Electronic Supplementary Material (ESM)

Carbon footprint of plastic from biomass and recycled feedstock: Methodological insights

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Davide Tonini[1*], Dieuwertje Schrijvers[2], Simone Nessi[1], Pelayo Garcia-Gutierrez[1], Jacopo Giuntoli[1]

[1]European Commission Joint Research Centre

[2]Univ. Bordeaux, CNRS, Bordeaux INP, ISM, UMR 5255, F-33400, Talence, France

[1*]Corresponding author

davide.tonini@ec.europa.eu

European Commission Joint Research Centre, Calle Inca Garcilaso, 41092, Sevilla, Spain

This ESM document provides details on i) the life cycle inventories and ii) the methodology for dynamic modelling of biogenic and fossil carbon emissions, as applied in the study.

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1. Life Cycle inventory

1.1 Rigid packaging

Table S1. List of processes included in the LCI model of high-density polyethylene (HDPE) bottles and respective quantities (for a reference flow of 1 kg of product post-manufacture). EF: Pool of Environmental Footprint-compliant datasets; EI: Ecoinvent; Lit: dataset built from literature; TS: Thinkstep. The End-of-Life illustrated herein is the average EU End-of-Life treatment mix used in the default scenario calculation.

<table>
<tr><th>Life Cycle Stage</th><th>Process</th><th>Dataset</th><th>Source</th><th>Quantity</th><th>Unit</th><th>Comments</th></tr>
<tr><td rowspan="5">Feedstock supply</td><td>Crude oil extraction and transport</td><td>[EU-27] Crude oil mix; technology mix of conventional (primary, secondary and tertiary production) and unconventional production (oil sands, in-situ) | consumption mix, to consumer {03bcbe8f-b957-43dc-9c9e-020836c954a6}</td><td>EF</td><td>0.876</td><td>kg</td><td>As input to Naphtha production (oil refining)
1.08 kg crude oil / kg naphtha</td></tr>
<tr><td rowspan="2">Natural gas extraction and transport</td><td rowspan="2">[EU-27] Natural gas mix; technology mix | consumption mix, to consumer | medium pressure level (< 1 bar) {8ede8686-62d3-46d6-9ce6-59476542bdb0}</td><td rowspan="2">EF</td><td>0.0173</td><td>kg</td><td>As input to Naphtha production (oil refining)
0.0213 kg natural gas / kg naphtha</td></tr>
<tr><td>0.276</td><td>kg</td><td>As input to Ethylene production (naphtha cracking)
0.276 kg natural gas / kg HDPE</td></tr>
<tr><td>Oil refining (naphtha production)</td><td>[EU-28] Naphtha at refinery - open flows crude oil, natural gas; from crude oil | production mix, at refinery | 44 MJ/ kg net calorific value {914dfb2a-bc7b-4829-942f-c3089fb10de8}</td><td>TS</td><td>0.811</td><td>kg</td><td>As input to Ethylene production
0.81 kg naphtha / kg HDPE</td></tr>
<tr><td>Transport of naphtha to cracking</td><td>[EU-28] Naphtha transport to industrial user, via pipeline
Based on transport-related burdens in the ecoinvent dataset "[RER] market for naphtha {b1561c62-5141-4469-82bb-65a2f6287017}", with the adjustments reported in the comment field</td><td>EI + EF</td><td>0.811</td><td>kg</td><td>The original ecoinvent dataset was adjusted as follows:
-Transport by rail, road and barge were converted to onshore pipeline transport
- The electricity input was modelled via EF datasets
- Geography of sub-processes was changed to reflect European background conditions (where appropriate)</td></tr>
<tr><td rowspan="3">Polymer production</td><td>Cracking (ethylene production), polymerisation</td><td>[EU-28] Polyethylene high density granulate (HDPE/PE-HD) - open flows naphtha, natural gas; polymerisation of ethylene | production mix, at plant | 0.91- 0.96 g/cm3, 28 g/mol per repeating unit {acf2a034-3564-47ad-8953-6dd344f7aa4d}</td><td>TS</td><td>1.001</td><td>kg</td><td>Black-box dataset covering all supply-chain processes from naphtha/feedstock conversion to polymerisation
Process quantity accounts for 0.1% losses at the production stage</td></tr>
<tr><td rowspan="2">Transport of polymer granulate to article production site (from supplier to factory) - EU production (78%)</td><td>[EU-28+3] Articulated lorry transport, Euro 4, Total weight >32 t (without fuel); diesel driven, Euro 4, cargo | consumption mix, to consumer | more than 32t gross weight / 24,7t payload capacity {938d5ba6-17e4-4f0d-bef0-481608681f57}</td><td>EF</td><td>102</td><td>kg*km</td><td>130 km by truck (>32 t, EURO 4, default utilisation ratio)</td></tr>
<tr><td>[EU-28+3] Freight train, average (without fuel); technology mix, electricity and diesel driven, cargo | consumption mix, to consumer | average train, gross tonne weight 1000t / 726t payload capacity {02e87631-6d70-48ce-affd-1975dc36f5be}</td><td>EF</td><td>187</td><td>kg*km</td><td>240 km by train (average freight train)</td></tr>
</table>

		[EU-28+3] Barge; technology mix, diesel driven, cargo | consumption mix, to consumer | 1500 t payload capacity {4cfacea0-cce4-4b4d-bd2b-223c8d4c90ae}	EF	211	kg*km	270 km by ship (barge)
	Transport of polymer granulate to article production site (from supplier to factory) - Extra-EU production (22%)	*[ROW: w/o EU-28+3] Articulated lorry transport, Total weight >32 t, mix Euro 0-5, diesel driven, Euro 0 - 5 mix, cargo | consumption mix, to consumer | more than 32t gross weight / 24,7t payload {794afe57-dca3-462c-8988-8f1790dfd8b2}*	EF	220	kg*km	1000 km by truck (>32 t, EURO 4, default utilisation ratio), for the sum of distances from harbour/airport to factory outside of Europe
		[GLO] Transoceanic ship, containers; heavy fuel oil driven, cargo | consumption mix, to consumer | 27.500 dwt payload capacity, ocean going {6ca61112-1d5b-473c-abfa-4accc66a8a63}	EF	1430	kg*km	Based on an overall weighted average sea distance between importing countries and EU equal to 7,982 km
		[EU-28+3] Articulated lorry transport, Euro 4, Total weight >32 t (without fuel); diesel driven, Euro 4, cargo | consumption mix, to consumer | more than 32t gross weight / 24,7t payload capacity {938d5ba6-17e4-4f0d-bef0-481608681f57}	EF	220	kg*km	1000 km by truck (>32 t, EURO 4, default utilisation ratio), for the sum of distances from harbour/airport to factory inside of Europe
Product manufacturing (incl. distribution)	(Extrusion) blow moulding	*[EU-28+EFTA] Blow moulding; blow moulding | production mix, at plant | PET, HDPE and PP {215dd4d8-52ad-4eee-bd63-7a6193f2b8d5}*	EF	1.001	kg	Approximates "extrusion blow moulding" used for HDPE bottles (99.9 % efficiency, i.e. 0.1% losses)
	Recycling of loss from blow moulding	*[EU-28] Polyethylene, high-density, granulate, secondary, from post-consumer plastic waste* Based on the *ecoinvent* dataset "*[Europe without Switzerland] Polyethylene production, high density, granulate, recycled*" updated with data in the latest Franklin Associates (2018) report, and replacing background datasets with EF datasets	Lit. + EF	0.000420	kg	η = 84% (recycling efficiency)
	Avoided virgin HDPE production	*[EU-28] Polyethylene high density granulate (HDPE/PE-HD); polymerisation of fossil-based ethylene | production mix, at plant* Cradle-to-gate dataset based on EF datasets for crude oil/natural gas supply, and TS datasets for refining and downstream conversion and polymerisation (black-box) as better detailed above for the stages of "Feedstock supply" and "Polymer production"	TS + EF	0.000353	kg	Replacement of fossil-based HDPE only is assumed (the estimated market share of bio-based HDPE is negligible, i.e. 0.2%). We assumed that recycled HDPE only replaces EU domestically produced virgin resin.
	Transport of bottles from factory to final user	*[EU-28+3] Articulated lorry transport, Euro 4, Total weight >32 t (without fuel); diesel driven, Euro 4, cargo | consumption mix, to consumer | more than 32t gross weight / 24,7t payload capacity {938d5ba6-17e4-4f0d-bef0-481608681f57}*	EF	1200	kg*km	From factory to retail Local supply chain: 1'200 km by truck (>32 t, EURO 4, default utilisation ratio)
		[GLO] Passenger car, average; technology mix, gasoline and diesel driven, Euro 3-5, passenger car | consumption mix, to consumer | engine size from 1,4l up to >2l {1ead35dd-fc71-4b0c-9410-7e39da95c7dc}	EF	3.10	km	From retail to final client: 62% by car - 5 km (passenger car, average, default allocation)
		[EU-28+3] Articulated lorry transport, Euro 3, Total weight <7.5 t (without fuel) diesel driven, Euro 3, cargo | consumption mix, to consumer | up to 7,5t gross weight / 3,3t payload capacity {aea613ae-573b-443a-aba2-6a69900ca2ff}	EF	0.250	kg*km	From retail to final client: 5% by delivery van – 5 km round trip (lorry <7.5t, EURO 3, with utilisation ratio of 20%)

End-of-Life	Recycling (64%)	*[EU-28] Plastic waste collection for recycling* Developed based on data from Rigamonti et al. (2013) and EF background datasets	Lit. + EF	0.320	kg	R2 = 64% η = 84% (recycling efficiency)
		[EU-28] Plastic waste sorting at MRF Developed based on foreground LCI data from Franklin Associates (2018) and background EF datasets	Lit. + EF	0.320	kg	
		[EU-28] Polyethylene, high-density, granulate, secondary, from post-consumer plastic waste Based on the *ecoinvent* dataset "*[Europe without Switzerland] Polyethylene production, high density, granulate, recycled*" updated with data in the latest Franklin Associates (2018) report, and replacing background datasets with EF datasets	Lit. + EF	0.269	kg	
	Avoided virgin HDPE production	*[EU-28] Polyethylene high density granulate (HDPE/PE-HD); polymerisation of fossil-based ethylene | production mix, at plant* Cradle-to-gate dataset based on EF datasets for crude oil/natural gas supply, and TS datasets for refining and downstream conversion and polymerisation (black-box) as better detailed above for the stages of "Feedstock supply" and "Polymer production"	TS + EF	0.242	kg	Qs/Qp = 0.9 Replacement of fossil-based HDPE only is assumed (the estimated market share of bio-based HDPE is negligible, i.e. 0.2%). We assumed that recycled HDPE only replaces EU domestically produced virgin resin.
	Incineration (19%)	*[EU-28] Plastic waste collection, as residual waste* Developed based on data from Rigamonti et al. (2013) and EF background datasets	Lit. + EF	0.190	kg	R3 = 19%
		[EU-28+EFTA] Waste incineration of PE; waste-to-energy plant with dry flue gas treatment, including transport and pre-treatment | production mix, at consumer | polyethylene waste {0370baaf-8923-4e26-b3b8-abcebb89f974}	EF	0.190	kg	
	Landfilling (17%)	*[EU-28] Plastic waste collection, as residual waste* Developed based on data from Rigamonti et al. (2013) and EF background datasets	Lit. + EF	0.170	kg	(1-R2-R3)=17%
		[EU-28+EFTA] Landfill of plastic waste; landfill including leachate treatment and with transport without collection and pre-treatment | production mix (region specific sites), | The carbon and water content are respectively of 62%C and 0% Water (in weight %) {f2bea0f5-e4b7-4a2c-9f34-4eb32495cbc6}	EF	0.170	kg	

Table S2. List of processes included in the LCI model of recycled high-density polyethylene (R-HDPE) bottles and respective quantities (for a reference flow of 1 kg of product post-manufacture). EF: Pool of Environmental Footprint-compliant datasets; EI: Ecoinvent; Lit: dataset built from literature; TS: Thinkstep. The End-of-Life illustrated herein is the average EU End-of-Life treatment mix used in the default scenario calculation.

Life Cycle Stage	**Process**	**Dataset**	**Source**	**Quantity**	**Unit**	**Comments**
Feedstock supply (recycled)	Plastic waste collection	*[EU-28] Plastic waste collection for recycling* Developed based on data in Rigamonti et al. (2013) and EF background datasets	Lit. + EF	0.608	kg	Process quantity accounts for 82.3% recycling efficiency and 0.1% losses at the production stage
	Plastic waste sorting	*[EU-28] Plastic waste sorting at MRF* Developed based on foreground LCI data from Franklin Associates (2018) and background EF datasets	Lit. + EF	0.608	kg	
Polymer production	Secondary, bottle-grade HDPE production	*[EU-28] Polyethylene, high density (HDPE), granulate, bottle grade, secondary; from post-consumer plastic waste* Developed based on the *ecoinvent* dataset "*CH polyethylene terephthalate production, granulate, bottle grade, recycled*", adapted to EU conditions and replacing background energy datasets with EF datasets	EI + EF	0.501	kg	The recycling process for bottle-grade PET is used as an approximation also for bottle-grade HDPE (in the absence of more specific data) Process quantity accounts for 0.1% losses at the production stage
	Virgin HDPE production (Cracking (ethylene production), polymerisation	*[EU-28] Polyethylene high density granulate (HDPE/PE-HD) - open flows naphtha, natural gas; polymerisation of ethylene | production mix, at plant | 0.91- 0.96 g/cm3, 28 g/mol per repeating unit {acf2a034-3564-47ad-8953-6dd344f7aa4d}*	TS	0.501	kg	Black-box dataset covering all supply-chain processes from naphtha/feedstock conversion to polymerisation Process quantity accounts for 0.1% losses at the production stage
	Transport of polymer granulate to article production site (from supplier to factory)	*[EU-28+3] Articulated lorry transport, Euro 4, Total weight >32 t (without fuel); diesel driven, Euro 4, cargo | consumption mix, to consumer | more than 32t gross weight / 24,7t payload capacity {938d5ba6-17e4-4f0d-bef0-481608681f57}*	EF	130	kg*km	130 km by truck (>32 t, EURO 4, default utilisation ratio)
		[EU-28+3] Freight train, average (without fuel); technology mix, electricity and diesel driven, cargo | consumption mix, to consumer | average train, gross tonne weight 1000t / 726t payload capacity {02e87631-6d70-48ce-affd-1975dc36f5be}	EF	240	kg*km	240 km by train (average freight train)
		[EU-28+3] Barge; technology mix, diesel driven, cargo | consumption mix, to consumer | 1500 t payload capacity {4cfacea0-cce4-4b4d-bd2b-223c8d4c90ae}	EF	270	kg*km	270 km by ship (barge)
Product manufacturing (incl. distribution)	(Extrusion) blow moulding	*[EU-28+EFTA] Blow moulding; blow moulding | production mix, at plant | PET, HDPE and PP {215dd4d8-52ad-4eee-bd63-7a6193f2b8d5}*	EF	1.0	kg	Approximates "extrusion blow moulding" used for HDPE bottles (99.9 % efficiency, i.e. 0.1% losses)
	Recycling of loss from blow moulding	*[EU-28] Polyethylene, high-density, granulate, secondary, from post-consumer plastic waste* Based on the *ecoinvent* dataset "*[Europe without Switzerland] Polyethylene production, high density, granulate, recycled*" updated with data in the latest Franklin Associates (2018) report, and replacing background datasets with EF datasets	Lit. + EF	0.000420	kg	η = 84% (recycling efficiency)

	Avoided virgin HDPE production	*[EU-28] Polyethylene high density granulate (HDPE/PE-HD); polymerisation of fossil-based ethylene | production mix, at plant* Cradle-to-gate dataset based on EF datasets for crude oil/natural gas supply, and TS datasets for refining and downstream conversion and polymerisation (black-box) as better detailed above for the stages of "Virgin feedstock supply" and "Polymer production"	EF + TS	0.000353	kg	Replacement of fossil-based HDPE only is assumed (the estimated market share of bio-based HDPE is negligible, i.e. 0.2%). We assumed that recycled HDPE only replaces EU domestically produced virgin resin.
	Transport of bottles from factory to final user	*[EU-28+3] Articulated lorry transport, Euro 4, Total weight >32 t (without fuel); diesel driven, Euro 4, cargo | consumption mix, to consumer | more than 32t gross weight / 24,7t payload capacity {938d5ba6-17e4-4f0d-bef0-481608681f57}*	EF	1200	kg*km	From factory to retail Local supply chain: 1'200 km by truck (>32 t, EURO 4, default utilisation ratio)
		[GLO] Passenger car, average; technology mix, gasoline and diesel driven, Euro 3-5, passenger car | consumption mix, to consumer | engine size from 1,4l up to >2l {1ead35dd-fc71-4b0c-9410-7e39da95c7dc}	EF	3.10	km	From retail to final client: 62% by car - 5 km (passenger car, average, default allocation)
		[EU-28+3] Articulated lorry transport, Euro 3, Total weight <7.5 t (without fuel) diesel driven, Euro 3, cargo | consumption mix, to consumer | up to 7,5t gross weight / 3,3t payload capacity {aea613ae-573b-443a-aba2-6a69900ca2ff}	EF	0.250	kg*km	From retail to final client: 5% by delivery van – 5 km round trip (lorry <7.5t, EURO 3, with utilisation ratio of 20%)
End-of-Life	Recycling (64%)	*[EU-28] Plastic waste collection for recycling* Developed based on data in Rigamonti et al. (2013) and EF background datasets	Lit. + EF	0.320	kg	R2 = 64% η = 84% (recycling efficiency)
		[EU-28] Plastic waste sorting at MRF Developed based on foreground LCI data from Franklin Associates (2018) and background EF datasets	Lit. + EF	0.320	kg	
		[EU-28] Polyethylene, high-density, granulate, secondary, from post-consumer plastic waste Based on the *ecoinvent* dataset "*[Europe without Switzerland] Polyethylene production, high density, granulate, recycled*" updated with data in the latest Franklin Associates (2018) report, and replacing background datasets with EF datasets	Lit. + EF	0.269	kg	
	Avoided virgin HDPE production	*[EU-28] Polyethylene high density granulate (HDPE/PE-HD); polymerisation of fossil-based ethylene | production mix, at plant* Cradle-to-gate dataset based on EF datasets for crude oil/natural gas supply, and TS datasets for refining and downstream conversion and polymerisation (black-box) as better detailed above for the stages of "Feedstock supply" and "Polymer production"	TS + EF	0.242	kg	Qs/Qp = 0.9 Replacement of fossil-based HDPE only is assumed (the estimated market share of bio-based HDPE is negligible, i.e. 0.2%). We assumed that recycled HDPE only replaces EU domestically produced virgin resin.
	Incineration (19%)	*[EU-28] Plastic waste collection, as residual waste* Developed based on data in Rigamonti et al. (2013) and EF background datasets	Lit. + EF	0.190	kg	R3 = 19%
		[EU-28+EFTA] Waste incineration of PE; waste-to-energy plant with dry flue gas treatment, including transport and pre-treatment | production mix, at consumer | polyethylene waste {0370baaf-8923-4e26-b3b8-abcebb89f974}	EF	0.190	kg	

	Landfilling (17%)	*[EU-28] Plastic waste collection, as residual waste* Developed based on data in Rigamonti et al. (2013) and EF background datasets	Lit. + EF	0.170	kg	(1-R2-R3) = 17%
		[EU-28+EFTA] Landfill of plastic waste; landfill including leachate treatment and with transport without collection and pre-treatment | production mix (region specific sites), | The carbon and water content are respectively of 62%C and 0% Water (in weight %) {f2bea0f5-e4b7-4a2c-9f34-4eb32495cbc6}	EF	0.170	kg	

Table S3. List of processes included in the LCI model of bio-based high-density polyethylene (Bio-HDPE) bottles and respective quantities (for a reference flow of 1 kg of product post-manufacture). EF: Pool of Environmental Footprint-compliant datasets; EI: Ecoinvent; Lit: dataset built from literature; TS: Thinkstep. The End-of-Life illustrated herein is the average EU End-of-Life treatment mix used in the default scenario calculation.

Life Cycle Stage	**Process**	**Dataset**	**Source**	**Quantity**	**Unit**	**Comments**
Feedstock supply	Sugarcane cultivation (Brazil)	*[BR]Sugar cane perennial (100% slash and burn); technology mix | production mix, to consumer | 74% H2O, 100% pre-harvest burning {b5b11cef-dc10-4aec-bfd8-775c4d881190}*	TS	12.9	kg	45% of sugarcane harvested via pre-harvest burning of residues (top & leaves); 55% without applying any pre-burning practice 15 kg sugarcane / kg ethanol (Jungbluth et al. 2007)
		[BR] Sugar cane perennial (0% slash and burn); technology mix | production mix, to consumer | 74% H2O, 0% pre-harvest burning {42013d80-2205-4882-b218-7ba02bfac157}	TS	15.8	kg	
	Transport of sugarcane to processing (fermentation & distillation)	*[EU-28+3] Articulated lorry transport, Euro 4, Total weight >32 t (without fuel); diesel driven, Euro 4, cargo | consumption mix, to consumer | more than 32t gross weight / 24,7t payload capacity {938d5ba6-17e4-4f0d-bef0-481608681f57}*	EF	717	kg*km	25 km by truck Brazilian diesel is considered as an input
Polymer production	Ethanol production (Brazil)	*[BR] Ethanol, without water, in 95% solution state, from fermentation | ethanol production from sugarcane* Developed based on the *ecoinvent* dataset "*[BR] Ethanol, without water, in 95% solution state, from fermentation | ethanol production from sugarcane*", replacing allocation with "direct substitution" of surplus energy from bagasse burning, and background energy datasets with EF datasets	EI + EF	1.92	kg	1.91 t bioethanol / t bio-ethylene Calculated as the average consumption from the values reported in IEA-ETSAP & IRENA (2013; 1.74 kg ethanol/kg ethylene) and IfBB (2018; 2.08 kg ethanol/kg ethylene)
	Transport of ethanol from Brazil to EU	*[EU-28+3] Articulated lorry transport, Euro 4, Total weight >32 t (without fuel); diesel driven, Euro 4, cargo | consumption mix, to consumer | more than 32t gross weight / 24,7t payload capacity {938d5ba6-17e4-4f0d-bef0-481608681f57}*	EF	1915.7	kg*km	1000 km by truck (>32 t, EURO 4, default utilisation ratio), for the sum of distances from harbour/airport to factory in Brazil Brazilian diesel is considered as an input
		[GLO] Transoceanic ship, containers; heavy fuel oil driven, cargo | consumption mix, to consumer | 27.500 dwt payload capacity, ocean going {6ca61112-1d5b-473c-abfa-4accc66a8a63}	EF	21648	kg*km	11300 km by ship (transoceanic container; Porto Alegre - Rotterdam)
		[EU-28+3] Articulated lorry transport, Euro 4, Total weight >32 t (without fuel); diesel driven, Euro 4, cargo | consumption mix, to consumer | more than 32t gross weight / 24,7t payload capacity {938d5ba6-17e4-4f0d-bef0-481608681f57}	EF	1916	kg*km	1000 km by truck (>32 t, EURO 4, default utilisation ratio), for the sum of distances from harbour/airport to factory inside of Europe
	Ethylene production (EU)	*[EU-28] Bio-ethylene production (dehydration of bio-based ethanol)* Developed based on foreground literature data related to a real industrial process (ACV Brasil, 2017) and background EF and *ecoinvent* datasets (for energy generation and material production, respectively)	Lit. + (EF+EI)	1.003	kg	1.002 kg (bio)-ethylene / kg HDPE (PlasticsEurope ecoprofile)

	HDPE production (polymerisation - EU)	*[EU-28] High Density Polyethylene (HDPE) production, granulate* Based on the PlasticsEurope ecoprofile "*[RER] Polyethylene production, high density, granulate*" (as implemented in *ecoinvent*) replacing background energy datasets with EF datasets	PlasticsEurope + (EI+EF)	1.001	kg	Process quantity accounts for 0.1% losses at the article production stage
Transport	Transport of polymer granulate to article production site (from supplier to factory)	*[EU-28+3] Articulated lorry transport, Euro 4, Total weight >32 t (without fuel); diesel driven, Euro 4, cargo | consumption mix, to consumer | more than 32t gross weight / 24,7t payload capacity {938d5ba6-17e4-4f0d-bef0-481608681f57}*	EF	130	kg*km	130 km by truck (>32 t, EURO 4, default utilisation ratio)
		[EU-28+3] Freight train, average (without fuel); technology mix, electricity and diesel driven, cargo | consumption mix, to consumer | average train, gross tonne weight 1000t / 726t payload capacity {02e87631-6d70-48ce-affd-1975dc36f5be}	EF	240	kg*km	240 km by train (average freight train)
		[EU-28+3] Barge; technology mix, diesel driven, cargo | consumption mix, to consumer | 1500 t payload capacity {4cfacea0-cce4-4b4d-bd2b-223c8d4c90ae}	EF	270	kg*km	270 km by ship (barge)
Product manufacturing (incl. distribution)	(Extrusion) blow moulding	*[EU-28+EFTA] Blow moulding; blow moulding | production mix, at plant | PET, HDPE and PP {215dd4d8-52ad-4eee-bd63-7a6193f2b8d5}*	EF	1.001	kg	Approximates "extrusion blow moulding" used for HDPE bottles (99.9 % efficiency, i.e. 0.1% losses)
	Recycling of losses from blow moulding	*[EU-28] Polyethylene, high-density, granulate, secondary, from post-consumer plastic waste* Based on the *ecoinvent* dataset "*[Europe without Switzerland] Polyethylene production, high density, granulate, recycled*" updated with data in the latest Franklin Associates (2018) report, and replacing background datasets with EF datasets	Lit. + EF	0.000420	kg	η = 84% (recycling efficiency)
	Avoided virgin HDPE production	*[EU-28] Polyethylene high density granulate (HDPE/PE-HD); polymerisation of fossil-based ethylene | production mix, at plant* Cradle-to-gate dataset based on EF datasets for crude oil/natural gas supply, and TS datasets for refining and downstream conversion and polymerisation (black-box) as better detailed in the fossil-based HDPE LCI model for the stages of "Feedstock supply" and "Polymer production"	EF + TS	0.000353	kg	Q_s/Q_p = 0.9 Replacement of fossil-based HDPE only is assumed (the estimated market share of bio-based HDPE is negligible, i.e. 0.2%). We assumed that recycled HDPE only replaces EU domestically produced virgin resin.
	Transport of bottles from factory to final user	*[EU-28+3] Articulated lorry transport, Euro 4, Total weight >32 t (without fuel); diesel driven, Euro 4, cargo | consumption mix, to consumer | more than 32t gross weight / 24,7t payload capacity {938d5ba6-17e4-4f0d-bef0-481608681f57}*	EF	1200	kg*km	From factory to retail Local supply chain: 1'200 km by truck (>32 t, EURO 4, default utilisation ratio)
		[GLO] Passenger car, average; technology mix, gasoline and diesel driven, Euro 3-5, passenger car | consumption mix, to consumer | engine size from 1,4l up to >2l {1ead35dd-fc71-4b0c-9410-7e39da95c7dc}	EF	3.10	km	From retail to final client: 62% by car - 5 km (passenger car, average, default allocation)

		[EU-28+3] Articulated lorry transport, Euro 3, Total weight <7.5 t (without fuel) diesel driven, Euro 3, cargo | consumption mix, to consumer | up to 7,5t gross weight / 3,3t payload capacity {aea613ae-573b-443a-aba2-6a69900ca2ff}	EF	0.250	kg*km	From retail to final client: 5% by delivery van – 5 km round trip (lorry <7.5t, EURO 3, with utilisation ratio of 20%)
End-of-Life	Recycling (64%)	*[EU-28] Plastic waste collection for recycling* Developed based on data in Rigamonti et al. (2013) and EF background datasets	Lit. + EF	0.320	kg	R2 = 64% η = 84% (recycling efficiency)
		[EU-28] Plastic waste sorting at MRF Developed based on foreground LCI data from Franklin Associates (2018) and background EF datasets	Lit. + EF	0.320	kg	
		[EU-28] Polyethylene, high-density, granulate, secondary, from post-consumer plastic waste Based on the *ecoinvent* dataset "*[Europe without Switzerland] Polyethylene production, high density, granulate, recycled*" updated with data in the latest Franklin Associates (2018) report, and replacing background datasets with EF datasets	Lit. + EF	0.269	kg	
	Avoided virgin HDPE production	*[EU-28] Polyethylene high density granulate (HDPE/PE-HD); polymerisation of fossil-based ethylene | production mix, at plant* Cradle-to-gate dataset based on EF datasets for crude oil/natural gas supply, and TS datasets for refining and downstream conversion and polymerisation (black-box) as better detailed in the fossil-based HDPE LCI model for the stages of "Feedstock supply" and "Polymer production"	EF + TS	0.242	kg	Qs/Qp = 0.9 Replacement of fossil-based HDPE only is assumed (the estimated market share of bio-based HDPE is negligible, i.e. 0.2%). We assumed that recycled HDPE only replaces EU domestically produced virgin resin.
	Incineration (19%)	*[EU-28] Plastic waste collection and transport, as residual waste* Developed based on data in Rigamonti et al. (2013) and EF background datasets	Lit. + EF	0.190	kg	R3 = 19%
		[EU-28] Polyethylene (PE) (biobased) in waste incineration plant; waste-to-energy plant with dry flue gas treatment, without collection, transport and pre-treatment | production mix, at plant | Net calorific value 43.5 MJ/kg {cc4b53c3-bffa-4285-b2ba-0fb9362f44e6}	TS	0.190	kg	
	Landfilling (17%)	*[EU-28] Plastic waste collection, as residual waste* Developed based on data in Rigamonti et al. (2013) and EF background datasets	Lit. + EF	0.170	kg	(1-R2-R3) = 17% Fossil CO_2 and CH_4 emissions converted to biogenic emissions

Table S4. List of processes included in the LCI model of polylactic acid from organic waste (OW-PLA). EF: Environmental Footprint; EI: Ecoinvent; Lit: dataset built from literature; TS: Thinkstep. The End-of-Life illustrated herein is the average EU End-of-Life treatment mix used in the default scenario calculation.

Life Cycle Stage	Process	Dataset	Source	Quantity	Unit	Comments
Feedstock supply	Organic waste collection	Separate collection of organic waste (OW) as modelled in Albizzati et al. (2020).	Lit.		kg	Taken from Albizzati et al. (2020). Please refer to Albizzati et al. (2020) for the complete inventory.
Polymer production	Lactic acid production	Inventory modelled departing from the study of Kwan et al. (2018) and adapted to the yield of glucose (and subsequently lactic acid) from food waste.	Lit.		kg	Taken from Albizzati et al. (2020). Please refer to Albizzati et al. (2020) for the complete inventory.
	PLA production	Lactic acid is converted into PLA. Note that the efficiencies for lactic acid to lactide (i.e. 73%), lactide recovery (93%), and lactide to polylactic acid (74%) reported in Kwan et al. (2018) are used to calculate the conversion of food waste powder into polylactic acid. Rejects arising with the target product manufacture are assumed to be treated through anaerobic digestion.	Lit.		kg	Taken from Albizzati et al. (2020). Please refer to Albizzati et al. (2020) for the complete inventory.
Transport	Transport of polymer granulate to article production site (from supplier to factory)	*[EU-28+3] Articulated lorry transport, Euro 4, Total weight >32 t (without fuel); diesel driven, Euro 4, cargo | consumption mix, to consumer | more than 32t gross weight / 24,7t payload capacity {938d5ba6-17e4-4f0d-bef0-481608681f57}*	EF		kg*km	130 km by truck (>32 t, EURO 4, default utilisation ratio)
		[EU-28+3] Freight train, average (without fuel); technology mix, electricity and diesel driven, cargo | consumption mix, to consumer | average train, gross tonne weight 1000t / 726t payload capacity {02e87631-6d70-48ce-affd-1975dc36f5be}	EF		kg*km	240 km by train (average freight train)
		[EU-28+3] Barge; technology mix, diesel driven, cargo | consumption mix, to consumer | 1500 t payload capacity {4cfacea0-cce4-4b4d-bd2b-223c8d4c90ae}	EF		kg*km	270 km by ship (barge)
Product manufacturing (incl. distribution)	Injection moulding	*Injection moulding plastic injection moulding production mix, at plant for PP, HDPE and PE [EU-28+EFTA] [LCI result] {ec9ca75e-abdb-4d2e-9e18-ca1f5709a76d}*	EF	1.023	kg	Approximates "extrusion blow moulding" used for HDPE bottles (99.9 % efficiency, i.e. 0.1% losses)
	Recycling of loss from injection moulding	*[EU-28] Polylactic acid (PLA) in waste incineration plant, waste-to-energy plant with dry flue gas treatment, without collection, transport and pre-treatment | production mix, at plant | Net calorific value 17.9 MJ/kg {00b5480b-b622-4acd-8481-812d866e15a9}*	Lit. + EF	0.031	kg	
	Transport of panel from factory to final client	*[EU-28+3] Articulated lorry transport, Euro 4, Total weight >32 t (without fuel); diesel driven, Euro 4, cargo | consumption mix, to consumer | more than 32t gross weight / 24,7t payload capacity {938d5ba6-17e4-4f0d-bef0-481608681f57}*	EF	552.960	kg*km	Qs/Qo = 0.9 Replacement of fossil-based HDPE only is assumed

	Transport of bottles from factory to final user	*[EU-28+3] Articulated lorry transport, Euro 3, Total weight <7.5 t (without fuel) diesel driven, Euro 3, cargo | consumption mix, to consumer | up to 7,5t gross weight / 3,3t payload capacity {aea613ae-573b-443a-aba2-6a69900ca2ff}*	EF	0.036	kg*km	From factory to retail Local supply chain: 1'200 km by truck (>32 t, EURO 4, default utilisation ratio)
		[GLO] Passenger car, average; technology mix, gasoline and diesel driven, Euro 3-5, passenger car | consumption mix, to consumer | engine size from 1,4l up to >2l {1ead35dd-fc71-4b0c-9410-7e39da95c7dc}	EF		km	From retail to final client: 62% by car - 5 km (passenger car, average, default allocation)
End-of-Life	Recycling (64%)	*[EU-28] Plastic waste collection for recycling* Developed based on data in Rigamonti et al. (2013) and EF background datasets	Lit. + EF		kg	R2 = 64% η = 84% (efficiency recycling)
		[EU-28] Plastic waste sorting at MRF Developed based on foreground LCI data from Franklin Associates (2018) and background EF datasets	Lit. + EF		kg	
		[EU-28] Polyethylene, high-density, granulate, secondary, from post-consumer plastic waste Based on the *ecoinvent* dataset "*[Europe without Switzerland] Polyethylene production, high density, granulate, recycled*" updated with data in the latest Franklin Associates (2018) report, and replacing background datasets with EF datasets	Lit. + EF		kg	
	Avoided virgin HDPE production	*[EU-28] Polyethylene high density granulate (HDPE/PE-HD); polymerisation of fossil-based ethylene | production mix, at plant* Cradle-to-gate dataset based on EF datasets for crude oil/natural gas supply, and TS datasets for refining and downstream conversion and polymerisation (black-box) as better detailed in the fossil-based HDPE LCI model for the stages of "Feedstock supply" and "Polymer production"	EF + TS		kg	Qs/Qo = 0.9 Replacement of fossil-based HDPE only is assumed. We assumed that recycled HDPE only replaces EU domestically produced virgin resin.
	Incineration (19%)	*[EU-28] Plastic waste collection and transport, as residual waste* Developed based on data in Rigamonti et al. (2013) and EF background datasets	Lit. + EF		kg	R3 = 19%
		[EU-28] Polyethylene (PE) (biobased) in waste incineration plant; waste-to-energy plant with dry flue gas treatment, without collection, transport and pre-treatment | production mix, at plant | Net calorific value 43.5 MJ/kg {cc4b53c3-bffa-4285-b2ba-0fb9362f44e6}	TS		kg	
	Landfilling (17%)	*[EU-28] Plastic waste collection, as residual waste* Developed based on data in Rigamonti et al. (2013) and EF background datasets	Lit. + EF		kg	(1-R2-R3) = 17% Fossil CO_2 and CH_4 emissions converted to biogenic

		[EU-28+EFTA] Landfill of plastic waste; landfill including leachate treatment and with transport without collection and pre-treatment | production mix (region specific sites), | The carbon and water content are respectively of 62%C and 0% Water (in weight %) {f2bea0f5-e4b7-4a2c-9f34-4eb32495cbc6}	EF		kg	emissions

1.2 Rigid panels for automotive sector

Table S5. List of processes included in the LCI model of polypropylene (PP). EF: Environmental Footprint; EI: Ecoinvent; Lit: dataset built from literature; TS: Thinkstep. The End-of-Life illustrated herein is the average EU End-of-Life treatment mix used in the default scenario calculation.

Life cycle stage	**Process**	**Dataset**	**Database**	**Quantity**	**Unit**	**Comments**
Feedstock supply	Crude oil extraction and transport	*[EU-27] Crude oil mix; technology mix of conventional (primary, secondary and tertiary production) and unconventional production (oil sands, in-situ) | consumption mix, to consumer {03bcbe8f-b957-43dc-9c9e-020836c954a6}*	EF	0.900	kg	As input to Naphtha production (oil refining) 1.08 kg crude oil / kg naphtha
	Natural gas extraction and transport	*[EU-27] Natural gas mix; technology mix | consumption mix, to consumer | medium pressure level (< 1 bar) {8ede8686-62d3-46d6-9ce6-59476542bdb0}*	EF	0.0175	kg	As input to Naphtha production (oil refining) 0.0213 kg natural gas / kg naphtha
				0.280	kg	As input to Propylene production (naphtha cracking) 0.272 kg natural gas/ kg PP (cracking)
	Oil refining (naphtha production)	*[EU-28] Naphtha at refinery - open flows crude oil, natural gas; from crude oil | production mix, at refinery | 44 MJ/ kg net calorific value {914dfb2a-bc7b-4829-942f-c3089fb10de8}*	TS	0.823	kg	As input to Propylene production 0.798 kg naphtha / kg PP
	Transport of naphtha to cracking	*[EU-28] Naphtha transport to industrial user, via pipeline* Based on transport-related burdens in the *ecoinvent* dataset "*[RER] market for naphtha* {b1561c62-5141-4469-82bb-65a2f6287017}", with the adjustments reported in the comment field	EI+EF	0.823	kg	The following adjustments are made, compared to the original ecoinvent datasets: - Transport by rail, road and barge have been entirely converted to onshore pipeline transport (more appropriate for industrial uses of naphtha). Distances could not be individually adjusted to be consistent with the share of pipeline transport already included - Background energy datasets (electricity) have been replaced with EF datasets - EoL treatment of fly ash & scrubber sludge, rainwater mineral oil storage, and wastewater treatment have been entirely modelled for the geography "Europe w/o Switzerland"
Polymer production	Cracking (propylene production) polymerisation	*[EU-28] Polypropylene Granulate (PP) - open flows naphta, natural gas; polymerisation of propene | production mix, at plant | 0.91 g/cm3, 42.08 g/mol per repeating unit {89f3d71a-73f4-4650-bd46-12978231871f}*	TS	1.031	kg	Black-box dataset covering all supply-chain processes from naphtha/feedstock conversion to polymerisation. Accounts for 3% losses at the production stage

	Transport of polymer granulate to article production site (from supplier to factory) - EU production (90%)	*[EU-28+3] Articulated lorry transport, Euro 4, Total weight >32 t (without fuel); diesel driven, Euro 4, cargo | consumption mix, to consumer | more than 32t gross weight / 24,7t payload capacity {938d5ba6-17e4-4f0d-bef0-481608681f57}*	EF	77.196	kg*km	130 km by truck (>32 t, EURO 4), case-specific utilisation ratio
		[EU-28+3] Freight train, average (without fuel); technology mix, electricity and diesel driven, cargo | consumption mix, to consumer | average train, gross tonne weight 1000t / 726t payload capacity {02e87631-6d70-48ce-affd-1975dc36f5be}	EF	222.680	kg*km	240 km by train (average freight train)
		[EU-28+3] Barge; technology mix, diesel driven, cargo | consumption mix, to consumer | 1500 t payload capacity {4cfacea0-cce4-4b4d-bd2b-223c8d4c90ae}	EF	250.515	kg*km	270 km by ship (barge)
	Transport of polymer granulate to article production site (from supplier to factory) - Extra-EU production (10%)	*[EU-28+3] Articulated lorry transport, Euro 4, Total weight >32 t (without fuel); diesel driven, Euro 4, cargo | consumption mix, to consumer | more than 32t gross weight / 24,7t payload capacity {938d5ba6-17e4-4f0d-bef0-481608681f57}*	EF	65.979	kg*km	1000 km by truck (>32 t, EURO 4, default utilisation ratio), for the sum of distances from harbour/airport to factory outside and inside Europe
		[GLO] Transoceanic ship, containers; heavy fuel oil driven, cargo | consumption mix, to consumer | 27.500 dwt payload capacity, ocean going {6ca61112-1d5b-473c-abfa-4accc66a8a63}	EF	887.596	kg*km	Based on an overall weighted average sea distance between importing countries and EU equal to 10,796 km
		[EU-28+3] Articulated lorry transport, Euro 4, Total weight >32 t (without fuel); diesel driven, Euro 4, cargo | consumption mix, to consumer | more than 32t gross weight / 24,7t payload capacity {938d5ba6-17e4-4f0d-bef0-481608681f57}	EF	65.979	kg*km	1000 km by truck (>32 t, EURO 4, default utilisation ratio), for the sum of distances from harbour/airport to factory outside and inside Europe
Product manufacturing (incl. distribution)	Injection moulding	Injection moulding plastic injection moulding production mix, at plant for PP, HDPE and PE *[EU-28+EFTA] [LCI result] {ec9ca75e-abdb-4d2e-9e18-ca1f5709a76d}*	EF	1.031	kg	30 g of waste per kg of product.
	Recycling of loss from injection moulding	*[EU-28] Polypropylene (PP) granulate, secondary, from post-consumer plastic waste* Based on the *ecoinvent* dataset "*[Europe without Switzerland] Polyethylene production, high density, granulate, recycled*" updated with data in the latest Franklin Associates (2018) report, and replacing background datasets with EF datasets	Lit. + EF	0.015	kg	
	Avoided virgin PP production	Cradle-to-gate dataset based on EF datasets for crude oil/natural gas supply, and TS datasets for refining and downstream conversion and polymerisation (black-box) as better detailed above for the stages of "Feedstock supply" and "Polymer production"	EF + TS	0.012	kg	
	Transport of panel from factory to final client	*[EU-28+3] Articulated lorry transport, Euro 4, Total weight >32 t (without fuel); diesel driven, Euro 4, cargo | consumption mix, to consumer | more than 32t gross weight / 24,7t payload capacity {938d5ba6-17e4-4f0d-bef0-481608681f57}*	EF	768.000	kg*km	From factory to retail Local supply chain: 1'200 km by truck (>32 t, EURO 4, default utilisation ratio)
		[EU-28+3] Articulated lorry transport, Euro 3, Total weight <7.5 t (without fuel) diesel driven, Euro 3, cargo | consumption mix, to consumer | up to 7,5t gross weight / 3,3t payload capacity {aea613ae-573b-443a-aba2-6a69900ca2ff}	EF	0.050	kg*km	From retail to final client: 5% by delivery van – 5 km round trip (lorry <7.5t, EURO 3, with utilisation ratio of 20%)
End-of-Life	Recycling/Reuse (97%)	*[EU-28] Polypropylene (PP) granulate, secondary, from post-consumer plastic waste* Based on the *ecoinvent* dataset "*[Europe without Switzerland] Polyethylene*	Lit. + EF	0.485	kg	R2 = 97% η = 85.8% (efficiency recycling)

		production, high density, granulate, recycled" updated with data in the latest Franklin Associates (2018) report, and replacing background datasets with EF datasets				
	Avoided virgin PP production	Cradle-to-gate dataset based on EF datasets for crude oil/natural gas supply, and TS datasets for refining and downstream conversion and polymerisation (black-box) as better detailed above for the stages of "Feedstock supply" and "Polymer production"	EF + TS	0.421	kg	Qs/Qo = 0.9 Displacement of PP is assumed
	Incineration (2%)	*Polypropylene (PP) in waste incineration plant, waste-to-energy plant with dry flue gas treatment, without collection, transport and pre-treatment, EU-28 {f39b6710-30b8-4672-9a73-cc06607e652d}*	EF	0.020	kg	R3 = 2%
	Landfill (1%)	*[EU-28+EFTA] Landfill of plastic waste; landfill including leachate treatment and with transport without collection and pre-treatment | production mix (region specific sites),* | The carbon and water content are respectively of 62%C and 0% Water (in weight %) {f2bea0f5-e4b7-4a2c-9f34-4eb32495cbc6}	EF	0.010	kg	(1-R2-R3) = 1%

Table S6. List of processes included in the LCI model of recycled polypropylene (R-PP). EF: Environmental Footprint; EI: Ecoinvent; Lit: dataset built from literature; TS: Thinkstep. The End-of-Life illustrated herein is the average EU End-of-Life treatment mix used in the default scenario calculation.

Life cycle stage	Process	Dataset	Database	Quantity	Unit	Comments
Feedstock supply (recycled)	Plastic waste collection	*[EU-28] Plastic waste collection for recycling* Developed based on data in Rigamonti et al. (2013) and EF background datasets	Lit. + EF	0.608	kg	
	Plastic waste sorting	*[EU-28] Plastic waste sorting at MRF* Developed based on foreground LCI data from Franklin Associates (2018) and background EF datasets	Lit. + EF	0.608	kg	
Polymer production	Secondary PP production (recycling)	*[EU-28] Polypropylene (PP) granulate, secondary, from post-consumer plastic waste* Based on the *ecoinvent* dataset "*[Europe without Switzerland] Polyethylene production, high density, granulate, recycled*" updated with data in the latest Franklin Associates (2018) report, and replacing background datasets with EF datasets	Lit. + EF	0.515	kg	
	Transport of polymer granulate to article production site (from supplier to factory)	*[EU-28+3] Articulated lorry transport, Euro 4, Total weight >32 t (without fuel); diesel driven, Euro 4, cargo | consumption mix, to consumer | more than 32t gross weight / 24,7t payload capacity {938d5ba6-17e4-4f0d-bef0-481608681f57}*	EF	85.773	kg*km	130 km by truck (>32 t, EURO 4), case-specific utilisation ratio
		[EU-28+3] Freight train, average (without fuel); technology mix, electricity and diesel driven, cargo | consumption mix, to consumer | average train, gross tonne weight 1000t / 726t payload capacity {02e87631-6d70-48ce-affd-1975dc36f5be}	EF	247.423	kg*km	240 km by train (average freight train)
		[EU-28+3] Barge; technology mix, diesel driven, cargo | consumption mix, to consumer | 1500 t payload capacity {4cfacea0-cce4-4b4d-bd2b-223c8d4c90ae}	EF	278.351	kg*km	270 km by ship (barge)
Product manufacturing (incl. distribution)	Injection moulding	*Injection moulding plastic injection moulding production mix, at plant for PP, HDPE and PE [EU-28+EFTA] [LCI result] {ec9ca75e-abdb-4d2e-9e18-ca1f5709a76d}*	EF	1.031	kg	30 g of waste per kg of product.
	Recycling of loss from injection moulding	*[EU-28] Polypropylene (PP) granulate, secondary, from post-consumer plastic waste* Based on the *ecoinvent* dataset "*[Europe without Switzerland] Polyethylene production, high density, granulate, recycled*" updated with data in the latest Franklin Associates (2018) report, and replacing background datasets with EF datasets	Lit. + EF	0.015	kg	
	Avoided virgin PP production	Cradle-to-gate dataset based on EF datasets for crude oil/natural gas supply, and TS datasets for refining and downstream conversion and polymerisation (black-box) as better detailed above for the stages of "Feedstock supply" and "Polymer production"	EF + TS	0.012	kg	
	Transport of panel from factory to final client	*[EU-28+3] Articulated lorry transport, Euro 4, Total weight >32 t (without fuel); diesel driven, Euro 4, cargo | consumption mix, to consumer | more than 32t gross weight / 24,7t payload capacity {938d5ba6-17e4-4f0d-bef0-481608681f57}*	EF	768.000	kg*km	From factory to retail Local supply chain: 1'200 km by truck (>32 t, EURO 4, default utilisation ratio)
		[EU-28+3] Articulated lorry transport, Euro 3, Total weight <7.5 t (without fuel) diesel driven, Euro 3, cargo | consumption mix, to	EF	0.050	kg*km	From retail to final client: 5% by delivery van – 5 km round

		consumer | up to 7,5t gross weight / 3,3t payload capacity {aea613ae-573b-443a-aba2-6a69900ca2ff}				trip (lorry <7.5t, EURO 3, with utilisation ratio of 20%)
End-of-Life	Recycling/Reuse (97%)	*[EU-28] Polypropylene (PP) granulate, secondary, from post-consumer plastic waste* Based on the *ecoinvent* dataset "*[Europe without Switzerland] Polyethylene production, high density, granulate, recycled*" updated with data in the latest Franklin Associates (2018) report, and replacing background datasets with EF datasets	Lit. + EF	0.485	kg	R2 = 97% η = 85.8% (efficiency recycling)
	Avoided virgin PP production	Cradle-to-gate dataset based on EF datasets for crude oil/natural gas supply, and TS datasets for refining and downstream conversion and polymerisation (black-box) as better detailed above for the stages of "Feedstock supply" and "Polymer production"	EF + TS	0.421	kg	Qs/Q o= 0.9 Displacement of PP is assumed
	Incineration (2%)	*Polypropylene (PP) in waste incineration plant, waste-to-energy plant with dry flue gas treatment, without collection, transport and pre-treatment, EU-28 {f39b6710-30b8-4672-9a73-cc06607e652d}*	EF	0.020	kg	R3 = 2%
	Landfill (1%)	*[EU-28+EFTA] Landfill of plastic waste; landfill including leachate treatment and with transport without collection and pre-treatment | production mix (region specific sites),* | The carbon and water content are respectively of 62%C and 0% Water (in weight %) {f2bea0f5-e4b7-4a2c-9f34-4eb32495cbc6}	EF	0.010	kg	(1-R2-R3) = 1%

Table S7. List of processes included in the LCI model of Polybutylene Succinate (B-PBS). EF: Environmental Footprint; EI: Ecoinvent; Lit: dataset built from literature; TS: Thinkstep. The End-of-Life illustrated herein is the average EU End-of-Life treatment mix used in the default scenario calculation.

Life cycle stage	**Process**	**Dataset**	**Database**	**Quantity**	**Unit**	**Comments**
Polymer production	Corn production transport, starch hydrolysis, fermentation, filtration, esterification, polycondensation	*Polybutylene succinate (PBS) (biobased from corn); technology mix, starch hydrolysis, fermentation, filtration, esterification, polycondensation; production mix, at producer; from US corn, water content <0,5 w% {dcd6c006-63aa-49c9-9e01-ba62ed597f52}*	TS	1.031	kg	Accounts for 3% losses at the production stage.
	Transport of polymer granulate to article production site (from supplier to factory)	*[EU-28+3] Articulated lorry transport, Euro 4, Total weight >32 t (without fuel); diesel driven, Euro 4, cargo | consumption mix, to consumer | more than 32t gross weight / 24,7t payload capacity {938d5ba6-17e4-4f0d-bef0-481608681f57}*	EF	85.773	kg*km	130 km by truck (>32 t, EURO 4), case-specific utilisation ratio
		[EU-28+3] Freight train, average (without fuel); technology mix, electricity and diesel driven, cargo | consumption mix, to consumer | average train, gross tonne weight 1000t / 726t payload capacity {02e87631-6d70-48ce-affd-1975dc36f5be}	EF	247.422	kg*km	240 km by train (average freight train)
		[EU-28+3] Barge; technology mix, diesel driven, cargo | consumption mix, to consumer | 1500 t payload capacity {4cfacea0-cce4-4b4d-bd2b-223c8d4c90ae}	EF	278.351	kg*km	270 km by ship (barge)
Product manufacturing (incl. distribution)	Injection moulding	*Injection moulding plastic injection moulding production mix, at plant for PP, HDPE and PE [EU-28+EFTA] [LCI result] {ec9ca75e-abdb-4d2e-9e18-ca1f5709a76d}*	EF	1.031	kg	30 g of waste per kg of product.
	Incineration of loss from injection moulding	*[EU-28] Incineration of Bio-PBS in MSW incineration plant* Dataset developed based on the Doka (2011) tool for the modelling of material incineration in waste-to-energy plants, and EF background datasets. The dataset already includes energy (electricity and heat) substitution	Lit. + EF	0.031	kg	
	Transport of panel from factory to final client	*[EU-28+3] Articulated lorry transport, Euro 4, Total weight >32 t (without fuel); diesel driven, Euro 4, cargo | consumption mix, to consumer | more than 32t gross weight / 24,7t payload capacity {938d5ba6-17e4-4f0d-bef0-481608681f57}*	EF	768.000	kg*km	From factory to retail Local supply chain: 1'200 km by truck (>32 t, EURO 4, default utilisation ratio)
		[EU-28+3] Articulated lorry transport, Euro 3, Total weight <7.5 t (without fuel) diesel driven, Euro 3, cargo | consumption mix, to consumer | up to 7,5t gross weight / 3,3t payload capacity {aea613ae-573b-443a-aba2-6a69900ca2ff}	EF	0.050	kg*km	From retail to final client: 5% by delivery van – 5 km round trip (lorry <7.5t, EURO 3, with utilisation ratio of 20%)
End-of-Life	Recycling/Reuse (97%)	*[EU-28] Plastic granulate secondary (low metal contamination); from post-consumer plastic waste, via grinding, metal separation, washing, pelletization; production mix, at plant; plastic waste with low metal fraction {3b801715-5e3f-426f-8b24-a84dbd4f3165}*	Lit. + EF	0.485	kg	R2 = 97% η = 85.8% (efficiency recycling)
	Avoided virgin PP production	Cradle-to-gate dataset based on EF datasets for crude oil/natural gas supply, and TS datasets for refining and downstream conversion and polymerisation (black-box) as better detailed above for the stages of "Feedstock supply" and "Polymer production"	EF + TS	0.445	kg	Qs/Qo = 0.9 Displacement of PP is assumed
	Incineration (2%)	*[EU-28] Incineration of Bio-PBS in MSW incineration plant* Dataset developed based on the Doka (2011) tool for the modelling of	EF	0.020	kg	R3 = 2%

		material incineration in waste-to-enery plants and EF background energy datasets (remaining datasets from ecoinvent). The dataset already includes energy (electricity and heat) substitution				
	Landfill (1%)	*[EU-28] Landfilling of Bio-PBS, sanitary landfill* Dataset developed based on the Doka (2011) tool for the modelling of waste disposal in sanitary landfill, and EF background energy datasets (remaining datasets from ecoinvent)	EF	0.010	kg	(1-R2-R3) = 1%

Table S8. List of processes included in the LCI model of polylactic acid from maize (MA-PLA). EF: Environmental Footprint; EI: Ecoinvent; Lit: dataset built from literature; TS: Thinkstep. The End-of-Life illustrated herein is the average EU End-of-Life treatment mix used in the default scenario calculation.

Life cycle stage	Process	Dataset	Database	Quantity	Unit	Comments
Feedstock supply	Maize cultivation (US)	*[US] Maize (corn grain) production; technology mix | at farm {ad979027-fa48-4ce4-a010-7b21a2bb9934}*	EF	3.175	kg	3.08 kg maize grain/kg PLA
	Transport of maize to processing	*[EU-28+3] Articulated lorry transport, Euro 4, Total weight >32 t (without fuel); diesel driven, Euro 4, cargo | consumption mix, to consumer | more than 32t gross weight / 24,7t payload capacity {938d5ba6-17e4-4f0d-bef0-481608681f57}*	EF	317.526	kg	100 km by truck (default distance assumed in the underlying aggregated GaBi dataset) US diesel is considered as an input
Polymer production	Wet milling, lactic acid production (dextrose fermentation), lactide formation, polymerisation	*[EU-28] Polylactic acid (PLA) (Polylactide, continuous process) - open flow corn grains; lactide production from corn, continuous process | single route, at plant | 1210–1430 kg/m3, 72.06 g/mol per repeating unit {6e6b78cf-15cc-4c65-bc59-6b93f8c539ec}*	TS	1.031	kg	Account for 3% losses at the production stage
	Transport of polymer granulate to article production site (from US supplier to EU factory)	*[EU-28+3] Articulated lorry transport, Euro 4, Total weight >32 t (without fuel); diesel driven, Euro 4, cargo | consumption mix, to consumer | more than 32t gross weight / 24,7t payload capacity {938d5ba6-17e4-4f0d-bef0-481608681f57}*	EF	659.794	kg*km	1000 km by truck for the sum of distances from harbour/airport to factory outside and inside Europe
		[GLO] Transoceanic ship, containers; heavy fuel oil driven, cargo | consumption mix, to consumer | 27.500 dwt payload capacity, ocean going {6ca61112-1d5b-473c-abfa-4accc66a8a63}	EF	6185.567	kg*km	6000 km by ship (6000 km from New York to Rotterdam)
		[EU-28+3] Articulated lorry transport, Euro 4, Total weight >32 t (without fuel); diesel driven, Euro 4, cargo | consumption mix, to consumer | more than 32t gross weight / 24,7t payload capacity {938d5ba6-17e4-4f0d-bef0-481608681f57}	EF	659.794	kg*km	1000 km by truck for the sum of distances from harbour/airport to factory outside and inside Europe
Product manufacturing (incl. distribution)	Injection moulding	*Injection moulding plastic injection moulding production mix, at plant for PP, HDPE and PE [EU-28+EFTA] [LCI result] {ec9ca75e-abdb-4d2e-9e18-ca1f5709a76d}*	EF	1.031	kg	30 g of waste per kg of product.
	Recycling of loss from injection moulding	*[EU-28] Polylactic acid (PLA) in waste incineration plant, waste-to-energy plant with dry flue gas treatment, without collection, transport and pre-treatment | production mix, at plant | Net calorific value 17.9 MJ/kg {00b5480b-b622-4acd-8481-812d866e15a9}*	Lit. + EF	0.015	kg	
	Transport of panel from factory to final client	*[EU-28+3] Articulated lorry transport, Euro 4, Total weight >32 t (without fuel); diesel driven, Euro 4, cargo | consumption mix, to consumer | more than 32t gross weight / 24,7t payload capacity {938d5ba6-17e4-4f0d-bef0-481608681f57}*	EF	768.000	kg*km	From factory to retail Local supply chain: 1200 km by truck (>32 t, EURO 4, default utilisation ratio)
		[EU-28+3] Articulated lorry transport, Euro 3, Total weight <7.5 t (without fuel) diesel driven, Euro 3, cargo | consumption mix, to consumer | up to 7,5t gross weight / 3,3t payload capacity {aea613ae-573b-443a-aba2-6a69900ca2ff}	EF	0.050	kg*km	From retail to final client: 5% by delivery van – 5 km round trip (lorry <7.5t, EURO 3, with utilisation ratio of 20%)
End-of-Life	Recycling/Reuse (97%)	*[EU-28] Plastic granulate secondary (low metal contamination); from post-consumer plastic waste, via grinding, metal separation, washing, pelletization; production mix, at plant; plastic waste with low metal fraction {3b801715-5e3f-426f-8b24-a84dbd4f3165}*	Lit. + EF	0.485	kg	R2 = 97% η = 85.8% (efficiency recycling)
	Avoided virgin PP production	Cradle-to-gate dataset based on EF datasets for crude oil/natural gas supply, and TS datasets for refining and downstream conversion and polymerisation (black-box) as better detailed above for the stages of "Feedstock supply" and "Polymer production"	EF + TS	0.421	kg	Qs/Qo = 0.9 Displacement of PP is assumed
	Incineration (2%)	*[EU-28] Polylactic acid (PLA) in waste incineration plant, waste-to-energy plant*	EF	0.020	kg	R3 = 2%

		with dry flue gas treatment, without collection, transport and pre-treatment | production mix, at plant | Net calorific value 17.9 MJ/kg {00b5480b-b622-4acd-8481-812d866e15a9}				
	Landfill (1%)	*[EU-28] Landfilling of PLA, sanitary landfill* Dataset developed based on the Doka (2011) tool for the modelling of waste disposal in sanitary landfill, and EF background energy datasets (remaining datasets from ecoinvent)	EF	0.010	kg	(1-R2-R3)=1%

2. Dynamic (t-dependent) modelling of biogenic-C cycle

All parameters for the modelling of the time-dependent climate change impact are taken from the Myhre et al. (2013). The Impulse Response Function (*IRF*) represents the atmospheric decay of a pulse of CO_2 emission at time *t* (Eq. S1). Eq. S2 calculates the Radiative Forcing associated with a pulse emission of CO_2. A_{CO2} represents the radiative efficiency of CO_2 on a mass basis, while RE_{CO2} represents the radiative efficiency of CO_2 on volume basis. Eq. S3 and Eq. S4 represent the symbolic and discrete formulations of the AGWP curves, as presented in Myhre et al. (2013). Eq. S5 describes the convolution operation between the AGWP curve with the function *z(t)* which represents the emission profile from the system considered. This calculation provides the Cumulative Radiative Forcing (*CRF*) associated to the emission profile *z(t)*. This metric represents the radiative forcing accumulated in the atmosphere due to the emission of z(t) up to the time *T* considered as the limit of integration. The parameters for Eq. S2 to S9 are taken from Myhre et al. (2013) and are detailed in Table S9 and Table S10.

$$IRF_{CO2}(t) = a_0 + \sum_{i=1}^{3} a_i \cdot exp\left(-\frac{t}{\tau_i}\right) \qquad \text{(Eq. S1)}$$

$$RF_{CO2}(t) = A_{CO2} \cdot IRF_{CO2}(t) \qquad \text{(Eq. S2)}$$

$$AGWP_{CO2}(t) = \int_0^t RF_{CO2}(t')\, dt' \qquad \text{(Eq. S3)}$$

$$AGWP_{CO2}(t) = A_{CO2} \cdot \left\{a_0 \cdot t + \sum_{i=1}^{3} a_i \cdot \tau_i \cdot \left(1 - exp\left(-\frac{t}{\tau_i}\right)\right)\right\} \qquad \text{(Eq. S4)}$$

$$CRF_{CO2}(T) = \int_0^T z(T-T')\left(\int_0^{T'}\left(\int_0^t RF_{CO2}(t') \cdot \delta T(t-t')\, dt'\right) dt\right) dT' \qquad \text{(Eq. S5)}$$

Table S9: Parameters used for the calculation of RF in Eq. S2.

Parameter	**Value**	**Unit**
A CO2	1.75E-15	W * m^{-2} * kg^{-1}
RE CO2	1.37E-5	W * m^{-2} * ppb^{-1}

Table S10: Parameters used for the calculation of IRF of CO2 (Eq. S1).

Parameter	**1st term**	**2nd term**	**3rd term**	**4th term**	**Unit**
a_i	0.2173	0.2240	0.2824	0.2763	-
τ_i *CO2*		394.4	36.54	4.304	years

2.1 Emission profiles for biogenic-C (z(t))

The temporal boundary of our analysis starts at time = 0 when the biomass is harvested. In that year, biogenic-C is transferred from the biosphere to the technosphere to be embedded into the bio-based plastic. We then define several alternatives for the curves representing C-sequestration due to biomass re-growth and for the curves representing C-emissions at the End-of-life. We can then combine these multiple curves to create a matrix of biogenic-C cycle curves for different rotation periods and different EoL options. Figure S1 presents an example of biogenic-C cycle profile for two types of biomass feedstocks, with 1 and 80 years of rotation time, and C-emission through incineration after use for 20 years.

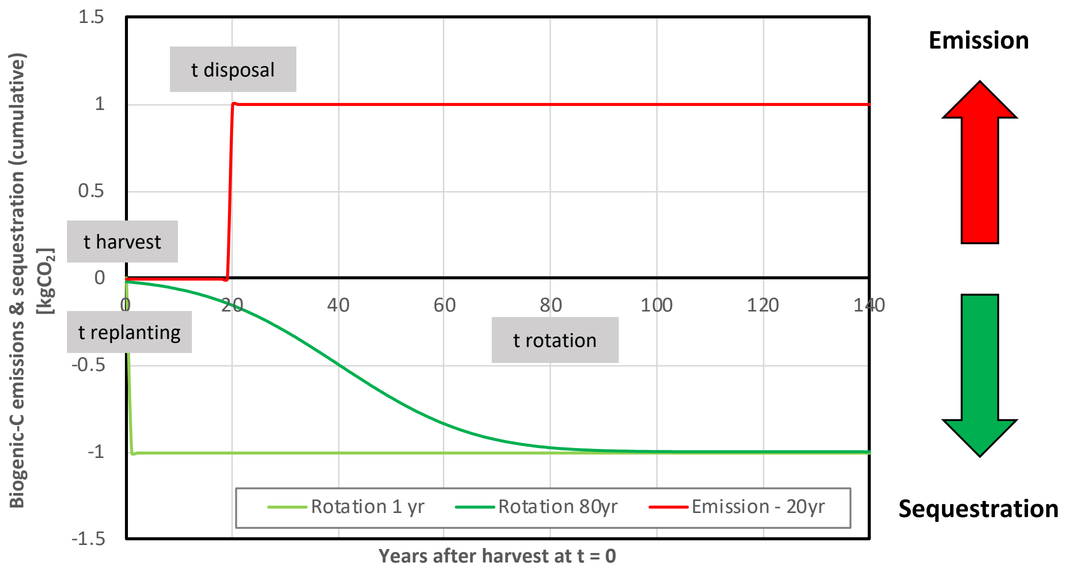


Figure S1: Biogenic-C emission and sequestration dynamics of 1 kg CO_2. Two biomass growth curves are represented with different rotation times (1 yr = annual crop and 80 yr = forest feedstock), and emission of CO_2 due to disposal through incineration after 20 years of use.

To be noticed that all the cycle profile curves are defined for a single event, i.e. harvest of 1 kg CO_2, re-sequestration of 1 kg CO_2, and release or landfilling of 1 kg CO_2 at disposal. In other words, we do not model here the sustained harvest, sequestration, and EoL across multiple years. Additionally, we report in the SM different examples of emission profiles and characterization factors (GWP_bio) even though only one case is considered in the article.

2.2 Biomass growth ($z_{growth}(t)$)

We define the growth curves for various rotation periods, thus representing different biomass feedstocks. We model the annual crop re-growth simply as re-absorbing within 1 year all the CO_2 removed through harvest. Following Guest et al. (2013), the other growth curves are simplified as Gaussian curves, with a mean value equal to half the rotation time, and the standard deviation equal to 0.25 times the rotation time, as illustrated in Eq. S6 where *r* stands for rotation time. All calculations are normalized over 1 kg CO_2.

$$z_{Growth}(t,r) = -\frac{1}{\frac{r}{4}\sqrt{2\pi}} e^{-0.5\left(\frac{t-r/2}{r/4}\right)^2} \qquad \text{(Eq. S6)}$$

Figure S2 presents five examples of cumulative growth curves.

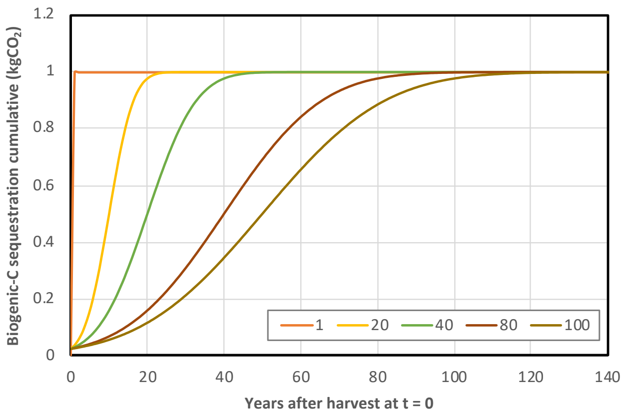


Figure S2: Cumulative curves for sequestration of biogenic-C after harvest taking place a t=0. The five curves represent five different rotation times for plant regrowth.

2.3 CO_2 emission curves / EoL curves ($z_{EoL}(t)$)

Secondly, we define a series of emission profiles for two options of EoL. For incineration, we model the pulse release of 1 kg CO_2 at different time steps after harvest. The time steps represent thus storage times of the biogenic-C in the technosphere before being released again to the atmosphere. Eq. S7 represents the function for the pulse release of 1 kg CO_2 in the year $j = t_{disposal}$.

For landfilling, we consider that 1% of the biogenic-C is released in 100 years, at the rate of 0.0001 kgC each year. As shown in Eq. S7, several options are considered as starting time for the landfilling (*j*) to account for different useful life times of the bio-based product.

These emission profiles are actually valid also for the fossil-C embedded in fossil-based plastics to which the impact of bio-based plastics is compared.

$$z_{Emission}(t,j) = \begin{cases} 0 \; if \; t \neq j \\ 1 \; if \; t = j \end{cases} \qquad \text{(Eq. S7)}$$

$$z_{Landfill}(t,j) = \begin{cases} 0 \; if \; t < j \\ 0.0001 \; if \; j \leq t < j + 100 \\ 0 \; if \; t \geq 100 + j \end{cases} \qquad \text{(Eq. S8)}$$

2.4 Cumulative Radiative Forcing curves

Once the biogenic-C and fossil-C profile curves are defined analytically, they can be convoluted with the analytical curve for AGWP to obtain the Cumulative Radiative Forcing (CRF) curves.

$$CRF_{CO2\_Growth}(T,r) = \int_0^T z_{Growth}(T - T', r) \left(\int_0^{T'} \left(\int_0^t RF_{CO2}(t') \cdot \delta T(t - t') \, dt' \right) dt \right) dT' \qquad \text{(Eq. S9)}$$

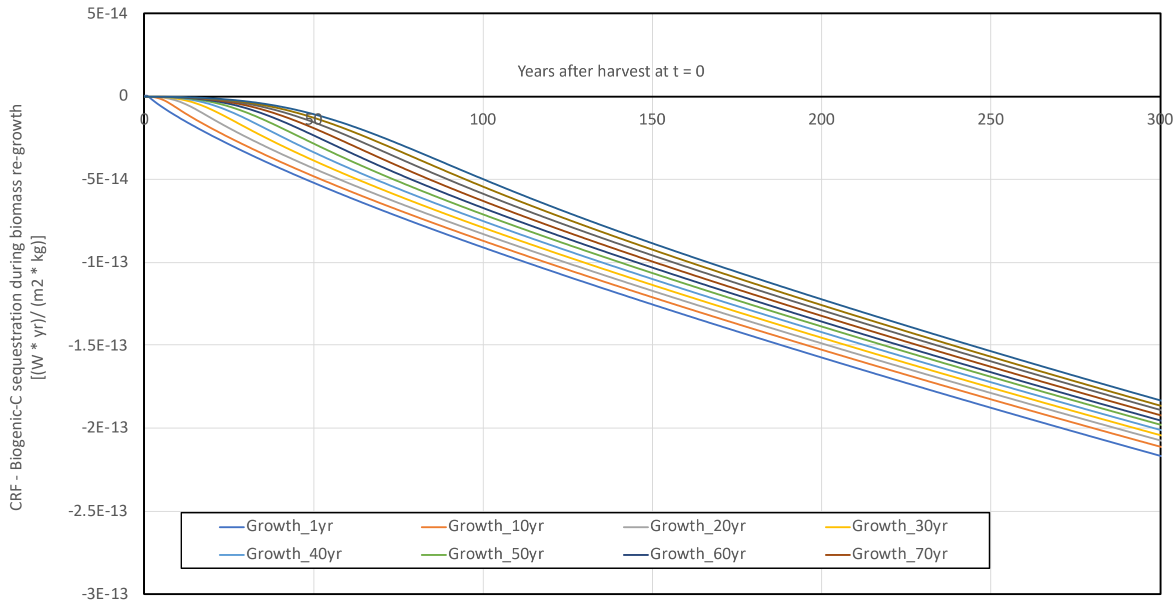
$$CRF_{CO2\_Incineration}(T,j) = \int_0^T z_{Emission}(T - T', j) \left(\int_0^{T'} \left(\int_0^t RF_{CO2}(t') \cdot \delta T(t - t') \, dt' \right) dt \right) dT' \qquad \text{(Eq. S10)}$$

$$CRF_{CO2\_Landfill}(T,j) = \int_0^T z_{Landfill}(T-T',j)\left(\int_0^{T'}\left(\int_0^t RF_{CO2}(t')\cdot\delta T(t-t')\,dt'\right)dt\right)dT'$$
(Eq. S11)

For this work, we defined both the growth-emission profiles as well as the climate metrics curves as discrete vectors, and then performed a discrete convolution using the software R. The function used to carry out the discrete convolution between vector x and y, is the following:

```
conv_numerical <- function(x, y) {
  nx <- length(x)
  ny <- length(y)
  xy <- nx + ny - 1
  xy <- rep(0, xy)
  for(i in (1:nx)){
    j <- 1:ny
    ij <- i + j - 1
    xy[i+(1:ny)-1] <- xy[ij] + x[i] * y
  }
  xy
}
```

The CRF curves for the various profiles of C-sequestration and C-emissions are represented in Figure S3 for clarity and transparency. To be noticed that the curve named ‘Emission_0yr’ in Figure S3 (bottom), represents also the curve used by IPCC AR5 as a denominator in the definition of the GWP factors for all gases.



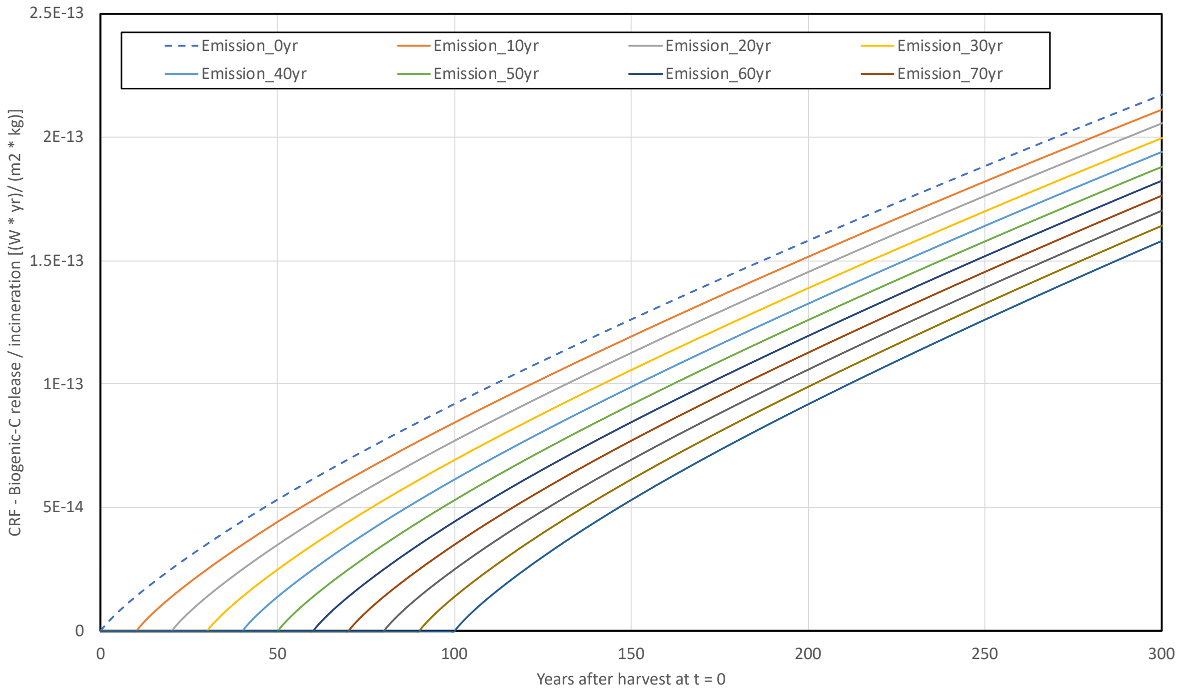


Figure S3: Cumulative Radiative Forcing Curves for C-sequestration with different biomass growth curves (top) and for C-emission through incineration with different storage time in the technosphere (bottom).

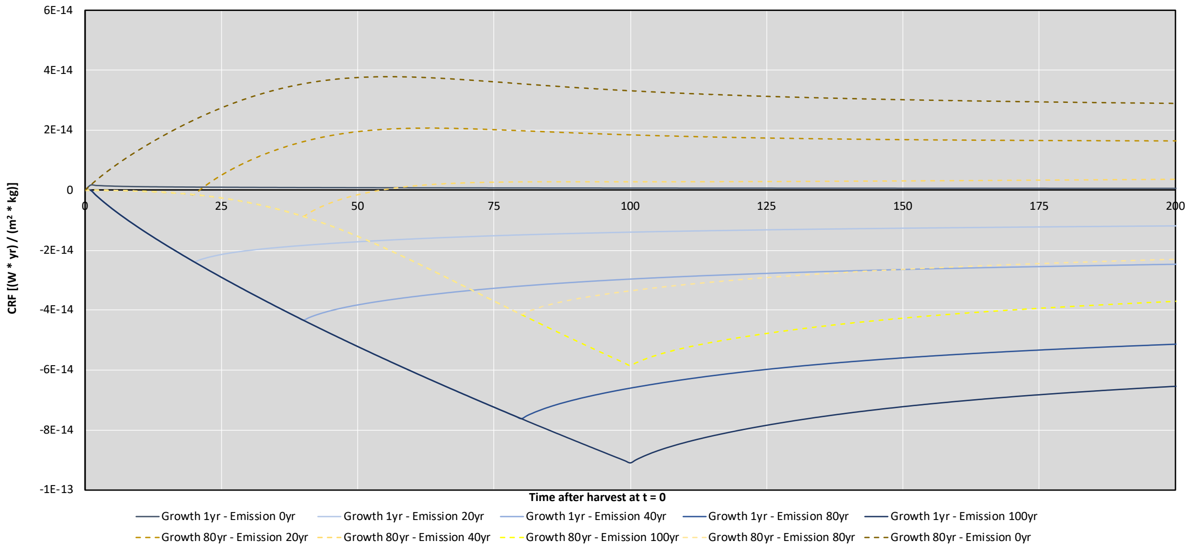


Figure S4: Explicit representation of the Cumulative Radiative Forcing curves for bio-based products using annual crops (Growth 1yr curves) and biomass feedstock with a 80 years rotation cycle (Growth 80yr), and being disposed through incineration after a useful life of 0, 20, 40, 80, or 100 years.

Figure S4 represents the curves for CRF for different possible combinations of rotation periods and EoL scenarios. Such representation provides a clear picture of the climate impacts of using different biomass feedstocks to produce bio-products with different lifetimes and different EoL treatments. Specifically, by using absolute climate metrics, the value judgement of choosing the temporal boundary of the analysis is left to the reader.

Figure S5a, represents the CRF curves explicitly in time, both for fossil-based PP and bio-based PBS. Additionally, in Figure S5b we plot the Climate Mitigation Index, simply defined as in Eq. S6.

$$CMI = \frac{(CRF_{fossil} - CRF_{bio})}{CRF_{fossil}} \qquad \text{(Eq. S12)}$$

This curve shows clearly that the long-term mitigation of the bio-based product is independent from the biogenic-C cycle and the effect of temporary storage is irrelevant. However, in the short-term, there is a clear advantage in storing the biogenic-C in the anthroposphere. This effect would be missed by excluding the time-dependent phenomena taking place, as highlighted also by Levasseur et al. (2010).

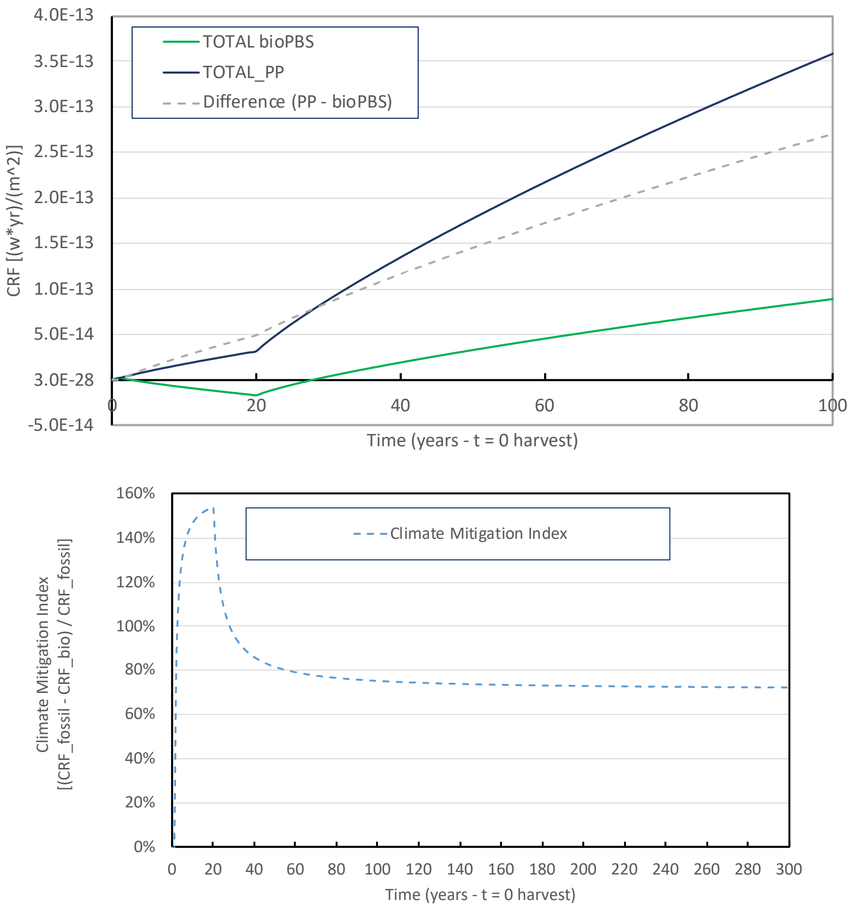


Figure S5: a) CRF curves for fossil-based PP and bio-based PBS plastics. Both curves account for supply-chain emissions at time t=0 and incineration of the plastic after 20 years of use (see details on the LCI in Section 1 of this SM); b) Climate Mitigation Index between the two products.

2.5 GWP_{bio} factors

While a time-explicit representation has many advantages (Giuntoli et al. 2016), reporting normalized characterization factors can be very useful for LCA practitioners, as Guest et al. (2012) illustrated.

Therefore, we normalize the CRF curves above over the same AGWP CO2 factors as done by the IPCC.

$$GWP_{Growth}(100, r) = \frac{CRF_{Growth}(100,r)}{AGWP_{CO2}(100)} \quad \text{(Eq. S13)}$$

$$GWP_{Incineration}(100, j) = \frac{CRF_{Incineration}(100,j)}{AGWP_{CO2}(100)} \quad \text{(Eq. S14)}$$

$$GWP_{Landfill}(100, j) = \frac{CRF_{Landfill}(100,j)}{AGWP_{CO2}(100)} \quad \text{(Eq. S15)}$$

The characterization factors in Table S11 and Table S12 are indeed the same as presented by Guest et al. (2012), but we present them as disaggregated factors for the biomass growth and biogenic-C emission / EoL factors. These CFs can be flexibly combined to obtain the final CF for many different combinations of rotation periods and EoL scenarios. Specifically:

$$GWP_{bio}(100)_{r,j} = GWP_{growth}(100)_r + GWP_{EoL}(100)_j \quad \text{(Eq. S16)}$$

$$GWP_{fossil}(100)_j = GWP_{EoL}(100)_j \quad \text{(Eq. S17)}$$

Where *i* represents the rotation time for biomass growth, and *j* represents the storage time (or the use period). Looking at Figure S1, if $t_{harvest} = t_{replanting} = t_{production} = 0$, then $r = t_{rotation}$ and $j = t_{disposal}$. Additionally, as indicated in brackets, the values are presented at a fixed time horizon of 100 years, as this is the common TH for climate change CFs in LCA.

Table S11: GWP characterization factors capturing the sequestration of 1 kg of CO2 from the atmosphere during the growth of the biomass after harvest. The CFs are differentiated based on the rotation time needed for the biomass to fully regrow after harvest at t = 0.

	Rotation time [years] (*r*)										
	1	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
GWP_growth	-0.99	-0.95	-0.90	-0.86	-0.82	-0.77	-0.73	-0.68	-0.64	-0.59	-0.54

Table S12: GWP characterization factors for two different EoL scenarios (incineration and landfilling). The CFs are differentiated based on the storage period, i.e. the time at which the product is disposed.

	Storage period [years] (*j*)										
	0	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
GWP_Incineration	1.00	0.92	0.84	0.76	0.67	0.58	0.48	0.38	0.27	0.15	0.00
GWP_Landfill	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

However, as highlighted above and as discussed in depth by UNEP/SETAC (2016), assessing different time horizons and multiple climate metrics can provide additional important information about the climate impact of a product. For this reason, we also calculate the GWP factors as a function of the time horizon considered for one specific case relevant to this paper. Figure S6 represents the GWP as a function of time for three different sources of CO_2: 1) GWP_bio represents the GWP(t) for biogenic-C embedded in a bio-based plastic which is produced from annual crop and is in use for 20 years before incineration; 2) GWP_fossil represents the GWP(t) for fossil-CO_2 released from a fossil-based plastic at t = t disposal (20 years in this case); 3) GWP_supply chain represents the GWP(t) for fossil-CO_2 released during the production of the bio-based or fossil plastic at t = 0, and it is thus always equal to 1. The exact mathematical formulation is reported in Eq. S18 and Eq. S19. The values of GWP(100) from Figure S6 are used in Figure 5 of the manuscript.

$$GWP_{bio}(t) = \frac{CRF_{Growth}(t,1) - CRF_{Incineration}(t,20)}{AGWP_{CO2}(t)} \quad \text{(Eq. S18)}$$

$$GWP_{fossil}(t) = \frac{CRF_{Incineration}(t,20)}{AGWP_{CO2}(t)} \quad \text{(Eq. S19)}$$

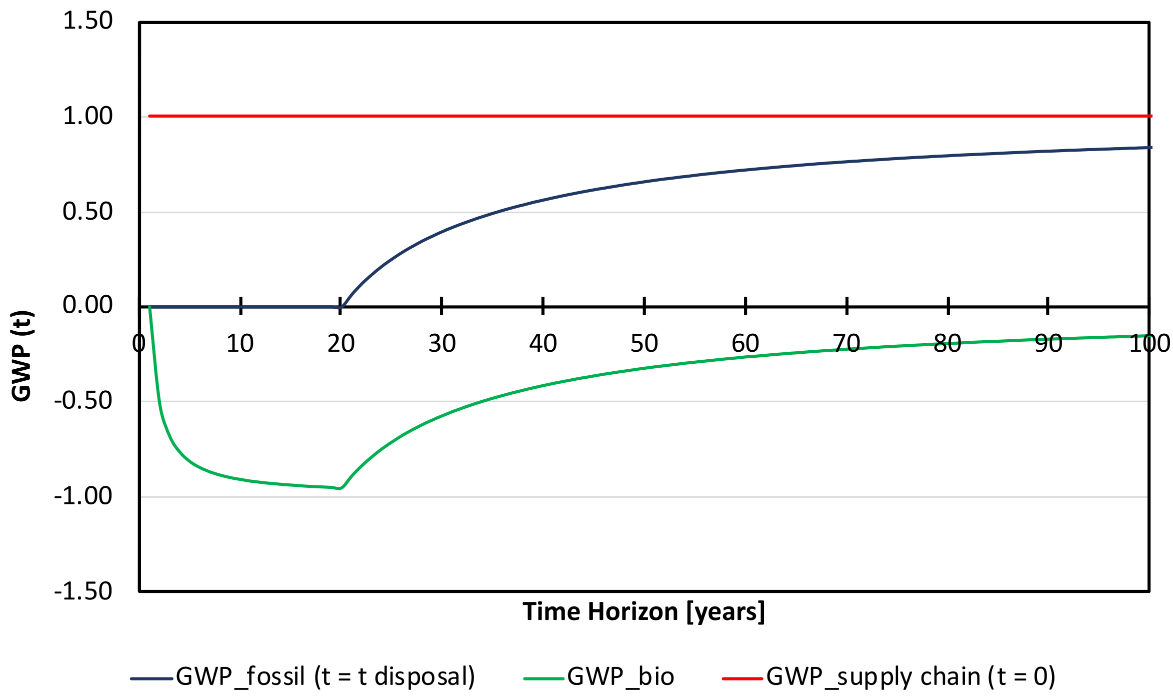


Figure S6: GWP for biogenic-C (GWP_bio), for fossil-C embedded in the product (GWP_fossil), and for fossil-C released during the product supply chain (GWP_supply chain), as a function of the time horizon considered. Values for GWP_bio consider an annual crop incinerated after 20 years of use (the value of GWP_bio (100) is equal to the value obtained adding up GWP_growth and GWP_incineration in Table S11 and Table S12).

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