

Supplementary information

Environmental impacts of food packaging: is it all a matter of raw materials?

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S1: Inventory data

Table S 1: Inventory data of both Oriented Polypropylene Based packaging (OPPb) and Paper Based packaging (PBp)

ENERGY											
Plastic-based						Paper-based					
Electricity	Speed (lm/min)	Time (h)	Hourly consumption (kWh/h)	Consumption (kWh/1000kg)	Consumption (kWh/FU)	Electricity	Speed (lm/min)	Time (h)	Hourly consumption (kWh/h)	Consumption (kWh/1000kg)	Consumption (kWh/FU)
Printing - flexo	200	7.6	77	588.3	1.219	Printing - flexo	150	6.5	77	501.4	1.626
Lamination	150	10.2	38	387.1	0.802	/	/	/	38	/	/
Cold sealing	90	17.0	38	645.1	1.337	Cold sealing	90	10.9	38	412.4	1.337
Slithering	80	19.1	19	362.9	0.752	Slitering	80	12.2	19	232.0	0.752
Total	170	36.1	57	1008.0	4.111	Total	170	23.1	57	644.4	3.715
LPG	Speed (lm/min)	Time (h)	Hourly consumption (L/h)	Consumption (dm ³ /1000kg)	Consumption (dm ³ /FU)	LPG	Speed (lm/min)	Time (h)	Hourly consumption (L/h)	Consumption (dm ³ /1000kg)	Consumption (dm ³ /FU)
Printing - flexo	200	7.6	7	53.5	0.111	Printing - flexo	150	6.5	7	45.6	0.148
Cold sealing	90	17.0	3	50.9	0.106	Cold sealing	90	10.9	3	32.6	0.106
Total	290	24.6	10	104.4	0.216	Total	240	17.4	10	78.1	0.253

RAW MATERIALS AND WASTE											
Plastic-based						Paper-based					
Item	Specific amount (g/m ²)	Amount (kg/1000)	Waste (kg)	Amount (kg/FU)	Waste (kg/FU)	Item	Specific amount (g/m ²)	Amount (kg/1000)	Waste (kg)	Amount (kg/FU)	Waste (kg/FU)
OPP	18.2	400.4	40.0	0.8298	0.08	Paper	75.0	989.4	40.0	3.208	0.130
OPP metalised	27.3	560.6	20.0	1.1618	0.04	/	/	/	/	/	/
Cold Seal	1.0	39.8	20.0	0.0825	0.04	Cold Seal	1.0	32.7	20.0	0.106	0.065
Inks	2.0	59.6	20.0	0.1235	0.04	Inks + varnish	3.0	43.0	5.0	0.139	0.016
Adhesive	2.0	49.6	10.0	0.1028	0.02	/	/	/	/	/	/
Total	50.5	1000.0	110.0	2.0725	0.23	Total	79.0	1000	65.0	3.2	0.2

S2: Proxy processes

Table S 2A: List of proxy processes and relative unitary environmental impacts calculated with ReCiPe 2016 method (Huijbregts et al., 2017) for the environmental categories GWP: Global warming (kg CO₂ eq); ODP, Stratospheric ozone depletion (kg CFC11 eq); IRP, Ionizing radiation (kBq Co-60 eq); HOFp, Ozone formation-human health (kg NO_x eq); PMFP, Fine particulate matter formation (kg PM 2.5 eq); EOfp, Ozone formation Terrestrial ecosystems kg NO_x eq); TAP, Terrestrial acidification (kg SO₂ eq); FEP, Freshwater eutrophic. (kg P eq); MEP, Marine eutrophic. (kg N eq);

Proxy	GWP (kg CO ₂ eq)	ODP (kg CFC11 eq)	IRP (kBq Co-60 eq)	HOFp (kg NO _x eq)	PMFP (kg PM2.5 eq)	EOfp (kg NO _x eq)	TAC (kg SO ₂ eq)	FEP (kg P eq)	MEP (kg N eq)
_Electricity, medium voltage, at grid/PL U 2021 IEA	0.84	4.91*10 ⁻⁷	1.33*10 ⁻²	1.27*10 ⁻³	3.57*10 ⁻⁴	1.53*10 ⁻³	1.09*10 ⁻³	9.93*10 ⁻⁵	1.46E-05
Transport, freight, lorry 16-32 metric ton, euro5 {RER} market for transport, freight, lorry 16-32 metric ton, EURO5 APOS, U	0.17	1.24*10 ⁻⁷	4.07*10 ⁻⁶	5.15*10 ⁻⁴	1.76*10 ⁻⁴	5.16*10 ⁻⁴	4.02*10 ⁻⁴	1.82*10 ⁻⁵	1.12*10 ⁻⁶
_Adhesive	4.90	4.33*10 ⁻⁶	0.44	1.02*10 ⁻²	8.27*10 ⁻³	1.06*10 ⁻²	2.00*10 ⁻²	1.95*10 ⁻³	1.40*10 ⁻³
Methylene diphenyl diisocyanate {RER} market for methylene diphenyl diisocyanate APOS, U	5.45	6.87*10 ⁻⁶	0.72	1.18*10 ⁻²	1.02*10 ⁻²	1.25*10 ⁻²	2.55*10 ⁻²	2.75*10 ⁻³	2.05*10 ⁻³
Polyol {RoW} market for polyol APOS, U	4.06	5.17*10 ⁻⁷	3.92*10 ⁻³	7.82*10 ⁻³	5.32*10 ⁻³	7.82*10 ⁻³	1.18*10 ⁻²	7.59*10 ⁻⁴	4.36*10 ⁻⁴
Ink	1.01	1.74*10 ⁻⁷	1.28	2.13*10 ⁻³	1.11*10 ⁻³	2.14*10 ⁻³	2.92*10 ⁻³	4.96*10 ⁻⁴	4.11*10 ⁻⁵
cellulose fibre {CH} market for cellulose fibre APOS, U	0.45	3.07*10 ⁻⁷	4.21	2.24*10 ⁻³	1.27*10 ⁻³	2.25*10 ⁻³	2.86*10 ⁻³	5.19*10 ⁻⁴	1.17*10 ⁻⁴
Ethanol, without water, in 99.7% solution state, from ethylene {RER} market for ethanol, without water, in 99.7% solution state, from ethylene APOS, U	1.25	1.17*10 ⁻⁷	2.08*10 ⁻²	2.08*10 ⁻³	1.04*10 ⁻³	2.09*10 ⁻³	2.95*10 ⁻³	4.86*10 ⁻⁴	8.36*10 ⁻⁶
Cold seal	1.37	1.34*10 ⁻⁸	5.25*10 ⁻⁴	5.10*10 ⁻³	2.00*10 ⁻³	5.11*10 ⁻³	5.95*10 ⁻³	4.77*10 ⁻⁵	2.78*10 ⁻⁵
Tap water {RER} market group for APOS, U	3.43*10 ⁻⁴	1.64*10 ⁻¹⁰	1.08*10 ⁻⁴	7.85*10 ⁻⁷	5.76*10 ⁻⁷	7.87*10 ⁻⁷	1.28*10 ⁻⁶	2.59*10 ⁻⁷	2.44*10 ⁻⁸
Latex {RER} market for latex APOS, U	2.75	2.67*10 ⁻⁸	1.14*10 ⁻³	1.02*10 ⁻²	4.00*10 ⁻³	1.02*10 ⁻²	1.19*10 ⁻²	9.51*10 ⁻⁵	5.56*10 ⁻⁵
kraft paper {RER} market for kraft paper APOS, U	0.57	6.78*10 ⁻⁷	0.10	2.66*10 ⁻³	1.02*10 ⁻³	2.67*10 ⁻³	2.86*10 ⁻³	1.37*10 ⁻³	1.76*10 ⁻⁴
Polypropylene, granulate {GLO} market for APOS, U	2.36	3.14*10 ⁻⁷	4.79*10 ⁻²	4.38*10 ⁻³	2.38*10 ⁻³	4.40*10 ⁻³	6.14*10 ⁻³	4.34*10 ⁻⁴	3.57*10 ⁻⁵
_Electricity, medium voltage, at grid/EU U 2021	0.34	1.72*10 ⁻⁷	0.25	1.15*10 ⁻³	4.01*10 ⁻⁴	1.41*10 ⁻³	1.19*10 ⁻³	1.24*10 ⁻⁴	8.59*10 ⁻⁶

Table S 2B: List of proxy processes and relative unitary environmental impacts calculated with ReCiPe 2016 method (Huijbregts et al., 2017) for the environmental categories TETP, Terrestrial ecotoxicity (kg 1,4-DCB eq); FETP, Freshwater ecotoxicity (kg 1,4-DCB eq); METP, Marine ecotoxicity (kg 1,4-DCB eq); HTPc, Human carcinogenic toxicity (kg 1,4-DCB eq); HTPnc, Human non-carcinogenic toxicity (kg 1,4-DCB eq); LOP, Land use occupation (m²a crop eq); SOP, Mineral resource scarcity (kg Cu eq); FFP, Fossil resource scarcity (kg oil eq); WCP, Water consumption (m³);

Proxy	TETP (kg 1,4-DCB)	FETP (kg 1,4-DCB)	METP (kg 1,4-DCB)	HTPc (kg 1,4-DCB)	HTPnc (kg 1,4-DCB)	LOP (m ² a crop eq)	SOP (kg Cu eq)	FFP (kg oil eq)	WCP (m ³)	SS (mpts)
_Electricity, medium voltage, at grid/PL U 2021 IEA	0.10	2.16*10 ⁻⁴	3.78*10 ⁻⁴	1.86*10 ⁻⁴	1.32*10 ⁻³	1.07*10 ⁻²	4.21*10 ⁻⁴	0.24	0.23	27.40
Transport, freight, lorry 16-32 metric ton, euro5 {RER} market for transport, freight, lorry 16-32 metric ton, EURO5 APOS, U	5.90*10 ⁻²	1.54*10 ⁻⁴	2.55*10 ⁻⁴	3.11*10 ⁻⁵	1.58*10 ⁻³	1.06*10 ⁻²	2.94*10 ⁻⁴	5.70*10 ⁻²	2.86*10 ⁻⁴	4.81
_Adhesive	0.59	1.01*10 ⁻²	8.08*10 ⁻³	0.23	0.22	0.32	1.25*10 ⁻²	2.17	0.12	192.13
Methylene diphenyl diisocyanate {RER} market for methylene diphenyl diisocyanate APOS, U	0.95	1.62*10 ⁻²	1.27*10 ⁻²	0.38	0.36	0.53	2.01*10 ⁻²	2.46	0.12	231.71
Polyol {RoW} market for polyol APOS, U	3.75*10 ⁻²	7.82*10 ⁻⁴	1.13*10 ⁻³	4.36*10 ⁻⁴	6.27*10 ⁻³	7.85*10 ⁻³	1.15*10 ⁻³	1.73	0.13	132.76
Ink	0.37	1.09*10 ⁻³	1.75*10 ⁻³	1.26*10 ⁻⁴	1.04*10 ⁻²	0.82	1.23*10 ⁻²	0.72	6.51*10 ⁻²	33.26
cellulose fibre {CH} market for cellulose fibre APOS, U	0.69	2.04*10 ⁻³	3.18*10 ⁻³	2.28*10 ⁻⁴	1.49*10 ⁻²	2.55	3.46*10 ⁻²	0.12	0.19	28.34
Ethanol, without water, in 99.7% solution state, from ethylene {RER} market for ethanol, without water, in 99.7% solution state, from ethylene APOS, U	0.23	6.86*10 ⁻⁴	1.13*10 ⁻³	8.20*10 ⁻⁵	8.44*10 ⁻³	8.15*10 ⁻²	2.76*10 ⁻³	0.97	1.10*10 ⁻²	35.37
Cold seal	4.67*10 ⁻³	1.45*10 ⁻⁴	2.06*10 ⁻⁴	4.33*10 ⁻⁵	1.02*10 ⁻³	1.32*10 ⁻³	1.29*10 ⁻⁴	0.95	3.19*10 ⁻²	47.85
Tap water {RER} market group for APOS, U	5.10*10 ⁻⁵	1.58*10 ⁻⁶	2.27*10 ⁻⁶	1.55*10 ⁻⁷	6.29*10 ⁻⁶	4.55*10 ⁻⁵	3.93*10 ⁻⁶	8.95*10 ⁻⁵	1.01*10 ⁻³	5.28*10 ⁻²
Latex {RER} market for latex APOS, U	9.29*10 ⁻³	2.89*10 ⁻⁴	4.09*10 ⁻⁴	8.65*10 ⁻⁵	2.03*10 ⁻³	2.59*10 ⁻³	2.54*10 ⁻⁴	1.89	6.28*10 ⁻²	95.64
kraft paper {RER} market for kraft paper APOS, U	8.01	1.84*10 ⁻³	8.02*10 ⁻³	2.21*10 ⁻⁴	3.59*10 ⁻²	1.63*10 ⁻²	1.56*10 ⁻³	0.16	1.28*10 ⁻²	60.50
Polypropylene, granulate {GLO} market for APOS, U	9.88*10 ⁻²	2.17*10 ⁻³	3.10*10 ⁻³	1.75*10 ⁻⁴	1.41*10 ⁻²	5.66*10 ⁻²	4.78*10 ⁻³	1.71	2.09*10 ⁻²	69.79
_Electricity, medium voltage, at grid/EU U 2021	3.99*10 ⁻²	1.94*10 ⁻⁴	2.99*10 ⁻⁴	1.45*10 ⁻⁴	1.06*10 ⁻³	3.10*10 ⁻³	7.75*10 ⁻⁴	9.73*10 ⁻²	0.17	16.80

S3: Recycling inventories

Table S 3A: Paper recycling inventory adapted from De Feo et al. (2015). Functional unit = 1kg of input waste

Input	1ton of recycled paper		1kg of waste paper	
	Amount	Unit	Amount	Unit
Waste paper	1130.75	kg	1.00	kg
Tap water	6.01	m ³	5.32*10 ⁻³	m ³
Diesel	0.78	kg	6.90*10 ⁻⁴	kg
Acetic acid	3.19	kg	2.82*10 ⁻³	kg
Starch from corn and potato	24.18	kg	2.14*10 ⁻²	kg
NaCl	0.35	kg	3.10*10 ⁻⁴	kg
Aluminum polychloride	6.32	kg	5.59*10 ⁻³	kg
Biocides	0.26	kg	2.30*10 ⁻⁴	kg
Ethoxylated fatty alcol	1.09	kg	9.64*10 ⁻⁴	kg
HCl	0.13	kg	1.15*10 ⁻⁴	kg
NaOH	0.36	kg	3.18*10 ⁻⁴	kg
Retention aid	14.00	kg	1.24*10 ⁻²	kg
Adipic acid	0.22	kg	1.95*10 ⁻⁴	kg
Anti-foam agent	0.39	kg	3.45*10 ⁻⁴	kg
Coagulant	0.62	kg	5.48*10 ⁻⁴	kg
Hydrazine	0.04	kg	3.54*10 ⁻⁵	kg
Actived silca	2.59	kg	2.29*10 ⁻³	kg
Sodium silicate	0.02	kg	1.77*10 ⁻⁵	kg
Sodium hypochlorite	0.12	kg	1.06*10 ⁻⁴	kg

Table S 3B: Polypropylene mechanical recycling inventory, adapted from Shan et al. (2023). Functional unit = 1kg of input waste

Input	Amount	Unit
Electricity	0.50	kWh
Light oil	5.00*10 ⁻⁴	L
Industrial water	0.20	m ³
Tap water	0.50	m ³

S4: Pedigree matrix

Table S 4: Uncertainty values estimated by applying the pedigree matrix (Weidema and Wesnæs, 1996)

	Trasport		1. Electricity 2. Inbound Raw material 3. Ethanol combustion 4. Inbound semifinished products 5. Waste management		Electricity metalization		LPG combustion		Electricity supplier		Recycling	
	1	0	1.05	$2.38 \cdot 10^{-3}$	1.05	$2.38 \cdot 10^{-3}$	1.05	$2.38 \cdot 10^{-3}$	1.1	$9.08 \cdot 10^{-3}$	1.1	$9.08 \cdot 10^{-3}$
U1 (reliability)	1	0	1.05	$2.38 \cdot 10^{-3}$	1.05	$2.38 \cdot 10^{-3}$	1.05	$2.38 \cdot 10^{-3}$	1.1	$9.08 \cdot 10^{-3}$	1.1	$9.08 \cdot 10^{-3}$
U2 (completeness)	1	0	1	0	1.05	$2.38 \cdot 10^{-3}$	1	0	1	0	1.05	$2.38 \cdot 10^{-3}$
U3 (temporal c.)	1	0	1	0	1.03	$8.74 \cdot 10^{-4}$	1	0	1	0	1	0
U4 (geographical c.)	1	0	1	0	1.05	$2.38 \cdot 10^{-3}$	1.001	$9.99 \cdot 10^{-7}$	1	0	1.02	$3.92 \cdot 10^{-4}$
U5 (technological c.)	1	0	1	0	1.2	$3.32 \cdot 10^{-2}$	1.2	$3.32 \cdot 10^{-2}$	1	0	1.2	$3.32 \cdot 10^{-2}$
Ub	2	0.48	1.05	$2.38 \cdot 10^{-3}$	1.05	$2.38 \cdot 10^{-3}$	1.05	$2.38 \cdot 10^{-3}$	1.05	$2.38 \cdot 10^{-3}$	1.05	$2.38 \cdot 10^{-3}$
SD		2.00		1.07		1.23		1.22		1.11		1.24

S5: Life Cycle Impact Assessment results

Table S 5: Life Cycle Impact Assessment (LCIA) results and contribution analysis related to the three evaluated scenarios. Environmental impacts are calculated with the method ReCiPe 2016 (Huijbregts et al., 2017)

		Global warming potential (kg CO ₂ eq)		Stratospheric ozone depletion (kg CFC11 eq)		Ionizing radiation (kBq Co-60 eq)		Ozone formation, Human health (kg NOx eq)		Fine particulate matter formation (kg PM2.5 eq)		Ozone formation, Terrestrial ecosystems (kg NOx eq)		Terrestrial acidification (kg SO ₂ eq)	
Cradle to gate	OPP/Paper	4.81	1.84	6.88*10 ⁻⁷	2.17*10 ⁻⁶	9.72*10 ⁻²	0.33	8.90*10 ⁻³	8.53*10 ⁻³	4.78*10 ⁻³	3.28*10 ⁻³	8.97*10 ⁻³	8.56*10 ⁻³	1.24*10 ⁻²	9.19*10 ⁻³
	Other raw materials	0.74	0.29	4.68*10 ⁻⁷	2.57*10 ⁻⁸	0.20	0.18	1.73*10 ⁻³	8.36*10 ⁻⁴	1.15*10 ⁻³	3.66*10 ⁻⁴	1.78*10 ⁻³	8.38*10 ⁻⁴	2.91*10 ⁻³	1.04*10 ⁻³
	OPP/paper (energy)	3.23	1.29	1.89*10 ⁻⁶	7.96*10 ⁻⁷	5.12*10 ⁻²	0.26	4.87*10 ⁻³	3.87*10 ⁻³	1.37*10 ⁻³	8.35*10 ⁻⁴	5.88*10 ⁻³	5.10*10 ⁻³	4.19*10 ⁻³	2.36*10 ⁻³
	Electricity	3.45	3.12	2.02*10 ⁻⁶	1.82*10 ⁻⁶	5.47*10 ⁻²	4.95*10 ⁻²	5.20*10 ⁻³	4.70*10 ⁻³	1.47*10 ⁻³	1.33*10 ⁻³	6.28*10 ⁻³	5.68*10 ⁻³	4.47*10 ⁻³	4.04*10 ⁻³
	Heat	0.84	0.98	1.20*10 ⁻⁷	1.41*10 ⁻⁷	4.07*10 ⁻³	4.76*10 ⁻³	6.67*10 ⁻⁴	7.81*10 ⁻⁴	2.87*10 ⁻⁴	3.36*10 ⁻⁴	1.19*10 ⁻³	1.39*10 ⁻³	5.33*10 ⁻³	6.24*10 ⁻³
	Combustor	0.58	0.23	-1.44*10 ⁻⁷	5.34*10 ⁻⁸	-4.92*10 ⁻³	-1.99*10 ⁻³	-3.81*10 ⁻⁴	-1.31*10 ⁻⁴	-1.20*10 ⁻⁴	-4.48*10 ⁻⁵	-4.81*10 ⁻⁴	-1.72*10 ⁻⁴	-3.71*10 ⁻⁴	-1.40*10 ⁻⁴
	Transport	0.66	0.56	4.97*10 ⁻⁷	4.17*10 ⁻⁷	1.63*10 ⁻²	1.37*10 ⁻²	2.06*10 ⁻³	1.73*10 ⁻³	7.04*10 ⁻⁴	5.91*10 ⁻⁴	2.06*10 ⁻³	1.73*10 ⁻³	1.61*10 ⁻³	1.35*10 ⁻³
	Total	14.31	8.31	5.54*10⁻⁶	5.43*10⁻⁶	0.42	0.83	2.30*10⁻²	2.03*10⁻²	9.65*10⁻³	6.69*10⁻³	2.57*10⁻²	2.31*10⁻²	3.05*10⁻²	2.41*10⁻²
<i>SD</i>	0.76	0.65	7.25*10 ⁻⁷	2.35*10 ⁻⁶	0.50	0.79	1.20*10 ⁻³	1.91*10 ⁻³	4.32*10 ⁻⁴	4.85*10 ⁻⁴	1.26*10 ⁻³	2.01*10 ⁻³	1.15*10 ⁻³	1.45*10 ⁻³	
Waste to energy	EoL	4.82	-3.85	-2.61*10 ⁻⁶	1.70*10 ⁻⁶	-8.91*10 ⁻²	-6.04*10 ⁻²	-6.84*10 ⁻³	-3.89*10 ⁻³	-2.15*10 ⁻³	-1.33*10 ⁻³	-8.68*10 ⁻³	-5.16*10 ⁻³	-6.68*10 ⁻³	-4.21*10 ⁻³
	Total	19.13	4.46	2.92*10⁻⁶	7.13*10⁻⁶	0.33	0.77	1.62*10⁻²	1.64*10⁻²	7.49*10⁻³	5.36*10⁻³	1.70*10⁻²	1.80*10⁻²	2.38*10⁻²	1.99*10⁻²
Recycling	EoL Recycling	-0.40	-2.11	2.23*10 ⁻⁷	-6.79*10 ⁻⁶	-0.01	-6.09	-2.66*10 ⁻³	-5.96*10 ⁻³	-3.42*10 ⁻³	-3.73*10 ⁻³	-2.11*10 ⁻³	-5.98*10 ⁻³	-3.71*10 ⁻³	-1.09*10 ⁻²
	Total	13.91	6.20	5.76*10⁻⁶	-1.36*10⁻⁶	0.41	-5.26	2.04*10⁻²	1.44*10⁻²	6.22*10⁻³	2.96*10⁻³	2.36*10⁻²	1.71*10⁻²	2.68*10⁻²	1.32*10⁻²

		Freshwater eutrophic. (kg P eq)		Marine eutrophic. (kg N eq)		Terrestrial ecotoxicity (kg 1,4-DCB)		Freshwater ecotoxicity (kg 1,4-DCB)		Marine ecotoxicity (kg 1,4-DCB)		Human carcinogenic toxicity (kg 1,4-DCB)		Human non-carcinogenic toxicity (kg 1,4-DCB)	
Cradle to gate	OPP/Paper	8.77*10 ⁻⁴	4.40*10 ⁻³	7.30*10 ⁻⁵	5.66*10 ⁻⁴	0.21	25.71	4.35*10 ⁻³	5.90*10 ⁻³	6.22*10 ⁻³	2.57*10 ⁻²	3.72*10 ⁻⁴	7.09*10 ⁻⁴	2.83*10 ⁻²	0.11
	Other raw materials	2.66*10 ⁻⁴	7.41*10 ⁻⁵	1.52*10 ⁻⁴	8.67*10 ⁻⁶	0.11	5.22*10 ⁻²	1.18*10 ⁻³	1.68*10 ⁻⁴	1.06*10 ⁻³	2.65*10 ⁻⁴	2.35*10 ⁻²	2.21*10 ⁻⁵	2.26*10 ⁻²	2.65*10 ⁻⁴
	OPP/paper (energy)	3.82*10 ⁻⁴	5.47*10 ⁻⁴	5.63*10 ⁻⁵	4.25*10 ⁻⁵	0.39	5.39*10 ⁻²	8.33*10 ⁻⁴	1.16*10 ⁻³	1.45*10 ⁻³	1.65*10 ⁻³	7.15*10 ⁻⁴	6.80*10 ⁻⁴	5.08*10 ⁻³	7.44*10 ⁻³
	Electricity	4.08*10 ⁻⁴	3.69*10 ⁻⁴	6.01*10 ⁻⁵	5.43*10 ⁻⁵	0.42	0.38	8.89*10 ⁻⁴	8.04*10 ⁻⁴	1.55*10 ⁻³	1.40*10 ⁻³	7.64*10 ⁻⁴	6.90*10 ⁻⁴	5.42*10 ⁻³	4.90*10 ⁻³
	Heat	2.21*10 ⁻⁵	2.58*10 ⁻⁵	4.44*10 ⁻⁶	5.19*10 ⁻⁷	0.14	0.16	7.22*10 ⁻⁵	8.45*10 ⁻⁵	1.99*10 ⁻⁴	2.32*10 ⁻⁴	1.58*10 ⁻⁵	1.85*10 ⁻⁵	7.61*10 ⁻⁴	8.91*10 ⁻⁴
	Combustor	-1.22*10 ⁻⁵	-7.32*10 ⁻⁶	-4.70*10 ⁻⁶	3.61*10 ⁻⁷	0.90	-5.76*10 ⁻⁵	3.09*10 ⁻²	4.76*10 ⁻³	4.41*10 ⁻²	6.27*10 ⁻³	1.89*10 ⁻³	2.37*10 ⁻³	0.37	0.15
	Transport	7.28*10 ⁻⁵	6.11*10 ⁻⁵	4.47*10 ⁻⁶	3.75*10 ⁻⁷	0.24	0.20	6.17*10 ⁻⁴	5.18*10 ⁻⁴	1.02*10 ⁻³	8.55*10 ⁻⁴	1.25*10 ⁻⁴	1.05*10 ⁻⁴	6.34*10 ⁻³	5.32*10 ⁻³
	Total	2.02*10⁻³	5.47*10⁻³	3.41*10⁻⁴	6.76*10⁻⁴	2.40	26.55	3.89*10⁻²	1.34*10⁻²	5.56*10⁻²	3.64*10⁻²	2.74*10⁻²	4.59*10⁻³	0.44	0.28
<i>SD</i>	5.14*10 ⁻⁴	2.37*10 ⁻³	1.44*10 ⁻⁵	1.08*10 ⁻⁴	7.37	27.47	0.28	0.10	0.39	0.14	2.12*10 ⁻²	6.56*10 ⁻²	7.68	3.90	

Waste to energy	EoL	-2.19*10 ⁻⁴	-2.21*10 ⁻⁴	-8.57*10 ⁻⁵	1.16*10 ⁻⁵	16.49	1.86*10 ⁻²	0.57	0.15	0.57	0.15	3.46*10 ⁻²	7.35*10 ⁻²	6.72	4.59
	Total	1.80*10⁻³	5.25*10⁻³	2.55*10⁻⁴	6.88*10⁻⁴	18.89	26.56	0.60	0.16	0.62	0.18	6.20*10⁻²	7.81*10⁻²	7.16	4.87
Recycling	EoL Recycling	-6.32*10 ⁻⁴	-2.37*10 ⁻³	-3.40*10 ⁻⁵	-5.65*10 ⁻⁴	2.68*10 ⁻²	-0.26	-2.92*10 ⁻³	7.92*10 ⁻³	-2.92*10 ⁻³	7.92*10 ⁻³	-2.64*10 ⁻⁴	-8.42*10 ⁻⁴	-1.30*10 ⁻²	-3.36*10 ⁻²
	Total	1.38*10⁻³	3.10*10⁻³	3.07*10⁻⁴	1.11*10⁻⁴	2.43	26.28	3.60*10⁻²	2.13*10⁻²	5.27*10⁻²	4.43*10⁻²	2.71*10⁻²	3.75*10⁻³	0.42	0.25

		Land use (m ² a crop eq)		Mineral resource scarcity (kg Cu eq)		Fossil resource scarcity (kg oil eq)		Water consumption (m ³)		Single score (mpts)	
Cradle to gate	OPP/Paper	0.11	52.20	9.57*10 ⁻³	5.00*10 ⁻³	3.44	0.50	7.96*10 ⁻²	4.12*10 ⁻²	142.87	194.05
	Other raw materials	1.52*10 ⁻³	2.65*10 ⁻⁴	1.27*10 ⁻²	2.65*10 ⁻⁴	0.39	0.20	1.07*10 ⁻²	1.25*10 ⁻²	8.06	9.70
	OPP/paper (energy)	4.10*10 ⁻²	6.24*10 ⁻²	1.62*10 ⁻³	2.43*10 ⁻³	0.91	0.34	0.88	5.08*10 ⁻²	105.42	32.76
	Electricity	4.38*10 ⁻²	3.96*10 ⁻²	1.73*10 ⁻³	1.56*10 ⁻³	0.40	0.36	0.69	0.62	69.06	62.41
	Heat	6.42*10 ⁻³	7.52*10 ⁻³	9.03*10 ⁻⁵	1.06*10 ⁻⁴	0.15	0.17	8.02*10 ⁻⁵	9.39*10 ⁻⁵	17.97	21.04
	Combustor	-3.55*10 ⁻³	-1.63*10 ⁻³	-1.19*10 ⁻⁴	-3.20*10 ⁻⁵	-8.79*10 ⁻²	-3.64*10 ⁻²	-0.11	-4.67*10 ⁻²	-0.43	-3.81
	Transport	4.25*10 ⁻²	3.57*10 ⁻²	1.18*10 ⁻³	9.88*10 ⁻⁴	0.23	0.19	1.14*10 ⁻³	9.60*10 ⁻⁴	19.23	16.14
	Total	0.25	52.34	2.67*10⁻²	1.03*10⁻²	5.42	1.72	1.55	0.68	362.17	332.28
<i>SD</i>	5.82E-02	6.16	1.42*10 ⁻³	1.34*10 ⁻³	0.18	0.20	0.45	0.52	0.45	0.52	

Waste to energy	EoL	-6.24*10 ⁻²	-4.68*10 ⁻²	-2.11*10 ⁻³	-8.91*10 ⁻⁴	-1.59	-1.11	-2.07	-1.45	-6.78	-116.70
	Total	0.18	52.30	2.46*10⁻³	9.42*10⁻³	3.82	0.61	-0.52	-0.77	355.39	215.58
Recycling	EoL Recycling	-7.06*10 ⁻²	-3.37	-1.20*10 ⁻³	-5.48*10 ⁻²	-3.68*10 ⁻³	-0.47	0.61	-0.47	-17.70	-99.65
	Total	0.18	48.98	2.55*10⁻²	-4.45*10⁻²	5.42	1.26	2.16	0.21	344.47	232.63

S6: Sensitivity analysis

Table S 6: Sensitivity analysis results related to the two packaging alternatives Oriented Polypropylene Based (OPPb) and Paper Based (PBp) packagings when produced with electricity deriving from Polish (PL) and European (EU) mixes. Environmental impacts estimated with the ReCiPe 2016 method (Huijbregts et al., 2017). *The percentage reported in the blue columns represent the relative differences between the two electricity mix scenarios (the percentage is red colored when the potential impacts are higher in the European mix scenario).* GWP: Global warming (kg CO₂ eq); ODP, Stratospheric ozone depletion (kg CFC11 eq); IRP, Ionizing radiation (kBq Co-60 eq); HOFp, Ozone formation-human health (kg NO_x eq); PMFP, Fine particulate matter formation (kg PM 2.5 eq); EOFp, Ozone formation Terrestrial ecosystems kg NO_x eq); TAP, Terrestrial acidification (kg SO₂ eq); FEP, Freshwater eutrophic. (kg P eq); MEP, Marine eutrophic. (kg N eq); TETP, Terrestrial ecotoxicity (kg 1,4-DCB eq); FETP, Freshwater ecotoxicity (kg 1,4-DCB eq); METP, Marine ecotoxicity (kg 1,4-DCB eq); HTPc, Human carcinogenic toxicity (kg 1,4-DCB eq); HTPnc, Human non-carcinogenic toxicity (kg 1,4-DCB eq); LOP, Land use occupation (m²a crop eq); SOP, Mineral resource scarcity (kg Cu eq); FFP, Fossil resource scarcity (kg oil eq); WCP, Water consumption (m³).

	OPPb, direct (PL)	OPPb, direct (EU)	Δ%	PBp, direct (PL)	PBp, direct (EU)	Δ%
GWP (kg CO ₂ eq)	14.31	12.24	14.5%	8.31	6.43	22.6%
ODP (kg CFC11 eq)	5.54*10 ⁻⁶	4.22*10 ⁻⁶	23.7%	5.43*10 ⁻⁶	4.24*10 ⁻⁶	21.8%
IRP (kBq Co-60 eq)	0.42	1.39	69.6%	0.83	1.70	51.2%
HOFp (kg NO _x eq)	2.30*10 ⁻²	2.26*10 ⁻²	2.1%	2.03*10 ⁻²	1.99*10 ⁻²	2.2%
PMFP (kg PM2.5 eq)	9.65*10 ⁻³	9.83*10 ⁻³	1.8%	9.69*10 ⁻³	9.85*10 ⁻³	2.4%
EOFp (kg NO _x eq)	2.57*10 ⁻²	2.52*10 ⁻²	2.0%	2.31*10 ⁻²	2.27*10 ⁻²	2.0%
TAC (kg SO ₂ eq)	3.05*10 ⁻²	3.09*10 ⁻²	1.3%	2.41*10 ⁻²	2.45*10 ⁻²	1.5%
FEP (kg P eq)	2.02*10 ⁻³	2.12*10 ⁻³	4.8%	5.47*10 ⁻³	5.56*10 ⁻³	1.6%
MEP (kg N eq)	3.41*10 ⁻⁴	3.16*10 ⁻⁴	7.3%	6.76*10 ⁻⁴	6.54*10 ⁻⁴	3.3%
TETP (kg 1,4-DCB)	2.40	2.14	10.6%	26.55	26.32	0.9%
FETP (kg 1,4-DCB)	3.89*10 ⁻²	3.88*10 ⁻²	0.2%	1.34*10 ⁻²	1.33*10 ⁻²	0.6%
METP (kg 1,4-DCB)	5.56*10 ⁻²	5.53*10 ⁻²	0.6%	3.64*10 ⁻²	3.61*10 ⁻²	0.8%
HTPc (kg 1,4-DCB)	2.74*10 ⁻²	2.72*10 ⁻²	0.6%	4.59*10 ⁻³	4.44*10 ⁻³	3.3%
HTPnc (kg 1,4-DCB)	0.44	0.43	0.2%	0.28	0.28	0.3%
LOP (m ² a crop eq)	0.25	0.21	12.6%	52.34	52.32	0.1%
SOP (kg Cu eq)	2.67*10 ⁻²	2.82*10 ⁻²	5.2%	1.03*10 ⁻²	1.16*10 ⁻²	11.3%
FFP (kg oil eq)	5.60	5.42	3.2%	2.04	1.72	15.4%
WCP (m ³)	1.79	1.55	13.5%	0.90	0.68	24.1%
SS (mpts)	397.69	362.17	8.9%	361.95	332.28	8.2%

S7: Comparison by the environmental impacts estimated according to the proxy and the estimated composition of waste

Table S 7: Difference between the environmental impacts estimated by drawing the inventory of the proxy processes (PWC) and the inventory elaborated with the laboratory results (EWC) of the Oriented Polypropylene (OPPb) and of the pape basedr packaging (PBp). GWP: Global warming (kg CO₂ eq); ODP, Stratospheric ozone depletion (kg CFC11 eq); IRP, Ionizing radiation (kBq Co-60 eq); HOFp, Ozone formation-human health (kg NO_x eq); PMFP, Fine particulate matter formation (kg PM 2.5 eq); EOFp, Ozone formation Terrestrial ecosystems kg NO_x eq); TAP, Terrestrial acidification (kg SO₂ eq); FEP, Freshwater eutrophic. (kg P eq); MEP, Marine eutrophic. (kg N eq); TETP, Terrestrial ecotoxicity (kg 1,4-DCB eq); FETP, Freshwater ecotoxicity (kg 1,4-DCB eq); METP, Marine ecotoxicity (kg 1,4-DCB eq); HTPc, Human carcinogenic toxicity (kg 1,4-DCB eq); HTPnc, Human non-carcinogenic toxicity (kg 1,4-DCB eq); LOP, Land use occupation (m²a crop eq); SOP, Mineral resource scarcity (kg Cu eq); FFP, Fossil resource scarcity (kg oil eq); WCP, Water consumption (m³)

OPPp	EWC_{OPPb}	PWC_{OPPb}	Δ%	PBp	EWC_{PBp}	PWC_{PBp}	Δ%
GWP	2.55	2.56	0.2%	GWP	3.48*10 ⁻²	3.48*10 ⁻²	0.0%
ODP	1.86*10 ⁻⁷	1.84*10 ⁻⁷	98.9%	ODP	6.23*10 ⁻⁷	6.23*10 ⁻⁷	0.0%
IRP	3.76*10 ⁻⁴	2.42*10 ⁻⁴	35.5%	IRP	5.70*10 ⁻⁴	5.70*10 ⁻⁴	0.0%
HOFp	3.93*10 ⁻⁴	4.02*10 ⁻⁴	2.2%	HOFp	3.31*10 ⁻⁴	3.31*10 ⁻⁴	0.0%
PMFP	5.51*10 ⁻⁵	5.92*10 ⁻⁵	7.0%	PMFP	5.59*10 ⁻⁵	5.59*10 ⁻⁵	0.0%
EOFp	3.96*10 ⁻⁴	4.05*10 ⁻⁴	2.3%	EOFp	3.34*10 ⁻⁴	3.34*10 ⁻⁴	0.0%
TAC	1.64*10 ⁻⁴	1.72*10 ⁻⁴	4.5%	TAC	1.55*10 ⁻⁴	1.55*10 ⁻⁴	0.0%
FEP	5.97*10 ⁻⁵	6.56*10 ⁻⁵	9.0%	FEP	4.01*10 ⁻⁵	4.01*10 ⁻⁵	0.0%
MEP	3.91*10 ⁻⁶	3.96*10 ⁻⁶	1.1%	MEP	1.27*10 ⁻⁵	1.27*10 ⁻⁵	0.0%
TETP	3.18*10 ⁻²	7.46	99.6%	TETP	5.55*10 ⁻²	7.63*10 ⁻²	40.4%
FETP	1.31*10 ⁻³	0.18	99.3%	FETP	4.75*10 ⁻⁴	2.28*10 ⁻²	97.9%
METP	1.78*10 ⁻³	0.26	99.3%	METP	6.54*10 ⁻⁴	3.00*10 ⁻²	97.8%
HTPc	2.66*10 ⁻³	1.28*10 ⁻²	79.3%	HTPc	2.95*10 ⁻³	1.14*10 ⁻²	74.1%
HTPnc	1.17*10 ⁻²	1.46	99.2%	HTPnc	1.08*10 ⁻²	0.70	98.5%
LOP	2.11*10 ⁻⁴	3.03*10 ⁻⁴	30.5%	LOP	2.96*10 ⁻⁴	2.96*10 ⁻⁴	0.0%
SOP	1.69*10 ⁻⁴	1.88*10 ⁻⁴	10.0%	SOP	1.65*10 ⁻⁴	1.65*10 ⁻⁴	0.0%
FFP	4.33*10 ⁻³	5.65*10 ⁻³	23.3%	FFP	4.73*10 ⁻³	4.73*10 ⁻³	0.0%
WCP	4.85*10 ⁻⁴	1.46*10 ⁻⁴	69.8%	WCP	5.78*10 ⁻⁴	5.78*10 ⁻⁴	0.0%
SS	42.24	48.50	12.9%	SS	1.41	4.51	68.7%

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