Supplementary Information

Title: Environmental and littering impacts of disposable cups made of polypropylene and polylactic acid in Germany

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Content

S1. Life cycle inventory of the disposable cups

Table S1 presents the life cycle inventory (LCI) of plastic cup manufacturing, transport, usage, and end-of-life per functional unit (FU) of 1 plastic cup for cold drinks with a filling volume of 500 mL over its entire life cycle. Figure S1 displays the corresponding LCA models compiled in the software "LCA for Experts". Figure S2 shows a photo of a cup.

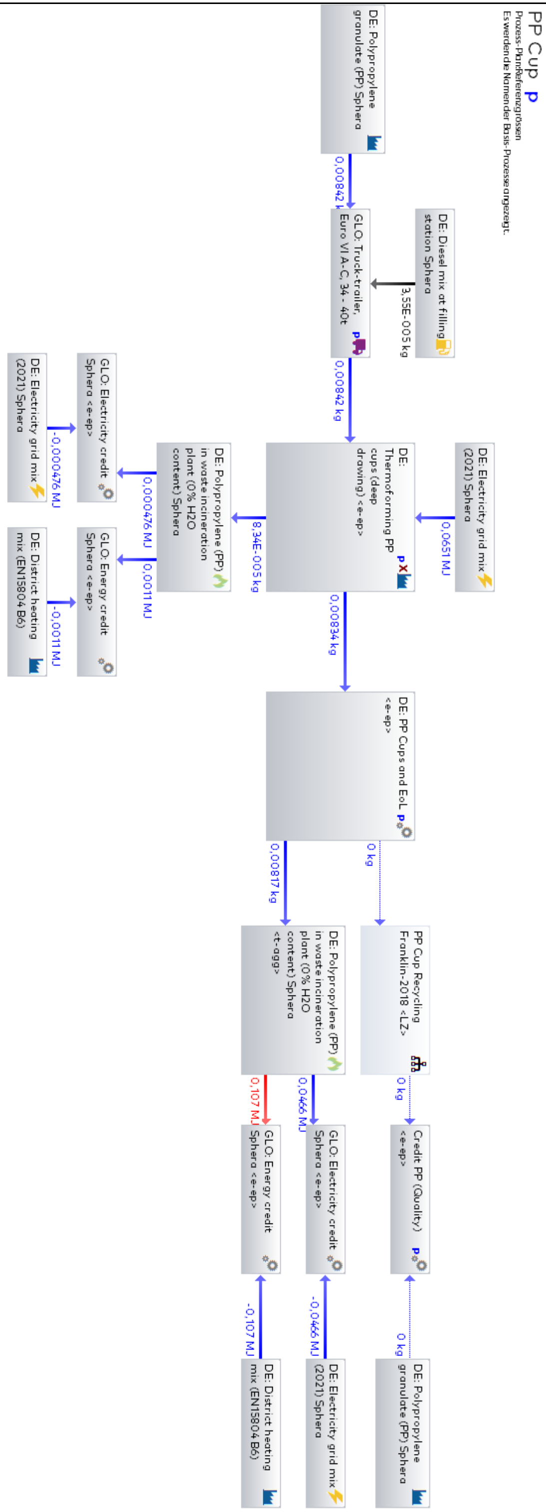
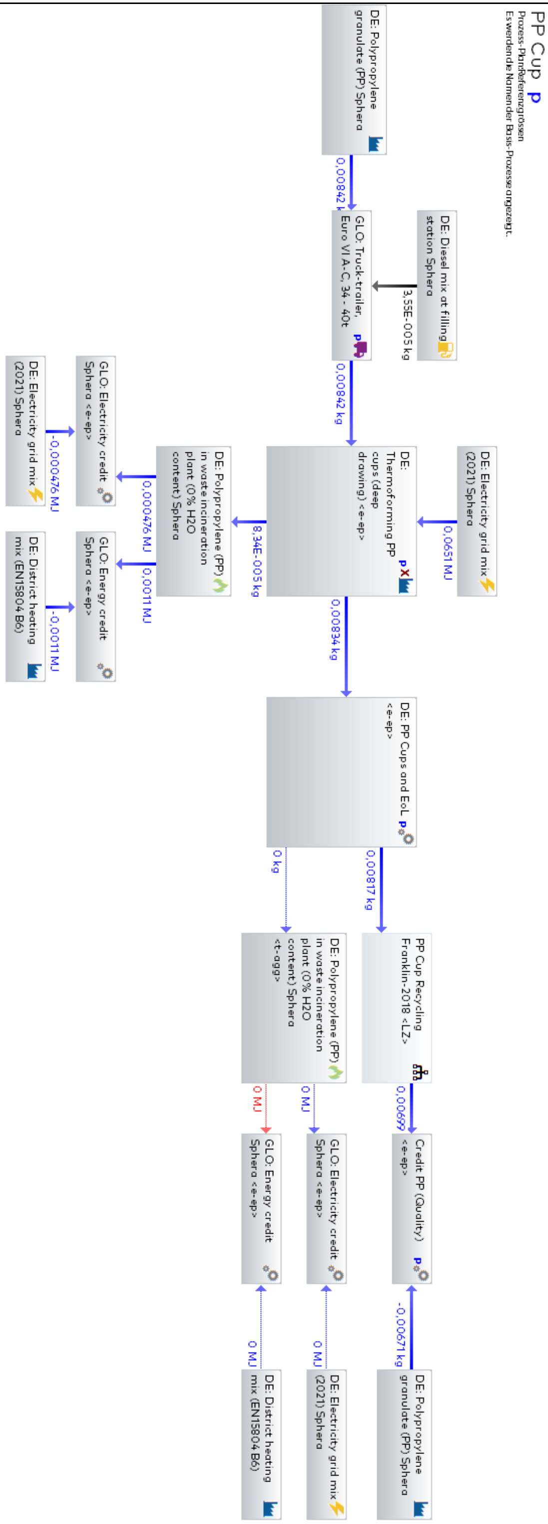
Table S1. LCI of plastic cup manufacturing, transport, usage, and end-of-life per FU

Process	PLA	Dataset	PP	Dataset
Polymer pellet production [in g]	7.71 3.8	US: Ingeo Polylactide (PLA) biopolymer production NatureWorks GLO: Polylactic Acid (PLA) TH 2018 System Total Corbion PLA	8.42	DE: Polypropylene granulate (PP) Sphera
Transport (freight train) [in km]	2000 (US) 200 (TH)	GLO: Rail transport cargo - average, average train, gross tonne weight 1,000t / 726t payload capacity Sphera <e-ep>	--	Included in polymer pellet production
Transport (transoceanic ship) [in km]	6000 (US) 17 000 (TH)	GLO: Container ship, 5,000 to 200,000 dwt payload capacity, ocean going Sphera <e-ep>	--	Included in polymer pellet production
Transport (truck) [in km]	300	GLO: Truck-trailer, Euro 6A-C, 34-40t gross weight	200	GLO: Truck-trailer, Euro 6A-C, 34-40t gross weight
Electricity demand extrusion & thermoforming [in kWh]	0.215	DE: Electricity grid mix (2021) Sphera	0.0138	DE: Electricity grid mix (2021) Sphera
Residues extrusion & thermoforming [in %]	1	DE: Polylactic acid (PLA) in waste incineration plant Sphera <t-agg>	1	DE: Polypropylene (PP) in waste incineration plant Sphera <t-agg>
Stamping scrap [in %]	35	Re-enters extrusion & thermoforming	35	Re-enters extrusion & thermoforming
Plastic mass treated at the EoL [in g]	11.4	Incineration scenario: DE: Polylactic acid (PLA) in waste incineration plant Sphera <t-agg> Recycling scenario: LCA model based on Maga et al. (2019) (scenario 2)	8.34	Incineration scenario: DE: Polypropylene (PP) in waste incineration plant Sphera <t-agg> Recycling scenario: LCA model based on Franklin Associates (2018)

DE = Germany, GLO = global, US = USA; TH = Thailand

Table S2. LCI of PP recycling based on Franklin Associates (2018)

Mass/energy flow name	Amount	Unit	Description	LCI data set
INPUT				
Sorted PP (baled)	1.17	kg	Amount of sorted PP	
Transport of sorted PP (baled) to mechanical recycling	30	km	Assumed distance	GLO: Truck-trailer, Euro 6, 34 - 40t gross weight / 27t pay- load capacity Sphera
Diesel for transportation	0.00074	kg	Amount of fuel calculated with Sphera software	DE: Diesel mix at filling station Sphera
Water	1.03	kg	Water demand for washing for recycling	DE: Tap water from surface water Sphera
Diesel for forklift	6.72E-04	kg	Demand for diesel for forklift	Forklift (DSL 1) (Fuc et al. 2016) DE: Diesel mix at filling station Sphera
Natural gas	3.54E-06	kg	Demand natural gas	DE: Thermal energy from natural gas Sphera
Electricity	0.53	kWh	Demand for electricity	DE: Electricity grid mix (2021) Sphera
LPG for forklift	0.00032	kg	Demand for LPG for forklift	Forklift (LPG1) (Fuc et al. 2016) DE: Liquefied Petroleum Gas (LPG) (70% propane, 30% butane) Sphera
Detergent	0.0017	kg	Demand for detergent	GLO: Detergent (fatty acid sulphonate derivate) Sphera
Sodium hydroxide	6.90E-04	kg	Demand for Sodium hydroxide	DE: Sodium hydroxide mix (50%) Sphera
Output				
Recycled granulate	1	kg		
Incineration good (waste for treatment)	0.17	kg	Residues from sorting (for thermal treatment). The treatment of residues is attributed to the EoL	DE: Polypropylene (PP) in waste incineration plant Sphera Credits: DE: Electricity grid mix (2021) Sphera, DE: District heating mix (EN15804 B6) Sphera
Waste water	1.03	kg	Equals water consumption	DE: Municipal waste water treatment (mix) Sphera

PP cups Thermal treatment	 Recycling (0.96 substitution factor)
	

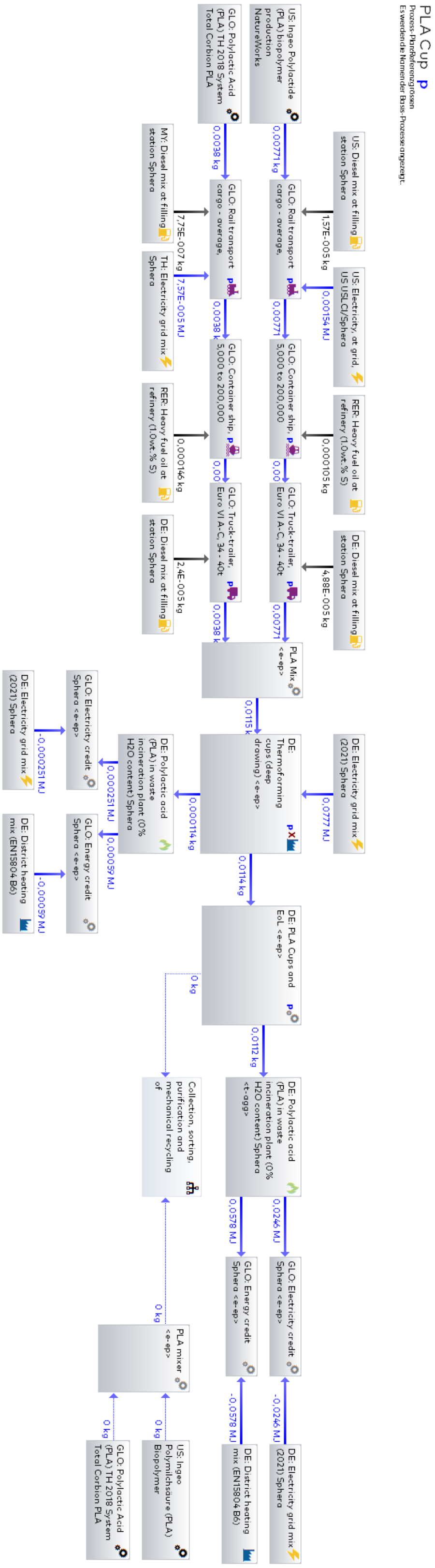
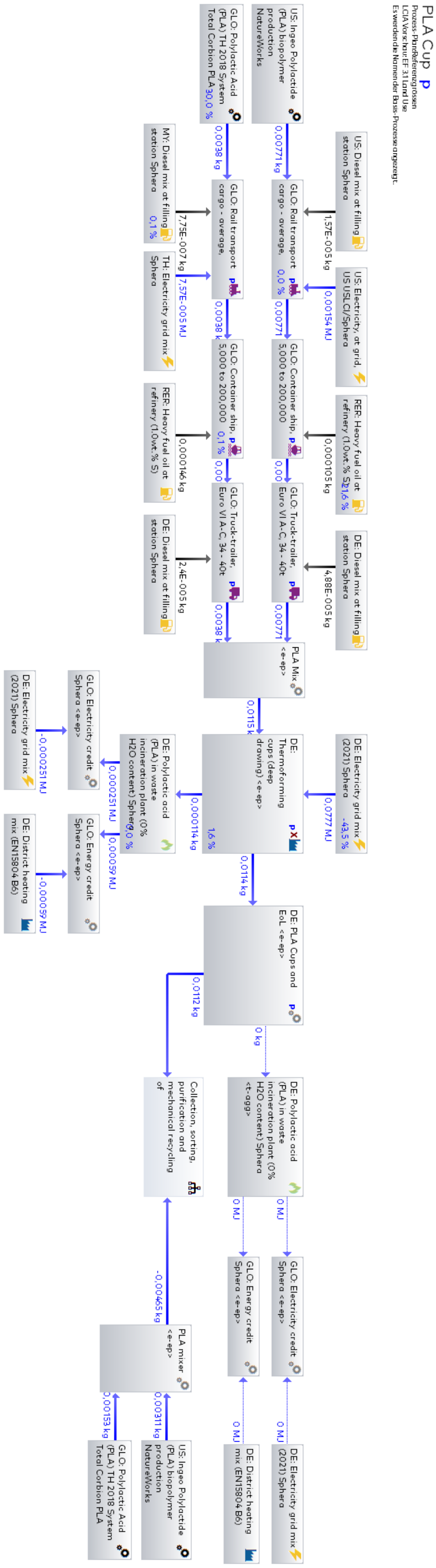
PLA cups Thermal treatment	Recycling (0.42 substitution factor)
	

Figure S1. LCA models compiled in the software “LCA for Experts”

Figure S2. Photo of the assessed product

S2. Detailed results of the degradation experiment

1. Fourier-transform infrared spectroscopy (FTIR)

Chemical changes during weathering of PP and PLA could be confirmed by FTIR. The weathered PP_{500h} and PP_{1000h} with oxidized backbone shows peaks at 3100-3700, 1600-1680, 1690-1810 and 1000-1200 cm^{-1}, corresponding to hydroxyl group, alkene or carbon double bond, carbonyls, carbon-oxygen bond respectively as displayed in Figure S3. The Carbonyl Index (CI) value for PP_{0h} is 0.263 with accelerated weathering it increases for PP_{500h} and PP_{1000h} to 1.796 and 3.320, respectively. Similarly, the Ester Index (EI), Hydroxy Index (HI), Vinyl index (VI) and Internal Bond Index (IBI) for weathered PP_{500h} and PP_{1000h} show high increases as compared to pristine PP_{0h} confirming the higher extent of degradation.

Weathered PLA shows increased intensities of carbonyls and lower intensities of the ester groups signals. With an increase in exposure time, the photodegraded by-products, such as hydroperoxides and vinyl groups, appear in the spectra. Weathered PLA_{500h} and PLA_{1000h} showed a lower extent of degradation compared to weathered PP (Litauszki et al. 2019). There is a marginal increase in the CI values from 5.254 to 5.386 for PLA_{0h} and PLA_{1000h}, respectively. However, EI values show a steep decrease for PLA_{0h} and PLA_{1000h} from 27.421 to 4.765, respectively. PLA_{1000h} also shows HI and VI values of 0.789 and 0.880, respectively, which confirm degradation. CI, EI, HI, VI and IBI for PP_{0h}, PP_{500h}, PP_{1000h}, PLA_{0h}, PLA_{500h} and PLA_{1000h} is reported in Table S3.

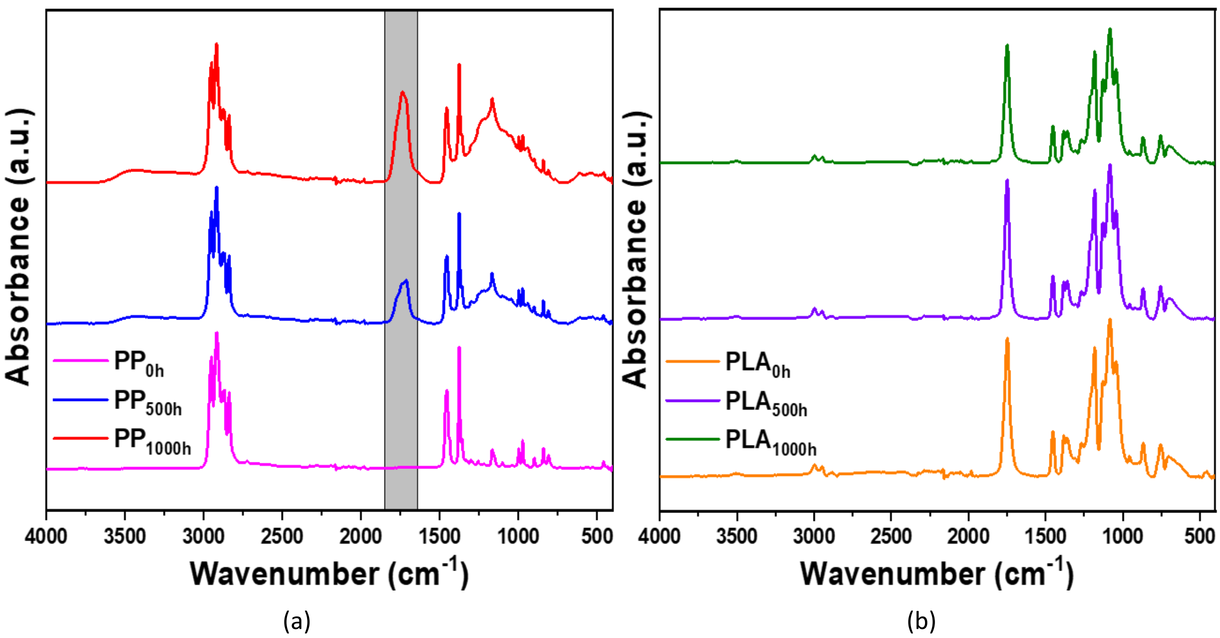


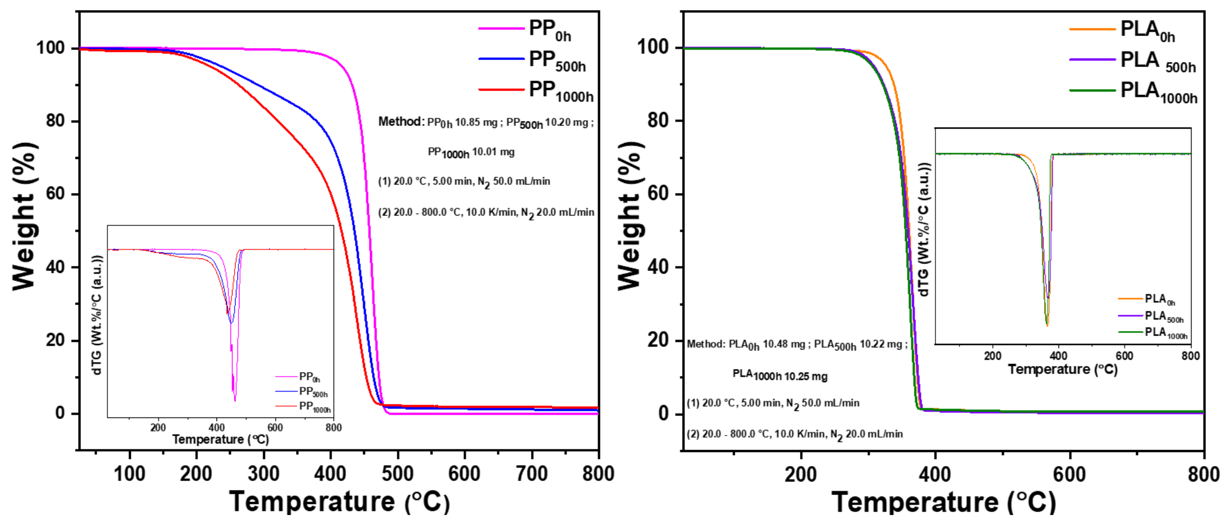
Figure S3. Fourier-transform infrared spectroscopy results of (a) PP_{0h}, PP_{500h}, PP_{1000h} (b) PLA_{0h}, PLA_{500h}, PLA_{1000h}

Table S3. Carbonyl Index (CI), Ester Index (EI), Hydroxy Index (HI), Vinyl index (VI) and Internal Bond Index (IBI) for PP_{0h}, PP_{500h}, PP_{1000h}, PLA_{0h}, PLA_{500h} and PLA_{1000h}

Polymer	Carbonyl Index (CI)	Ester Index (EI)	Hydroxy Index (HI)	Vinyl Index (VI)	Inter Bond Index (IBI)
PP_{0h}	0.263	0.241	0.217	0.253	0.289
PP_{500h}	1.796	1.550	0.472	0.414	0.647
PP_{1000h}	3.320	2.940	0.527	0.520	0.843
PLA_{0h}	5.254	27.421	0.0	0.0	2.170
PLA_{500h}	5.351	19.410	0.0	0.227	1.692
PLA_{1000h}	5.386	4.765	0.789	0.880	1.129

2. Thermogravimetric analysis (TGA)

The thermal properties of PP and PLA are affected by accelerated weathering, as shown by TGA and Differential scanning calorimetry (DSC) analysis in Figures S4 and S5, respectively. The TGA of weathered PP_{500h} and PP_{1000h} demonstrate significant losses in thermal property as compared to pristine PP_{0h}. The onset temperature (T_{os}) for PP_{0h} is 436°C, which reduces after 500 hours of weathering to 396°C and after 1000 hours of weathering to 205°C and 405°C. The midset temperature (T_{mid}, $T_{50\%}$), which is the temperature at which 50 % weight loss occurs, is an important indicator for determining thermal stability. $T_{90\%}$ is the temperature at 90 % weight loss and T_p is the first derivative peak temperature, also called the inflection point. The $T_{50\%}$, $T_{90\%}$, and T_p show significant reductions for weathered PP_{500h} and PP_{1000h}. The weathered PLA does not show a great reduction in thermal stability. A small drop in T_{os} from 339°C for PLA_{0h} to 328°C for PLA_{1000h} and other thermal profile indicators were observed (Litauszki et al. 2019). Table S4 depicts the T_{os}, $T_{50\%}$, $T_{90\%}$ and T_p for PP_{0h}, PP_{500h}, PP_{1000h}, PLA_{0h}, PLA_{500h}, and PLA_{1000h}.



(a) (b)

Figure S4. Results of the thermogravimetric analysis of (a) PP_{0h}, PP_{500h}, PP_{1000h} (b) PLA_{0h}, PLA_{500h}, PLA_{1000h}

Table S4. Thermal profile determined for PP_{0h}, PP_{500h}, PP_{1000h}, PLA_{0h}, PLA_{500h} and PLA_{1000h}

Polymer	T_{os} (°C)	$T_{50\%}$ (°C)	$T_{90\%}$ (°C)	T_p (°C)
PP_{0h}	436	458	472	462
PP_{500h}	396	434	464	449
PP_{1000h}	205, 405	416	453	435
PLA_{0h}	339	360	373	365
PLA_{500h}	330	359	374	366
PLA_{1000h}	328	356	368	362

3. Differential scanning calorimetry (DSC)

The DSC of PP and PLA is represented in Figure S5 displaying the melting point (T_m), glass transition temperature (T_g), and crystallinity. In general, the crystallinity of plastic is expected to increase with degradation because the amorphous regions of plastic degrade more with the increased availability of oxygen and polymer chains released from entanglements, leading to secondary crystallization, also called 'chemi crystallization. However, we found that the crystallinity of PP decreases from 51 % for pristine PP_{0h} to 41 % and 22 % for PP_{500h} and PP_{1000h}, respectively, whereas for PLA the values remained stable, as comparable to Litauszki et al. (2019). This could be because the carbonyl group did not fit and reduced the crystalline order in the crystal lattice (Sarkar et al. 2021). The T_m for degraded PP shows a drastic reduction from 161°C for PP_{0h} to 132°C and 117°C for PP_{500h} and PP_{1000h}, respectively, whereas for PLA, the T_m and T_g values depict a marginal reduction. The crystallinity, T_m and T_g for PP_{0h}, PP_{500h}, PP_{1000h}, PLA_{0h}, PLA_{500h} and PLA_{1000h} are reported in Table S5.

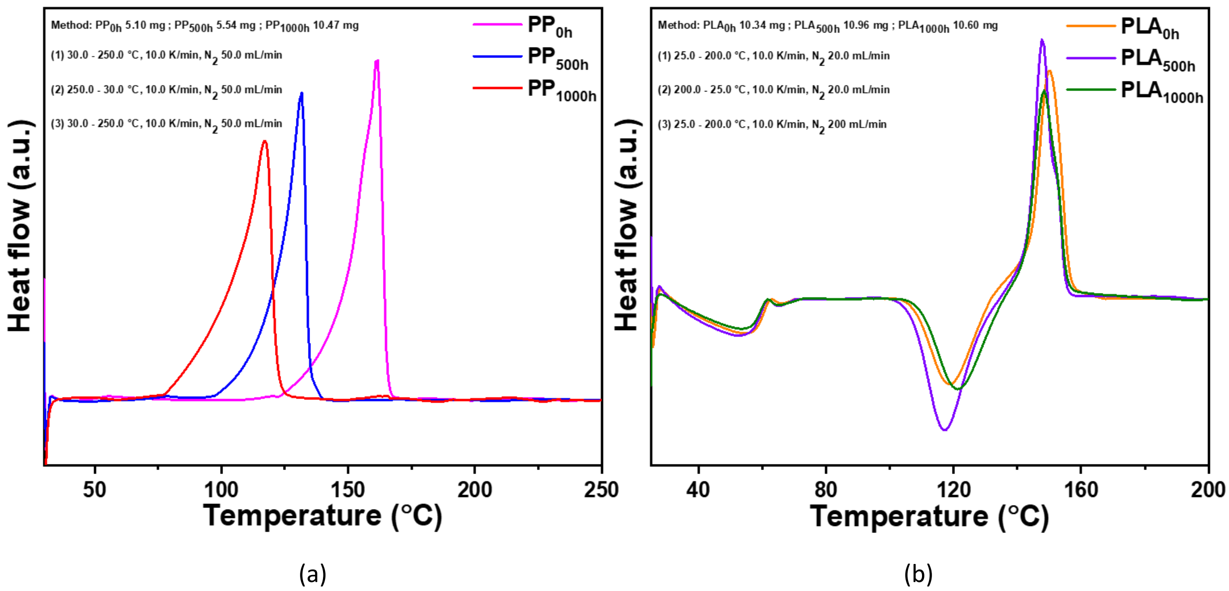


Figure S5. Differential scanning calorimetry results of (a) PP_{0h}, PP_{500h}, PP_{1000h} (b) PLA_{0h}, PLA_{500h}, PLA_{1000h}

Table S5. Crystallinity, melting point, and glass transition temperature for PP_{0h}, PP_{500h}, PP_{1000h}, PLA_{0h}, PLA_{500h}, and PLA_{1000h}

Polymer	Crystallinity (%)	Melting Point (T_m,°C)	Glass-Transition Temperature (T_g,°C)
PP_{0h}	34	161	-
PP_{500h}	37	132	-
PP_{1000h}	28	117	-
PLA_{0h}	44	150	63
PLA_{500h}	31	148	62
PLA_{1000h}	25	148	62

4. Contact Angle (CA)

The surface wettability of PP and PLA cups were evaluated by CA. Generally, if the CA is greater than 90°, the surface is considered hydrophobic and possesses a lower concentration of polar groups at the surface, resulting in poor wettability. If the CA is less than 90°, the surface is considered hydrophilic and water spreads on the surface. The CA of pristine PP_{0h} is 111° which decreases after 500 hours of weathering to 101° and to 93° after 1000 hours of weathering due to the formation of polar functional groups like C=O and –OH that leads to increase in hydrophilicity of the surface (Al Harraq et al. 2022). The CA of pristine PLA_{0h} is 82° and remains almost constant after 500 hours of weathering (81°) but decreases to 68° after 1000 hours of weathering confirming the surface roughness. This is in line with the findings of Qin et al. (2022) who showed that the surface of PLA after weathering in marine water does not change significantly. The CA values can easily be correlated to the weathering extent of oxidation as indicated by FTIR and SEM micrograph.

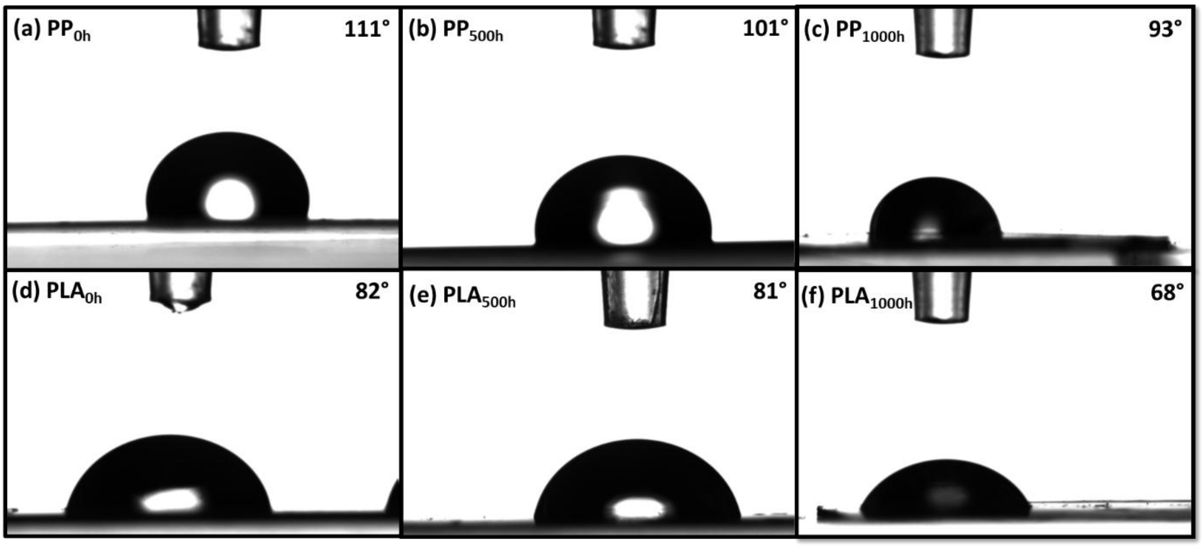


Figure S6. Contact angles of (a) PP_{0h} (b) PP_{500h} (c) $PP_{5'1000h}$ (d) PLA_{0h} (e) PLA_{500h} (f) PLA_{1000h}

5. Scanning Electron Microscopy (SEM)

The pristine PP and PLA have irregular shapes and roughness on the surface due to cryogenic grinding. The weathered PP and PLA has a fractured surface due to oxidation, as revealed in CI values calculated by the Surface Area Under Band (SAUB) method (Budhiraja et al. 2022).

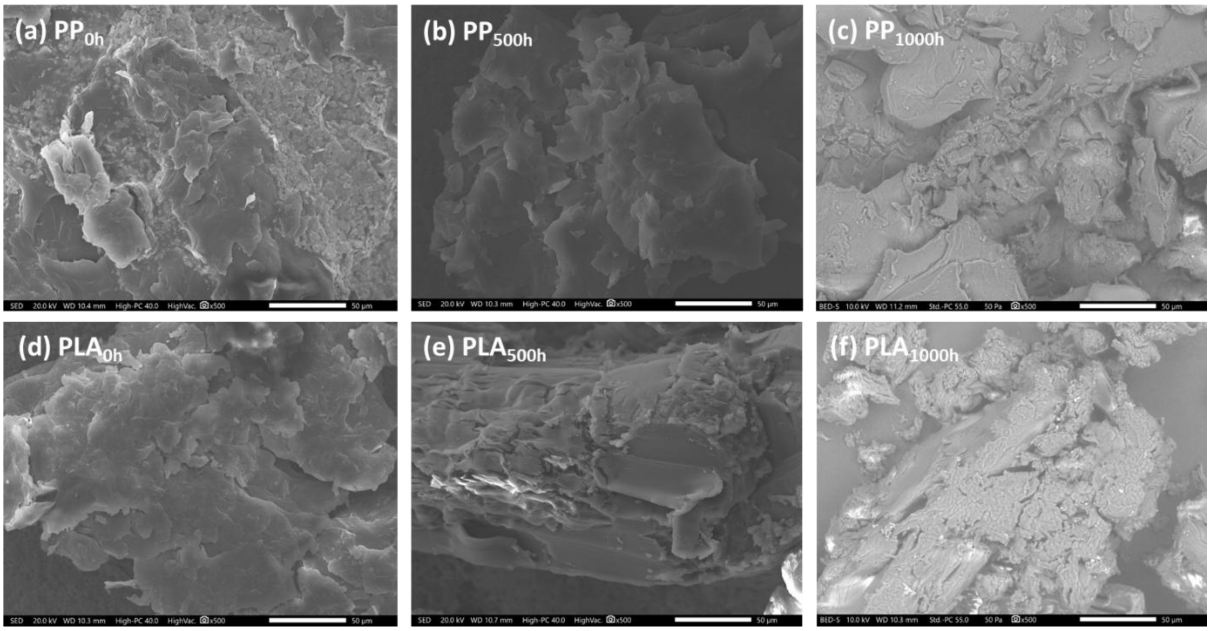


Figure S7. SEM micrograph of (a) PP_{0h} (b) PP_{500h} (c) PP_{1000h} (d) PLA_{0h} (e) PLA_{500h} (f) PLA_{1000h}

6. Specific Surface Degradation Rate (SSDR)

The specific surface degradation rate (SSDR) provides information about the mass loss of the sample, but the estimation of polymer lifetimes is highly uncertain. Numerous factors, such as changes in crystallinity, surface area, shape, constant reaction order, degradation mechanism, etc., affect every stage of plastic degradation (Chamas et al. 2020). Figure S8 displays the SSDR at different weathering times for the analyzed materials.

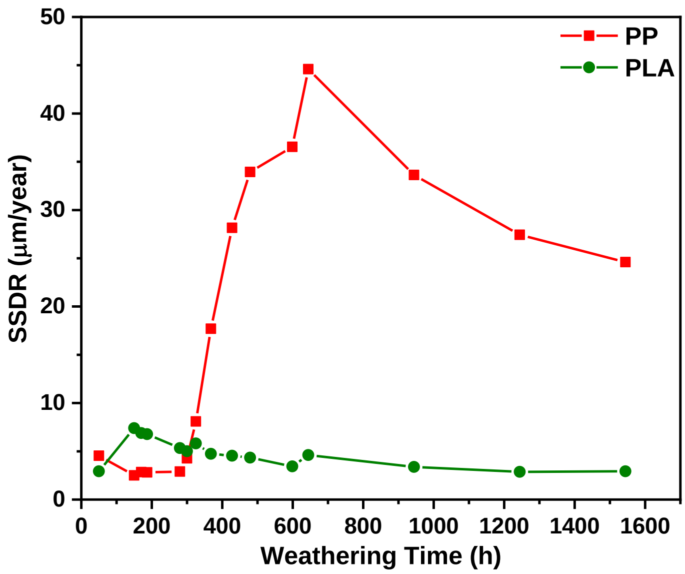


Figure S8. Specific surface degradation rate of PP and PLA at different weathering times

The SSDR of PP cups varied between 2.51 - 44.59 µm/year with a mean of 18.31 µm/year and a median of 17.71 µm/year, whereas the SSDR of PLA cups varied between 2.86 - 7.39 µm/year with a mean of 4.73 µm/year and a median of 4.61 µm/year. The SSDR of PP starts off low initially and remains so until 280 hours of weathering, potentially due to the presence of additives like antioxidants and UV inhibitors preventing the plastic from degrading. Subsequently, after 280 hours, there is a sharp increase in SSDR, reaching a peak value of 44.59 µm/year at 644 hours of weathering, followed by a declining trend. This trend in the graph indicates significant degradation of the PP surface at 644 hours and then shows a decreasing trend until cracks are formed and new surfaces are exposed.

PLA is known to undergo complete degradation under industrial composting conditions in the presence of oxygen and moisture at temperatures exceeding 60°C (Chamas et al. 2020). However, when leaked into the marine environment, its degradation rate is significantly lower compared to industrial composting facilities (Qin et al. 2022). The temperature in the weathering chamber was maintained at 38°C, lacking the thermal energy required for the efficient degradation of PLA. Consequently, the SSDR of PLA is lower than that of PP under similar conditions. There were not a lot of changes in chemical, thermal, and surface properties recorded for weathered PLA. The data on SSDR for PP and PLA cups at different weathering time is given in Table S6.

Table S6. Specific surface degradation rate of PP and PLA at different weathering times

Weathering Time (h)	SSDR PP (µm/year)	SSDR PLA (µm/year)
50	4.54819	2.93025
150	2.51126	7.39555
170	2.84317	6.88382
187	2.81666	6.77632
280	2.90737	5.33680
300	4.26735	5.00871
325	8.09440	5.81719
368	17.70628	4.74581
428	28.14809	4.54032
479	33.94405	4.34632
599	36.54461	3.43857
644	44.59399	4.60719
944	33.62940	3.37839
1244	27.43761	2.86964
1544	24.60189	2.93532

The weathering experiment lasted for 1544 h, which is equivalent to 1 year 2 months and 11 days of degradation at Sanary-sur-Mer, France. The average UV solar radiation observed in Sanary-sur-Mer, France, for the wavelength range 295-385 nm during the years 2021 and 2022 was 259 MJ/m^2 and 287 MJ/m^2 at 0°, and 273 MJ/m^2 and 297 MJ/m^2 at 45°, respectively (Atlas Material Testing Technology GmbH & Atlas Material Testing Technology GmbH). An average of 279 MJ/m^2 is used for the calculations.

Radiant Exposure (H) = Irradiance (E) × time (t)

$H = E \times t$

$t = H/E$

$t = 279\ MJ/m^2 / 60\ W/m^2$

$t = 4650000s$ or $1291.66\ h$ or 53.82 days

Concluding, approximately 54 days of degradation in the weathering chamber according to the ISO 4892-2 standard are equivalent to 1 year of degradation at Sanary-sur-Mer, France.

Conclusions

The accelerated weathering of PP and PLA cups under similar conditions shows altogether different results. Weathered PP shows more pronounced deterioration in characteristics than weathered PLA regarding surface morphology, chemical properties, and thermal properties. After 1000 h of weathering, the PP cups were difficult to handle, and any manual tempering led to their fragmentation. On the other hand, PLA did not show any fragmentation after the same interval of weathering. This could be because PLA is compostable in particular industrial environments only and non-biodegradable in the majority of environmental compartments found in nature where it shows little mineralization.

The degradation data can be accessed from Budhiraja (2025).

S3. Results of the literature review regarding degradation data

Table S7 indicates the number of articles identified during the literature review including their assigned classification based on their title and abstracts. Table S8 displays the specific surface degradation rates (SSDRs) calculated based on data extracted from existing literature. The rows in bold writing with green background indicate the datasets used per polymer type and compartment to calculate the fate factors. If several datasets per compartment had the same lowest coefficient of variation (CV), the average was calculated.

Table S7. Classification of the articles identified during the literature review

PLA	PP	
326	146	Results of the search using the given search terms
2	11	different meaning of the abbreviation of the polymer types
10	12	Wrong polymer type or polymers with additives
199	72	Optimization of plastic products, e.g., for medical use, flame retardancy, wastewater treatment, or other purposes
13	14	Plastics end-of-life treatment
6	1	simulation / mathematical model
84	30	Degradation experiments under non-natural conditions, e.g., in a laboratory with mineral salt solution, with pre-treatment (e.g., exposure to UV light), specific microorganisms, or incomplete data
5	6	irrelevant for other reasons
4	**0**	**Remaining articles**
11	4	Articles identified via snowball sampling
15	**4**	**Total articles used for data extraction**

Table S8. Specific surface degradation rates (SSDRs) based on existing literature

Source	**Environmental compartment**	**SSDR** [in µm/year]	**CV**
Polylactic Acid			
Adhikari et al. 2016	Soil (buried)	0.000	0.586
Adhikari et al. 2016	**Soil (buried)**	**78.695**	**0.438**
Artru and Lecerf 2019	**River sediment**	**0.001**	0.435
Baccar Chaabane et al. 2022	Marine water	0.000	0.584
Baccar Chaabane et al. 2022	Marine water	0.000	0.584
Baccar Chaabane et al. 2022	Marine water	0.000	0.584
Bagheri et al. 2017	Marine water	0.000	0.616
Datta et al. 2019	Soil (buried)	7.729	0.440
Dharmalingam et al. 2015	Soil (buried)	51.784	0.616
Dharmalingam et al. 2015	Soil (buried)	34.727	0.616
Karamanlioglu and Robson 2013	Soil (buried)	0.000	0.603
Palsikowski et al. 2018	Soil (buried)	65.396	0.459
Palsikowski et al. 2018	Soil (buried)	48.667	0.477
Pelegrini et al. 2016	Marine water	8.449	0.616
Phosri et al. 2022	Marine water	0.000	0.602
Phosri et al. 2022	**Marine sediment**	**0.000**[1]	**0.602**
Sashiwa et al. 2018	Marine water	10.682	0.459
Scoponi et al. 2020	Marine water	0.000	0.440
Scoponi et al. 2020	**Marine water**	4516.875	0.153
Scoponi et al. 2020	Marine water	730.000	0.205
Scoponi et al. 2020	Marine water	1003.750	0.205
Scoponi et al. 2020	Marine water	1095.000	0.205
Scoponi et al. 2020	Marine water	1825.000	0.159
Shogren et al. 2003	Soil (buried)	0.000	1.318
Stroe et al. 2021	Soil (buried)	1.272	0.602
Stroe et al. 2021	Soil (buried)	0.411	0.602
Stroe et al. 2021	Soil (buried)	0.204	0.602
Vasile et al. 2018	Soil (buried)	0.000	0.600
Wu 2012	Soil (buried)	186.224	0.603
Zuo et al. 2015	Soil (buried)	3.103	0.586
Polypropylene			
Artham et al. 2009	**Marine water**	**4.875**	0.601
Gómez and Michel 2013	**Soil (buried)**	**1.330**	0.460
Sudhakar et al. 2007	Marine water	7.604	0.609
Yabannavar and Bartha 1994	Soil (buried)	4.671	0.624
Yabannavar and Bartha 1994	Soil (buried)	0.884	0.488

[1] While a degradation rate of 0 was measured, a degradation rate of 0.001 was used as the formula does not allow calculating with 0.

S4. Detailed results of the toxicity assessment

Table S9. Comparison of toxicity induced by PP and PLA cup migrates according to Zimmermann et al. (2021)

Effect		PP	PLA	Rel. Change
Baseline toxicity	EC_{20} [mg well^{-1}]	22.2	109	4.9 (491 %)
	EC_{50} [mg well^{-1}]	53.1	247	4.7 (465 %)
	Average ecotoxicity			4.8 (478 %)
Oxidative stress response	ECIR2 [mg well^{-1}]	3.2	103.5	32.3 (3234 %)
Cytotoxicity	Non-cytotoxic conc. [mg well^{-1}]	12.5	200	16 (1600 %)
Estrogenic activity	rEA (%)	—	—	
Cytotoxicity YES	EC_{20} [mg well^{-1}]	75.7	22.1	3.4 (343 %)
Antiandrogenic activity	rAA (%)	40.6 [a]	42.5 [b]	5.2 (523 %)
Cytotoxicity YAAS	EC_{20} [mg well^{-1}]	19.9	>100	5.0 (503 %)
	Average human toxicity			11 (1103 %)

Effective concentration (EC) in mg plastic extracted resulting in a luciferase induction ratio of 2.0 over the control (IR 2). Relative (r) estrogenic (EA) and antiandrogenic (AA) activity at the highest tested non-cytotoxic concentration. a = highest tested concentration 25 mg well^{-1}, b = highest tested concentration 100 mg well^{-1}

S5. Environmental impacts of disposable cups

Tables S10, S11, and S12 display the normalized, and weighted impact scores of the compared scenarios (i) PP thermal treatment, (ii) PP recycling (0.96), (iii) PP recycling (0.9), (iv) PLA thermal treatment, (v) PLA recycling (0.42), and (vi) PLA recycling (0.75). Figures S9 and S10 indicate the contribution of the different life cycle stages to the scores of the different impact categories.

Table S10. Normalized impact scores of the compared scenarios

Impact category	Unit	Normalization factor per person	PP cups thermal	PP cups recycling (0.96)	PP cups recycling (0.9)	PLA cups thermal	PLA cups recycling (0.42)	PLA cups recycling (0.75)
Acidification	mol H^+ eq.	5.56E+01	3.19E-07	3.14E-07	3.31E-07	3.36E-06	2.56E-06	1.76E-06
Climate change	kg CO_2 eq.	7.55E+03	4.79E-06	2.05E-06	2.16E-06	4.28E-06	3.97E-06	2.80E-06
Ecotoxicity, freshwater	CTUe	5.67E+04	4.71E-06	1.76E-06	2.00E-06	1.79E-05	1.15E-05	6.10E-06
Eutrophication, freshwater	kg P eq.	1.61E+00	7.05E-09	3.49E-08	3.56E-08	8.86E-07	5.60E-07	2.85E-07
Eutrophication, marine	kg N eq.	1.95E+01	2.07E-07	2.66E-07	2.80E-07	4.26E-06	3.03E-06	1.87E-06
Eutrophication, terrestrial	mol N eq.	1.77E+02	2.99E-07	3.14E-07	3.30E-07	2.83E-06	2.25E-06	1.59E-06
Human toxicity, cancer	CTUh	1.73E-05	3.78E-07	2.07E-07	2.26E-07	2.73E-06	1.76E-06	9.23E-07
Human toxicity, non-cancer	CTUh	1.29E-04	1.81E-06	6.93E-07	7.95E-07	1.96E-06	1.54E-06	9.52E-07
Ionizing radiation	kBq U_{-235} eq.	4.22E+03	1.40E-07	2.98E-07	3.01E-07	5.71E-07	5.77E-07	4.63E-07
Land use	pt	8.19E+05	-2.32E-08	9.15E-08	9.27E-08	1.26E-06	8.61E-07	4.72E-07
Ozone depletion	kg CFC_{-11} eq.	5.23E-02	2.40E-12	5.08E-12	5.14E-12	1.53E-08	9.12E-09	4.28E-09
Particulate matter	disease inc.	5.95E-04	2.64E-07	2.35E-07	2.50E-07	3.73E-06	2.83E-06	2.01E-06
Photochemical ozone formation	kg NMVOC eq.	4.09E+01	5.07E-07	3.65E-07	3.95E-07	2.89E-06	2.33E-06	1.66E-06
Resource use, fossils	MJ	6.50E+04	8.00E-06	3.57E-06	4.00E-06	7.02E-06	6.26E-06	4.38E-06
Resource use, minerals & metals	kg Sb eq.	6.36E-02	2.36E-08	3.01E-08	3.13E-08	3.34E-07	2.24E-07	1.24E-07
Water use	m^3 water eq. of deprived water	1.15E+04	1.81E-07	5.13E-08	5.23E-08	1.46E-06	8.02E-07	3.94E-07
Plastic pollution	pt	1.50E+02	5.60E-06	5.60E-06	5.60E-06	6.11E-05	6.11E-05	6.11E-05

Table S11. Weighted impact scores of the compared scenarios applying a weighting factor for plastic pollution of 1.84 %

Impact category	Weighting factor (original)	Weighting factor (adjusted)	PP cups thermal treatment abs.	%	PP cups recycling (0.96) abs.	%	PP cups recycling (0.9) abs.	%	PLA cups thermal treatment abs.	%	PLA cups recycling (0.42) abs.	%	PLA cups recycling (0.75) abs.	%
Acidification	0.0620	0.0609	1.94E-08	1.0	1.91E-08	2.0	2.01E-08	1.9	2.05E-07	4.9	1.56E-07	4.3	1.07E-07	3.9
Climate change	0.2106	0.2068	9.90E-07	50.0	4.25E-07	43.7	4.46E-07	42.8	8.86E-07	21.2	8.20E-07	22.8	5.78E-07	20.8
Ecotoxicity, freshwater	0.0192	0.0189	8.89E-08	4.5	3.33E-08	3.4	3.78E-08	3.6	3.37E-07	8.0	2.18E-07	6.0	1.15E-07	4.1
Eutrophication, freshwater	0.0280	0.0275	1.94E-10	0.0	9.59E-10	0.1	9.78E-10	0.1	2.44E-08	0.6	1.54E-08	0.4	7.83E-09	0.3
Eutrophication, marine	0.0296	0.0291	6.01E-09	0.3	7.73E-09	0.8	8.14E-09	0.8	1.24E-07	3.0	8.81E-08	2.4	5.44E-08	2.0
Eutrophication, terrestrial	0.0371	0.0364	1.09E-08	0.6	1.14E-08	1.2	1.20E-08	1.2	1.03E-07	2.5	8.18E-08	2.3	5.79E-08	2.1
Human toxicity, cancer	0.0213	0.0209	7.91E-09	0.4	4.34E-09	0.4	4.72E-09	0.5	5.71E-08	1.4	3.68E-08	1.0	1.93E-08	0.7
Human toxicity, non-cancer	0.0184	0.0181	3.26E-08	1.6	1.25E-08	1.3	1.44E-08	1.4	3.53E-08	0.8	2.78E-08	0.8	1.72E-08	0.6
Ionizing radiation	0.0501	0.0492	6.89E-09	0.3	1.46E-08	1.5	1.48E-08	1.4	2.81E-08	0.7	2.84E-08	0.8	2.28E-08	0.8
Land use	0.0794	0.0780	-1.81E-09	-0.1	7.14E-09	0.7	7.23E-09	0.7	9.84E-08	2.4	6.71E-08	1.9	3.68E-08	1.3
Ozone depletion	0.0631	0.0620	1.49E-13	0.0	3.15E-13	0.0	3.18E-13	0.0	9.47E-10	0.0	5.65E-10	0.0	2.65E-10	0.0
Particulate matter	0.0896	0.0880	2.32E-08	1.2	2.07E-08	2.1	2.20E-08	2.1	3.29E-07	7.8	2.49E-07	6.9	1.77E-07	6.4
Photochemical ozone formation	0.0478	0.0469	2.38E-08	1.2	1.71E-08	1.8	1.85E-08	1.8	1.36E-07	3.2	1.09E-07	3.0	7.79E-08	2.8
Resource use, fossils	0.0832	0.0817	6.53E-07	33.0	2.91E-07	30.0	3.27E-07	31.4	5.74E-07	13.7	5.11E-07	14.2	3.58E-07	12.9
Resource use, minerals & metals	0.0755	0.0741	1.75E-09	0.1	2.24E-09	0.2	2.32E-09	0.2	2.48E-08	0.6	1.66E-08	0.5	9.16E-09	0.3
Water use	0.0851	0.0836	1.52E-08	0.8	4.28E-09	0.4	4.37E-09	0.4	1.22E-07	2.9	6.71E-08	1.9	3.29E-08	1.2
Plastic pollution	--	0.0181	1.01E-07	5.1	1.01E-07	10.4	1.01E-07	9.7	1.10E-06	26.4	1.10E-06	30.7	1.10E-06	39.8
Total			**1.98E-06**		**9.73E-07**		**1.04E-06**		**4.19E-06**		**3.60E-06**		**2.77E-06**	

Table S12. Weighted impact scores of the compared scenarios applying a weighting factor for plastic pollution of 21.06 %

Impact category	Weighting factor (original)	Weighting factor (adjusted)	PP cups thermal treatment abs.	%	PP cups recycling (0.96) abs.	%	PP cups recycling (0.9) abs.	%	PLA cups thermal treatment abs.	%	PLA cups recycling (0.42) abs.	%	PLA cups recycling (0.75) abs.	%
Acidification	0.0620	0.0512	1.64E-08	0.6	1.61E-08	0.9	1.69E-08	1.0%	1.72E-07	1.3	1.31E-07	1.0%	9.02E-08	0.7%
Climate change	0.2106	0.1740	8.33E-07	32.6	3.57E-07	20.9	3.75E-07	21.2%	7.45E-07	5.6	6.90E-07	5.4%	4.86E-07	4.0%
Ecotoxicity, freshwater	0.0192	0.0159	7.48E-08	2.9	2.80E-08	1.6	3.18E-08	1.8%	2.83E-07	2.1	1.83E-07	1.4%	9.67E-08	0.8%
Eutrophication, freshwater	0.0280	0.0231	1.63E-10	0.0	8.06E-10	0.0	8.22E-10	0.0%	2.05E-08	0.2	1.30E-08	0.1%	6.58E-09	0.1%
Eutrophication, marine	0.0296	0.0245	5.06E-09	0.2	6.50E-09	0.4	6.84E-09	0.4%	1.04E-07	0.8	7.41E-08	0.6%	4.57E-08	0.4%
Eutrophication, terrestrial	0.0371	0.0306	9.17E-09	0.4	9.61E-09	0.6	1.01E-08	0.6%	8.67E-08	0.7	6.88E-08	0.5%	4.87E-08	0.4%
Human toxicity, cancer	0.0213	0.0176	6.65E-09	0.3	3.65E-09	0.2	3.97E-09	0.2%	4.81E-08	0.4	3.09E-08	0.2%	1.62E-08	0.1%
Human toxicity, non-cancer	0.0184	0.0152	2.74E-08	1.1	1.05E-08	0.6	1.21E-08	0.7%	2.97E-08	0.2	2.34E-08	0.2%	1.45E-08	0.1%
Ionizing radiation	0.0501	0.0414	5.80E-09	0.2	1.23E-08	0.7	1.25E-08	0.7%	2.36E-08	0.2	2.39E-08	0.2%	1.92E-08	0.2%
Land use	0.0794	0.0656	-1.52E-09	-0.1	6.00E-09	0.4	6.08E-09	0.3%	8.28E-08	0.6	5.65E-08	0.4%	3.10E-08	0.3%
Ozone depletion	0.0631	0.0521	1.25E-13	0.0	2.65E-13	0.0	2.68E-13	0.0%	7.97E-10	0.0	4.75E-10	0.0%	2.23E-10	0.0%
Particulate matter	0.0896	0.0740	1.95E-08	0.8	1.74E-08	1.0	1.85E-08	1.0%	2.76E-07	2.1	2.10E-07	1.6%	1.49E-07	1.2%
Photochemical ozone formation	0.0478	0.0395	2.00E-08	0.8	1.44E-08	0.8	1.56E-08	0.9%	1.14E-07	0.9	9.18E-08	0.7%	6.55E-08	0.5%
Resource use, fossils	0.0832	0.0687	5.50E-07	21.5	2.45E-07	14.4	2.75E-07	15.6%	4.83E-07	3.7	4.30E-07	3.4%	3.01E-07	2.5%
Resource use, minerals & metals	0.0755	0.0624	1.47E-09	0.1	1.88E-09	0.1	1.95E-09	0.1%	2.09E-08	0.2	1.40E-08	0.1%	7.71E-09	0.1%
Water use	0.0851	0.0703	1.28E-08	0.5	3.60E-09	0.2	3.68E-09	0.2%	1.03E-07	0.8	5.64E-08	0.4%	2.77E-08	0.2%
Plastic pollution	--	0.1740	9.74E-07	38.1	9.74E-07	57.1	9.74E-07	55.2%	1.06E-05	80.4	1.06E-05	83.5%	1.06E-05	88.3%
Total			**2.55E-06**		**1.71E-06**		**1.77E-06**		**1.32E-05**		**1.27E-05**		**1.20E-05**	

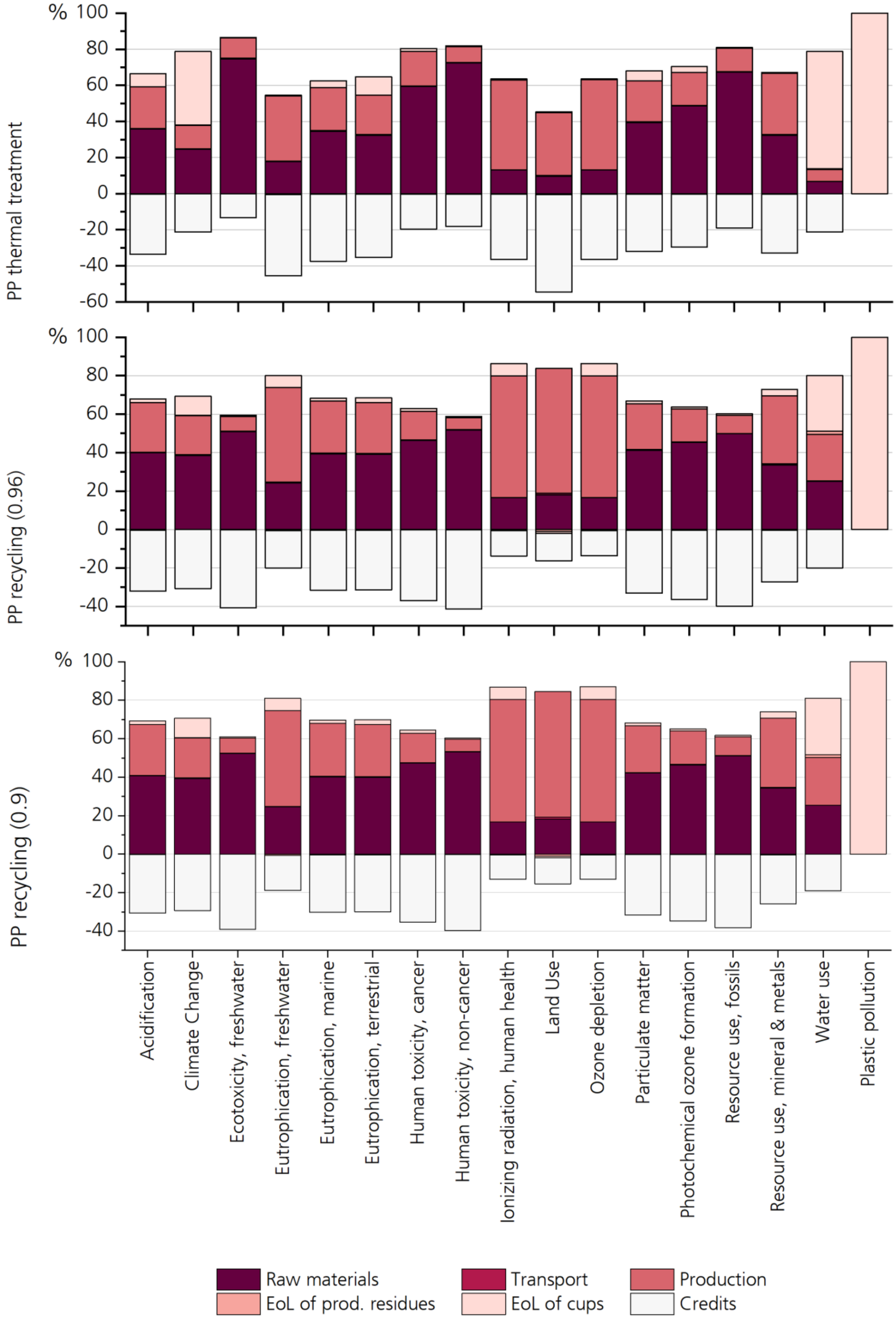


Figure S9. Impact scores of the compared scenarios of PP cups

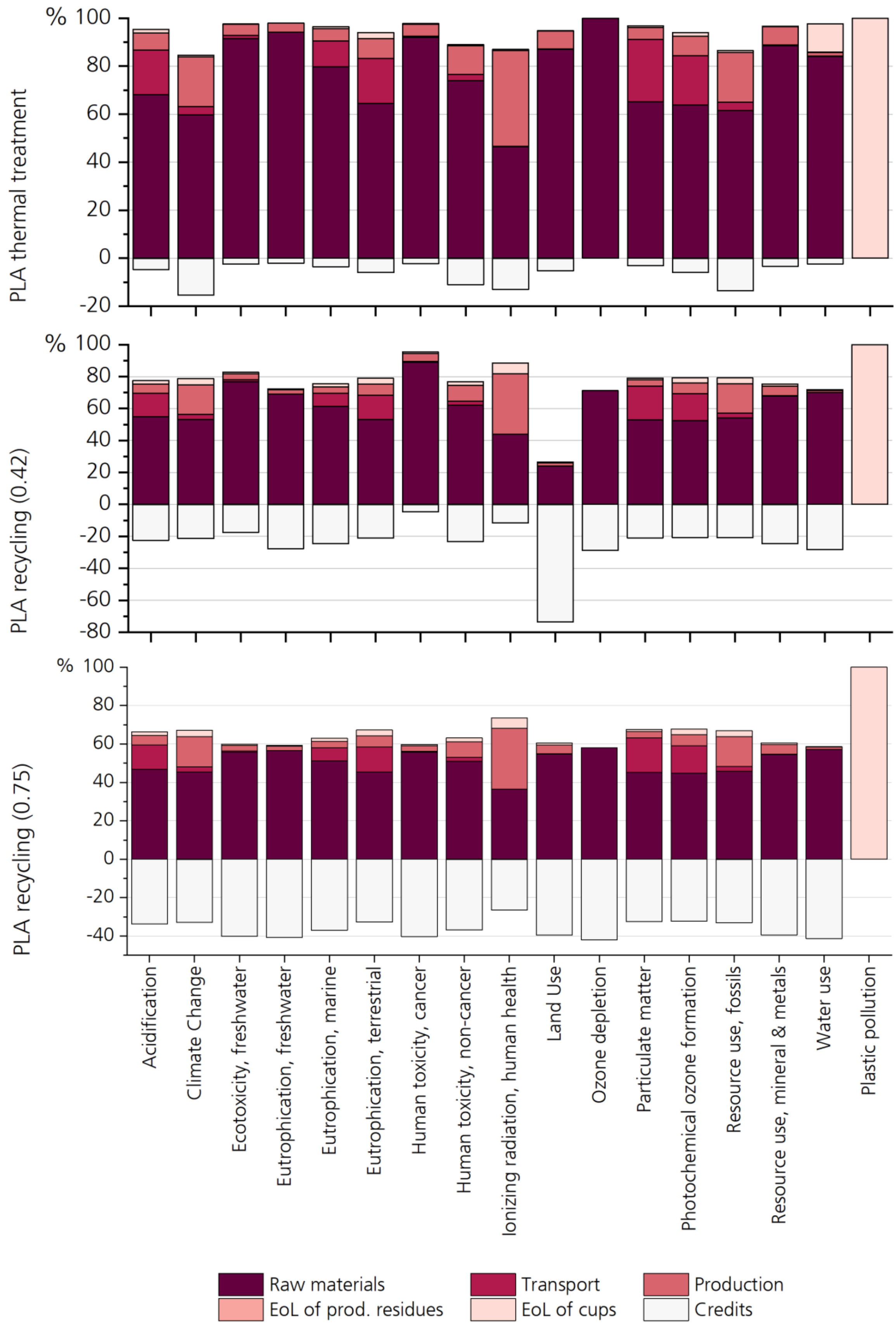


Figure S10. Impact scores of the compared scenarios of PLA cups

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