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Life cycle assessment of PHA-based polymers with improved barrier properties

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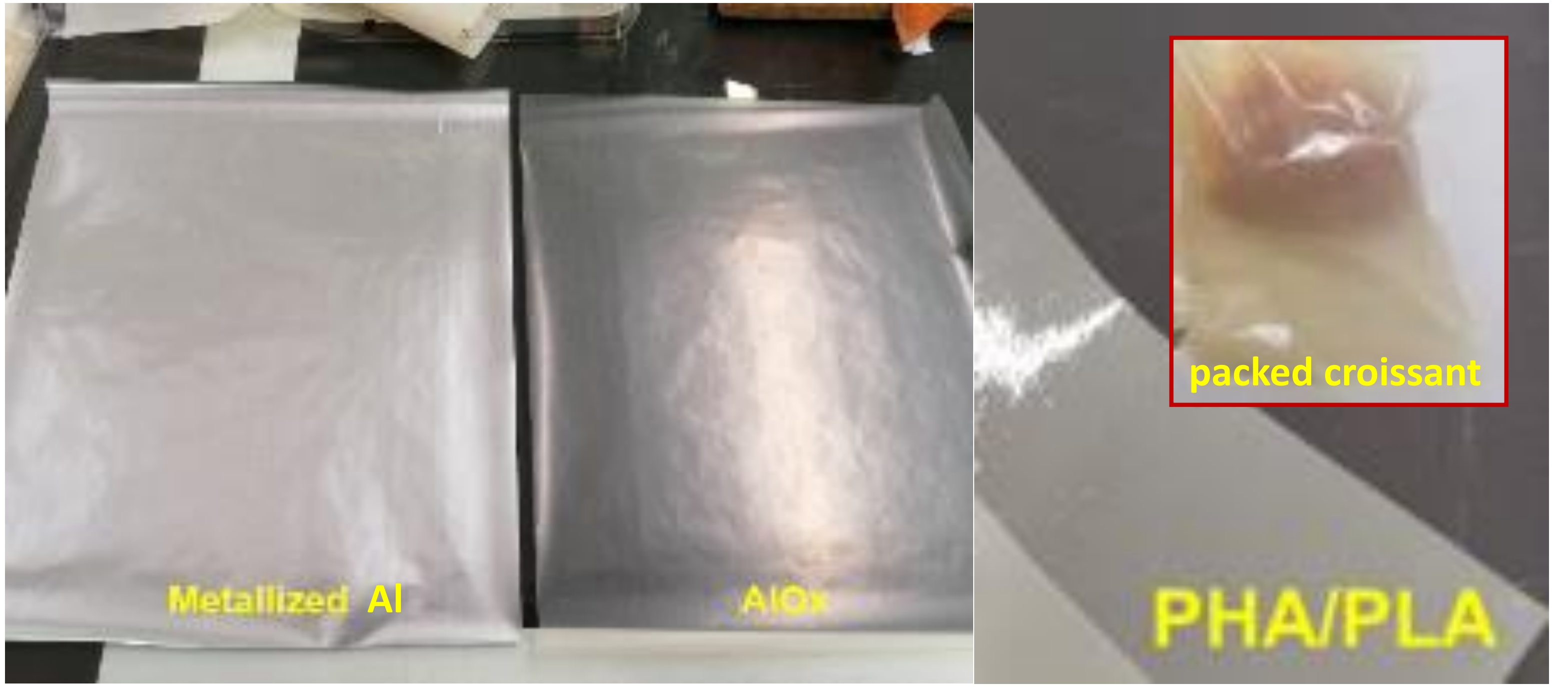
Quantitative Sustainability Assessment
Department of Technology, Management and Economics

Goal

- To identify environmental weak points of the (PHA)-based polymers with improved barrier properties
- To compare them with existing alternatives



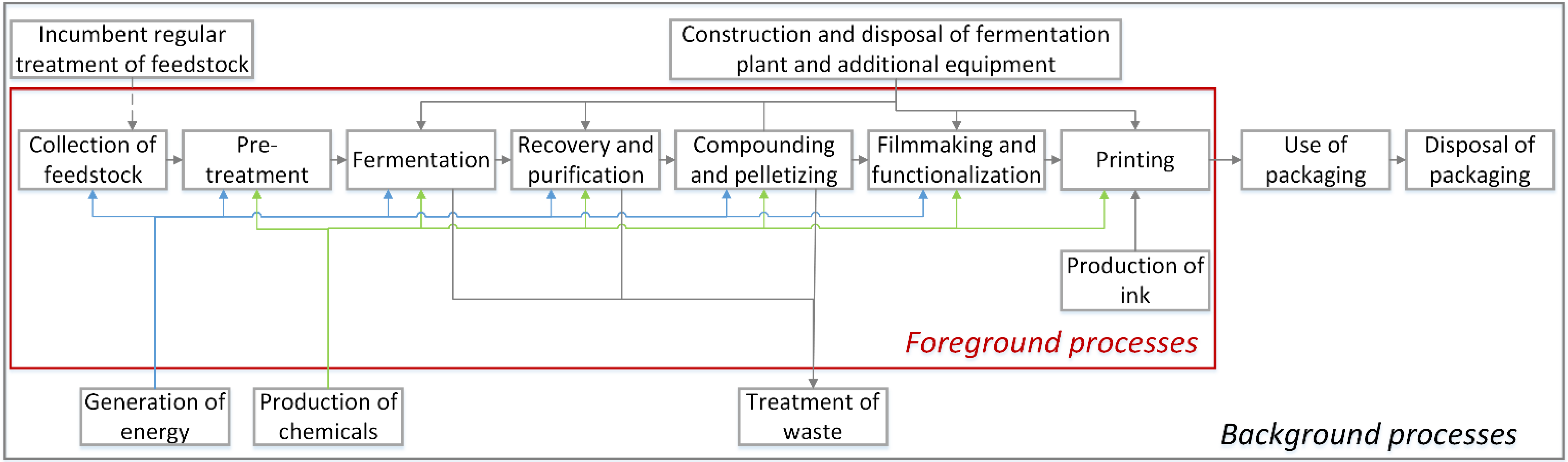
PE reel

Functional unit

Protection of one average croissant (ca. 40 g) against migration of oxygen, water and aromas (according to global and specific migration standards BS EN 1186 and UNE-EN 13130 for migration of aromatic primary amines, phthalic acid, crotonic acid, acrylic acid and the elements Al, B, Ba, Cu, Co, Fe, Li, Mn, Ni and Zn) during transport and storage for 30 days”

A systems perspective

- Full life cycle from cradle to grave



Life Cycle Inventory modelling

- LCA according to ISO 14044 and EU guidelines (ILCD)
- Attributional modelling framework

LCI modelling framework	Question to be answered	Handling of multifunctional processes when subdivision is not possible		Modelling of background system
		Before ILCD	ILCD	
Attributional	What environmental impact can be attributed to product X?	Allocation	System expansion or allocation	Average processes
Consequential	What are the environmental consequences of consuming X?	System expansion	System expansion	Marginal processes

EC-JRC, 2010. International Reference Life Cycle Data System (ILCD) Handbook – General guide for Life Cycle Assessment–Detailed guidance, Constraints. European Commission - Joint Research Centre - Institute for Environment and Sustainability https:// doi.org/10.2788/38479

ISO (2006) ISO 14044: Environmental management—Life cycle assessment—Requirements and guidelines. International Organization for Standardization.

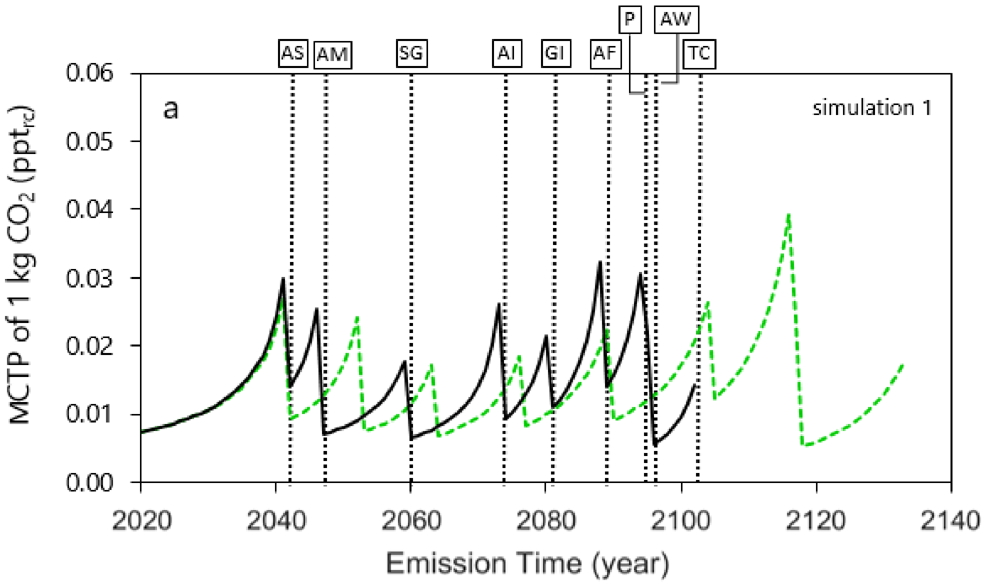
Data sources

- PHA installations modelled mainly based on measured data from literature
- Functionalization modelled mainly based on measured data from project partners

Study	Scale	Parameters used in modelling of PHA installations
(Harding et al. 2007)	Pilot	Steam for sterilization and spray drying, yield of fermented PHA, wastewater, consumptions of water, surfactant, enzyme and hydrogen peroxide and bill of materials
(Leong et al. 2017)	Large scale	Yield of fermented and recovered PHA, waste and wastewater, consumption of water and surfactant and NaOCl and bill of materials
(Kookos et al. 2019)	Large scale	Steam for sterilization and spray drying, yield of fermented and recovered PHA, consumptions of electricity, ammonia and surfactant and NaOCl, CO_2 emissions.
(Pavan et al. 2019)	Large scale	Yield of fermented PHA and consumptions of ammonia

Life Cycle Impact Assessment

- ReCiPe 2016 as starting point *(17 impact categories)*
- **GWP$_{100}$** with credits for temporary carbon storage *(radiative forcing increase)*
- Recommended **GTP$_{100}$** *(global temperature change)*
- New **MCTP** *(multiple climate tipping points)*



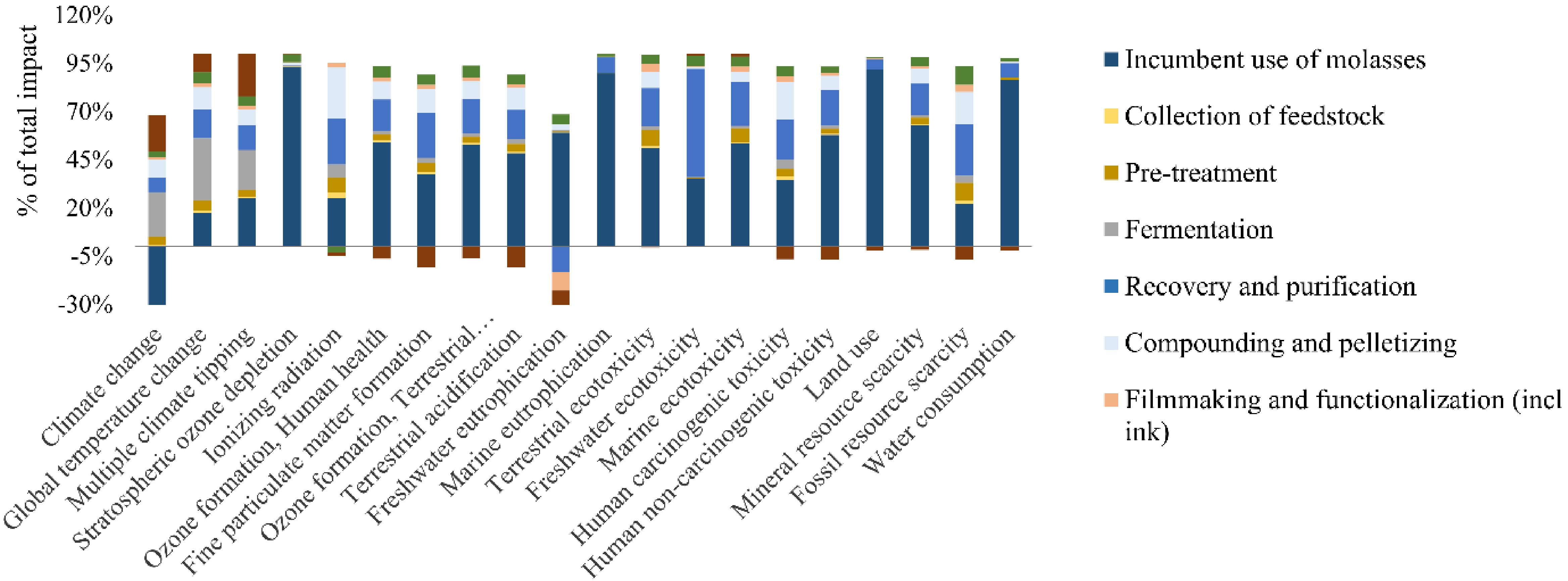
$$MCTP_i(T_{\text{emission}}) = \sum_{j=1}^{m} \frac{I_{\text{emission},i,j}\,(T_{\text{emission}})}{CAP_j\,(T_{\text{emission}})}$$

$$I_{\text{emission},i,j}(T_{\text{emission}}) = \frac{ACTP_{i,j}(T_{\text{emission}})}{RE_{CO_2}} = \frac{\sum_{k=1}^{n} RF_i(T_{k-1})\cdot\Delta T}{RE_{CO_2}}$$

$$CAP_j(T_{\text{emission}}) = C(T_{\text{tipping},j})\cdot(T_{\text{tipping},j} - T_{\text{emission}}) - \sum_{k=1}^{n}\left[C(T_{k-1}) + C_{\text{tip}}(T_{k-1})\right]\cdot\Delta T$$

Fabbri, S., Hauschild, M.Z., Lenton, T.M., Owsianiak, M., 2021. Multiple Climate Tipping Points Metrics for Improved Sustainability Assessment of Products and Services. Environ. Sci. Technol 55, 2800−2810. https://doi.org/10.1021/acs.est.0c02928.

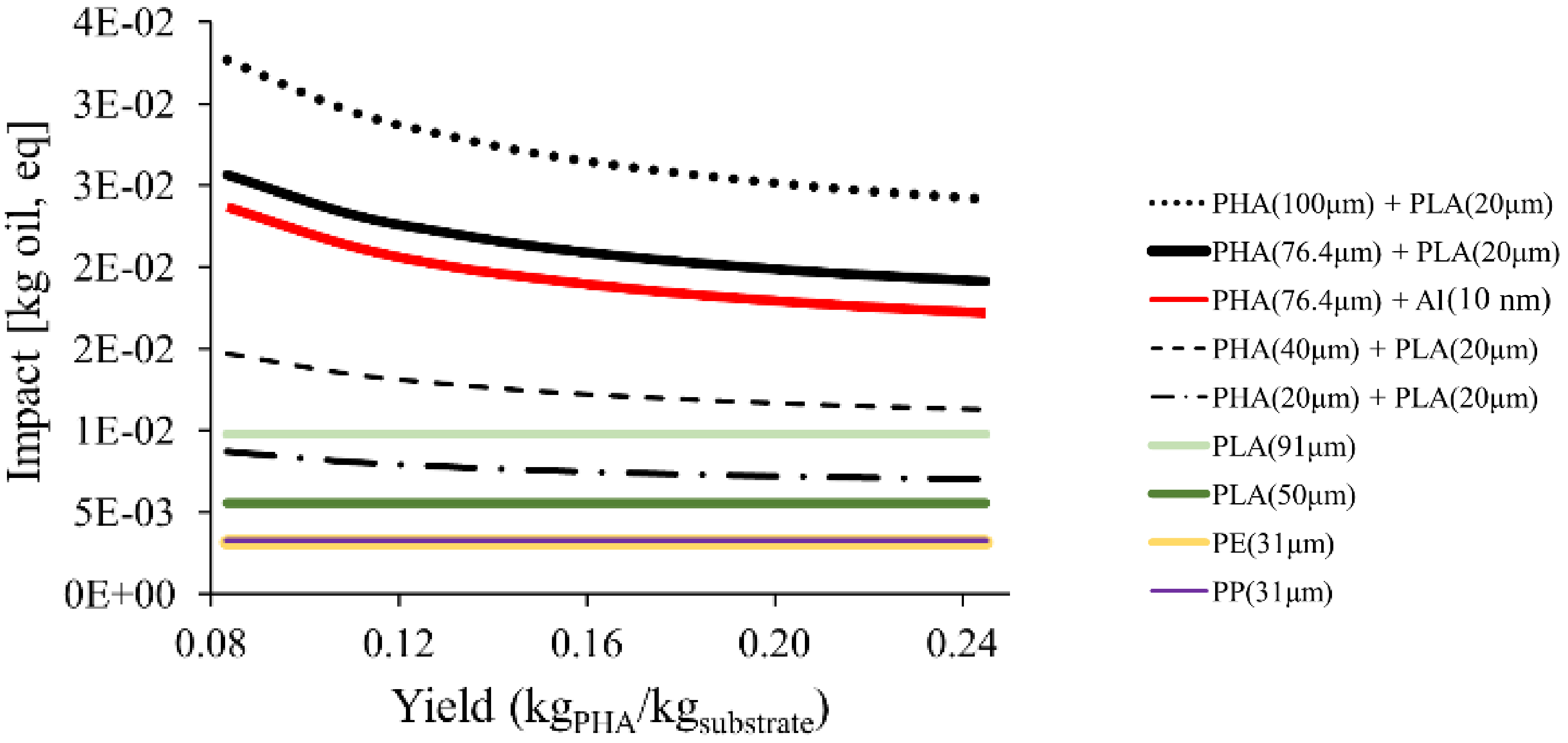
Environmental weak points



Effects of biodegradation kinetics

	GWP$_{100}$ (kg CO_2eq/f.u.)
90% degradation in 2 years	5.25E-02
90% degradation in 31 years	4.53E-02
90% degradation in 105 years	3.57E-02
1% degradation in 100 years	2.81E-02

Comparisons with alternative polymers



Main findings

- Sugar beet is environmental weak point *consider second-generation feedstocks*
- Full-scale performance depends mainly on PHA yield *scale-up focusing on achieving high yield*
- Further product optimization may be necessary for PHA to perform better *aim at reducing PHA thickness to ~30 µm*
- PHA with high biodegradability have lowest climate tipping but not highest climate change impacts *determine the influence of functionalization on PHA biodegradability*

Further reading

Environmental Science & Technology

pubs.acs.org/est

Article

Multiple Climate Tipping Points Metrics for Improved Sustainability Assessment of Products and Services

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Inclusion of multiple climate tipping as a new impact category in life cycle assessment of polyhydroxyalkanoate (PHA)-based plastics

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