Bio-based and circular carbon for material transition

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Word cloud of titles of my articles

Utrecht University

Technology assessment – technological solutions for the challenges in resources, climate change and the environment

1. Do bio-based materials offer environmental benefits? If so, why and how? What are the trade-offs and constraints?
2. For technology innovation: can we avoid potential environmental problems from the early stage?
3. How do we assess the circularity of plastic products? Is “circularity” the same as “sustainability”?

Bio-based materials (plastics) are not new…

Industrial Revolution in the 1800s: the rise of wood-based chemistry (modified cellulose)

- Celluloid obsoleted ivory in the 1870s
- Viscose invented in the 1890s, as cotton and silk replacement

(Perhaps) First plastics film: cellophane (1912)

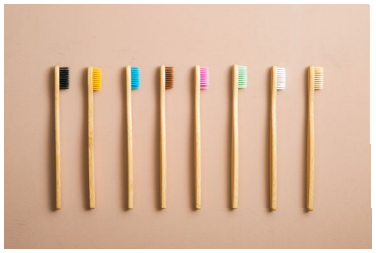
The first Lego was made via injection moulding of cellulose acetate in the 1940s (Kiddicraft)

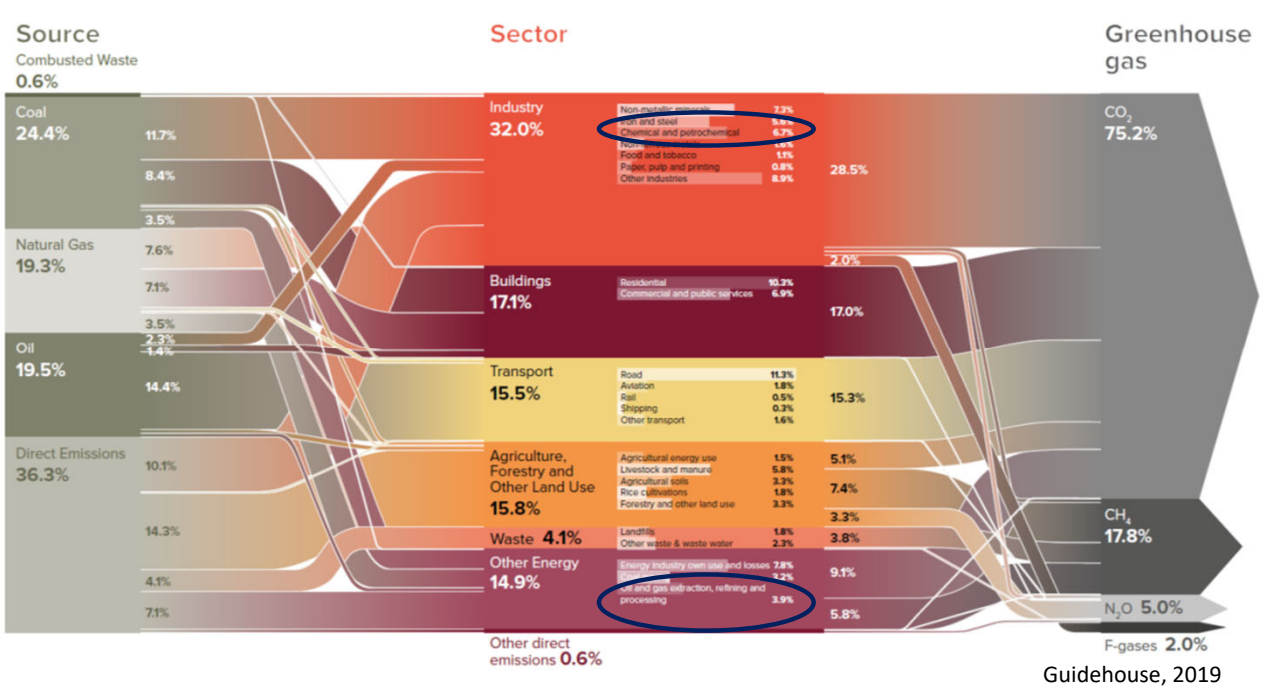
In the first half of the 20th century…

Henry Ford (right) unveiling his handmade plastic automobile in Dearborn, Michigan, in August 1941. The body's plastic was made from soybean and fibers such as field straw, hemp, and flax. The car ran on gasoline and ethanol from corn. Source: Bloomberg https://www.bloomberg.com/news/features/2017-09-20/henry-ford-and-soy-set-up-antibiotic-resistance-deadly-superbugs

- Late 1930s: world-wide large scale oil extraction
- 1930-1950: invention and commercialisation of PVC, PS, PE, Nylons
- 1947: PET patented
- 1950s: commercialisation of PET, LLDPE, HIPS, PP, PUR and epoxy resin
- Global annual plastics production in 1950s: ca. 2 Mt

Every year, about 350-400 million metric tonnes of synthetic polymers are produced globally





Guidehouse, 2019

- Plastics are convenient.
- Plastics are problematic.
- Can we live without plastic?

Can we live without plastic? .....for a day?

The New York Times | https://www.nytimes.com/2023/01/11/style/plastic-free.html

Trying to Live a Day Without Plastic

It's all around us, despite its adverse effects on the planet. In a 24-hour experiment, one journalist tried to go plastic free.

By A. J. Jacobs

Jacobs is a journalist in New York who has written books on trying to live by the rules of the Bible and reading the Encyclopaedia Britannica from A to Z.

Jan. 11, 2023

"I had made 164 violations, by my count."

https://www.nytimes.com/2023/01/11/style/plastic-free.html

If not, what then?

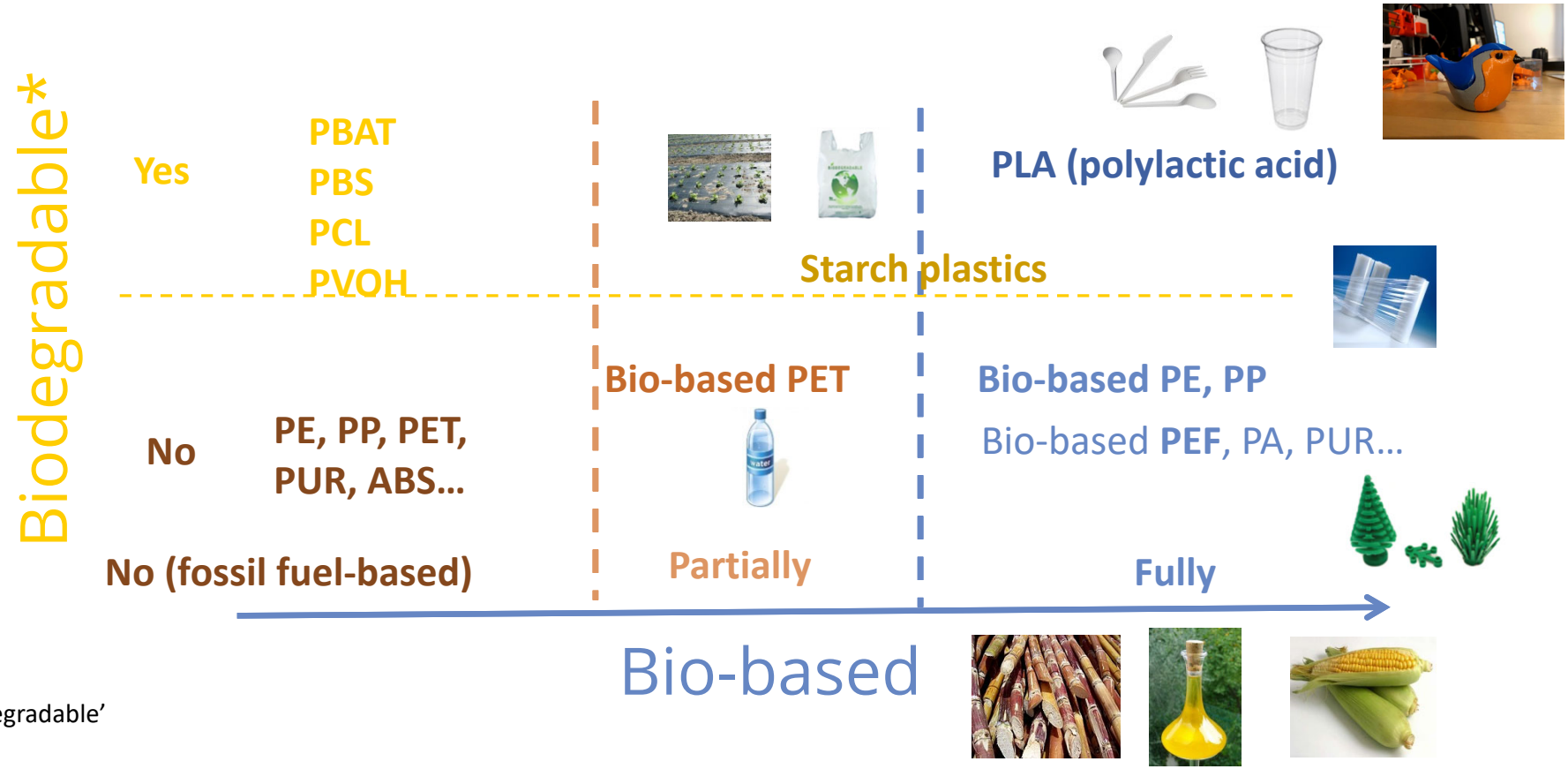
- **Can we make better plastics?**
- **Better?**

Part of the puzzle - **alternative carbon sources**:

1. Use biogenic carbon
2. Recycle bio-based carbon: Circular biobased

Are bio-based plastics a solution?

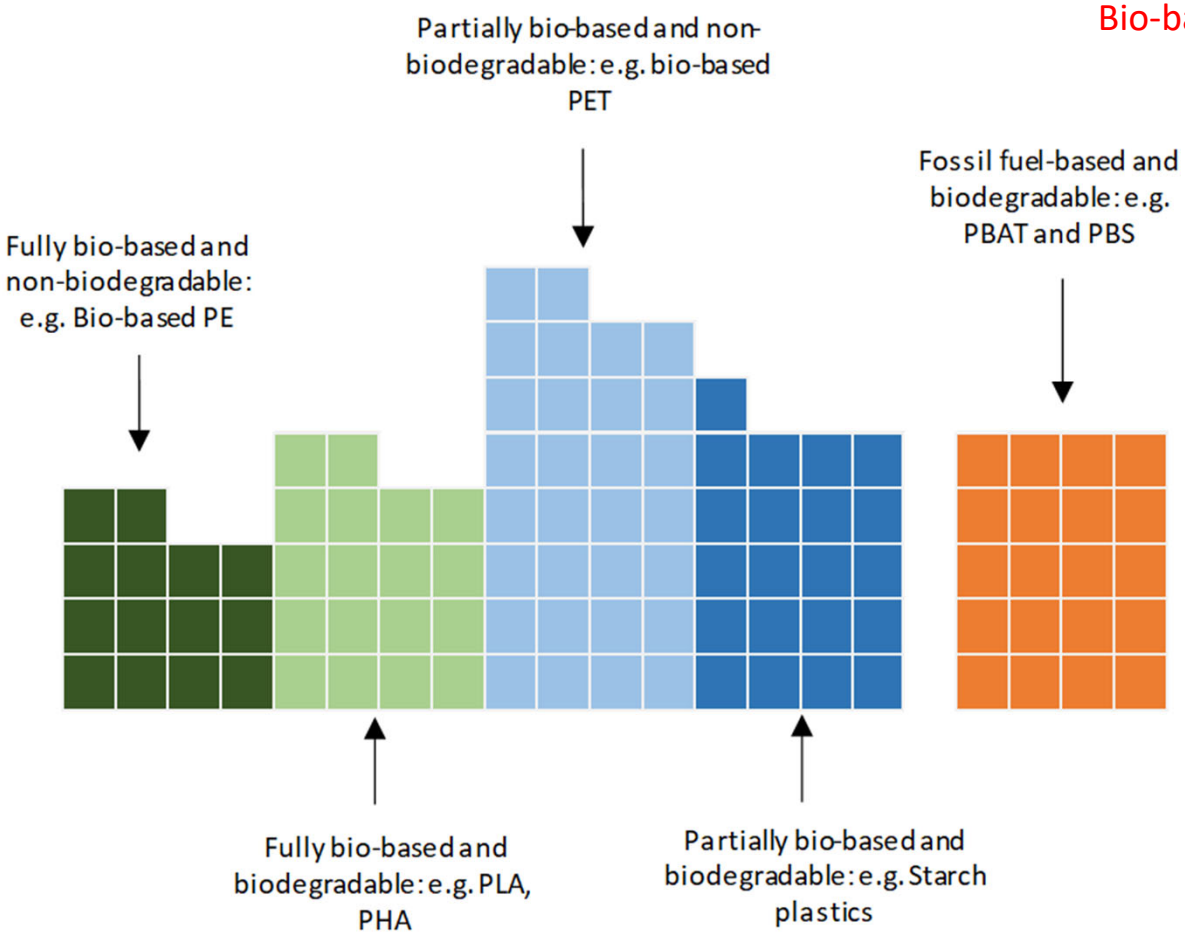
What is "bioplastic"?



*certified as 'biodegradable'

Global production capacity 2019: 2.11 million metric tonnes

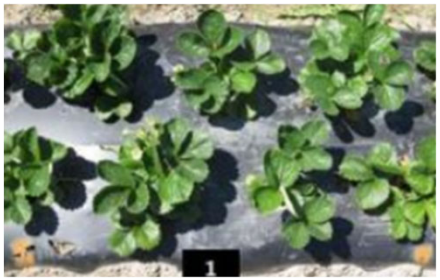
Bio-based carbon: less than 50%!



Compiled based on European Bioplastics (2021)

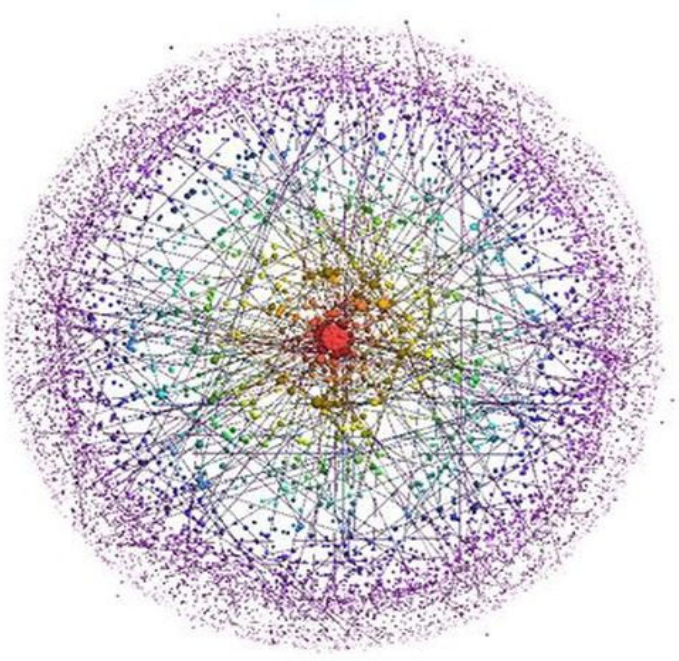
BIO-SPRI: Seven bio-based products

- Beverage bottles
- Horticultural clips
- Single-use drinking cups
- Single-use carrier bags
- Food packaging films
- Single-use cutlery
- Agricultural mulch films



Life Cycle Assessment

"Best framework for assessing the potential environmental impacts of products" (COM (2003)302)



Picture courtesy to Dr. Blanca Corona Bellostas

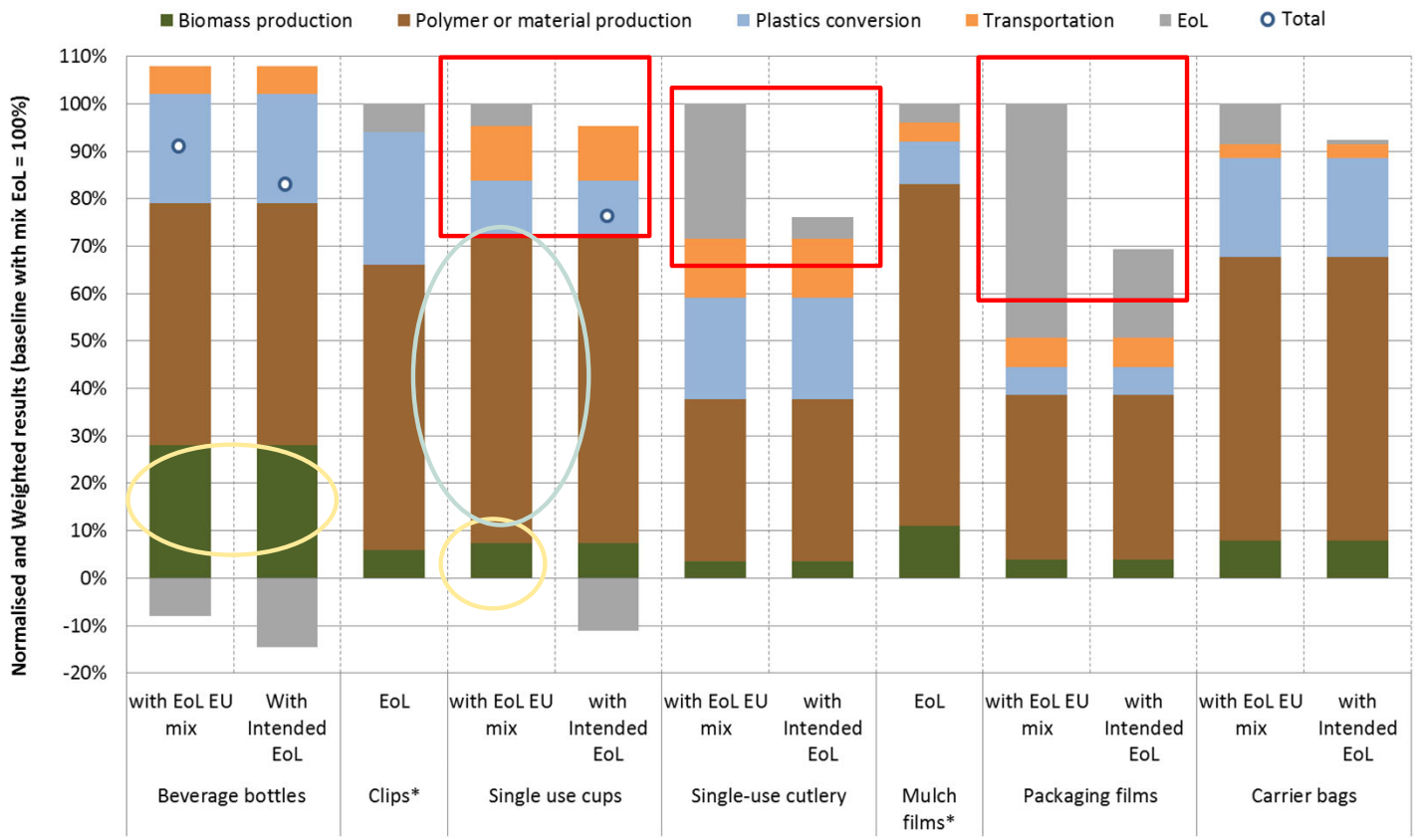
Cases studied by BIO-SPRI

Case studies	Bio-based baseline	Reference system(s)
Beverage bottles	30% bio-based PET	PChemPET
Single-use drinking cups	PLA	PET PP
Single-use cutlery		PS
Food packaging films		PP
Horticultural clips	Starch plastics	PP
Agricultural mulch films		LDPE
Single-use carrier bags		LDPE

Status-quo average technology mix; primary data from industry.

PET=polyethylene terephthalate; PLA=Polylactic acid, UCO=Used cooking oil, PP=polypropylene, PS=polystyrene, LDPE=low-density polyethylene
PChem=petrochemical

Cradle-to-grave impacts of seven bio-based products, normalised and weighted results without Land use change (LUC) effects, comparing EoL EU mix with intended EoL



* For case studies Clips and Mulch films, the EoL mix is assumed the same as the intended EoL, which is in-situ soil biodegradation.

Comparing with the petrochemicals…

Out of 16 PEFCR impact categories, only ***five*** are recommended to be used for comparison

Cradle to grave baseline results excluding LUC effects, environmental impact reduction on median values (with ranges)

Biobased polymers clearly offer benefits, but the trade-offs of other environmental impacts are not always well-understood.

Climate Change (GWP 100a)

Abiotic depletion (fossil fuels)

Particulate matter

Photochemical ozone formation
Terrestrial eutrophication

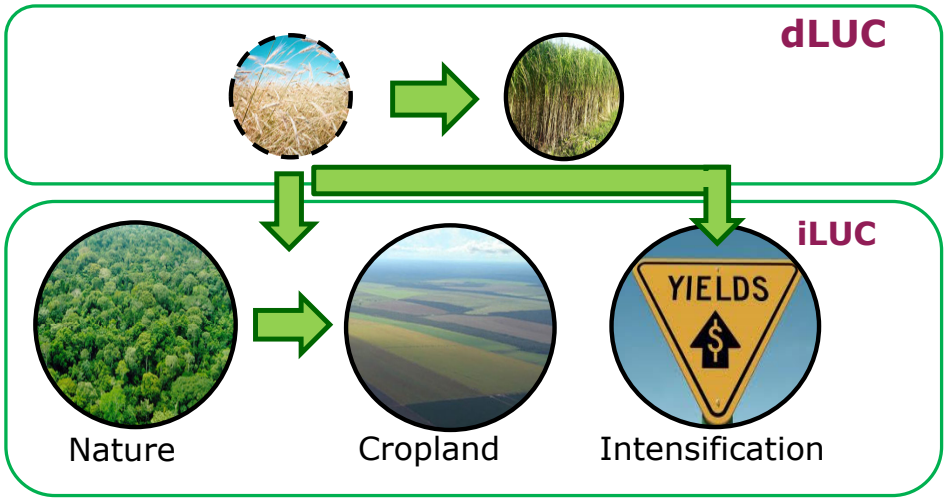
*Median savings based on the eight comparisons of the seven case studies (two comparisons were made for single-use cups).

Land Use Changes (LUC)

- Direct LUC Modelled in accordance with the PEFCR Guidance (v.6.3); consistent with PAS2050 requirements.
- Indirect LUC modelled separately based on a *deterministic method* adapted for this study

Picture courtesy to Dr. Lorie Hamelin

Indirect land use changes: a deterministic model*



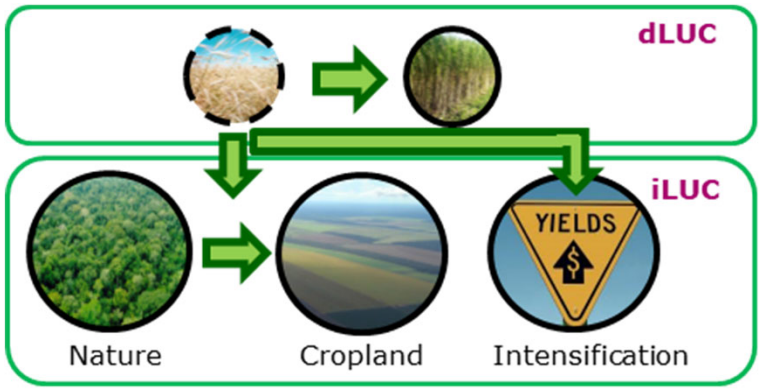
1.Establish plausible cause-effect chain events, understanding of service displaced and reacting supply.
2.Determine expansion/intensification based on *past* time-series data (e.g. FAO).
3.Calculate impacts resulted from expansion
4.Calculate impacts resulted from intensification

** GCB Bioenergy 8, 690–706. (2016); Slide credit Dr. Lorie Hamelin*

Land use change in BIOSPRI project

Land use change will lead to increases in impacts:

- 14% for climate change
- 10% for photochemical ozone formation
- 0.01-2.4% for all other impact categories



Simplified message: the shorter the production chain, the stronger effect observed from LUC

LCA bio-based materials
What we learned from the current “classical LCAs” for innovative biobased plastics:

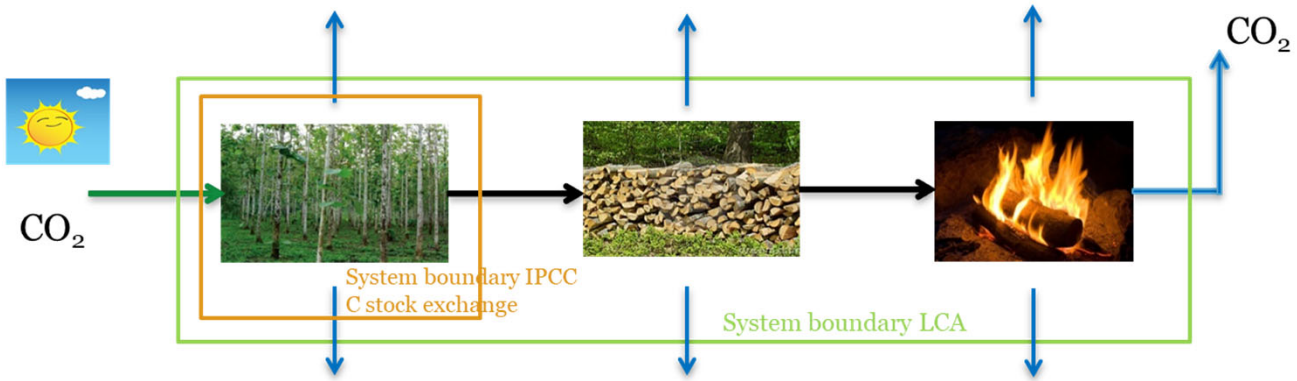
Compared to their petrochemical counterparts :

- The established biobased systems often have lower cradle-to-gate GHG emissions:
  - If cumulative biogenic carbon removals are accounted as a direct credit (e.g. as defined in PAS 2050).
  - (bio)chemical conversion processes can be carbon-intensive.
  - Sensitive to the choice of allocation/multifunctionalities

- Biobased systems often lead to a higher impact on land and water – the tradeoffs are not always fully understood

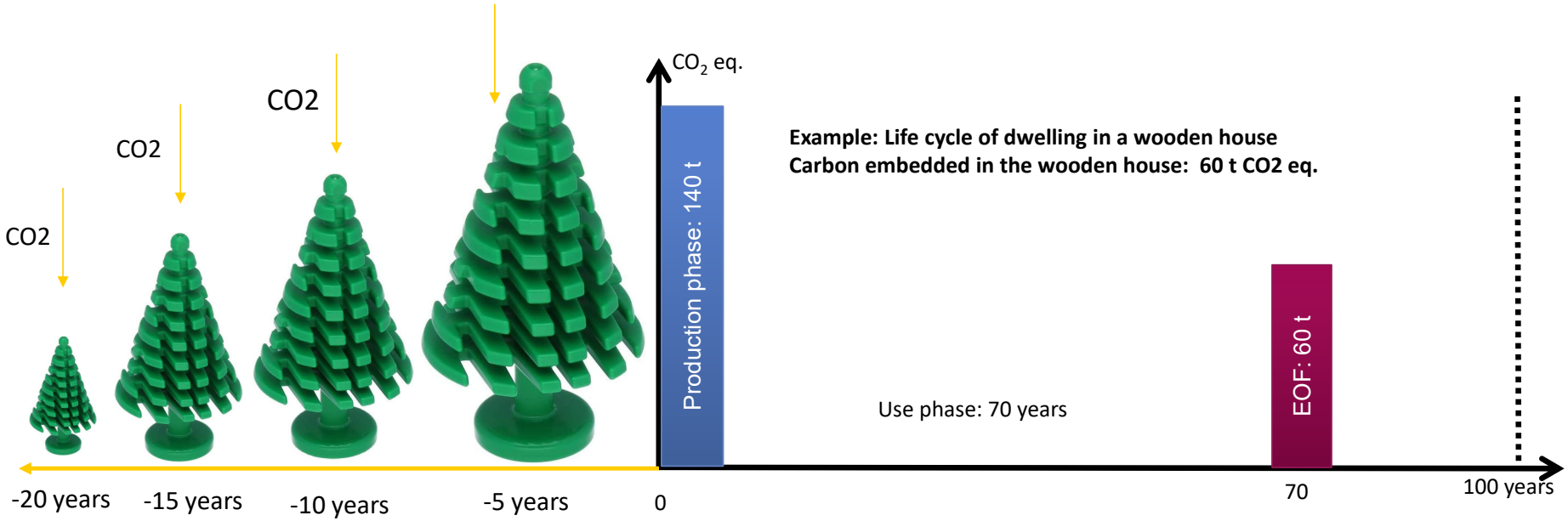
* See Broeren et al (2017) DOI: 10.1002/bbb

Biogenic carbon removals



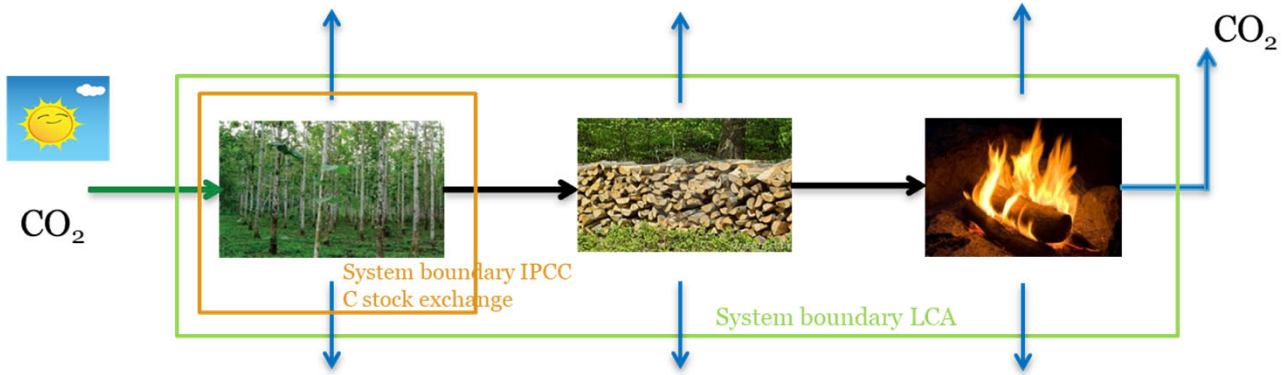
Timings of carbon emissions and removals

Cumulative carbon removals over 20 years (60 t CO2 eq.)



Land use impacts are more complex than what the current LCIA method can offer: impact of "carbon removals" (1/2)

- Cumulative removals do not account for time-depend effects
- Do we extend the temporal scope? How?
- How to attribute removals from different biomass sources?
- Dynamic LCA: what resolution is sufficient?
- Consequential LCA: How to determine counterfactuals?



Land use impacts are more complex than the current LCIA method can offer (1/2)

For perennial crops and woody biomass, land use and land use changes disturb:

- Carbon balances
  - Direct carbon balance change: biomass growth
  - Indirect carbon balance change: soil organic carbon content
- Nitrogen balances
- Available fresh water
- Biodiversity

Spatial and temporal explicit models are urgently needed for LCA: Horizon Europe ESCIB (2024-2028)

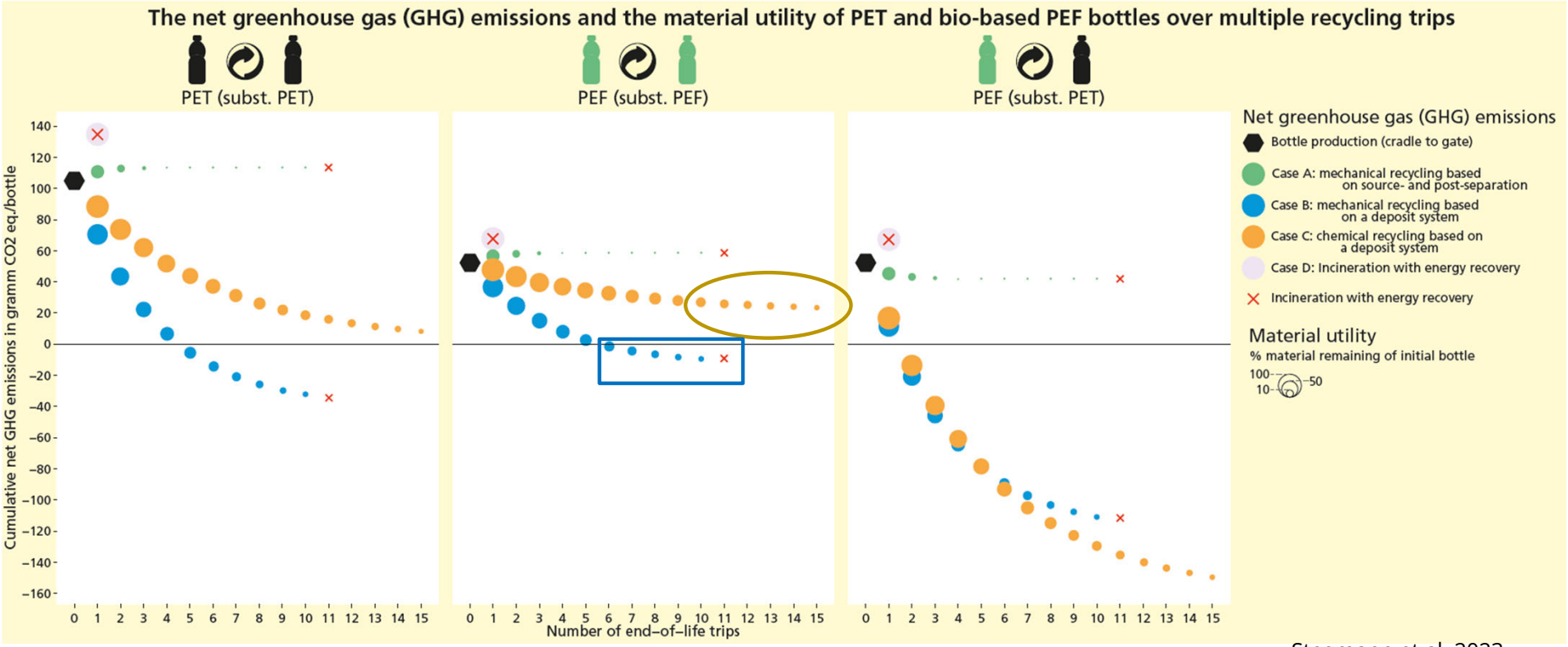
If not, what now?

- **Make better plastics…..better?**

Part of the puzzle piece - alternative carbon sources:

1. Use biogenic carbon: “bio-based”
2. Recycle the biogenic carbon: “circular biobased”

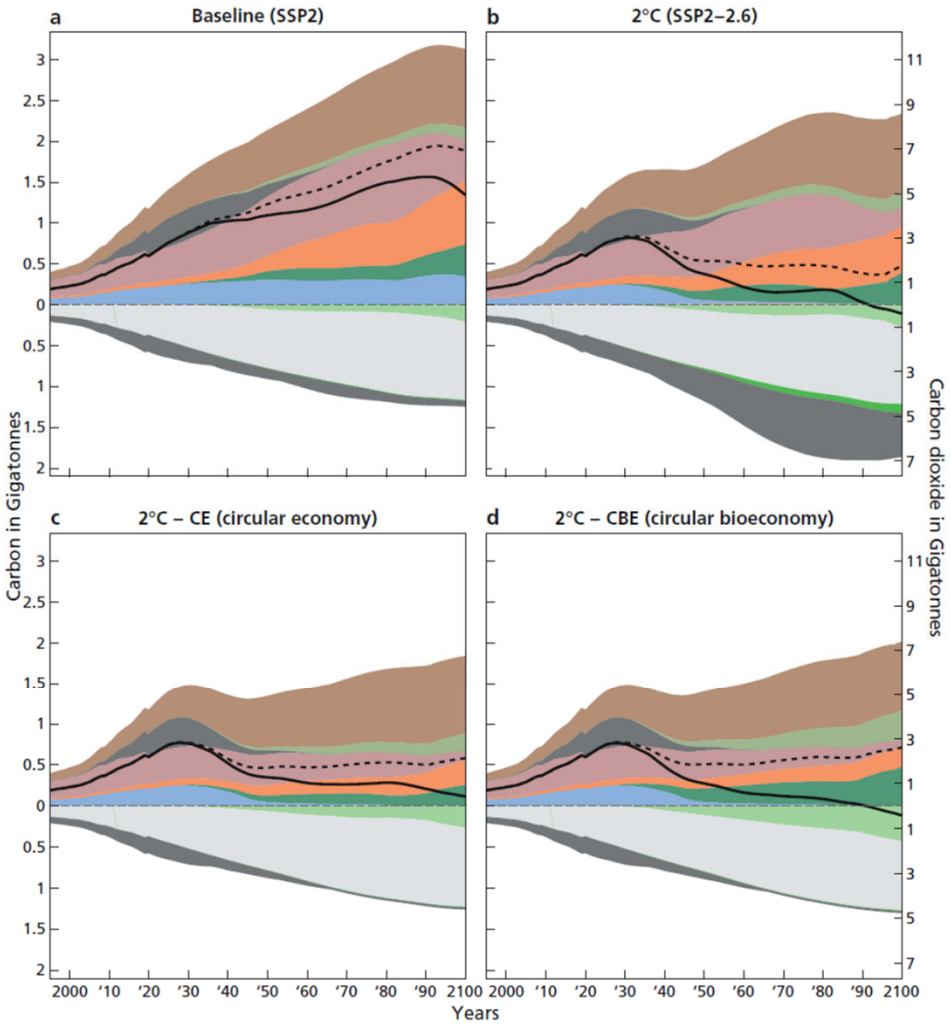
Circular biobased: bio-based plastics in multiple recycling trips

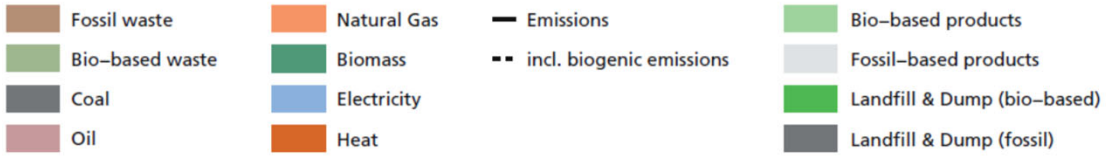


Stegmann et al. 2023
doi.org/10.1016/j.jclepro.2023.136426

Circularity does not automatically lead to Sustainability.

Carbon balance of the plastic sector over the entire life cycle: the PLAIA model





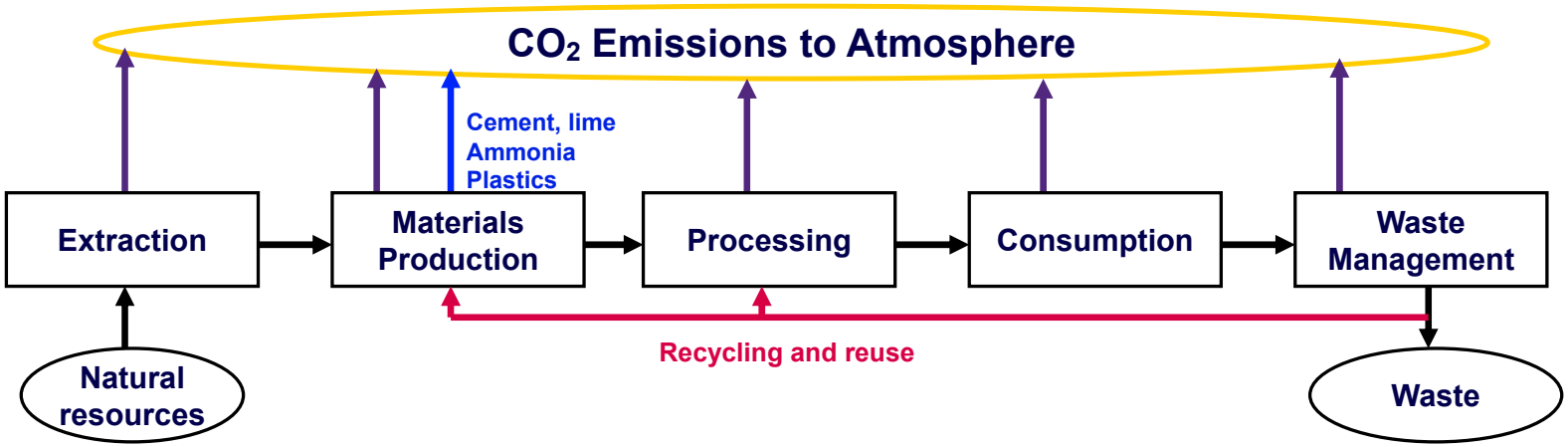
The Plastic Integrated Assessment model (Stegmann et al. 2022):

- Combining LCA with IAM
- A CBE combining recycling with higher biomass use could ultimately turn the sector into a net carbon sink.
- However, this involves continued reliance on primary feedstock.

Stegmann et al. (2022) Nature. DOI: 10.1038/s41586-022-05422-5

For the audience: Two questions

Do we fully understand circular bio-based systems?



Make better plastics…..better?

Part of the puzzle piece - alternative carbon sources:

1. Use biogenic carbon: “bio-based”
2. Recycle the biogenic carbon: “circular biobased”

How about the measures high in circularity priority: <u>reduce, reuse and repair?</u>

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Sharing science,
shaping tomorrow

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