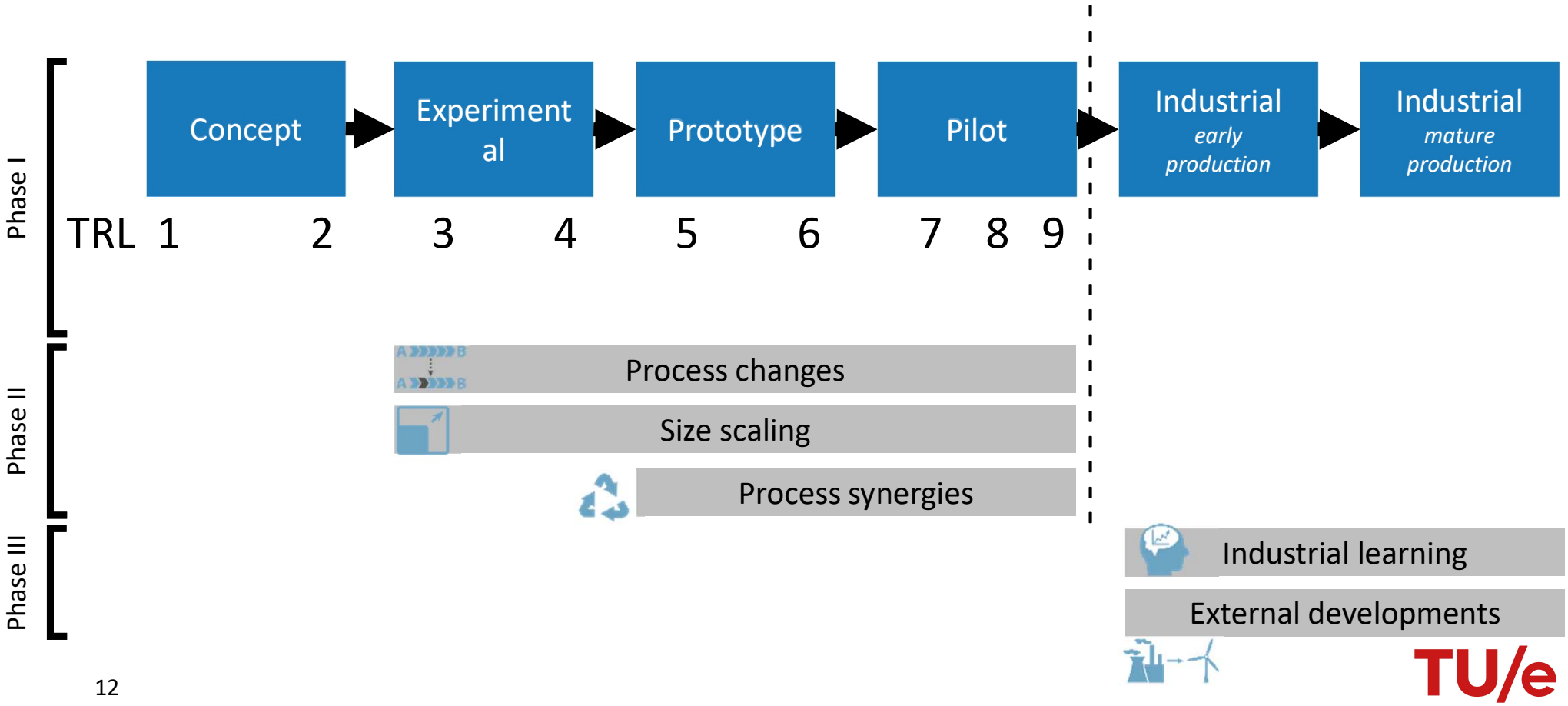
- **Technology changes**
- Alternatives might change
- **Economy changes (e.g., energy transition)**

- Iterative and communicative

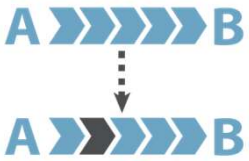


Mitchell van der Hulst

SYSTEMATIC APPROACH BY VAN DER HULST ET AL.



ASSESSMENT OF DEVELOPMENTS (PHASE II), EXAMPLE CIGS 2014 -> 2030



PROCESS CHANGES

Replacement of materials, equipment or processing methods for alternatives.

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

Up-scaling of the product, production equipment and/or production capacity.

Size: 30x30 cm^2 (pilot scale)
→ 60x120 cm^2 (commercial scale)

PRODUCTION LINE SYNERGIES

Recovery and re-use of waste streams in and between production lines.

Recovery of metal(loid)s:
copper (Cu), indium (In), gallium (Ga), selenium (Se), molybdenum (Mo)

ASSESSMENT OF DEVELOPMENTS (PHASE III), EXAMPLE CIGS 2014 -> 2030

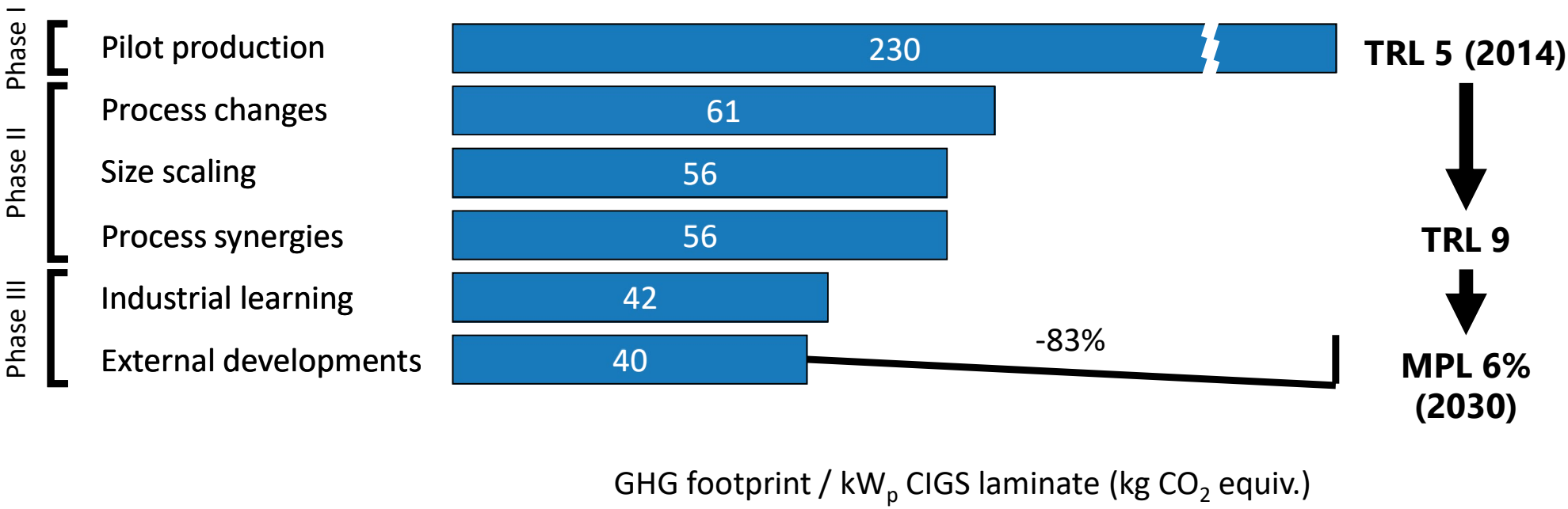
Quantification of the continuous progression occurring at the industrial scale.

Photovoltaic efficiency: 15% → 20%

Developments in external processes that feed into the studied process.

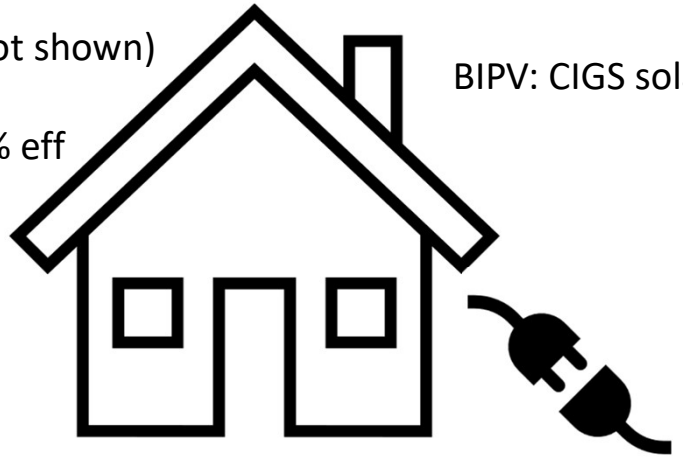
Electricity: decarbonization of Dutch electricity generating industry

VAN DER HULST ET AL. - RESULTS



Current work - Example BIPV

BAPV: Rigid CIGS (or Si, not shown) mounted and rooftiles
Possible replacement +2% eff

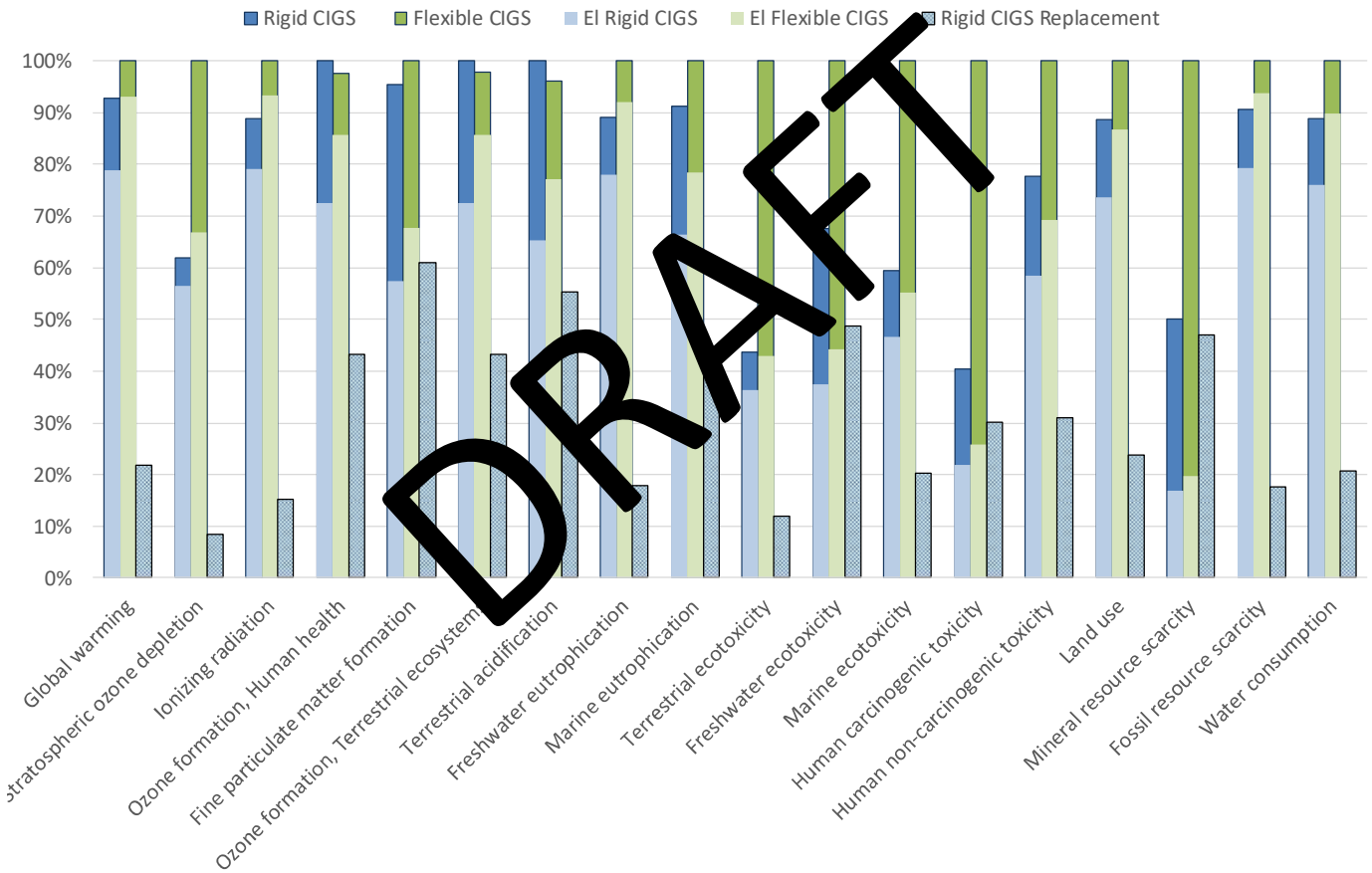


BIPV: CIGS solar rooftile

Supply 3600 kWh/year of electricity, for 50 years

EoL is excluded because of lack of data

Current work - Example BIPV



If a more renewable energy mix (e.g. based on the KEV estimate for 2030) is assumed for house electricity demand, advantage of replacement vanishes.

CHALLENGES FOR LCA FOR SUSTAINABLE PV

- Account of small material quantities (thin film etc.)
- Modelling and allocation end of life and several life cycle stages (circularity)
- Multi-functionality (integration)
- Energy and material transition and impact assessment (future)
- Steering and screening indicators for technology development (development)

… AND BEYOND

- ‘System’
  - Integration in the energy system
  - Exchange of materials etc. with other parts of the economy
  - Exploring system implications of large-scale introduction of solar
- ‘Humans’
  - Responsible innovation
  - Transitions and pathway exploration
  - Stakeholder empowerment