

S1. Application of the LiSET method to the choice of the process parameters for the paper recycling regionalization tool (Hung, Ellingsen, & Majeau-Bettez, 2018)

Step 1: Decomposing the total life cycle causal connections by separating direct and embodied impacts

Direct impact sources (“arise from direct exchanges between the technology under evaluation and the environment”):

- Water input of the paper recycling process
- Direct water emissions of the process (U.S. Environmental Protection Agency, 2003)
 - o Biological oxygen demand
 - o Chemical oxygen demand
 - o Dissolved solids
 - o Pb
 - o Hg
 - o Ni
 - o Sulfide
 - o Suspended solids
 - o Zn
 - o Al
 - o Ammonia
 - o Fe
 - o Nitrate
 - o Oil
 - o Phenol
- Direct air emissions of the process (the majority of direct air emissions can be deduced from emission factors linked to energy production processes (U.S. Environmental Protection Agency, 2003, 2009))

Embodied impact sources (“mediated through the value chains supplying the technology during manufacturing, operation, or disposal of the technology”):

- Transport of wastepaper to the recycling facility
- Production of the recycling facility (infrastructure and equipment)
- Virgin material input production
- Chemicals production
- Generation of the electricity required for the recycling process
- Generation of the energy required for the recycling process

- Treatment of solid waste
- Substitution of virgin material

Step 2: Categorize direct exchanges as material emissions of pollutants and energy releases in the form of heat

All the direct impact sources are material emissions of pollutants (water input is considered as a resource use).

Step 3: Categorize the embodied impact sources into value chains of material inputs, energy in the form of electricity or heat requirement and services

- Transport of wastepaper to the recycling facility: service
- Production of the recycling facility (infrastructure and equipment): material input
- Virgin material input production: material input
- Chemicals production: material input
- Generation of the electricity required for the recycling process: energy input
- Generation of the energy required for the recycling process: energy input
- Treatment of solid waste: material input
- Substitution of virgin material: material input

Step 4: Translate these decomposition terms into evaluable metrics and distinguish case-specific and regionalizable metrics

Table 1: Translation of the impact sources into evaluable metrics

Impact source	Evaluable metric(s)	Case-specific or regionalizable parameter? (Case-specific parameters need to be provided directly by the LCA practitioner, because they do not depend on the region of the recycling process.)
Water input of the paper recycling process	Water use in the paper recycling process (kg/ kg wastepaper recycled)	Regionalizable

Direct water emissions of the process (U.S. Environmental Protection Agency, 2003) ○ Biological oxygen demand ○ Chemical oxygen demand ○ Dissolved solids ○ Pb ○ Hg ○ Ni ○ Sulfide ○ Suspended solids ○ Zn ○ Al ○ Ammonia ○ Fe ○ Nitrate ○ Oil ○ Phenol	Water output (kg/ kg wastepaper recycled): this parameter can be determined from the water input and a mass balance Direct water emissions of the process (kg/ kg water output)	Regionalizable
Direct air emissions of the process (the majority of direct air emissions can be deduced from emission factors linked to energy production processes (U.S. Environmental Protection Agency, 2003, 2009))	Because the direct air emissions are directly calculated from the energy production processes (another impact source mentioned), this parameter is excluded at this step.	-
Transport of wastepaper to the recycling facility	Transport mode (train, truck, plane, boat) Transport distance (t*km of transport/kg wastepaper recycled)	Case-specific (the transport mode and the distance between the initial location of the wastepaper and the location of the recycling facility needs to be provided by the user)
Production of the recycling facility (infrastructure and equipment)	The impact of the production of the recycling facility is considered negligible and is excluded at this step.	-
Virgin material input production	Virgin material input (kg/ kg wastepaper recycled)	Regionalizable
Chemicals production	Chemicals mix Chemicals use (kg/ kg wastepaper recycled)	Regionalizable

Generation of the electricity required for the recycling process	Electricity mix Electricity use (kg/ kg wastepaper recycled)	Regionalizable
Generation of the energy required for the recycling process	Energy mix Energy use (kg/kg wastepaper recycled)	Regionalizable
Treatment of solid waste	Solid waste composition (the solid waste categories were divided into sludge, newspaper, mixed paper, old corrugated cardboard, polyethylene terephthalate, high-density polyethylene, plastic film, glass, metal and other) Solid waste treatment mix – Sludge Solid waste treatment mix – Other solid waste Efficiency - Solid waste production (kg/ kg wastepaper recycled): this parameter can be derived from the efficiency of the recycling process and a mass balance calculation	The solid waste composition is case-specific and derived from the composition of the wastepaper input, provided by the user. The other parameters (solid waste treatment mix and efficiency) are regionalizable
Substitution of virgin material	Efficiency - Quantity of recycled product (kg/ kg wastepaper recycled): this parameter can be derived from the efficiency of the recycling process and a mass balance calculation (there is already a process parameter for efficiency) Substitution ratio	Regionalizable

The evaluable metrics in blue in Table 1 have been selected as process parameters to regionalize. The ones in green were defined as input data to be provided by the user of the paper recycling regionalization tool. The ones in red were not considered in the tool, because they were considered negligible or could be calculated from another chosen process parameter. For example, solid waste and wastewater productions can respectively be calculated from efficiency data and water input using mass balance, and the majority of direct air emissions can be deduced from emission factors linked to energy production processes (U.S. Environmental Protection Agency, 2003, 2009)

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S2. Sensitivity analysis bounds and results

S2.1 Sensitivity analysis bounds

Table 2: Lower bound, upper bound and references for sensitivity analysis on process parameters

Process parameters to test in sensitivity analysis	Lower bound	Lower bound source	Upper bound	Upper bound source	Unit (per kg of paper produced)
Efficiency	6,00E-01	(Confederation of Indian Industry, 2020)	1,10E+00	Ecoinvent 3.7.1 (global, not used in regionalized model)	
Electricity use – Newsprint	3,14E-01	(Wang, Templer, & Murphy, 2012)	1,60E+00	Ecoinvent 3.7.1	kWh
Electricity use – Graphic paper	4,69E-01	(Hong & Li, 2012)	1,07E+00	(Wang et al., 2012)	kWh
Electricity use – Corrugated cardboard	1,63E-01	Ecoinvent 3.7.1	5,72E-01	(U.S. Environmental Protection Agency, 2003)	kWh
Energy use – Newsprint	1,21E-03	(U.S. Environmental Protection Agency, 2003)	1,01E-02	(Christensen & Damgaard, 2010)	GJ
Energy use – Graphic paper	2,16E-03	(Confederation of Indian Industry, 2020)	8,60E-03	(Wang et al., 2012)	GJ
Energy use – Corrugated cardboard	1,90E-03	(Christensen & Damgaard, 2010)	8,47E-03	(Sun, Wang, Shi, & Klemeš, 2018; U.S. Environmental Protection Agency, 2003)	GJ
Chemicals' use – Newsprint	7,67E-02	Ecoinvent 3.7.1	9,00E-02	(Christensen & Damgaard, 2010)	kg
Chemicals' use – Graphic paper	2,52E-01	Ecoinvent 3.7.1	1,27E+00	(Hong & Li, 2012)	kg
Chemicals' use – Corrugated cardboard	4,20E-02	(Wang et al., 2012)	2,73E-01	(Confederation of Indian Industry, 2020)	kg
Water use - Newsprint	2,11E-02	(Christensen & Damgaard, 2010)	7,11E-02	Ecoinvent 3.7.1	m ³
Water use – Graphic paper	3,20E-03	(Hong & Li, 2012)	1,70E-02	(Wang et al., 2012)	m ³
Water use – Corrugated cardboard	3,80E-03	(Christensen & Damgaard, 2010)	6,14E-03	(FEFCO Corrugated Packaging, 2017)	m ³
BOD water emission - Newsprint	3,30E-04	Ecoinvent 3.7.1	6,47E-03	Ecoinvent 3.7.1	kg
BOD water emission – Graphic paper	9,98E-05	(U.S. Environmental Protection Agency, 2003)	3,16E-03	(Devi, Yadav, Shihua, Singh, & Belagali, 2011)	kg
BOD water emission – Corrugated cardboard	1,60E-04	(Arena, Mastellone, Perugini, & Clift, 2004)	2,70E-03	(U.S. Environmental Protection Agency, 2003)	kg
COD water emission – Newsprint	3,27E-03	Ecoinvent 3.7.1	7,50E-03	Ecoinvent 3.7.1	kg
COD water emission – Graphic paper	4,52E-04	(Devi et al., 2011)	2,33E-03	Ecoinvent 3.7.1	kg
COD water emission – Corrugated cardboard	0,00E+00	(Christensen & Damgaard, 2010)	2,22E-02	(MDDELCC, 2016)	kg
DS water emission – Newsprint	0,00E+00	Ecoinvent 3.7.1	1,37E-02	(U.S. Environmental Protection Agency, 2003)	kg
DS water emission – Graphic paper	0,00E+00	Ecoinvent 3.7.1	3,56E-03	(Devi et al., 2011)	kg
DS water emission – Corrugated cardboard	0,00E+00	Ecoinvent 3.7.1	5,90E-01	(U.S. Environmental Protection Agency, 2003)	kg
Pb water emission – Newsprint	0,00E+00	Ecoinvent 3.7.1	3,86E-11	(Wang et al., 2012)	kg
Pb water emission – Graphic paper	0,00E+00	Ecoinvent 3.7.1	4,80E-08	Hypothesis from corrugated cardboard process in (Arena et al., 2004)	kg

Pb water emission – Corrugated cardboard	3,64E-08	Ecoinvent 3.7.1	4,80E-08	(Arena et al., 2004)	kg
Hg water emission - Newsprint	0,00E+00	Ecoinvent 3.7.1 from Ecoinvent 3.7.1	5,99E-11	(U.S. Environmental Protection Agency, 2003)	kg
Hg water emission corrugated cardboard	1,00E-09	(Arena et al., 2004)	4,10E-09	Ecoinvent 3.7.1	kg
Ni water emission - Newsprint	0,00E+00	Ecoinvent 3.7.1	2,30E-08	(U.S. Environmental Protection Agency, 2003)	kg
Ni water emission - Graphic paper	0,00E+00	Ecoinvent 3.7.1	2,30E-08	Hypothesis from newsprint process in (U.S. Environmental Protection Agency, 2003)	kg
Ni water emission corrugated cardboard	0,00E+00	Ecoinvent 3.7.1	2,13E-08	Ecoinvent 3.7.1	kg
Sulfide water emission - Newsprint	0,00E+00	Ecoinvent 3.7.1	1,41E-09	U.S. Environmental Protection Agency, 2003)	kg
Sulfide water emission – Corrugated cardboard	0,00E+00	Ecoinvent 3.7.1	1,77E-04	U.S. Environmental Protection Agency, 2003)	kg
SS water emission - Newsprint	0,00E+00	Ecoinvent 3.7.1	8,44E-03	U.S. Environmental Protection Agency, 2003)	kg
SS water emission - Graphic paper	2,75E-04		3,07E-04	U.S. Environmental Protection Agency, 2003)	kg
SS water emission corrugated cardboard	0,00E+00	Ecoinvent 3.7.1	2,69E-03	U.S. Environmental Protection Agency, 2003)	kg
Zn water emission - Newsprint	0,00E+00	Ecoinvent 3.7.1	2,09E-07	U.S. Environmental Protection Agency, 2003)	kg
Zn water emission - Graphic paper	0,00E+00	Ecoinvent 3.7.1	8,00E-07	(Devi et al., 2011)	kg
Zn water emission – Corrugated cardboard	1,00E-07	(FEFCO Corrugated Packaging, 2017)	2,49E-06	U.S. Environmental Protection Agency, 2003)	kg
Al water emission	0,00E+00	Ecoinvent 3.7.1	9,07E-05	U.S. Environmental Protection Agency, 2003)	kg
Ammonia water emission	0,00E+00	Ecoinvent 3.7.1	4,85E-06	U.S. Environmental Protection Agency, 2003)	kg
Fe water emission - Graphic paper	0,00E+00	Ecoinvent 3.7.1	1,00E-06	U.S. Environmental Protection Agency, 2003)	kg
Fe water emission – Corrugated cardboard	0,00E+00	Ecoinvent 3.7.1	2,22E-04	U.S. Environmental Protection Agency, 2003)	kg
Nitrates water emission	0,00E+00	Ecoinvent 3.7.1	4,99E-09	U.S. Environmental Protection Agency, 2003)	kg
Oil water emission	0,00E+00	Ecoinvent 3.7.1	2,31E-04	U.S. Environmental Protection Agency, 2003)	kg
Phenol water emission	0,00E+00	Ecoinvent 3.7.1	2,13E-06	U.S. Environmental Protection Agency, 2003)	kg
Phosphates water emission – Corrugated cardboard	0,00E+00	Ecoinvent 3.7.1	6,30E-05	U.S. Environmental Protection Agency, 2003)	kg
Sludge treatment process	Landfarming	Ecoinvent 3.7.1	Landfill	Ecoinvent 3.7.1	
Other solid wastes treatment process	Incineration with energy recovery	Ecoinvent 3.7.1	Open dump	Ecoinvent 3.7.1	

Electricity mix	Québec, Canada	Ecoinvent 3.7.1	India	Ecoinvent 3.7.1	
Energy mix	Biomass	Ecoinvent 3.7.1	Coal	Ecoinvent 3.7.1	
Substitution ratio	100%	Ecoinvent 3.7.1	62%	(Viau et al., 2020)	
Virgin material input	0%	Ecoinvent 3.7.1	100%	Ecoinvent 3.7.1	

S2.2 Sensitivity analysis results

S2.2.1 Summary

Table 3: Sensitivity analysis on parameters results

Analysis number	Analysis name	Lower bound	Upper bound	Unit	Threshold	Maximum impact variation result (V)
1	Efficiency	6,00E-01	1,10E+00		15%	148%
2	Electricity use – Newsprint	3,14E-01	1,60E+00	kWh/kg	15%	190%
3	Electricity use – Graphic paper	4,69E-01	1,07E+00	kWh/kg	15%	169%
4	Electricity use – Corrugated cardboard	1,63E-01	5,72E-01	kWh/kg	15%	197%
5	Energy use – Newsprint	1,21E-03	1,01E-02	GJ/kg	15%	130%
6	Energy use – Graphic paper	2,16E-03	8,60E-03	GJ/kg	15%	44%
7	Energy use – Corrugated cardboard	1,90E-03	8,47E-03	GJ/kg	15%	187%
8	Chemicals’ use – Newsprint	7,67E-02	9,00E-02	kg/kg	15%	60%
9	Chemicals’ use – Graphic paper	2,52E-01	1,27E+00	kg/kg	15%	197%
10	Chemicals’ use – Corrugated cardboard	4,20E-02	2,73E-01	kg/kg	15%	194%
11	Water use - Newsprint	2,00E-03	1,42E-02	m3/kg	15%	92%
12	Water use – Graphic paper	6,40E-04	3,40E-03	m3/kg	15%	24%
13	Water use – Corrugated cardboard	7,60E-04	2,00E-03	m3/kg	15%	179%
14	BOD water emission - Newsprint	3,30E-04	6,47E-03	kg/kg	15%	0%
15	BOD water emission – Graphic paper	9,98E-05	3,16E-03	kg/kg	15%	0%
16	BOD water emission – Corrugated cardboard	1,60E-04	2,70E-03	kg/kg	15%	0%
17	COD water emission – Newsprint	3,27E-03	7,50E-03	kg/kg	15%	0%
18	COD water emission – Graphic paper	4,52E-04	2,33E-03	kg/kg	15%	0%
19	COD water emission – Corrugated cardboard	0,00E+00	2,22E-02	kg/kg	15%	0%
20	DS water emission – Newsprint	0,00E+00	1,37E-02	kg/kg	15%	0%
21	DS water emission – Graphic paper	0,00E+00	3,56E-03	kg/kg	15%	0%
22	DS water emission – Corrugated cardboard	0,00E+00	5,90E-01	kg/kg	15%	0%
23	Pb water emission – Newsprint	0,00E+00	3,86E-11	kg/kg	15%	0%
24	Pb water emission – Graphic paper	0,00E+00	4,80E-08	kg/kg	15%	0%
25	Pb water emission – Corrugated cardboard	3,64E-08	4,80E-08	kg/kg	15%	1%
26	Hg water emission - Newsprint	0,00E+00	5,99E-11	kg/kg	15%	0%
27	Hg water emission corrugated cardboard	1,00E-09	4,10E-09	kg/kg	15%	11%
28	Ni water emission - Newsprint	0,00E+00	2,30E-08	kg/kg	15%	0%

29	Ni water emission - Graphic paper	0,00E+00	2,30E-08	kg/kg	15%	0%
30	Ni water emission corrugated cardboard	0,00E+00	2,13E-08	kg/kg	15%	2%
31	Sulfide water emission - Newsprint	0,00E+00	1,41E-09	kg/kg	15%	0%
32	Sulfide water emission – Corrugated cardboard	0,00E+00	1,77E-04	kg/kg	15%	0%
33	SS water emission - Newsprint	0,00E+00	8,44E-03	kg/kg	15%	0%
34	SS water emission - Graphic paper	2,75E-04	3,07E-04	kg/kg	15%	0%
35	SS water emission corrugated cardboard	0,00E+00	2,69E-03	kg/kg	15%	0%
36	Zn water emission - Newsprint	0,00E+00	2,09E-07	kg/kg	15%	0%
37	Zn water emission - Graphic paper	0,00E+00	8,00E-07	kg/kg	15%	1%
38	Zn water emission – Corrugated cardboard	1,00E-07	2,49E-06	kg/kg	15%	11%
39	Al water emission	0,00E+00	9,07E-05	kg/kg	15%	0%
40	Ammonia water emission	0,00E+00	4,85E-06	kg/kg	15%	5%
41	Fe water emission - Graphic paper	0,00E+00	1,00E-06	kg/kg	15%	0%
42	Fe water emission – Corrugated cardboard	0,00E+00	2,22E-04	kg/kg	15%	0%
43	Nitrates water emission	0,00E+00	4,99E-09	kg/kg	15%	0%
44	Oil water emission	0,00E+00	2,31E-04	kg/kg	15%	0%
45	Phenol water emission	0,00E+00	2,13E-06	kg/kg	15%	0%
46	Phosphates water emission – Corrugated cardboard	0,00E+00	6,30E-05	kg/kg	15%	67%
47	Sludge treatment process	Landfarming	Landfill		15%	181%
48	Other solid wastes treatment process	Incineration with energy recovery	Open dump		15%	18%
49	Electricity mix	Québec, Canada	India		15%	144%
50	Energy mix	Biomass	Coal		15%	124%
51	Substitution ratio	100%	62%		15%	199%
52	Virgin material input	0%	100%		15%	198%

S2.2.2 Graph

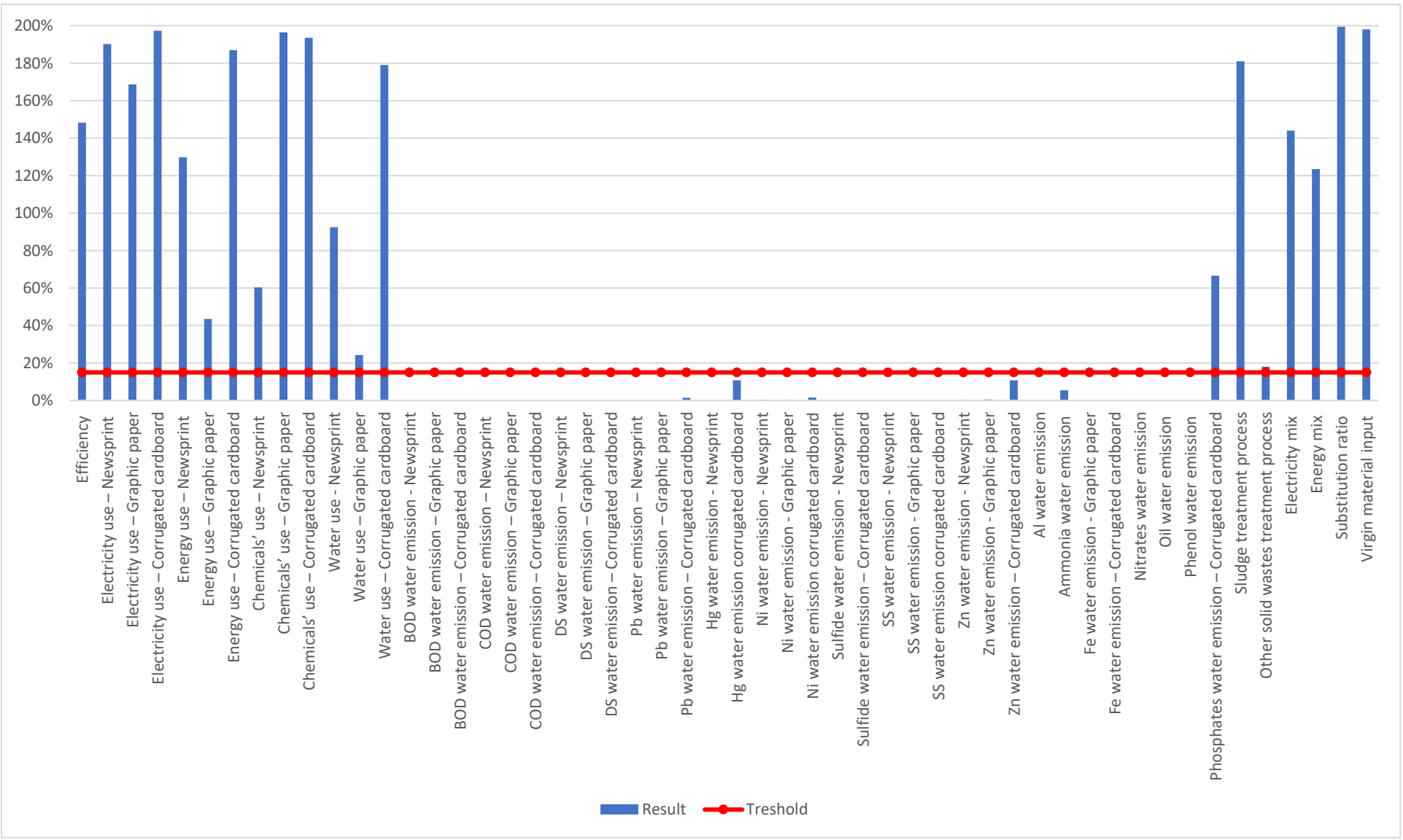


Figure 1: Sensitivity analysis on parameters results

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S3. Inventory data quality

The ISO 3166-1 alpha 3 country codes related to each indicator score are used.

Table 4: Inventory data quality

Independent process parameter	LCA impacts sensitivity	Geographical correlation – Economic development indicator score	Geographical correlation – Resources and infrastructure indicator score	Technological correlation – Paper recycling technology indicator score	Technological correlation – Specific paper grade indicator score	Sensitivity analysis recommended on results
Efficiency	Yes	1 : DNK, IND, CHE, CHN, ITA 2 : North America 3-4 : Others		2 : All countries		No
Electricity use – Newsprint	Yes	1: DNK, CHE 2: North America 3-4: Others			2: All countries	No
Electricity use – Graphic paper	Yes	1: DNK, CHN 2: North America 3-4: Others			2: All countries	No
Electricity use – Corrugated cardboard	Yes	1: DNK, ITA 2: North America 3-4: Others			2: All countries	No
Electricity mix	Yes		1: All countries	2 : All countries		No
Energy use – Newsprint	Yes	1: DNK, IND, CHE 2: North America 3-4: Others			2: All countries	No
Energy use – Graphic paper	Yes	1: India, DNK 2: North America 3-4: Others			2: All countries	No
Energy use – Corrugated cardboard	Yes	1: BRA, ESP, PRT, NOR, ITA, DNK, IND 2: North America 3-4: Others			2: All countries	No
Energy mix	Yes		1: All countries	4: Available countries in IEA database or in literature 5: Others		Yes
Chemicals' use – Newsprint	Yes	1: DNK, IND, CHE 3-4: Others			2: All countries	No
Chemicals' use – Graphic paper	Yes	1: IND, DNK, CHN 3-4: Others			2: All countries	No
Chemicals' use – Corrugated cardboard	Yes	1: ITA, DNK, IND 3-4: Others			2: All countries	No
Water use – Newsprint	Yes	1: DNK, CHE 3-4: Others			2: All countries	No
Water use – Graphic paper	Yes	1: IND, DNK, CHN 3-4: Others			2: All countries	No

Water use – Corrugated cardboard	Yes	1: ITA, DNK 3-4: Others			2: All countries	No
Direct water emissions – Newsprint	No for all emissions					
Direct water emissions – Graphic paper	No for all emissions					
Direct water emissions – Corrugated cardboard	No for all emissions except Phosphate	5: All countries			2: All countries	Yes
Sludge treatment mix	Yes		1: All countries	2: CAN, USA, IND 5: Others		Yes
Other solid wastes treatment mix	Yes		1: All countries	5: All countries		Yes
Virgin material input	Yes			2: All countries		Yes
Substitution ratio	Yes			2: All countries		Yes

S4. Regionalization results

The process parameters regionalization results are available in the repository cited at the end of this document.

S5. List of activities

Table 5: Life-cycle inventory used for the regionalized paper recycling LCA tool

Parameter	Activity / Product	Geography	Unit	Regionalized value estimation methods for 1 kg of wastepaper recycled <i>Indicator scores abbreviations:</i> <i>G: Geographical correlation</i> <i>T: Technological correlation</i> <i>Example:</i> <i>G1-T2 means geographical correlation indicator score is 1 and technological correlation indicator score is 2.</i>	Assumptions
Waste paper input (with impurities) (<i>I</i>) – Newsprint	Market for waste paper, sorted / Waste paper, sorted	GLO	kg	1 kg	Value of the functional unit.
Waste paper input (with impurities) (<i>I</i>) – Graphic paper	Market for waste paper, unsorted / Waste paper, unsorted	RoW	kg		
Waste paper input (with impurities) (<i>I</i>) – Corrugated cardboard	Market for waste paperboard, sorted / Waste paperboard, unsorted	GLO	kg		
Virgin material input (V_{input})	Choice in template between: Market for sulfate pulp, bleached / Sulfate pulp, bleached Market for sulfate pulp, unbleached / Sulfate pulp, unbleached Market for pulpwood, softwood, measured as solid wood under bark / Pulpwood, softwood, measured as solid wood under bark	RoW	kg	Virgin material input (V_{input}): $V_{input} = \frac{(1 - v)}{v \times U^{rec}}$ Recyclable fraction of bale (U^{rec}): User defined (input parameter) Ratio virgin input/total input without impurities (v): Regionalizable process parameter with a default value of 0 (T2)	Softwood has a density of 522,5 kg/m ³ . The virgin input/total input without impurities ratio (v) is assumed to be 0, but a sensitivity analysis on this parameter is recommended.
Electricity	Most specific market is chosen for specified geography (The following order is preferred, based on existing paper recycling models in ecoinvent): 1. Market for electricity, medium voltage / Electricity, medium voltage 2. Market group for electricity, medium voltage / Electricity, medium voltage 3. Market for electricity, high voltage / Electricity, high voltage 4. Market group for electricity, high voltage / Electricity, high voltage 5. Market for electricity, low voltage / Electricity, low voltage	Most specific geography is chosen.	kWh	- G1-T2: DNK (Christensen & Damgaard, 2010; Wang et al., 2012); IND (Confederation of Indian Industry, 2020); CHE (Ecoinvent 3.7.1); CHN (Hong & Li, 2012); ITA (Arena et al., 2004) - G2-T2 : North America (U.S. Environmental Protection Agency, 2003) - G3/4-T2 : Geographic clustering with PIB/capita	Electricity mix used for paper recycling is the same as national mix.

	6. Market group for electricity, low voltage / Electricity, low voltage				
Energy – oil production / combustion	Production: Market for light fuel oil / Light fuel oil	RoW	kg / MJ	Total energy use: - G1-T2: BRA (Sun et al., 2018); ESP (Sun et al., 2018); PRT (Sun et al., 2018); NOR (Sun et al., 2018) - G2-T2 : North America (U.S. Environmental Protection Agency, 2003); ITA (Arena et al., 2004); DEN (Christensen & Damgaard, 2010; Wang et al., 2012); IND (Confederation of Indian Industry, 2020; Tewari, Batra, & Balakrishnan, 2009); CHE (Ecoinvent 3.7.1) - G3/4-T2 : Geographic clustering with PIB/capita Share of total energy use for each energy source: - G1-T4: IEA database - G1-T5: U.S. Energy Information Administration Database	Lower heating value: 42,69 MJ/kg
	Combustion: Heat production, light fuel oil, at industrial furnace 1 MW / heat, district or industrial, other than natural gas	RoW			
Energy – coal production / combustion	Production: Market for hard coal / Hard coal	RoW	kg / MJ		Lower heating value: 22,73 MJ/kg
	Combustion: Heat production, at hard coal industrial furnace 1-10MW / Heat, district or industrial, other than natural gas	RoW			
Energy – Natural gas production / combustion	Production: Market for natural gas, high pressure / Natural gas, high pressure	RoW	m³ / MJ		Lower heating value: 36,62 MJ/kg
	Combustion: Heat production, natural gas, at industrial furnace >100kW / Heat, district or industrial, natural gas	RoW			
Energy – Biofuel production / combustion	Production: Ethanol production from wood / Ethanol, without water, in 95% solution state, from fermentation	RoW	kg / MJ		Biofuel is assumed to have the same production impact as ethanol and the same combustion impacts as biodiesel, but with biogenic carbon emissions.
	Combustion: Heat and power co-generation, diesel, 200kW electrical, SCR-NOx reduction / Heat, district or industrial, other than natural gas <i>(fossil carbon emissions replaced by non fossil carbon emissions)</i>	RoW			Lower heating value: 26,95 MJ/kg
Energy – Biomass production / combustion	Production: Market for wood chips, dry, measured as dry mass	RoW	kg	Total energy use: - G1-T2: BRA (Sun et al., 2018); ESP (Sun et al., 2018); PRT (Sun et al., 2018); NOR (Sun et al., 2018) - G2-T2 : North America (U.S. Environmental Protection Agency, 2003); ITA (Arena et al., 2004); DEN (Christensen & Damgaard, 2010; Wang et al., 2012); IND (Confederation of Indian Industry, 2020; Tewari et al., 2009); CHE (Ecoinvent 3.7.1) - G3/4-T2 : Geographic clustering with PIB/capita Share of total energy use: - G1-T4: IEA database - G1-T5: U.S. Energy Information Administration Database	Lower heating value: 15,40 MJ/kg
	Combustion: Heat production, softwood chips from forest, at furnace 1000kW / Heat, district or industrial, other than natural gas	RoW			

Chemicals - Newsprint	Market for bentonite / Bentonite	GLO	kg	Total chemicals use: - G1-T2: DNK (Christensen & Damgaard, 2010; Wang et al., 2012); IND (Confederation of Indian Industry, 2020); CHE (Ecoinvent 3.7.1); CHN (Hong & Li, 2012); ITA (Arena et al., 2004) - G2-T2 : North America (U.S. Environmental Protection Agency, 2003) - G3/4-T2 : Geographic clustering with PIB/capita Share of total chemicals use for each chemical: Value from ecoinvent pre-built processes: Graphic paper production, 100% recycled / Graphic paper, 100% recycled / RoW	The share of total chemicals use for each chemical is the same in every country.
	Market for malusil / Malusil	GLO	kg		
	Market for silica sand / Silica sand	GLO	kg		
	Market for lime / Lime	RER	kg		
	Market for potato starch / Potato starch	GLO	kg		
	Market for DTPA, diethylenetriaminepentaacetic acid / DTPA, diethylenetriaminepentaacetic acid	RER	kg		
	Market for EDTA, ethylenediaminetetraacetic acid / EDTA, ethylenediaminetetraacetic acid	GLO	kg		
	Market for aluminium sulfate, powder / Aluminium sulfate, powder	RER	kg		
	Market for chemical, organic / Chemical, organic	GLO	kg		
	Market for chemicals, inorganic / Chemical, inorganic	GLO	kg		
	Market for deinking emulsion, in paper production / Deinking emulsion	RER	kg		
	Market for fatty acid / Fatty acid	GLO	kg		
	Market for hydrogen peroxide, without water, in 50% solution state	RER	kg		
	Market for neutralising agent, sodium hydroxide-equivalent / Neutralising agent, sodium hydroxide-equivalent	GLO	kg		
	Market for nitrogen, liquid / Nitrogen, liquid	RER	kg		
	Market for optical brighteners, for paper production / Optical brighteners, for paper production	RER	kg		
	Market for phosphoric acid, industrial grade, without water, in 85% solution state / Phosphoric acid, industrial grade, without water, in 85% solution state	GLO	kg		
	Market for phosphorus, white, liquid / Phosphorus, white, liquid	GLO	kg		
	Market for polyacrylamide / Polyacrylamide	GLO	kg		
	Market for retention aid, for paper production / Retention aid, for paper production	RER	kg		
	Market for sodium dithionite, anhydrous / Sodium dithionite, anhydrous	RER	kg		
	Market for sodium hydroxide, without water, in 50% solution state / Sodium hydroxide, without water, in 50% solution state	GLO	kg		
	Market for sodium hypochlorite, without water, in 15% solution state	RER	kg		
	Market for sodium silicate, solid / Sodium silicate, solid	RER	kg		
	Market for sodium silicate, spray powder, 80% / Sodium silicate, spray powder, 80%	RER	kg		
	Market for sulfur dioxide, liquid / Sulfur dioxide, liquid	RER	kg		
	Market for sulfuric acid / Sulfuric acid	RER	kg		
	Market for urea	RER	kg		
Chemicals – Corrugated cardboard	Market for maize starch / Maize starch	GLO	kg		
	Market for potato starch / Potato starch	GLO	kg		
	Market for pitch despersents, in paper production / Pitch despersents, in paper production	RoW	kg		
	Market for retention aid, for paper production / Retention aid, for paper production	RoW	kg		
	Market for sodium hydroxide, without water, in 50% solution state / Sodium hydroxide, without water, in 50% solution state	GLO	kg		
	Market for dithiocarbamate-compound / Dithiocarbamate compound	GLO	kg		
	Market for triazine-compound, unspecified / Triazine-compound, unspecified	GLO	kg		
	Market for ethoxylated alcohol (AE3) / Ethoxylated alcohol (AE3)	RoW	kg		
Chemicals – Graphic paper	Market for lime / Lime	RoW	kg		
	Market for sodium chloride, powder / Sodium chloride, powder	GLO	kg		
	Market for potato starch / Potato starch	GLO	kg		
	Market for chemical, organic / Chemical, organic	GLO	kg		
	Market for chemicals, inorganic	GLO	kg		
	Market for hydrogen peroxide, without water, in 50% solution state	RoW	kg		

	Market for hydrogen sulfide	RoW	kg		
	Market for optical brighteners, for paper production / Optical brighteners, for paper production	RoW	kg		
	Market for sodium dithionite, anhydrous / Sodium dithionite, anhydrous	RoW	kg		
	Market for sodium hydroxide, without water, in 50% solution state / Sodium hydroxide, without water, in 50% solution state	GLO	Kg		
	Market for sodium silicate, spray powder, 80%	RoW	kg		
	Market for latex / Latex	RoW	kg		
	Market for quicklime, milled, loose / Quicklime, milled, loose	RoW	kg		
Sludge treatment – Incineration (with substitution)	Custom process (see supporting information S6)	-	kg	Total sludge production (S): Calculated from mass balance:	Deinking sludge is only produced when producing newsprint or graphic paper.
Sludge treatment - Landfill	Treatment of sludge from pulp and paper production, sanitary landfill / Sludge from pulp and paper production	RoW	kg	$S = \frac{((U^{rec} + V_{input})(1 - w_{input}) - \eta^{rec}(U^{rec} + V_{input})(1 - w_{output}))}{(1 - w_{sludge})}$	Deinking sludge doesn't contain chemicals added during the recycling process, since these chemicals are added after the deinking step.
Sludge treatment – Landfarming (with substitution)	Treatment of sludge from pulp and paper production, landfarming / Sludge from pulp and paper production	RoW	kg	U^{rec} is the recyclable fraction of the bale (user defined) V_{input} is the virgin material input w_{input} is the water mass fraction in waste and virgin paper input without impurities w_{output} is the water mass fraction in paper output w_{sludge} is the water mass fraction in sludge Efficiency (η^{rec}): - G1-T2: DNK (Christensen & Damgaard, 2010; Wang et al., 2012); IND (Confederation of Indian Industry, 2020); CHE (Ecoinvent 3.7.1); CHN (Hong & Li, 2012); ITA (Arena et al., 2004) - G2-T2 : North America (U.S. Environmental Protection Agency, 2003) - G3/4-T2 : Geographic clustering with PIB/capita Share of total sludge production sent to each treatment: - G1-T2: CAN (MDDELCC, 2016); USA (Bajpai, 2015); IND (Confederation of Indian Industry, 2020) - G1-T5: Waste management practices by country from (Kaza, Yao, Bhada-Tata, & Van Woerden, 2018). Open dump and landfill practices are associated with sludge landfill and composting practices are associated to sludge landfarming.	Deinking sludge doesn't contain impurities from the initial bale. These impurities are perfectly separated before the deinking step.
Sludge treatment - Filler	-	-	-		No dewatering is performed before sludge incineration. Deinking sludge can be burned without the use of additional fuel. All water contained in sludge is evaporated to air. Sludge incineration produces 1,8 MJ/kg (Deviatkin, Kapustina, Vasilieva, Isyanov, & Horttanainen, 2016), and 35% of this energy can be recovered (Mohammadi et al., 2019). The energy produced by sludge incineration replaces energy from the energy mix used by the recycling facility. No electricity is produced from sludge incineration.

					Dry deinking sludge contains 50% ash (Gavrilescu, 2008). $w_{input} = 9\%$ $w_{output} = 5\%$ $w_{sludge} = 58\%$ (Faubert, Barnabé, Bouchard, Côté, & Villeneuve, 2016) No impact and no substitution are associated with sludge used as filler material. Each kg of landfarmed sludge substitutes 0,00415 kg of P_2O_5 organo-mineral fertiliser, 0,001 kg of K_2O organo-mineral fertiliser and 0,116 kg of $CaCO_3$ pH raising agent, as specified in ecoinvent sludge landfarming process.
Other solid wastes treatment – Landfill	Newspaper, mixed papers: Treatment of waste graphical paper, sanitary landfill / Waste graphical paper	RoW	kg	Total other solid wastes production (W): Calculated from mass balance (for 1 kg of output): $W = 1 - U^{rec}$ U^{rec} is the recyclable fraction of the bale (user defined) *Composition of other solid wastes is provided by user (input parameter). If product is corrugated cardboard, losses due to efficiency (L) are not resulting in sludge like in processes producing newsprint and graphical paper. These losses are assumed to be treated like other solid wastes and are calculated as follow from mass balance (for 1 kg of output): $L = \frac{((U^{rec} + V_{input})(1 - w_{input}) - \eta^{rec}(U^{rec} + V_{input})(1 - w_{output}))}{(1 - w_{losses})}$ U^{rec} is the recyclable fraction of the bale (user defined) V_{input} is the virgin material input w_{input} is the water mass fraction in waste and virgin paper input without impurities w_{output} is the water mass fraction in paper output w_{losses} is the water mass fraction in losses due to efficiency Efficiency (η^{rec}):	All impurities in waste paper bales are separated during the recycling process and sent to municipal solid waste treatments. The energy produced from the incineration of other solid wastes doesn't substitute any other form of energy. Plastic films are assumed to be composed of polyethylene. <i>Tetrapaks</i> are assumed to have the same impacts as paperboard. Metal is assumed to have the same impacts as steel.
	Old corrugated cardboard, Tetrapak: Treatment of waste paperboard, sanitary landfill / Waste paperboard	RoW	kg		
	Polyethylene terephthalate: Treatment of waste polyethylene terephthalate, sanitary landfill / Waste polyethylene terephthalate	RoW	kg		
	High-density polyethylene, plastic film: Treatment of waste polyethylene, sanitary landfill / Waste polyethylene	RoW	kg		
	Glass: Treatment of waste glass, sanitary landfill / Waste glass	GLO	kg		
	Metal: Treatment of scrap steel, inert material landfill / Scrap steel	RoW	kg		
	Other: Treatment of municipal solid waste, sanitary landfill / Municipal solid waste	RoW	kg		
Other solid wastes treatment – Incineration (without incineration)	Newspaper, mixed papers: Treatment of waste graphical paper, municipal incineration / Waste graphical paper	RoW	kg		
	Old corrugated cardboard, Tetrapak: Treatment of waste paperboard, municipal incineration / Waste paperboard	RoW	kg		
	Polyethylene terephthalate: Treatment of waste polyethylene terephthalate, municipal incineration / Waste polyethylene terephthalate	RoW	kg		All landfill categories in the World Bank Group report (2018) are assumed to refer to sanitary landfill.

	High-density polyethylene, plastic film: Treatment of waste polyethylene, municipal incineration / Waste polyethylene	RoW	kg	- G1-T2: DNK (Christensen & Damgaard, 2010; Wang et al., 2012); IND (Confederation of Indian Industry, 2020); CHE (Ecoinvent 3.7.1); CHN (Hong & Li, 2012); ITA (Arena et al., 2004) - G2-T2 : North America (U.S. Environmental Protection Agency, 2003) - G3/4-T2 : Geographic clustering with PIB/capita Share of total other solid wastes sent to each treatment: - G1-T5: Waste management practices by country from (Kaza et al., 2018).	Rejects from the recycling process are exclusively sent to landfill, open dump or incineration and are not sent to composting, recycling, anaerobic digestion, waterways or any other treatment type. If solid wastes are sent to open dump, the geography specific infiltration class is chosen (Doka, 2018). w_{losses} = 40% (Gavrilescu, 2008)
	Glass: Treatment of waste glass, municipal incineration / Waste glass	RoW	kg		
	Metal: Treatment of scrap steel, municipal incineration / Scrap steel	RoW	kg		
	Other: Treatment of municipal solid waste, incineration / Municipal solid waste	RoW	kg		
Other solid wastes treatment – Open dump	Newspaper, mixed papers: Treatment of waste graphical paper, open dump, X infiltration class / Waste graphical paper	GLO	kg		
	Old corrugated cardboard, Tetrapak: Treatment of waste paperboard, open dump, X infiltration class / Waste paperboard	GLO	kg		
	Polyethylene terephthalate: Treatment of waste polyethylene terephthalate, open dump, X infiltration class / Waste polyethylene terephthalate	GLO	kg		
	High-density polyethylene, plastic film: Treatment of waste polyethylene, open dump, X infiltration class / Waste polyethylene	GLO	kg		
	Glass: Treatment of waste glass, open dump, X infiltration class / Waste glass	GLO	kg		
	Metal: Treatment of scrap steel, inert material landfill	RoW	kg		
	Other: Treatment of municipal solid waste, open dump, X infiltration class / Municipal solid waste	GLO	kg		
Substitution – Newsprint	Paper production, newsprint, virgin / Paper, newsprint	RoW	kg	Total quantity of virgin material substituted (M_{sub}): $M_{sub} = (U^{rec} + V_{input}) \eta^{rec} \times \alpha^{rec:disp}$ U^{rec} is the recyclable fraction of the bale (user defined) V_{input} is the virgin material input $\alpha^{rec:disp}$ is the substitution ratio, a regionalizable process parameter with a default value of 100% (T2) Efficiency (η^{rec}): - G1-T2: DNK (Christensen & Damgaard, 2010; Wang et al., 2012); IND (Confederation of Indian Industry, 2020); CHE (Ecoinvent 3.7.1); CHN (Hong & Li, 2012); ITA (Arena et al., 2004) - G2-T2 : North America (U.S. Environmental Protection Agency, 2003) - G3/4-T2 : Geographic clustering with PIB/capita	A substitution ratio ($\alpha^{rec:disp}$) of 100% is assumed. A sensitivity analysis on this parameter is recommended.
Substitution – Graphic paper	Containerboard production, fluting medium, semichemical	RoW	kg		
Substitution – Corrugated cardboard	Paper production, woodcontaining, lightweight coated / Paper, woodcontaining, lightweight coated	RoW	kg		
Transport	Boat: Transport, freight, sea, containership / Transport, freight, sea, container ship	GLO	Metric ton*km	Travel distance is calculated between exporting and importing country. Transport type is user defined.	-
	Truck: Transport, freight, lorry 7.5-16 metric ton, EURO3	RoW	Metric ton*km		
	Train: Transport, freight train, electricity / Transport, freight train	RoW	Metric ton*km		
	Plane: Transport, freight, aircraft, all distacnes to generic market for transport, freight, aircraft, unspecified / Transport, freight, aircraft, unspecified	GLO	Metric ton*km		

Parameter	Emission	Compartment / Sub-compartment	Unit	Regionalized value estimation methods for 1 kg of wastepaper recycled	Assumptions
Water input (W_{input})	Water, cooling, unspecified natural origin	Natural resource / In water	m ³	- G1-T2: IND (Central Pulp & Paper Research Institute, s.d.; Confederation of Indian Industry, 2020); DEN (Christensen & Damgaard, 2010; Wang et al., 2012); CHN (Hong & Li, 2012); CHE (Ecoinvent 3.7.1); ITA (Arena et al., 2004) - G3/4-T2 : Geographic clustering with PIB/capita	
Water discharge	To water: Water	Water / Surface water	m ³	Total water discharge calculated with water mass balance ($W_{discharge}$): $W_{discharge} = W_{input} + W_{input} - (U^{rec} + V_{input}) \eta^{rec} \times w_{output} - S * w_{sludge} - L * w_{losses}$ W_{input} is the water mass fraction in waste and virgin paper input without impurities U^{rec} is the recyclable fraction of the bale (user defined) V_{input} is the virgin material input w_{output} is the water mass fraction in paper output S is the total sludge produced w_{sludge} is the water mass fraction in sludge L are the losses due to efficiency w_{losses} is the water mass fraction in losses due to efficiency Efficiency (η^{rec}): - G1-T2: DNK (Christensen & Damgaard, 2010; Wang et al., 2012); IND (Confederation of Indian Industry, 2020); CHE (Ecoinvent 3.7.1); CHN (Hong & Li, 2012); ITA (Arena et al., 2004) - G2-T2 : North America (U.S. Environmental Protection Agency, 2003) - G3/4-T2 : Geographic clustering with PIB/capita Water input (W_{input}) - G1-T2: IND (Central Pulp & Paper Research Institute, s.d.; Confederation of Indian Industry, 2020); DEN (Christensen & Damgaard, 2010; Wang et al., 2012); CHN (Hong & Li, 2012); CHE (Ecoinvent 3.7.1); ITA (Arena et al., 2004) - G3/4-T2 : Geographic clustering with PIB/capita	Water contained in chemicals is negligible. $w_{losses} = 40\%$ (Gavrilescu, 2008) $w_{input} = 9\%$ $w_{output} = 5\%$ $w_{sludge} = 58\%$ (Faubert et al., 2016)
	To air: Water	Air / Unspecified	m ³		
Water emissions	BOD5, Biological Oxygen Demand	Water / Unspecified	kg	G5-T2: Average values from North American recycling mills are used for all water emissions (U.S. Environmental Protection Agency, 2003).	
	COD, Chemical Oxygen Demand	Water / Unspecified	kg		
	Dissolved solids	Water / Unspecified	kg		
	Lead	Water / Unspecified	kg		
	Mercury	Water / Unspecified	kg		
	Nickel, ion	Water / Unspecified	kg		
	Sulfide	Water / Unspecified	kg		
	Suspended solids, unspecified	Water / Unspecified	kg		
	Zinc, ion	Water / Unspecified	kg		
	Aluminium	Water / Unspecified	kg		
	Ammonia, ion	Water / Unspecified	kg		
	Iron, ion	Water / Unspecified	kg		
	Nitrate	Water / Unspecified	kg		
	Oils, unspecified	Water / Unspecified	kg		
	Phenol	Water / Unspecified	kg		
	Phosphate	Water / Unspecified	kg		

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S6. Deinking sludge incineration process

S6.1 NO_x, CO, benzopyrene, CO₂ and non-methane volatile organic compounds (NMVOC) air emissions

Table 6: Parameters used in the process model

Parameter	Symbol	Unit	Value	Source
Amount of deinking sludge incinerated	D	kg	1	Functional unit
Heat losses due to mechanically incomplete fuel combustion	h_{mec}	mass fraction	0,03	(Deviatkin et al., 2016)
Sludge water content	w	mass fraction	0,58	(Deviatkin et al., 2016; Faubert et al., 2016)
HHV of sludge on wet basis	$\dot{q}$	MJ/kg	1,8	(Deviatkin et al., 2016)
Power of boiler based on heat supplied	P	MW	3,12	(Deviatkin et al., 2016)
Specific amount of nitrogen oxides emissions	$\dot{m}_{NO_x}$	kg/MJ	0,000049	(Deviatkin et al., 2016)
Outcome of CO from deinking sludge combustion	$\dot{m}_{CO}$	kg/kg	0,000018	(Deviatkin et al., 2016)
Concentration of benzopyrene in dry flue gases at the exit of the furnace	c_{bp}	mg/m ³	0,000752	(Deviatkin et al., 2016)
Volume of dry gases generated during deinking sludge combustion	V_{dg}	m ³ /kg	1,17	(Deviatkin et al., 2016)
Coefficient of oxidation of carbon contained in fuel	K	-	0,98	(Deviatkin et al., 2016)
CO ₂ emission coefficient	K_{CO_2}	t/TJ	28,9	(Deviatkin et al., 2016)
CH ₄ emission coefficient	K_{CH_4}	t/TJ	0,03	(Deviatkin et al., 2016)
N ₂ O emission coefficient	K_{N_2O}	t/TJ	0,004	(Deviatkin et al., 2016)
NMVOC emission coefficient	K_{NMVOC}	t/TJ	0,05	(Deviatkin et al., 2016)

Estimated deinking sludge to be burned effectively (D_{eff}):

$$D_{eff} = D(1 - h) = 1(1 - 0,03) = 0,97 \text{ kg} \quad (1)$$

Total amount of NO_x emitted into the atmosphere (m_{NO_x}):

$$m_{NO_x} = D_{eff} \times \dot{q} \times \dot{m}_{NO_x} = 0,97 \text{ kg} \times 1,8 \text{ MJ/kg} \times 0,000049 \text{ kg/MJ} = 0,00008555 \text{ kg} \quad (2)$$

Total amount of CO emitted into the atmosphere (m_{CO}):

$$\dot{m}_{CO} = D \times \dot{m}_{CO} \times (1 - h_{mec}) = 1 \text{ kg} \times 0,000018 \text{ kg/kg} \times (1 - 0,03) = 0,00001746 \text{ kg} \quad (3)$$

Total amount of benzopyrene released into the atmosphere (m_{BP}):

$$m_{BP} = c_{bp} \times V_{dg} \times (1 - h_{mec}) = 0,000752 \frac{mg}{m^3} \times 1,17 m^3/kg \times (1 - 0,03) \times \frac{1 kg}{1\,000\,000 mg} = 8,53 \times 10^{-10} \quad (4)$$

Total amount of CO₂ released into the atmosphere (m_{CO_2}):

$$m_{CO_2} = D \times K \times \dot{q} \times K_{CO_2} \times \frac{44}{12} = 1 kg \times 0,98 \times 1,8 \frac{MJ}{kg} \times 28,9 t/TJ \times \frac{44}{12} \times \frac{1000 kg}{1 t} \times \frac{1 TJ}{1000000 MJ} = 0,1869 kg \quad (5)$$

Total amount of CH₄ released into the atmosphere (m_{CH_4}):

$$m_{CH_4} = D \times K \times \dot{q} \times K_{CH_4} = 1 kg \times 0,98 \times 1,8 \frac{MJ}{kg} \times 0,03 t/TJ \times \frac{1000 kg}{1 t} \times \frac{1 TJ}{1000000 MJ} = 0,00005292 kg \quad (6)$$

Total amount of N₂O released into the atmosphere (m_{N_2O}):

$$m_{N_2O} = D \times K \times \dot{q} \times K_{N_2O} = 1 kg \times 0,98 \times 1,8 \frac{MJ}{kg} \times 0,004 t/TJ \times \frac{1000 kg}{1 t} \times \frac{1 TJ}{1000000 MJ} = 0,000007056 kg \quad (7)$$

Total amount of NMVOC released into the atmosphere (m_{NMVOC}):

$$m_{NMVOC} = D \times K \times \dot{q} \times K_{NMVOC} = 1 kg \times 0,98 \times 1,8 MJ/kg \times 0,05 t/TJ \times \frac{1000 kg}{1 t} \times \frac{1 TJ}{1000000 MJ} = 0,00008820 kg \quad (8)$$

S6.2 Other emissions

Table 7 provides the composition of paper from *ecoinvent* 3.7.1 paper municipal incineration process (treatment of waste graphical paper, municipal incineration, GLO) and the composition of the deinking sludge from (Abdullah, Ishak, Kadir, & Bakar, 2015) and (Gavrilescu, 2008). Only the elements for which a composition is provided in the literature for deinking sludge are presented.

Table 7: Paper and deinking sludge composition

	Paper dry composition	Paper wet composition	Sludge dry composition	Sludge wet composition
H ₂ O	0,00E+00	1,11E-01	0,00E+00	5,80E-01
C	4,54E-01	4,04E-01	1,90E-01	7,98E-02
S	1,58E-03	1,41E-03	5,00E-04	2,10E-04
N	4,22E-03	3,76E-03	1,00E-02	4,20E-03
P	1,27E-04	1,13E-04	1,80E-03	7,56E-04
Cd	1,87E-06	1,66E-06	2,34E-06	9,83E-07
Cr	1,63E-05	1,45E-04	2,06E-05	8,64E-06
Cu	6,85E-05	6,09E-05	1,30E-04	5,48E-05
Mn	4,52E-05	4,02E-05	2,04E-04	8,56E-05
Ni	1,06E-05	9,44E-06	2,16E-05	9,06E-06
Pb	9,04E-05	8,04E-05	1,27E-04	5,31E-05
Zn	1,40E-04	1,25E-04	3,15E-04	1,32E-04
Fe	1,34E-03	1,19E-03	3,40E-03	1,43E-03
Ca	3,87E-03	3,44E-03	6,60E-03	2,77E-03
Al	1,45E-02	1,29E-02	1,68E-02	7,06E-03
K	1,49E-03	1,33E-03	1,20E-03	5,04E-04
Mg	4,83E-03	4,30E-03	6,10E-03	2,56E-03
Na	1,03E-03	9,19E-04	6,70E-03	2,81E-03

1. For the elements in table 7, the emissions from the incineration of deinking sludge were deduced from the paper incineration process. It was assumed that the mass fraction of the element emitted in a particular compartment on the total content of this element in the wet material incinerated is the same in the paper and the sludge incineration processes. For the compounds containing one or more element in table 7, it was assumed that the mass fraction of the limiting element emitted in a particular compartment on the total content of this element in the wet material incinerated is the same in the paper and the sludge incineration processes.

For example:

Aluminium emitted to air, urban air close to ground in paper incineration *ecoinvent* process:

$$1,94 \times 10^{-5} \frac{kg}{kg \text{ wet paper incinerated}} \quad (9)$$

Mass fraction of total aluminium contained in 1 kg of paper emitted to air, urban air close to ground in *ecoinvent* process:

$$\frac{1,94 \times 10^{-5} \frac{kg}{kg \text{ paper incinerated}}}{1,29 \times 10^{-2} \frac{kg}{kg \text{ wet paper}}} = 1,50 \times 10^{-3} \quad (10)$$

Estimation of aluminium emitted to air, urban air close to ground in new deinking sludge incineration process:

$$1,50 \times 10^{-3} \times 7,06 \times 10^{-3} \frac{kg}{kg \text{ wet sludge}} = 1,06 \times 10^{-5} \frac{kg}{kg \text{ wet sludge incinerated}} \quad (11)$$

2. For the elements and compounds released to air or water in the *ecoinvent* process, but not available in the composition of deinking sludge, it was assumed that the emission per mass unit of dry material incinerated of these elements or compounds is the same for paper and deinking sludge.

For example:

Antimony emitted to air, urban air close to ground in paper incineration *ecoinvent* process:

$$2,76 \times 10^{-15} \frac{kg}{kg \text{ wet paper incinerated}} \times \frac{1 \text{ kg wet paper incinerated}}{(1 - 0,111) \text{ kg dry paper incinerated}} = 3,10 \times 10^{-15} \frac{kg}{kg \text{ dry paper incinerated}} \quad (12)$$

Estimation of antimony emitted to air, urban air close to ground in new deinking sludge incineration process:

$$3,10 \times 10^{-15} \frac{kg}{kg \text{ dry sludge incinerated}} \times \frac{(1 - 0,58) \text{ kg dry sludge incinerated}}{kg \text{ wet sludge incinerated}} = 1,30 \times 10^{-15} \frac{kg}{kg \text{ wet sludge incinerated}} \quad (13)$$

3. It was assumed that the water contained in the deinking sludge was completely evaporated and emitted to air (0,58 kg of water emitted to air by kg of sludge incinerated).

S6.3 Emission results

Table 8 contains the emissions and their values calculated with the previously presented method for the sludge incineration process created.

Table 8: Emissions of the new sludge incineration process created

Element / Compound	Unit	Compartment	Sub-compartment	Value
Aluminium	kg	air	urban air close to ground	1,06E-05
Ammonia	kg	air	urban air close to ground	1,41E-06
Antimony	kg	air	urban air close to ground	1,30E-15
Arsenic	kg	air	urban air close to ground	9,87E-15
Barium	kg	air	urban air close to ground	5,38E-08
Beryllium	kg	air	urban air close to ground	4,60E-10
Boron	kg	air	urban air close to ground	9,73E-07
Cadmium	kg	air	urban air close to ground	5,41E-11
Calcium	kg	air	urban air close to ground	4,62E-06
Carbon dioxide, non-fossil	kg	air	urban air close to ground	1,87E-01
Carbon monoxide, non-fossil	kg	air	urban air close to ground	1,75E-05
Chromium	kg	air	urban air close to ground	6,40E-14
Cobalt	kg	air	urban air close to ground	1,11E-14
Copper	kg	air	urban air close to ground	4,05E-10
Cyanide	kg	air	urban air close to ground	6,68E-07
Dinitrogen monoxide	kg	air	urban air close to ground	7,06E-06
Hydrogen chloride	kg	air	urban air close to ground	9,64E-09
Hydrogen fluoride	kg	air	urban air close to ground	4,82E-09
Iron	kg	air	urban air close to ground	4,77E-08
Lead	kg	air	urban air close to ground	1,97E-09
Magnesium	kg	air	urban air close to ground	3,53E-06
Manganese	kg	air	urban air close to ground	4,66E-13
Mercury	kg	air	urban air close to ground	2,27E-15
Methane, non-fossil	kg	air	urban air close to ground	5,29E-05
Molybdenum	kg	air	urban air close to ground	4,06E-09
Nickel	kg	air	urban air close to ground	3,91E-13
Nitrogen oxides	kg	air	urban air close to ground	8,56E-05
Phosphorus	kg	air	urban air close to ground	7,56E-07
Potassium	kg	air	urban air close to ground	1,52E-06
Selenium	kg	air	urban air close to ground	6,14E-15
Silicon	kg	air	urban air close to ground	2,34E-05
Silver	kg	air	urban air close to ground	2,93E-13

Sodium	kg	air	urban air close to ground	2,65E-05
Strontium	kg	air	urban air close to ground	2,75E-09
Sulfur dioxide	kg	air	urban air close to ground	8,94E-07
Thallium	kg	air	urban air close to ground	8,12E-10
Titanium	kg	air	urban air close to ground	8,12E-08
Zinc	kg	air	urban air close to ground	2,16E-09
Aluminium	kg	water	ground-, long-term	5,00E-03
Aluminium	kg	water	surface water	5,62E-07
Antimony	kg	water	ground-, long-term	2,14E-07
Antimony	kg	water	surface water	1,16E-07
Arsenic, ion	kg	water	ground-, long-term	5,29E-07
Arsenic, ion	kg	water	surface water	4,36E-07
BOD5, Biological Oxygen Demand	kg	water	ground-, long-term	1,54E-03
BOD5, Biological Oxygen Demand	kg	water	surface water	7,13E-06
Barium	kg	water	ground-, long-term	4,77E-05
Barium	kg	water	surface water	7,42E-09
Beryllium	kg	water	ground-, long-term	3,71E-07
Beryllium	kg	water	surface water	2,86E-10
Boron	kg	water	ground-, long-term	5,34E-06
Boron	kg	water	surface water	1,27E-06
COD, Chemical Oxygen Demand	kg	water	ground-, long-term	4,71E-03
COD, Chemical Oxygen Demand	kg	water	surface water	1,28E-05
Cadmium, ion	kg	water	ground-, long-term	9,87E-09
Cadmium, ion	kg	water	surface water	4,46E-10
Calcium, ion	kg	water	ground-, long-term	2,41E-03
Calcium, ion	kg	water	surface water	1,05E-05
Chloride	kg	water	ground-, long-term	2,05E-05
Chloride	kg	water	surface water	8,46E-04
Chromium VI	kg	water	ground-, long-term	9,15E-08
Chromium VI	kg	water	surface water	2,82E-08
Chromium, ion	kg	water	surface water	2,76E-09
Cobalt	kg	water	ground-, long-term	3,04E-07
Cobalt	kg	water	surface water	5,95E-11
Copper, ion	kg	water	ground-, long-term	4,42E-05

Copper, ion	kg	water	surface water	2,22E-09
DOC, Dissolved Organic Carbon	kg	water	ground-, long-term	7,78E-04
DOC, Dissolved Organic Carbon	kg	water	surface water	2,19E-06
Fluoride	kg	water	ground-, long-term	8,22E-06
Fluoride	kg	water	surface water	7,09E-07
Iron, ion	kg	water	ground-, long-term	6,69E-04
Iron, ion	kg	water	surface water	4,89E-07
Lead	kg	water	ground-, long-term	3,79E-06
Lead	kg	water	surface water	1,48E-09
Magnesium	kg	water	ground-, long-term	3,97E-03
Magnesium	kg	water	surface water	1,50E-05
Manganese	kg	water	ground-, long-term	7,37E-05
Manganese	kg	water	surface water	4,79E-09
Mercury	kg	water	ground-, long-term	3,42E-09
Mercury	kg	water	surface water	7,04E-10
Molybdenum	kg	water	ground-, long-term	1,68E-06
Molybdenum	kg	water	surface water	3,47E-07
Nickel, ion	kg	water	ground-, long-term	8,48E-06
Nickel, ion	kg	water	surface water	5,68E-09
Nitrate	kg	water	ground-, long-term	1,51E-04
Nitrate	kg	water	surface water	5,38E-05
Phosphate	kg	water	ground-, long-term	8,84E-05
Phosphate	kg	water	surface water	1,48E-07
Potassium, ion	kg	water	ground-, long-term	4,14E-04
Potassium, ion	kg	water	surface water	8,73E-05
Selenium	kg	water	ground-, long-term	1,73E-06
Selenium	kg	water	surface water	8,40E-07
Silicon	kg	water	ground-, long-term	1,85E-03
Silicon	kg	water	surface water	4,50E-06
Silver, ion	kg	water	ground-, long-term	3,01E-08
Silver, ion	kg	water	surface water	5,68E-12
Sodium, ion	kg	water	ground-, long-term	2,18E-03
Sodium, ion	kg	water	surface water	6,09E-04
Strontium	kg	water	ground-, long-term	5,82E-05

Strontium	kg	water	surface water	3,67E-08
Sulfate	kg	water	ground-, long-term	5,27E-04
Sulfate	kg	water	surface water	1,02E-04
TOC, Total Organic Carbon	kg	water	ground-, long-term	1,85E-03
TOC, Total Organic Carbon	kg	water	surface water	5,22E-06
Thallium	kg	water	ground-, long-term	1,00E-06
Thallium	kg	water	surface water	1,05E-09
Titanium, ion	kg	water	ground-, long-term	5,15E-05
Titanium, ion	kg	water	surface water	8,29E-10
Zinc, ion	kg	water	ground-, long-term	2,04E-06
Zinc, ion	kg	water	surface water	2,42E-08
Benzo(a)pyrene	kg	air	urban air close to ground	8,53E-10
NMVOC, non-methane volatile organic compounds, unspecified origin	kg	air	urban air close to ground	8,82E-05
Water	m3	air	urban air close to ground	5,80E-04

S6.4 Activities

Activities linked to the sludge incineration process were also deduced from the activities of the paper incineration process. However, it was assumed that deinking sludge can be burned without the use of additional fuel. It was also assumed that deinking sludge incineration produces a mass of ash corresponding to 50% of its dry input mass (0,21 kg of ash produced by kg of sludge incinerated) (Gavrilescu, 2008). It was assumed that no slag was produced from sludge incineration, and that no cement was produced as a by-product, unlike the paper incineration *ecoinvent* process. These activities were all removed or added to the paper incineration process to produce the sludge incineration process. The other activities were assumed to remain unchanged in the new process. Table 8 provides the activities used to model the new sludge incineration process.

Table 9: Activities of the new sludge incineration process created

Activity	Product name	Geography	Unit	Value
market for chemical, organic	chemical, organic	GLO	kg	6,92E-06
market for chemicals, inorganic	chemical, inorganic	GLO	kg	7,41E-06
market for chromium oxide, flakes	chromium oxide, flakes	GLO	kg	1,11E-07
market for hydrochloric acid, without water, in 30% solution state	hydrochloric acid, without water, in 30% solution state	RER	kg	4,45E-06
market for iron (III) chloride, without water, in 40% solution state	iron (III) chloride, without water, in 40% solution state	GLO	kg	1,92E-05
market for sodium hydroxide, without water, in 50% solution state	sodium hydroxide, without water, in 50% solution state	GLO	kg	2,32E-03
market for titanium dioxide	titanium dioxide	RER	kg	5,42E-06

market for ammonia, anhydrous, liquid	ammonia, anhydrous, liquid	RER	kg	1,90E-04
market for quicklime, milled, packed	quicklime, milled, packed	RER	kg	3,19E-04
process-specific burdens, municipal waste incineration	process-specific burdens, municipal waste incineration	CH	kg	1,00E+00
municipal waste incineration facility construction	municipal waste incineration facility	CH	unit	2,50E-10
market for ash from paper production sludge	ash from paper production sludge	RoW	kg	2,10E-01

It was finally assumed that 35% of total energy content of the sludge (1,8 MJ/kg) can be recovered as heat (Mohammadi et al., 2019). The sludge incineration process therefore substitutes 0,630 MJ of electricity per kg of sludge incinerated.

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S7. Regionalized LCA climate change results

Regionalized LCA climate change numerical results are available in the repository cited at the end of this document.

S8. Quebec's mixed paper destinations

Quebec's mixed paper destinations are available in the repository cited at the end of this document.

S9. LCA scenarios results

LCA scenarios results are available in the repository cited at the end of this document.

S10. Sensitivity analysis on uncertain parameters

Figures 2 to 6 illustrate the normalized impacts (no long-term) of the sensitivity analysis. The Excel file available in the repository cited at the end of this document provides detailed results for every ReCiPe midpoint impact category and every analysis.

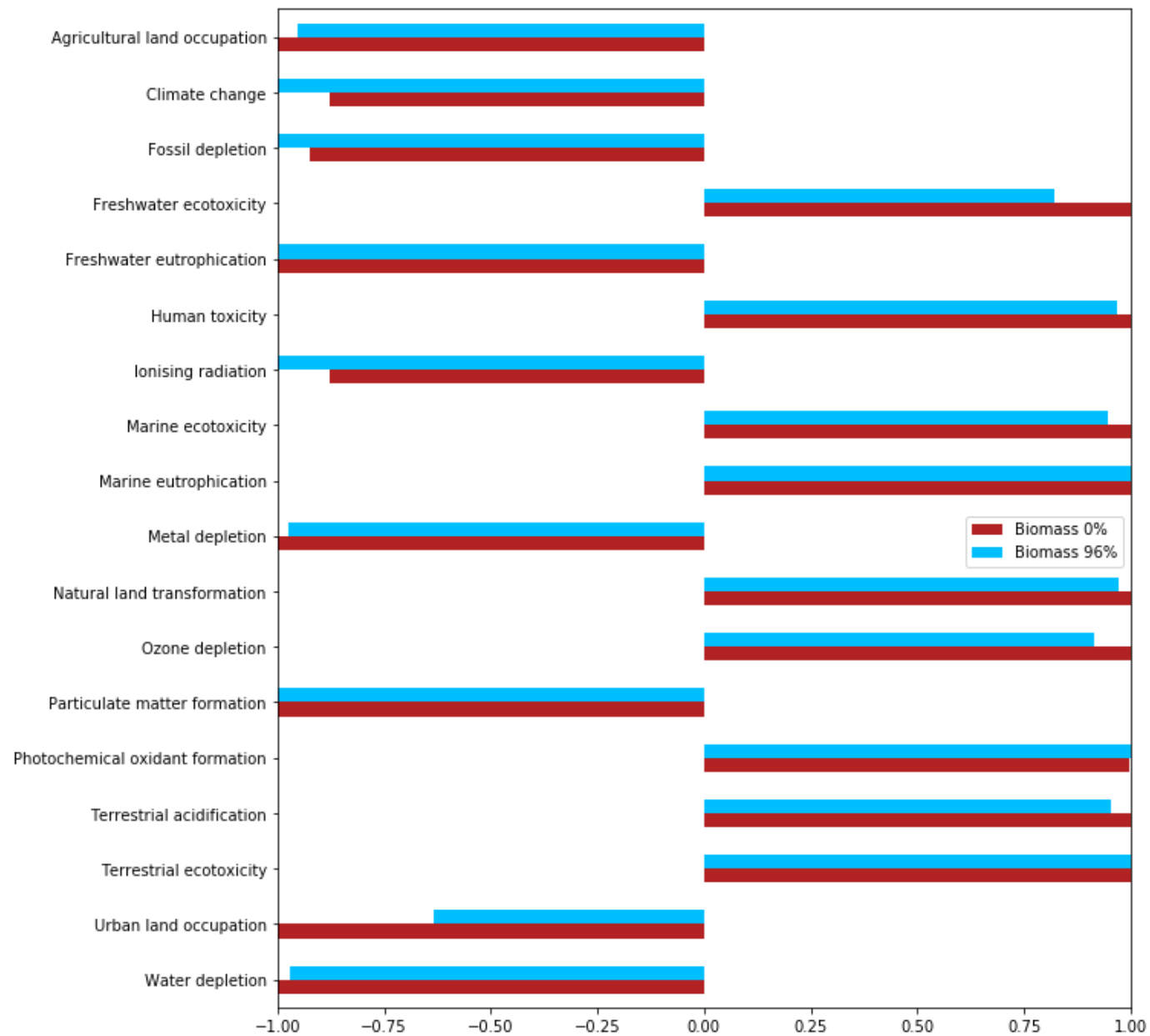


Figure 2: Biomass fraction of total energy use

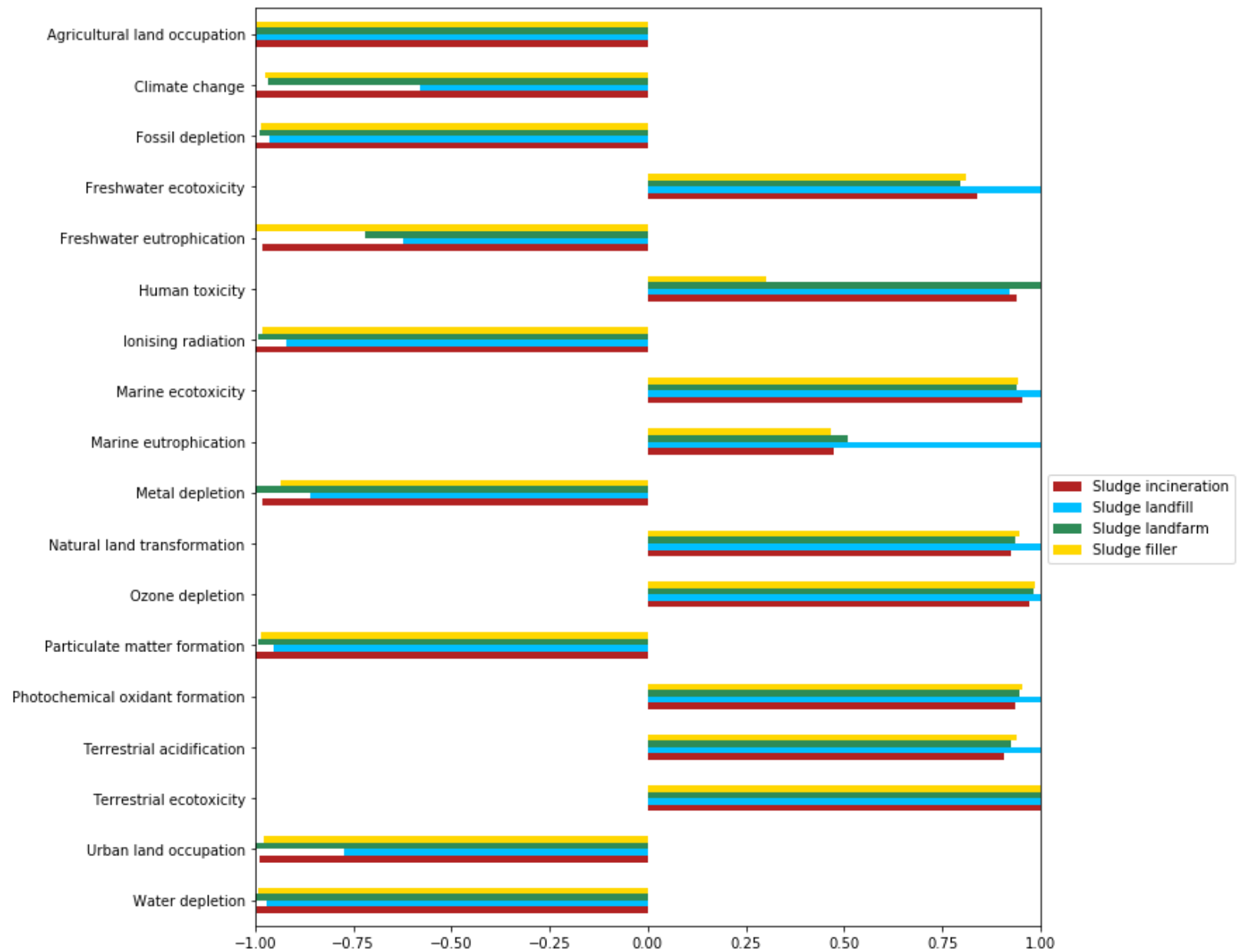


Figure 3: Sludge treatments

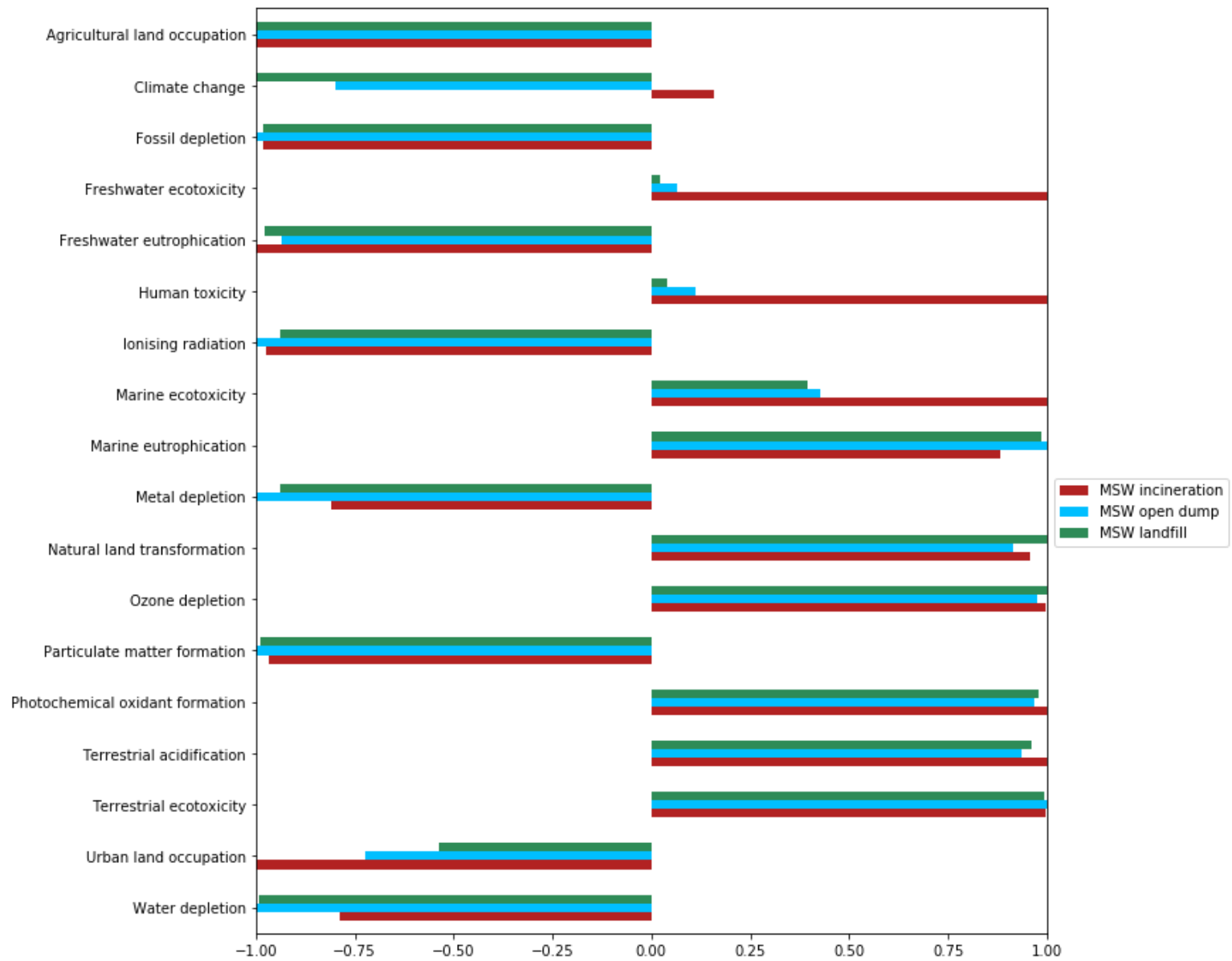


Figure 4: Other solid wastes treatments

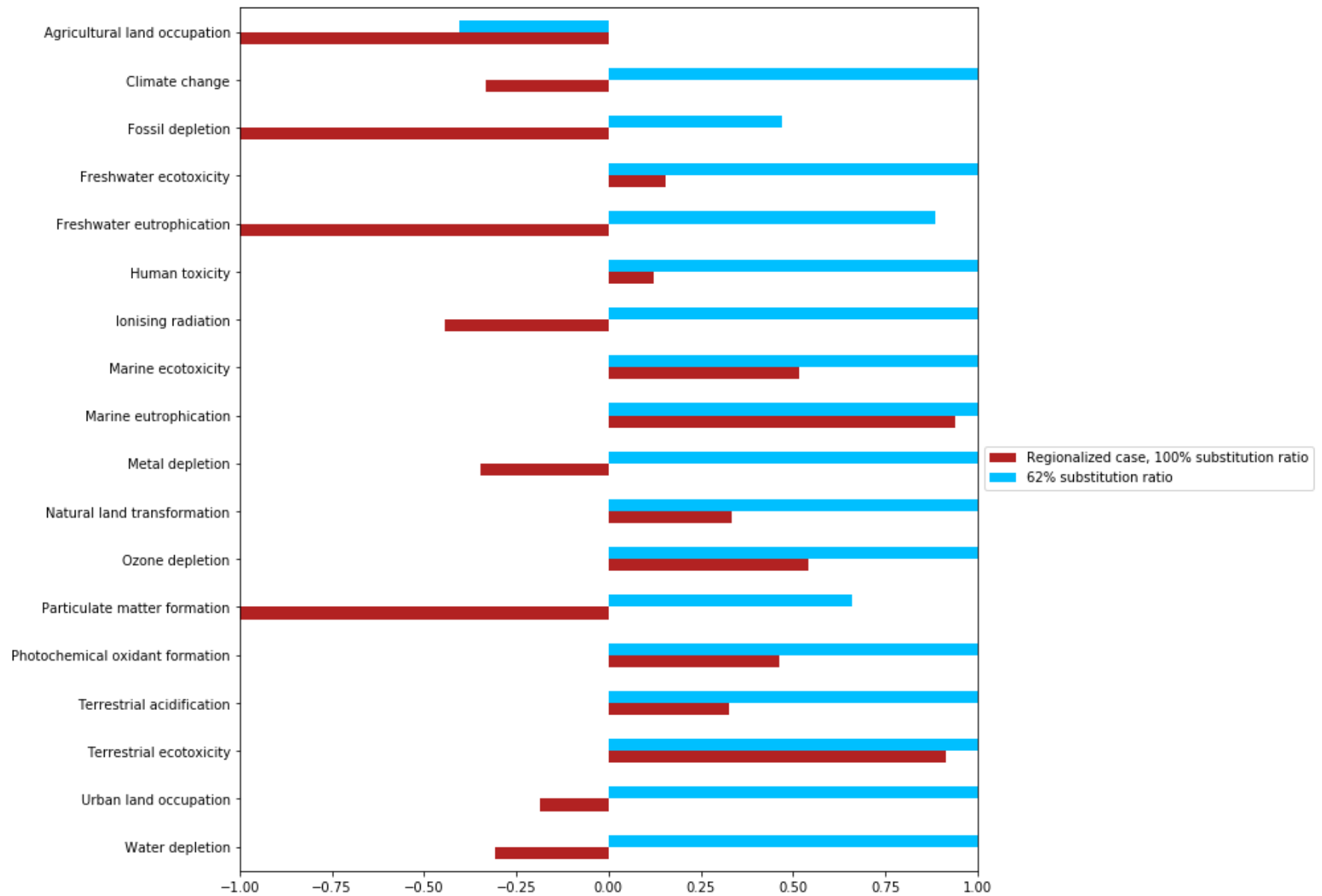


Figure 5: Substitution ratio

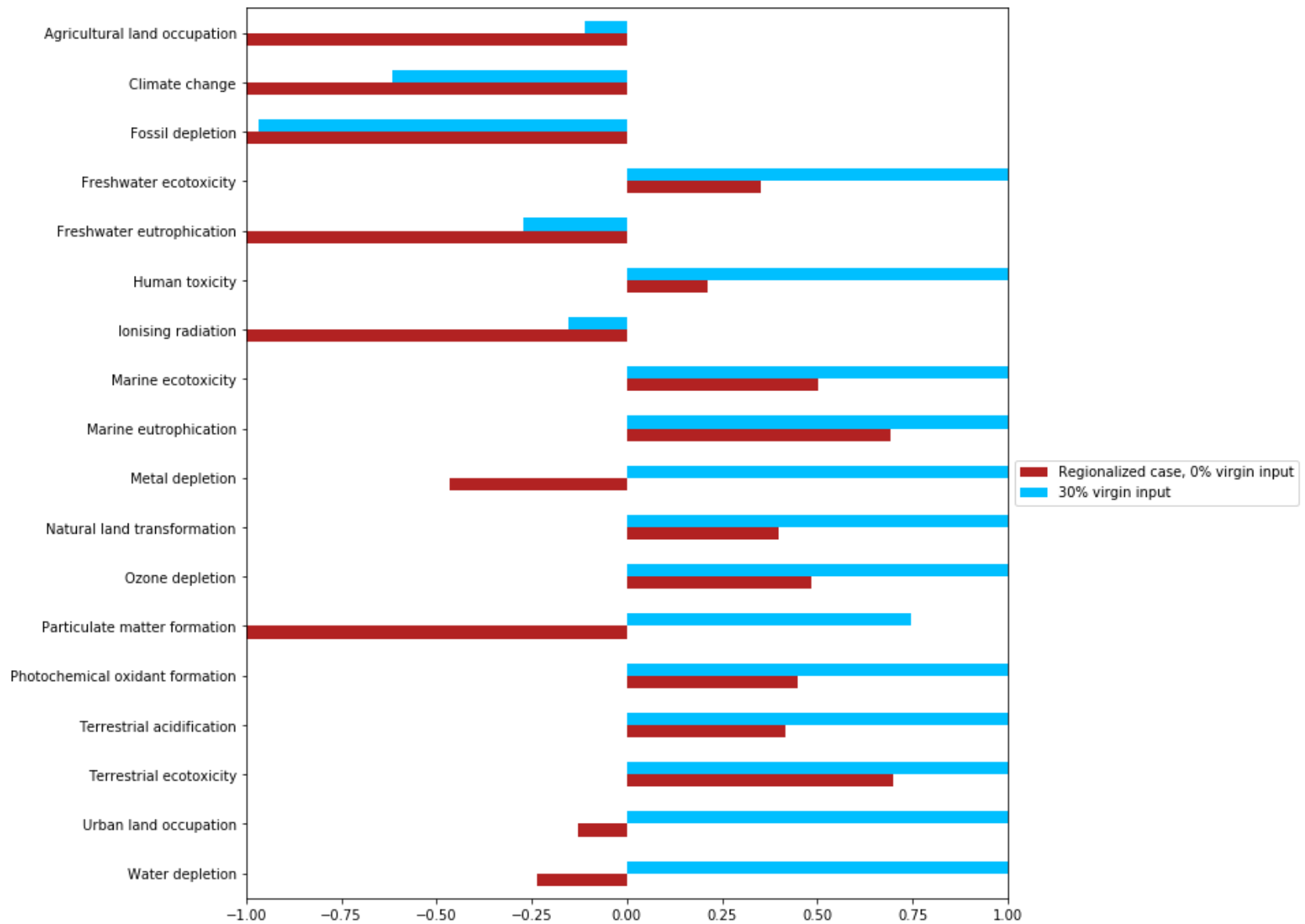


Figure 6: Virgin material input

[Link to the repository for S4, S7, S8, S9 and S10 \(numerical results\)](#)

[dataset] Provost-Savard, A. (2022). Supporting information for Parametrized regionalization of paper recycling life-cycle assessment (Version 2). Zenodo.
<https://doi.org/10.5281/zenodo.6833925>