Life Cycle Assessment of Reusable Plastic Crates (RPCs)

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Supplementary Material

RPCs System

RPCs System Description

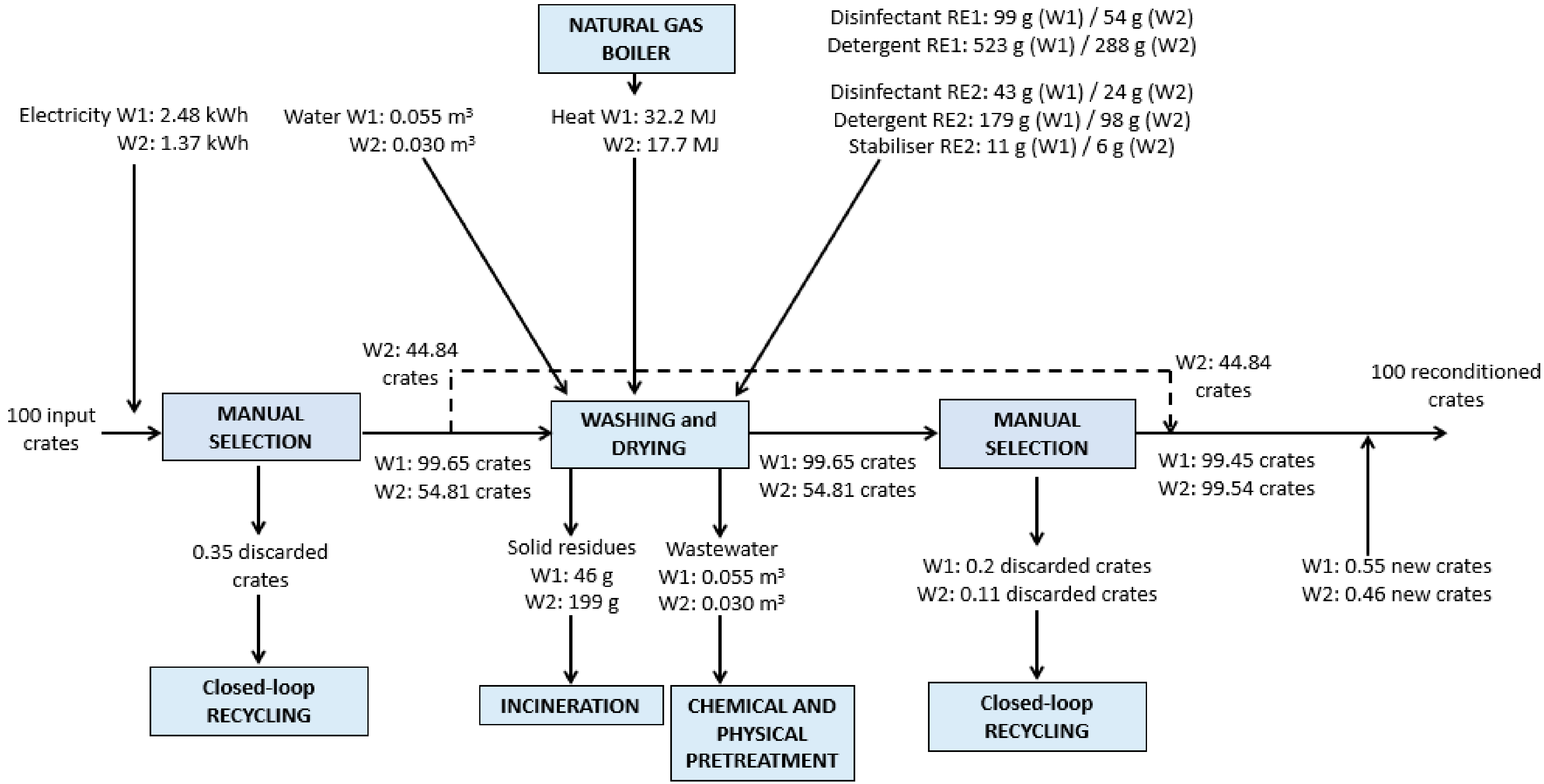


Figure S1. Layout and mass balance of an average reconditioning plant in Italy for 100 input crates. W1 = washing percentage of 100%; W2 = washing percentage of 55%; RE1 = chemicals of type RE1; RE2 = chemicals of type RE2.   .

RPCs System Inventory

Table S1. RPCs characteristics for the two surveyed societies.

Pooling society	Crate dimension - L x l x h (mm)	Average empty weight (g)	Capacity (kg)	Market share
Type A	600 x 400 x 229	1980	20	1.2
	600 x 400 x 180	1830	15	49.1
	600 x 400 x 119	1470	10	36.3
	400 x 300 x 180	1140	8	13.4
Type B	400 x 300 x 167	920	7	16.0
	600 x 400 x 125	1240	10	36.9
	600 x 400 x 160	1460	13	18.8
	600 x 400 x 190	1630	16	24.7
	600 x 400 x 250	2095	20	3.6

Table S2. Ecoinvent datasets (version 3.3) implemented in SimaPro 8.4 to model the production of crates (re-use system and single use system).

Process	ecoinvent datasets
Production of virgin PP granulate	*Polypropylene, granulate {GLO}|market for*
Injection moulding of PP granulate	*Injection moulding {RER}|processing*

Table S3. Ecoinvent datasets (version 3.3) implemented in SimaPro 8.4 to model the reconditioning process.

Transport		**ecoinvent datasets**
Transport of the crates from the users to the reconditioning plant (trucks of large size, Euro 5)		*Transport, freight, lorry > 32 metric ton, EURO5 {RER}*
Transport for the supply of chemicals (light commercial vehicles)		*Transport, freight, light commercial vehicle {Europe without Switzerland}|processing*
Input		**ecoinvent datasets**
Water for washing		*Tap water {Europe without Switzerland}|market for*
Heating of the water (gas conventional boiler)		*Heat, district or industrial, natural gas {Europe without Switzerland}|heat production, natural gas, at boiler condensing modulating >100 kW*. Modified considering the Italian context
Electric energy		*Electricity, low voltage {IT}|market for*
Disinfectant R1	Acetic acid	*Acetic acid, without water, in 98% solution state {GLO}|market for*. Modified by excluding the transport of the reagent from the manufacturer to the reconditioning plant (transport already included with primary data).
	Peracetic acid	In absence of a specific ecoinvent dataset for the production of the peracetic acid, the production of its two precursors was modelled according to the chemical reaction $(CH_3CO)_2O + H_2O_2 \rightarrow CH_3COOH + CH_3COOOH$: • acetic anhydride (1.34 kg/kg peracetic acid): *Acetic anhydride {RER}|market for* (transport voices excluded from the original dataset) • hydrogen peroxide, 50% aqueous solution (0.45 kg/kg peracetic acid): *Hydrogen peroxide, without water, in 50% solution state {RER}|hydrogen peroxide production, product in 50% solution state*
	Hydrogen peroxide	*Hydrogen peroxide, without water, in 50% solution state {RER}|hydrogen peroxide production, product in 50% solution state*
	Stabiliser	As the precise composition of the agent was not known, the stabiliser was modelled as *ethylenediaminetetraacetic* acid: *EDTA, ethylenediaminetetraacetic acid {RER}|EDTA production*
	Deionised water	*Water, deionised, from tap water, at user {Europe without Switzerland}|water production, deionised, from tap water, at user*
Disinfectant R2	Sodium hypochlorite 14% solution	*Sodium hypochlorite, without water, in 15% solution state {RER}|sodium hypochlorite production, product in 15% solution state*
Detergent R1	Soda	*Sodium hydroxide, without water, in 50% solution state {GLO}|market for* (transport voices were excluded from the original dataset)

	Alkyl alcohol alkoxylate	In absence of a specific ecoinvent dataset for this reagent, the production of another anionic surfactant (ethoxylated alcohol) was modelled: *Ethoxylated alcohol (AE3) {RER}|ethoxylated alcohol (AE3) production, petrochemical*
	Deionised water	*Water, deionised, from tap water, at user {Europe without Switzerland}|water production, deionised, from tap water, at user*
Detergent R2	Soda 30% aqueous solution	*Sodium hydroxide, without water, in 50% solution state {GLO}|market for*. The original dataset was modified by excluding the transport voices and by rectifying the strength of the solution from 50% to 30%
Stabilizer R2	Citric acid	*Citric acid {RER}|production*
	Lactic acid	*Lactic acid {RER}|production*
	Potassium iodate	In absence of a specific ecoinvent dataset for the production of the potassium iodate (KIO_3), the production of its precursors was modelled according to the chemical reaction $2KClO_3 + I_2 \rightarrow 2KIO_3 + Cl_2$ [A]: • iodine (0.59 kg/kg potassium iodate): *Iodine {RER}|production* • soda, 50% aqueous solution (1.12 kg/kg potassium iodate): *Sodium hydroxide, without water, in 50% solution state {GLO}|market for* (transport voices were excluded) • potassium hydroxide (0.26 kg/kg potassium iodate): *Potassium hydroxide {RER}|production* • chlorine gaseous (1.00 kg/kg potassium iodate): *Chlorine, gaseous {RER}|market for* (transport voices were excluded)
	Deionised water	*Water, deionised, from tap water, at user {Europe without Switzerland}|water production, deionised, from tap water, at user*
Output		**ecoinvent datasets**
Incineration of the solid residues removed from crates		• Transportation to the incinerator (100km, by trucks of medium size): *Transport, freight, lorry 16-32 metric ton*. The current Euro mix of the northern Italy was considered (ACI 2016) [B] • Incineration: *Municipal solid waste {IT}|treatment of, incineration.* The original dataset was modified by excluding the voice related to the recovery of metals from the bottom ash (the composition of the burned waste is mainly based on organic and paper residues)
Treatment of wastewater		See Table S4

[A] Potassium chlorate ($KClO_3$) is produced by the following chemical reaction: $6NaOH + 3Cl_2 + KOH \rightarrow KClO_3 + 5NaCl + 3H_2O + NaOH$.

[B] 80.8% Euro 1-2-3; 6.1% Euro 4; 12.7% Euro 5, and 0.4% Euro 6.

Table S4. Ecoinvent datasets (version 3.3) implemented in SimaPro 8.4 to model the treatment of the wastewater produced by the reconditioning process.

Input	**ecoinvent datasets**

Electric energy		*Electricity, low voltage {IT}|market for*
Polyaluminium chloride (10% aqueous solution)		In absence of a specific ecoinvent dataset for the production of the polyaluminum chloride, the consumption of another flocculating agent (aluminum sulfate) was modelled: *Aluminium sulfate, without water, in 4.33% aluminium solution state {RoW}|production*
Sulfuric acid (50% aqueous solution)	Sulfuric acid	*Sulfuric acid {RER}|production*
	Deionised water	*Water, deionised, from tap water, at user {Europe without Switzerland}|water production, deionised, from tap water, at user*
Transport		**ecoinvent datasets**
Transport for the supply of chemicals (light commercial vehicle)		*Transport, freight, light commercial vehicle {Europe without Switzerland}|processing*
Output		**ecoinvent datasets**
Pre-treated wastewater		Wastewater is discharged into the public drainage system to be treated in an urban wastewater treatment plant of medium size: *Wastewater, average {Europe without Switzerland}|treatment of wastewater, average, capacity 1E9l/year*
Sewage sludge and grit residues		• Transportation to the incinerator (100 km, by trucks of medium size): *Transport, freight, lorry 16-32 metric ton*. The current Euro mix of the northern Italy was considered (ACI 2016) • Incineration: *Raw sewage sludge {RoW}|treatment of, municipal incineration*. The original dataset was properly modified [1]

[1] The recovery of electricity and heat from the combustion of the sewage sludge was included in the original dataset, based on the lower heating value of the burned waste (3.20 MJ/kg; ecoinvent 2016a) and considering a conversion efficiency equal to 17.4% for electricity and 11.4% for heat in the incinerators of the northern Italy (ISPRA-Federambiente 2014). The avoided electricity (0.15 kWh/kg) was modelled as produced through the Italian electricity mix (*Electricity, low voltage {IT}\| market for*). For the avoided thermal energy, the produced heat was assumed to be delivered to a district heating network, with a 10% loss for the distribution. The substituted technology (0.33 MJ/kg) was modelled as heat generated by a domestic gas boiler (power < 100 kW), with an 87% efficiency. The emission factors of this technology are reported in Table S5.

Table S5. Air emission factors for the production of heat from a gas domestic boiler. Values are expressed per GJ of consumed natural gas.

Pollutant	Emission factor	Source	Pollutant	Emission factor	Source
CO	25 g	ISPRA (2015)	Hg	0.2 mg	ISPRA (2015)
N_2O	1 g		Ni	0.51 μg	EEA (2017)
CH_4	3 g		As	0.12 mg	
NO_X	31 g		Pb	1.5 μg	
VOC not methanogens	5 g		Cr	0.76 μg	
SO_2	0.3 g	EEA (2017)	Se	11 μg	
Total particulate (< 10 μm)	0.2 g	ISPRA (2015)	Cu	0.076 μg	
Fossil CO_2	57.2 kg		Benzene	2.2 μg	
Polycyclic aromatic hydrocarbons	9.9 mg	ANPA (2000)	Butane	1.8 g	ANPA (2000)
Dioxins and furans	1.5 ng	EEA (2017)	Ethane	2.7 g	
Cd	0.25 μg		Formaldehyde	0.9 g	
Pentane	1.8 g	ANPA (2000)	Propane	1.8 g	
Toluene	0.21 g		Zn	1.5 μg	EEA (2017)

Table S6. Ecoinvent datasets (version 3.3) implemented in SimaPro 8.4 to model the end of life process (re-use system and single use system).

Transport	**ecoinvent datasets**
Transportation of the crates to the recycling facility	*Transport, freight, lorry > 32 metric ton, EURO5 {RER}*
Input	**ecoinvent datasets**
Water	*Tap water {Europe without Switzerland}|tap water production, underground water without treatment*
Heat from natural gas	*Heat, district or industrial, natural gas {Europe without Switzerland}|heat production, natural gas, at industrial furnace > 100kW* (modified according to the Italian mix)
Electric energy	*Electricity, low voltage {IT}|market for*
Output	**ecoinvent datasets**

PP scraps	Transportation to the incineration facility	*Transport, freight, lorry 16-32 t metric ton* The current Euro mix of the northern Italy was considered (ACI 2016)
	Incineration process	*Waste polypropylene {CH}∣treatment of, municipal incineration.* The original dataset was properly modified [1]
PP secondary granulate	Case of the 100 input crates	The secondary granulate is used for applications such as the production of the beer crates (open-loop recycling). The avoided production of the virgin PP granulate was modelled as *Polypropylene, granulate {GLO}∣market for*
	Case of the crates discarded for the reconditioning process	The secondary granulate is used for the manufacturing of other RPCs (closed-loop recycling). No avoided primary production was modelled

[1] The recovery of electricity and heat from the combustion of plastic scraps was included in the original dataset, based on the LHV of the waste (32.78 MJ/kg, ecoinvent 2016b) and considering a conversion efficiency equal to 17.4% for electricity and 11.4% for heat in the incinerators of the northern Italy (ISPRA-Federambiente 2014).

RPCs System Results

Table S7. Impact indicators and water resources consumption associated with the life cycle of the 100 RPCs ready for *n*th use ($1 \leq n \leq 125$) for the scenario W1-RE1 (washing percentage equal to 100% and chemicals of type RE1).

	SCENARIO W1-RE1												
	Rotations	**1**	**3**	**5**	**8**	**20**	**30**	**40**	**50**	**70**	**90**	**100**	**125**
Climate change	kg CO_2 eq	327.89	343.60	359.31	382.87	477.13	555.68	634.23	712.78	869.88	1026.97	1105.52	1301.89
Ozone depletion	kg CFC-11 eq	2.80E-05	3.04E-05	3.28E-05	3.63E-05	5.07E-05	6.26E-05	7.46E-05	8.65E-05	1.10E-04	1.34E-04	1.46E-04	1.76E-04
Human toxicity, non-cancer effects	CTUh	4.26E-05	4.53E-05	4.80E-05	5.21E-05	6.85E-05	8.22E-05	9.58E-05	1.09E-04	1.37E-04	1.64E-04	1.78E-04	2.12E-04
Human toxicity, cancer effects	CTUh	1.36E-05	1.41E-05	1.46E-05	1.54E-05	1.83E-05	2.08E-05	2.33E-05	2.58E-05	3.07E-05	3.57E-05	3.81E-05	4.43E-05
Particulate matter	kg $PM_{2.5}$ eq	1.28E-01	1.34E-01	1.40E-01	1.48E-01	1.84E-01	2.14E-01	2.43E-01	2.73E-01	3.32E-01	3.91E-01	4.21E-01	4.95E-01
Photochemical ozone formation	kg NMVOC eq	0.93	0.97	1.01	1.07	1.31	1.50	1.70	1.90	2.29	2.68	2.88	3.37
Acidification	mol_c H^+ eq	1.50	1.56	1.62	1.71	2.06	2.36	2.65	2.95	3.54	4.14	4.43	5.17
Terrestrial eutrophication	mol_c N eq	2.45	2.57	2.69	2.86	3.56	4.14	4.72	5.31	6.47	7.63	8.22	9.67
Freshwater eutrophication	kg P eq	1.12E-01	1.15E-01	1.18E-01	1.23E-01	1.41E-01	1.57E-01	1.72E-01	1.88E-01	2.19E-01	2.50E-01	2.65E-01	3.04E-01
Marine eutrophication	kg N eq	2.45E-01	2.58E-01	2.72E-01	2.92E-01	3.71E-01	4.38E-01	5.05E-01	5.71E-01	7.04E-01	8.37E-01	9.04E-01	1.07
Freshwater ecotoxicity	CTUe	1933	2052	2171	2349	3062	3656	4251	4845	6033	7222	7816	9302

Mineral, fossil & renewable resource depletion	kg Sb eq	5.37E-03	5.71E-03	6.05E-03	6.57E-03	8.62E-03	1.03E-02	1.21E-02	1.38E-02	1.72E-02	2.06E-02	2.23E-02	2.66E-02
CED	MJ	8855	9161	9467	9925	11760	13288	14817	16345	19402	22459	23988	27809
Water depletion	m^3 water	4.29	4.44	4.60	4.83	5.75	6.51	7.28	8.05	9.58	11.11	11.88	13.80

Table S8. Impact indicators and water resources consumption associated with the life cycle of the 100 RPCs ready for n[th] use ($1 \leq n \leq 125$) for the scenario W1-RE2 (washing percentage equal to 100% and chemicals of type RE2).

	SCENARIO W1-RE2												
	Rotations	**1**	**3**	**5**	**8**	**20**	**30**	**40**	**50**	**70**	**90**	**100**	**125**
Climate change	kg CO_2 eq	327.89	342.81	357.73	380.11	469.64	544.25	618.86	693.46	842.68	991.89	1066.50	1253.01
Ozone depletion	kg CFC-11 eq	2.80E-05	3.01E-05	3.22E-05	3.53E-05	4.80E-05	5.85E-05	6.90E-05	7.95E-05	1.01E-04	1.22E-04	1.32E-04	1.58E-04
Human toxicity, non-cancer effects	CTUh	4.26E-05	4.50E-05	4.74E-05	5.11E-05	6.57E-05	7.79E-05	9.01E-05	1.02E-04	1.27E-04	1.51E-04	1.63E-04	1.94E-04
Human toxicity, cancer effects	CTUh	1.36E-05	1.41E-05	1.45E-05	1.52E-05	1.78E-05	1.99E-05	2.21E-05	2.43E-05	2.86E-05	3.30E-05	3.51E-05	4.06E-05
Particulate matter	kg $PM_{2.5}$ eq	1.28E-01	1.33E-01	1.38E-01	1.46E-01	1.77E-01	2.03E-01	2.30E-01	2.56E-01	3.08E-01	3.60E-01	3.86E-01	4.52E-01
Photochemical ozone formation	kg NMVOC eq	0.93	0.97	1.01	1.06	1.28	1.46	1.65	1.83	2.19	2.56	2.74	3.20
Acidification	mol_c H^+ eq	1.50	1.55	1.61	1.69	2.02	2.29	2.56	2.83	3.38	3.92	4.20	4.88
Terrestrial eutrophication	mol_c N eq	2.45	2.56	2.67	2.83	3.48	4.02	4.56	5.10	6.18	7.26	7.81	9.16
Freshwater eutrophication	kg P eq	1.12E-01	1.15E-01	1.17E-01	1.22E-01	1.38E-01	1.52E-01	1.66E-01	1.79E-01	2.07E-01	2.34E-01	2.48E-01	2.83E-01
Marine eutrophication	kg N eq	2.45E-01	2.57E-01	2.70E-01	2.89E-01	3.63E-01	4.26E-01	4.88E-01	5.50E-01	6.75E-01	8.00E-01	8.62E-01	1.02
Freshwater ecotoxicity	CTUe	1933	2044	2156	2323	2990	3547	4103	4659	5772	6885	7441	8832
Mineral, fossil & renewable resource depletion	kg Sb eq	5.37E-03	5.67E-03	5.98E-03	6.44E-03	8.27E-03	9.80E-03	1.13E-02	1.28E-02	1.59E-02	1.90E-02	2.05E-02	2.43E-02
CED	MJ	8855	9147	9438	9876	11625	13083	14541	15998	18914	21829	23287	26932
Water depletion	m^3 water	4.29	4.42	4.54	4.73	5.50	6.13	6.77	7.41	8.68	9.95	10.59	12.18

Table S9. Impact indicators and water resources consumption associated with the life cycle of the 100 RPCs ready for n[th] use ($1 \leq n \leq 125$) for the scenario W2-RE1 (washing percentage equal to 55% and chemicals of type RE1).

	SCENARIO W2-RE1											
	Rotations	**1**	**3**	**5**	**8**	**20**	**30**	**40**	**50**	**70**	**90**	**100**	**125**
Climate change	kg CO_2 eq	327.89	339.60	351.32	368.89	439.18	497.75	556.32	614.89	732.04	849.18	907.76	1054.19
Ozone depletion	kg CFC-11 eq	2.80E-05	2.97E-05	3.14E-05	3.40E-05	4.44E-05	5.30E-05	6.16E-05	7.02E-05	8.75E-05	1.05E-04	1.13E-04	1.35E-04
Human toxicity, non-cancer effects	CTUh	4.26E-05	4.49E-05	4.72E-05	5.06E-05	6.45E-05	7.60E-05	8.76E-05	9.91E-05	1.22E-04	1.45E-04	1.57E-04	1.86E-04
Human toxicity, cancer effects	CTUh	1.36E-05	1.40E-05	1.44E-05	1.49E-05	1.72E-05	1.90E-05	2.09E-05	2.27E-05	2.65E-05	3.02E-05	3.20E-05	3.67E-05
Particulate matter	kg $PM_{2.5}$ eq	1.28E-01	1.32E-01	1.37E-01	1.44E-01	1.71E-01	1.94E-01	2.16E-01	2.39E-01	2.85E-01	3.30E-01	3.53E-01	4.10E-01
Photochemical ozone formation	kg NMVOC eq	0.93	0.97	1.00	1.04	1.23	1.39	1.55	1.71	2.02	2.34	2.50	2.89
Acidification	mol_c H^+ eq	1.50	1.54	1.59	1.65	1.92	2.14	2.36	2.58	3.02	3.46	3.68	4.23
Terrestrial eutrophication	mol_c N eq	2.45	2.55	2.64	2.78	3.34	3.81	4.28	4.75	5.69	6.63	7.10	8.27
Freshwater eutrophication	kg P eq	1.12E-01	1.14E-01	1.16E-01	1.20E-01	1.33E-01	1.43E-01	1.54E-01	1.65E-01	1.87E-01	2.09E-01	2.19E-01	2.47E-01
Marine eutrophication	kg N eq	2.45E-01	2.55E-01	2.65E-01	2.80E-01	3.41E-01	3.92E-01	4.42E-01	4.93E-01	5.94E-01	6.96E-01	7.46E-01	8.73E-01
Freshwater ecotoxicity	CTUe	1933	2040	2147	2308	2951	3487	4023	4558	5630	6702	7237	8577
Mineral, fossil & renewable resource depletion	kg Sb eq	5.37E-03	5.65E-03	5.94E-03	6.36E-03	8.06E-03	9.48E-03	1.09E-02	1.23E-02	1.52E-02	1.80E-02	1.94E-02	2.29E-02
CED	MJ	8855	9080	9304	9640	10985	12106	13227	14347	16589	18831	19952	22754
Water depletion	m^3 water	4.29	4.39	4.50	4.65	5.28	5.80	6.32	6.84	7.88	8.92	9.45	10.75

Table S10. Impact indicators and water resources consumption associated with the life cycle of the 100 RPCs ready for n[th] use (1 ≤ n ≤ 125) for the scenario W2-RE2 (washing percentage equal to 55% and chemicals of type RE2).

	SCENARIO W2-RE2												
	Rotations	**1**	**3**	**5**	**8**	**20**	**30**	**40**	**50**	**70**	**90**	**100**	**125**
Climate change	kg CO_2 eq	327.89	339.17	350.45	367.37	435.06	491.46	547.87	604.27	717.08	829.89	886.29	1027.30
Ozone depletion	kg CFC-11 eq	2.80E-05	2.95E-05	3.11E-05	3.35E-05	4.29E-05	5.07E-05	5.85E-05	6.64E-05	8.20E-05	9.77E-05	1.06E-04	1.25E-04
Human toxicity, non-cancer effects	CTUh	4.26E-05	4.47E-05	4.69E-05	5.01E-05	6.30E-05	7.37E-05	8.45E-05	9.52E-05	1.17E-04	1.38E-04	1.49E-04	1.76E-04
Human toxicity, cancer effects	CTUh	1.36E-05	1.40E-05	1.43E-05	1.48E-05	1.68E-05	1.85E-05	2.02E-05	2.19E-05	2.53E-05	2.87E-05	3.04E-05	3.46E-05
Particulate matter	kg $PM_{2.5}$ eq	1.28E-01	1.32E-01	1.36E-01	1.42E-01	1.67E-01	1.88E-01	2.09E-01	2.30E-01	2.71E-01	3.13E-01	3.34E-01	3.86E-01
Photochemical ozone formation	kg NMVOC eq	0.93	9.64E-01	0.99	1.04	1.22	1.37	1.52	1.67	1.97	2.27	2.42	2.80
Acidification	mol_c H^+ eq	1.50	1.54	1.58	1.64	1.89	2.10	2.31	2.51	2.93	3.34	3.55	4.07
Terrestrial eutrophication	mol_c N eq	2.45	2.54	2.63	2.77	3.30	3.75	4.19	4.64	5.53	6.42	6.87	7.99
Freshwater eutrophication	kg P eq	1.12E-01	1.14E-01	1.16E-01	1.19E-01	1.31E-01	1.41E-01	1.51E-01	1.60E-01	1.80E-01	2.00E-01	2.10E-01	2.35E-01
Marine eutrophication	kg N eq	2.45E-01	2.55E-01	2.64E-01	2.79E-01	3.37E-01	3.85E-01	4.33E-01	4.82E-01	5.78E-01	6.75E-01	7.23E-01	8.44E-01
Freshwater ecotoxicity	CTUe	1933	2036	2139	2294	2912	3427	3941	4456	5486	6516	7031	8319
Mineral, fossil & renewable resource depletion	kg Sb eq	5.37E-03	5.63E-03	5.89E-03	6.29E-03	7.87E-03	9.18E-03	1.05E-02	1.18E-02	1.44E-02	1.71E-02	1.84E-02	2.17E-02
CED	MJ	8855	9072	9288	9613	10911	11993	13075	14157	16321	18484	19566	22271
Water depletion	m^3 water	4.29	4.38	4.47	4.60	5.14	5.59	6.04	6.49	7.39	8.28	8.73	9.86

Table S11. Percent change of the impacts and water consumption associated with the RPCs life cycle, according to the different ways of management for the reconditioning step. Considering for example the first column (coloured), the percentage change is calculated as: Δ% = [$IMPACT_{SC.W1}$ - $IMPACT_{SC.W2}$] / $IMPACT_{SC.W2}$, keeping constant the type of used reagents (RE1). The impact changes are reported for 20, 50, 80, and 125 rotations.

	W1 vs. W2 scenario								RE1 vs. RE2 scenario							
	Reagents of type RE1				Reagents of type RE2				Washing percentage (100%)				Washing percentage (55%)			
	n = 20	50	80	125	20	50	80	125	20	50	80	125	20	50	80	125
Climate change	8.6%	15.9%	20.0%	23.5%	7.9%	14.8%	18.6%	22.0%	1.6%	2.8%	3.4%	3.9%	0.9%	1.8%	2.2%	2.6%
Ozone depletion	14.3%	23.2%	27.4%	30.6%	11.9%	19.8%	23.6%	26.6%	5.7%	8.8%	10.2%	11.2%	3.5%	5.8%	6.9%	7.8%
Human toxicity, non-cancer effects	6.2%	10.4%	12.5%	14.1%	4.4%	7.5%	9.0%	10.3%	4.2%	7.0%	8.3%	9.3%	2.4%	4.1%	5.0%	5.7%
Human toxicity, cancer effects	6.8%	13.3%	17.2%	20.9%	5.4%	10.7%	14.1%	17.2%	3.3%	6.1%	7.8%	9.3%	1.9%	3.7%	4.9%	6.0%
Particulate matter	7.6%	14.1%	17.7%	20.8%	6.0%	11.3%	14.4%	17.1%	3.7%	6.6%	8.2%	9.5%	2.2%	4.1%	5.2%	6.1%
Photochemical ozone formation	5.9%	11.0%	13.9%	16.4%	5.0%	9.4%	12.0%	14.3%	2.0%	3.6%	4.5%	5.2%	1.2%	2.2%	2.8%	3.3%
Acidification	7.5%	14.5%	18.6%	22.3%	6.6%	12.7%	16.5%	19.9%	2.3%	4.1%	5.2%	6.1%	1.3%	2.6%	3.3%	4.0%
Terrestrial eutrophication	6.4%	11.7%	14.5%	16.9%	5.4%	10.0%	12.5%	14.7%	2.3%	4.0%	4.9%	5.6%	1.3%	2.4%	3.0%	3.5%
Freshwater eutrophication	6.7%	13.8%	18.6%	23.4%	5.6%	11.8%	16.1%	20.4%	2.4%	4.8%	6.2%	7.7%	1.4%	2.9%	4.0%	5.1%
Marine eutrophication	8.9%	15.8%	19.5%	22.6%	7.9%	14.3%	17.7%	20.6%	2.2%	3.7%	4.5%	5.1%	1.3%	2.4%	2.9%	3.4%
Freshwater ecotoxicity	3.8%	6.3%	7.5%	8.5%	2.7%	4.6%	5.5%	6.2%	2.4%	4.0%	4.7%	5.3%	1.4%	2.3%	2.7%	3.1%
Mineral, fossil & renewable resource depletion	7.0%	11.8%	14.1%	16.0%	5.1%	8.8%	10.6%	12.1%	4.3%	7.1%	8.5%	9.6%	2.5%	4.3%	5.2%	5.9%
CED	7.1%	13.9%	18.2%	22.2%	6.5%	13.0%	17.1%	20.9%	1.2%	2.2%	2.7%	3.3%	0.7%	1.3%	1.8%	2.2%
Water depletion	8.9%	17.6%	23.1%	28.4%	6.9%	14.1%	18.9%	23.6%	4.5%	8.7%	11.1%	13.3%	2.7%	5.4%	7.3%	9.1%

Table S12. Impact indicators and water resources consumption associated with the life cycle stages "production", "reconditioning", and "end of life" of the 100 RPCs for 20 and 125 uses in the scenario W1-RE1: absolute and relative values. For each number of uses, the stage with the highest contribution to the overall indicator is highlighted.

		N = 20						N = 125					
		Production		**Reconditioning**		**End of life**		**Production**		**Reconditioning**		**End of life**	
Climate change	kg CO_2 eq	**475.30**	**67%**	115.84	16%	-114.01	-16%	624.71	43%	**756.00**	**52%**	-78.82	-5%
Ozone depletion	kg CFC-11 eq	**2.63E-05**	**52%**	1.99E-05	39%	4.43E-06	9%	3.94E-05	22%	**1.30E-04**	**74%**	6.79E-06	4%
Human toxicity, non-cancer effects	CTUh	**4.34E-05**	**63%**	2.17E-05	32%	3.43E-06	5%	6.41E-05	30%	**1.41E-04**	**67%**	6.48E-06	3%
Human toxicity, cancer effects	CTUh	**1.85E-05**	**73%**	3.31E-06	13%	-3.50E-06	-14%	**2.56E-05**	**51%**	2.16E-05	43%	-2.86E-06	-6%
Particulate matter	kg $PM_{2.5}$ eq	**0.20**	**66%**	4.35E-02	15%	-0.06	-19%	0.26	44%	**0.28**	**48%**	-0.05	-8%
Photochemical ozone formation	kg NMVOC eq	**1.62**	**65%**	2.81E-01	11%	-0.59	-24%	**2.08**	**47%**	1.83	41%	-0.55	-12%
Acidification	mol_c H^+ eq	**2.14**	**70%**	4.13E-01	14%	-0.49	-16%	**2.87**	**48%**	2.70	45%	-0.39	-7%
Terrestrial eutrophication	mol_c N eq	**3.71**	**66%**	8.70E-01	16%	-1.02	-18%	4.87	43%	**5.68**	**50%**	-0.87	-8%
Freshwater eutrophication	kg P eq	**0.12**	**85%**	1.79E-02	13%	3.13E-03	2%	**0.18**	**59%**	0.12	38%	7.85E-03	3%
Marine eutrophication	kg N eq	**0.36**	**65%**	1.03E-01	18%	-9.45E-02	-17%	0.48	39%	**0.67**	**54%**	-0.08	-7%
Freshwater ecotoxicity	CTUe	**1723.64**	**56%**	929.92	30%	408.59	13%	2466.10	27%	**6068.98**	**65%**	766.70	8%
Mineral, fossil & renewable resource depletion	kg Sb eq	**5.81E-03**	**67%**	2.74E-03	32%	7.57E-05	1%	8.52E-03	32%	**1.79E-02**	**67%**	2.29E-04	1%
CED	MJ	**1.60E+04**	**66%**	2.00E+03	8%	-6.22E+03	-26%	**2.07E+04**	**52%**	1.30E+04	33%	-5.88E+03	-15%
Water depletion	m^3 water	**5.37**	**76%**	1.01	14%	-0.64	-9%	**7.41**	**52%**	6.61	46%	-0.22	-2%

Table S13. Impact indicators and water resources consumption associated with the reconditioning process of the 100 RPCs in the scenario W1-RE1 (washing percentage equal to 100% and chemicals of type RE1): total value and contribution analysis. For each indicator, the stage with the highest contribution is highlighted.

		RECONDITIONING STAGE IN THE SCENARIO W1-RE1										
		Total	**Transport user - plant**		**Electricity consumption**		**Washing step [1]**		**Solid residues management**		**Wastewater treatment**	
Climate change	kg CO_2 eq	6.10	1.79	29%	1.34	22%	**2.74**	**45%**	0.06	1%	0.17	3%
Ozone depletion	kg CFC-11 eq	1.05E-06	3.58E-07	34%	1.48E-07	14%	**5.27E-07**	**50%**	3.06E-10	0%	1.40E-08	1%
Human toxicity, non-cancer effects	CTUh	1.14E-06	**4.32E-07**	**38%**	2.16E-07	19%	2.59E-07	23%	3.80E-08	3%	1.95E-07	17%
Human toxicity, cancer effects	CTUh	1.74E-07	4.59E-08	26%	4.54E-08	26%	**6.48E-08**	**37%**	2.10E-09	1%	1.62E-08	9%
Particulate matter	kg $PM_{2.5}$ eq	2.29E-03	**9.88E-04**	**43%**	4.98E-04	22%	7.25E-04	32%	1.78E-06	0%	7.64E-05	3%
Photochemical ozone formation	kg NMVOC eq	1.48E-02	**7.84E-03**	**53%**	2.72E-03	18%	3.76E-03	25%	2.08E-05	0%	4.38E-04	3%
Acidification	mol_c H^+ eq	2.17E-02	**7.51E-03**	**35%**	6.87E-03	32%	6.33E-03	29%	1.94E-05	0%	1.02E-03	5%
Terrestrial eutrophication	mol_c N eq	4.58E-02	**2.45E-02**	**53%**	8.92E-03	19%	1.04E-02	23%	8.23E-05	0%	1.92E-03	4%
Freshwater eutrophication	kg P eq	9.40E-04	1.11E-04	12%	**3.68E-04**	**39%**	3.52E-04	37%	1.84E-06	0%	1.08E-04	11%
Marine eutrophication	kg N eq	5.41E-03	**2.24E-03**	**41%**	8.65E-04	16%	1.03E-03	19%	9.11E-06	0%	1.26E-03	23%
Freshwater ecotoxicity	CTUe	48.94	11.41	23%	**24.35**	**50%**	6.96	14%	3.35	7%	2.87	6%
Mineral, fossil & renewable resource depletion	kg Sb eq	1.44E-04	**8.73E-05**	**61%**	2.02E-05	14%	3.03E-05	21%	9.35E-08	0%	6.16E-06	4%
CED	MJ	105.03	31.46	30%	23.38	22%	**48.17**	**46%**	2.78-02	0%	1.98	2%
Water depletion	m^3 water	5.33E-02	6.54E-03	4%	1.93E-02	13%	**7.48E-02**	**51%**	5.54E-05	0%	-4.73E-02	-32%

[1] The washing step includes the water consumption, the chemicals consumption, and the water heating by a conventional gas boiler. See the Table S14 for the contribution analysis of the washing step in the scenario W1-RE1.

Table S14. Impact indicators and water resources associated to the washing step of the 100 RPCs in the scenario W1-RE1: total value and contribution analysis. For each indicator, the stage with the highest contribution is highlighted.

		WASHING STEP IN THE SCENARIO W1-RE1										
		Total	**Water consumption**		**Detergent production**		**Disinfectant production**		**Chemicals transportation**		**Water heating**	
Climate change	kg CO_2 eq	2.74	0.02	1%	0.12	4%	0.27	10%	0.12	4%	**2.20**	**80%**
Ozone depletion	kg CFC-11 eq	5.27E-07	2.04E-09	0%	1.85E-08	4%	1.55E-07	29%	2.00E-08	4%	**3.32E-07**	**63%**
Human toxicity, non-cancer effects	CTUh	2.59E-07	1.20E-08	5%	3.65E-08	14%	**1.11E-07**	**43%**	4.97E-08	19%	4.95E-08	19%
Human toxicity, cancer effects	CTUh	6.48E-08	8.90E-09	14%	1.46E-08	23%	1.62E-08	25%	7.04E-09	11%	**1.81E-08**	**28%**
Particulate matter	kg $PM_{2.5}$ eq	7.25E-04	1.30E-05	2%	8.24E-05	11%	**2.95E-04**	**41%**	8.42E-05	12%	2.50E-04	35%
Photochemical ozone formation	kg NMVOC eq	3.76E-03	6.08E-05	2%	3.86E-04	10%	7.57E-04	20%	6.74E-04	18%	**1.88E-03**	**50%**
Acidification	mol_c H^+ eq	6.33E-03	1.24E-04	2%	7.17E-04	11%	1.77E-03	28%	6.87E-04	11%	**3.03E-03**	**48%**
Terrestrial eutrophication	mol_c N eq	1.04E-02	1.94E-04	2%	9.32E-04	9%	2.68E-03	26%	2.17E-03	21%	**4.45E-03**	**43%**
Freshwater eutrophication	kg P eq	3.52E-04	1.41E-05	4%	4.74E-05	13%	**1.57E-04**	**45%**	2.49E-05	7%	1.08E-04	31%
Marine eutrophication	kg N eq	1.03E-03	2.02E-05	2%	1.03E-04	10%	2.82E-04	27%	2.00E-04	19%	**4.28E-04**	**41%**
Freshwater ecotoxicity	CTUe	6.96	2.68E-01	4%	1.26	18%	**2.35**	**34%**	1.40	20%	1.69	24%
Mineral, fossil & renewable resource depletion	kg Sb eq	3.03E-05	2.01E-06	7%	5.70E-06	19%	**1.28E-05**	**42%**	7.35E-06	24%	2.45E-06	8%
CED	MJ	48.17	0.39	1%	2.92	6%	4.16	9%	1.93	4%	**38.77**	**80%**
Water depletion	m^3 water	7.48E-02	5.51E-02	**74%**	6.88E-03	9%	8.67E-03	12%	4.60E-04	1%	3.61E-03	5%

Table S15. Impact indicators and water resources associated to the reconditioning process of the 100 RPCs in the scenario W2-RE1 (washing percentage equal to 55% and chemicals of type RE1): total value and contribution analysis. For each indicator, the stage with the highest contribution is highlighted.

		RECONDITIONING STAGE IN THE SCENARIO W2-RE1										
		Total	**Transport user - plant**		**Electricity consumption**		**Washing Step [1]**		**Solid residues management**		**Wastewater treatment**	
Climate change	kg CO_2 eq	4.39	**1.79**	**41%**	0.74	17%	1.51	34%	0.26	6%	0.09	2%
Ozone depletion	kg CFC-11 eq	7.39E-07	**3.58E-07**	**48%**	8.20E-08	11%	2.90E-07	39%	1.33E-09	0%	7.73E-09	1%
Human toxicity, non-cancer effects	CTUh	9.66E-07	**4.32E-07**	**45%**	1.19E-07	12%	1.42E-07	15%	1.65E-07	17%	1.07E-07	11%
Human toxicity, cancer effects	CTUh	1.25E-07	**4.59E-08**	**37%**	2.51E-08	20%	3.56E-08	29%	9.10E-09	7%	8.93E-09	7%
Particulate matter	kg $PM_{2.5}$ eq	1.71E-03	**9.88E-04**	**58%**	2.75E-04	16%	3.99E-04	23%	7.75E-06	0%	4.20E-05	2%
Photochemical ozone formation	kg NMVOC eq	1.17E-02	**7.84E-03**	**67%**	1.50E-03	13%	2.07E-03	18%	9.03E-05	1%	2.41E-04	2%
Acidification	mol_c H^+ eq	1.54E-02	**7.51E-03**	**49%**	3.80E-03	25%	3.48E-03	23%	8.40E-05	1%	5.59E-04	4%
Terrestrial eutrophication	mol_c N eq	3.65E-02	**2.45E-02**	**67%**	4.93E-03	13%	5.73E-03	16%	3.57E-04	1%	1.05E-03	3%
Freshwater eutrophication	kg P eq	5.75E-04	1.11E-04	19%	**2.03E-04**	**35%**	1.93E-04	34%	7.97E-06	1%	5.93E-05	10%
Marine eutrophication	kg N eq	4.02E-03	**2.24E-03**	**56%**	4.78E-04	12%	5.68E-04	14%	3.95E-05	1%	6.93E-04	17%
Freshwater ecotoxicity	CTUe	44.81	11.41	25%	13.45	30%	3.83	9%	**14.54**	**32%**	1.58	4%
Mineral, fossil & renewable resource depletion	kg Sb eq	1.19E-04	**8.73E-05**	**73%**	1.12E-05	9%	1.67E-05	14%	4.06E-07	0%	3.39E-06	3%
CED	MJ	72.09	**31.46**	**44%**	12.92	18%	26.50	37%	0.12	0%	1.09	2%
Water depletion	m^3 water	3.25E-02	6.54E-03	8%	1.06E-02	13%	**4.11E-02**	**49%**	2.40E-04	0%	-2.60E-02	-31%

[1] The washing step includes the water consumption, the chemicals consumption, and the water heating by a conventional gas boiler.

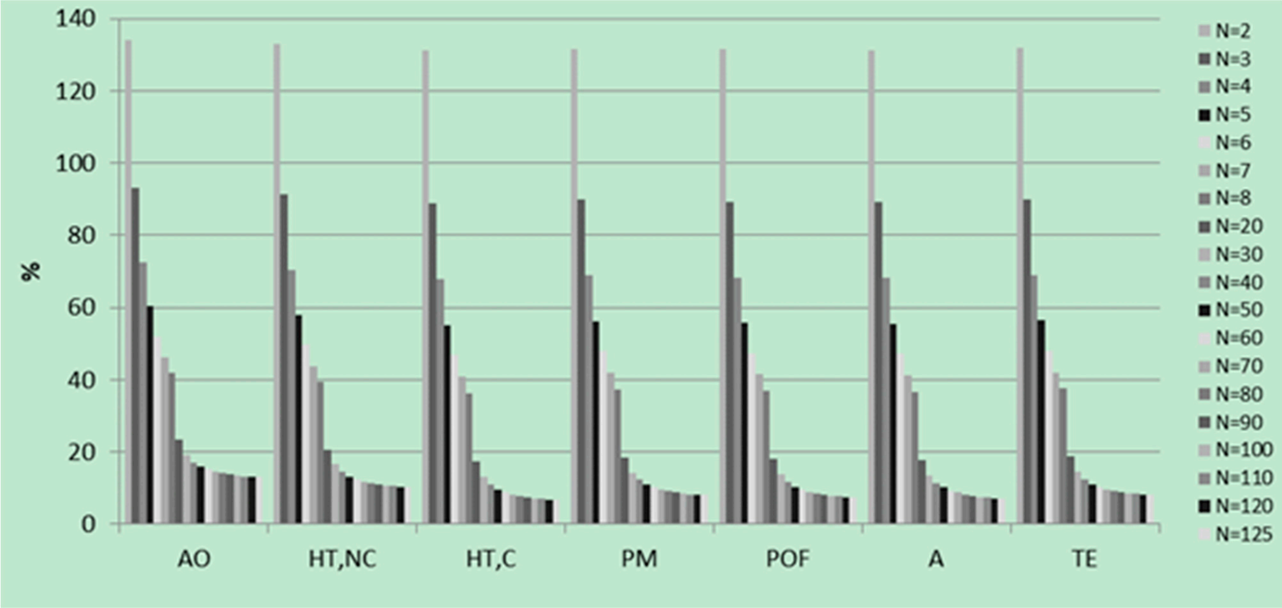
Reconditioning System (RPCs) vs. Single Use Plastic Crates System (SPCs)

Table S16. Characteristics of the single use plastic crates. The market share is assumed the same provided for the RCPs.

Manufacturer	Crate dimension - L x l x h (mm)	Average empty weight (g)	Capacity (kg)	Market share (%)
Type A	600 x 400 x 220	800	18	1.2
	600 x 400 x 200	770	16	49.1
	600 x 400 x 120	530	10	36.3
	400 x 300 x 155	180	8	13.4
Type B	400 x 300 x 155	180	8	16.0
	600 x 400 x 120	530	10	36.9
	600 x 400 x 150	580	12	18.8
	600 x 400 x 200	770	16	24.7
	600 x 400 x 220	800	18	3.6

Table S17. Impact indicators and water resources consumption associated with the life cycle of 100 single use plastic crates and the corresponding contribution analysis.

		Total value	**Crates production**		**End of life of crates**	
Climate change	kg CO_2 eq	127.41	174.19	79%	-46.78	- 21%
Ozone depletion	kg CFC-11 eq	1.09E-05	9.32E-06	86%	1.56E-06	14%
Human toxicity, non-cancer effects	CTUh	1.65E-05	1.54E-05	93%	1.12E-06	7%
Human toxicity, cancer effects	CTUh	5.30E-06	6.70E-06	83%	-1.40E-06	- 17%
Particulate matter	kg $PM_{2.5}$ eq	4.96E-02	7.24E-02	76%	-2.28E-02	- 24%
Photochemical ozone formation	kg NMVOC eq	3.63E-01	0.59	72%	-2.32E-01	- 28%
Acidification	mol_c H^+ eq	5.82E-01	0.78	80%	-0.20	- 20%
Terrestrial eutrophication	mol_c N eq	9.53E-01	1.36	77%	-0.40	- 23%
Freshwater eutrophication	kg P eq	4.35E-02	0.04	98%	8.84E-04	2%
Marine eutrophication	kg N eq	9.52E-02	0.13	78%	-3.77E-02	- 22%
Freshwater ecotoxicity	CTUe	751.18	617.58	82%	133.59	18%
Mineral, fossil & renewable resource depletion	kg Sb eq	2.09E-03	2.07E-03	99%	1.86E-05	1%
CED	MJ	3441	5881.99	71%	-2440.89	- 29%
Water depletion	m^3 water	1.67	1.94	88%	-0.28	- 12%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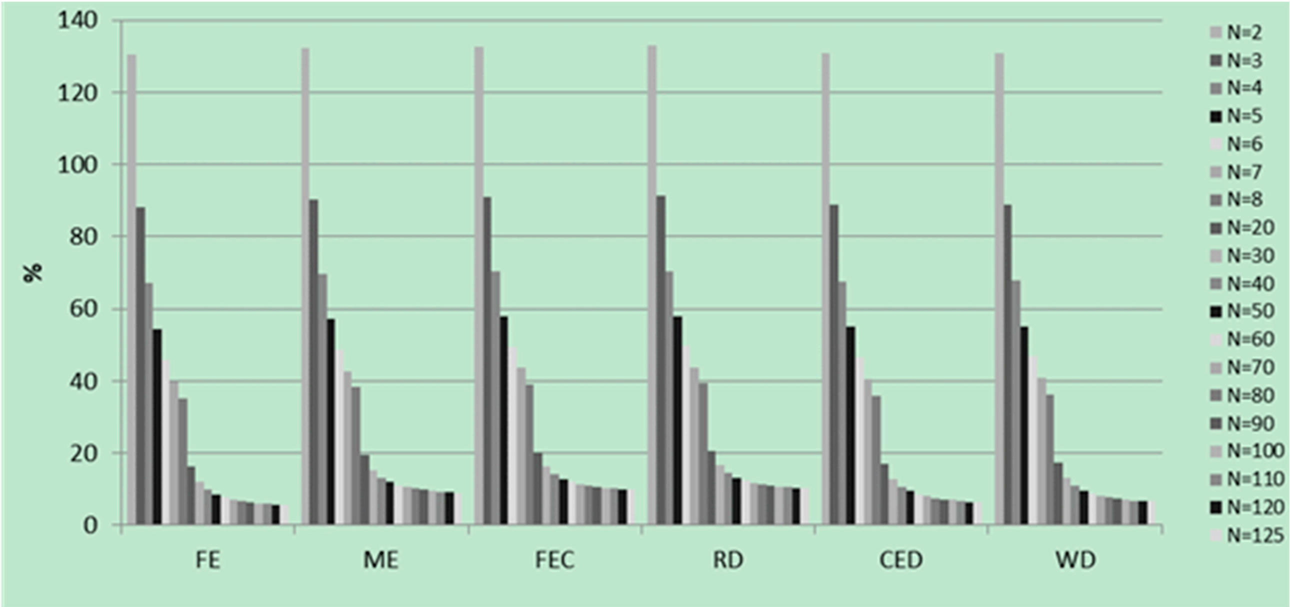
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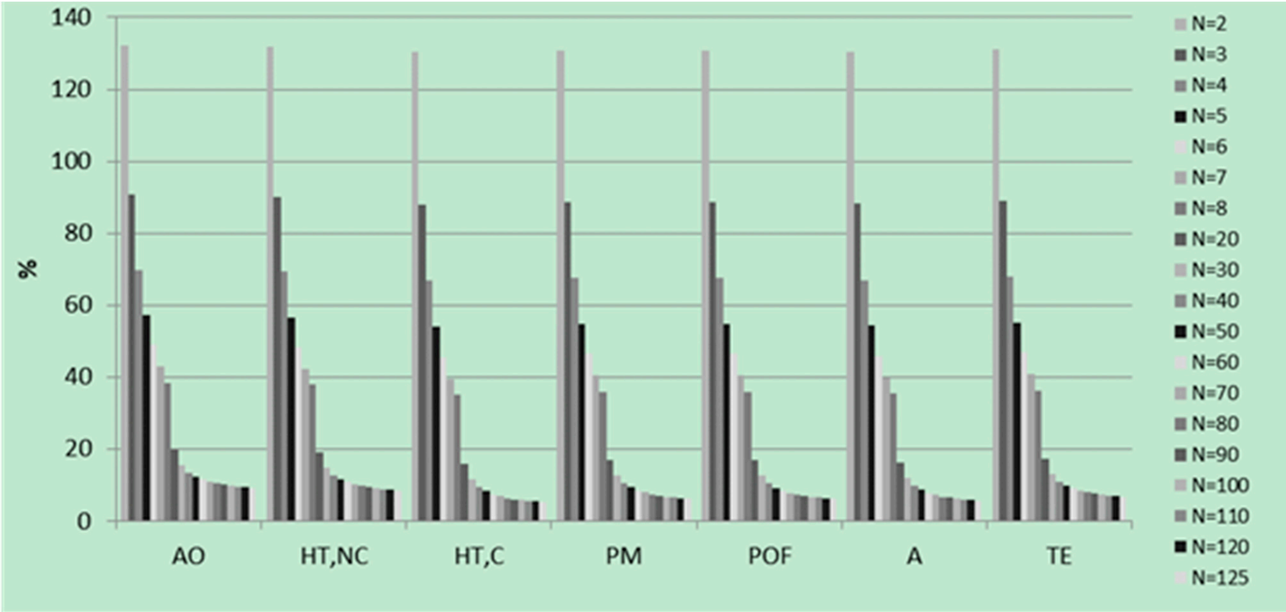
Figure S2. Comparison between the system based on reconditioning and re-use (RPCs system) and the single use system (SPCs system): for each number of rotations, the ratio between the value of the indicator in the RPCs and SPCs systems is reported. The figure is related to the scenario W1-RE1.



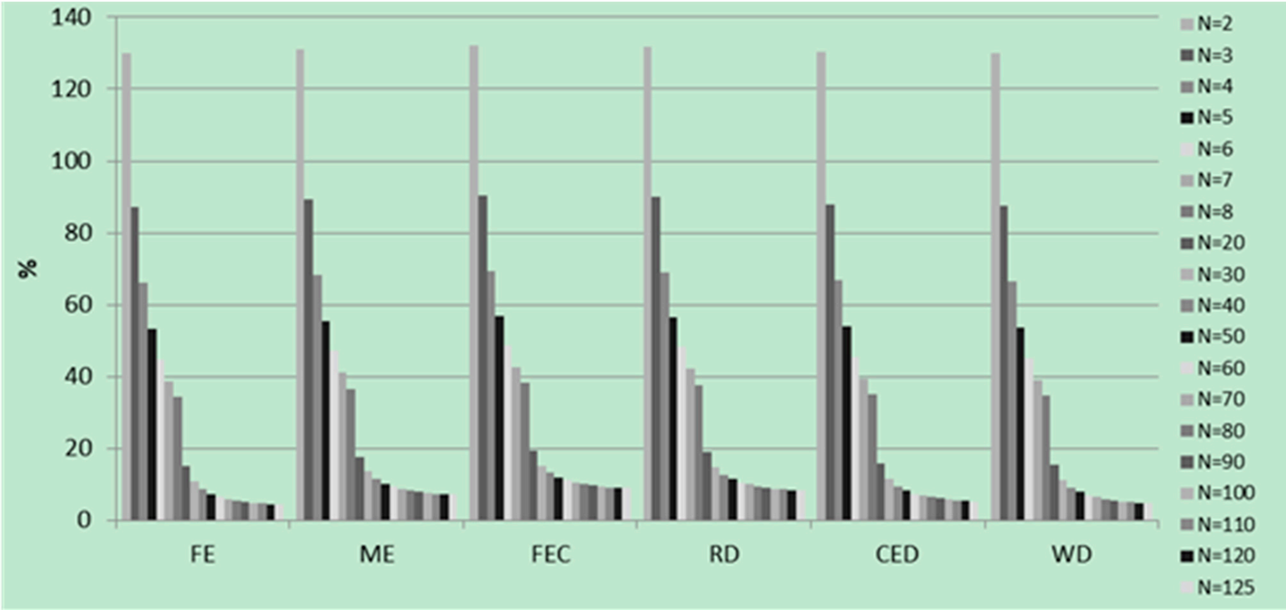


Figure S3. Comparison between the system based on reconditioning and re-use (RPCs system) and the single use system (SPCs system): for each number of rotations, the ratio between the value of the indicator in the RPCs and SPCs systems is reported. The figure is related to the scenario W2-RE2.

Sensitivity Analysis

Sensitivity on the Electricity Mix (Reconditioning Process)

Table S18. Impact indicators and water resources consumption for the reconditioning process in the scenario W1-RE1 and W2-RE2: comparison between the use of electricity from the Italian grid and by a photovoltaic system. The percent change is calculated as: Δ% = [IMPACT $_{PHOTOVOLTAIC}$ - IMPACT$_{GRID}$]/IMPACT $_{GRID}$.

		W1-RE1 scenario			W2-RE2 scenario		
		Italian grid	Photovoltaic system	Δ%	Italian grid	Photovoltaic system	Δ%
Climate change	kg CO_2 eq	6.10	4.94	-19%	4.17	3.53	-15%
Ozone depletion	kg CFC-11 eq	1.05E-06	9.29E-07	-11%	6.60E-07	5.94E-07	-10%
Human toxicity, non-cancer effects	CTUh	1.14E-06	1.16E-06	1%	8.85E-07	8.95E-07	1%
Human toxicity, cancer effects	CTUh	1.74E-07	1.56E-07	-11%	1.08E-07	9.75E-08	-10%
Particulate matter	kg $PM_{2.5}$ eq	2.29E-03	2.00E-03	-13%	1.52E-03	1.36E-03	-11%
Photochemical ozone formation	kg NMVOC eq	1.48E-02	1.28E-02	-14%	1.10E-02	9.88E-03	-10%
Acidification	mol_c H^+ eq	2.17E-02	1.64E-02	-25%	1.41E-02	1.11E-02	-21%
Terrestrial eutrophication	mol_c N eq	4.58E-02	3.89E-02	-15%	3.43E-02	3.04E-02	-11%
Freshwater eutrophication	kg P eq	9.40E-04	7.46E-04	-21%	4.79E-04	3.72E-04	-22%
Marine eutrophication	kg N eq	5.41E-03	4.77E-03	-12%	3.79E-03	3.43E-03	-9%
Freshwater ecotoxicity	CTUe	48.94	43.87	-10%	42.73	39.93	-7%
Mineral, fossil & renewable resource depletion	kg Sb eq	1.44E-04	1.87E-04	29%	1.09E-04	1.32E-04	22%
CED	MJ	105.03	93.93	-11%	68.20	62.07	-9%
Water depletion	m^3 water	5.33E-02	4.00E-02	-25%	2.53E-02	1.80E-02	-29%

Table S19. Percent change of the impacts and water resources consumption associated with the whole RPCs life cycle, according to the different source of electricity for the reconditioning stage. Considering for example the first column, the percent change is calculated as: $\Delta\% = [IMPACT_{PHOTOVOLTAIC} - IMPACT_{GRID}] / IMPACT_{GRID}$, keeping constant the type of scenario (W1-RE1) and the number of uses (*n*= 20). The impact changes are reported for 20, 50, 80, and 125 rotations.

	Scenario W1-RE1				**Scenario W2-RE2**			
	n = 20	**50**	**80**	**125**	**20**	**50**	**80**	**125**
Climate change	-4.6%	-7.9%	-9.6%	-11.0%	-2.8%	-5.2%	-6.5%	-7.7%
Ozone depletion	-4.5%	-6.8%	-7.7%	-8.4%	-2.9%	-4.9%	-5.8%	-6.5%
Human toxicity, non-cancer effects	0.5%	0.8%	0.9%	1.0%	0.3%	0.5%	0.6%	0.7%
Human toxicity, cancer effects	-2.0%	-3.6%	-4.5%	-5.3%	-1.2%	-2.3%	-3.0%	-3.7%
Particulate matter	-3.0%	-5.2%	-6.4%	-7.3%	-1.8%	-3.4%	-4.3%	-5.2%
Photochemical ozone formation	-2.9%	-5.2%	-6.4%	-7.5%	-1.7%	-3.3%	-4.2%	-5.0%
Acidification [1]	**-5.0%**	**-8.9%**	**-11.1%**	**-12.9%**	**-3.0%**	**-5.8%**	**-7.5%**	**-9.0%**
Terrestrial eutrophication	-3.7%	-6.4%	-7.8%	-8.9%	-2.2%	-4.0%	-5.1%	-5.9%
Freshwater eutrophication	-2.6%	-5.1%	-6.5%	-7.9%	-1.6%	-3.3%	-4.5%	-5.7%
Marine eutrophication	-3.3%	-5.5%	-6.6%	-7.4%	-2.0%	-3.6%	-4.5%	-5.2%
Freshwater ecotoxicity	-3.1%	-5.1%	-6.0%	-6.8%	-1.8%	-3.1%	-3.7%	-4.2%
Mineral, fossil & renewable resource depletion [2]	**9.3%**	**15.1%**	**17.7%**	**19.7%**	**5.7%**	**9.7%**	**11.7%**	**13.4%**
CED	-1.8%	-3.3%	-4.2%	-4.9%	-1.1%	-2.1%	-2.8%	-3.4%
Water depletion	-4.4%	-8.1%	-10.2%	-12.0%	-2.7%	-5.6%	-7.4%	-9.3%

[1] Impact category with the highest impact reduction compared to the baseline situation. [2] Impact category with the highest impact increment compared to the baseline situation.

Sensitivity on the Water Heating (Reconditioning Process)

Table S20. Stage of reconditioning - modelling of the energy consumption (electricity and heat production) by a gas heat and power combined boiler (inventory data and selected ecoinvent datasets). .

Process in the reconditioning stage	**Amount per FU**		**ecoinvent datasets**
	Scenario W1-RE1	**Scenario W2-RE2**	
Production of heat by a gas CHP boiler	32.2 MJ	17.7 MJ	*Heat, central or small- scale, natural gas {CH}| heat and power co-generation, natural gas, 50 kW electrical, lean burn*
Production of electricity by a gas CHP boiler[1]	1.46 kWh	0.806 kWh	*Electricity, low voltage {CH}|heat and power co-generation, natural gas, 50 kW electrical, lean burn*
Electricity from the Italian grid[2]	1.02 kWh	0.564 kWh	*Electricity, low voltage {IT}|market for*

[1] According to the ecoinvent 3.3 dataset, 45.51 Wh of electricity are produced as a by-product for every MJ of generated heat.

[2] The overall consumption of the reconditioning process is 2.48 kWh (scenario W1-RE1) and 1.37 kWh (scenario W2-RE2).

Table S21. Impact indicators and water resources consumption for the reconditioning stage in the scenarios W1-RE1 and W2-RE2: comparison between the use of conventional and CHP boiler. The percent change of the indicator is calculated as: $\Delta\% = [IMPACT_{CHP} - IMPACT_{CONVENTIONAL}] / IMPACT_{CONVENTIONAL}$.

		W1-RE1 scenario			W2-RE2 scenario		
		Conventional boiler	CHP boiler	Δ%	Conventional boiler	CHP boiler	Δ%
Climate change	kg CO_2 eq	6.10	5.05	-17%	4.17	3.59	-14%
Ozone depletion	kg CFC-11 eq	1.05E-06	7.76E-07	-26%	6.60E-07	5.10E-07	-23%
Human toxicity, non-cancer effects	CTUh	1.14E-06	1.02E-06	-11%	8.85E-07	8.19E-07	-7%
Human toxicity, cancer effects	CTUh	1.74E-07	1.45E-07	-17%	1.08E-07	9.17E-08	-15%
Particulate matter	kg $PM_{2.5}$ eq	2.29E-03	2.11E-03	-8%	1.52E-03	1.42E-03	-7%
Photochemical ozone formation	kg NMVOC eq	1.48E-02	1.50E-02	2%	1.10E-02	1.11E-02	1%
Acidification	mol_c H^+ eq	2.17E-02	2.19E-02	1%	1.41E-02	1.42E-02	1%
Terrestrial eutrophication	mol_c N eq	4.58E-02	4.61E-02	1%	3.43E-02	3.44E-02	0%
Freshwater eutrophication	kg P eq	9.40E-04	6.63E-04	-30%	4.79E-04	3.26E-04	-32%
Marine eutrophication	kg N eq	5.41E-03	5.39E-03	-0%	3.79E-03	3.78E-03	0%
Freshwater ecotoxicity	CTUe	48.94	34.43	-30%	42.73	34.72	-19%
Mineral, fossil & renewable resource depletion	kg Sb eq	1.44E-04	1.32E-04	-8%	1.09E-04	1.02E-04	-6%
CED	MJ	105.03	82.52	-21%	68.20	55.79	-18%
Water depletion	m^3 water	5.33E-02	3.92E-02	-26%	2.53E-02	1.76E-02	-31%

Table S22. Percent change of the impacts and water consumption associated with the whole RPCs life cycle, according to the different sources of heat production for the reconditioning step. Considering for example the first column, the percent change is calculated as: Δ% = [IMPACT$_{\text{CHP BOILER}}$ - IMPACT$_{\text{CONV. BOILER}}$] / IMPACT $_{\text{CONV. BOILER}}$, keeping constant the type of scenario (W1-RE1) and the number of uses (*n*= 20). The impact changes are reported for 20, 50, 80, and 125 rotations.

	Scenario W1-RE1				**Scenario W2-RE2**			
	n = 20	**50**	**80**	**125**	**20**	**50**	**80**	**125**
Climate change	-4.2%	-7.2%	-8.7%	-9.9%	-2.5%	-4.7%	-5.9%	-6.9%
Ozone depletion[1]	**-10.2%**	**-15.4%**	**-17.6%**	**-19.2%**	**-6.6%**	**-11.1%**	**-13.2%**	**-14.9%**
Human toxicity, non-cancer effects	-3.3%	-5.4%	-6.3%	-7.0%	-2.0%	-3.4%	-4.1%	-4.7%
Human toxicity, cancer effects	-3.0%	-5.6%	-7.0%	-8.2%	-1.8%	-3.6%	-4.7%	-5.8%
Particulate matter	-1.9%	-3.3%	-4.0%	-4.5%	-1.1%	-2.1%	-2.7%	-3.2%
Photochemical ozone formation	0.4%	0.6%	0.8%	0.9%	0.2%	0.4%	0.5%	0.6%
Acidification	0.2%	0.3%	0.4%	0.4%	0.1%	0.2%	0.2%	0.3%
Terrestrial eutrophication	0.1%	0.2%	0.3%	0.3%	0.1%	0.1%	0.2%	0.2%
Freshwater eutrophication	-3.7%	-7.2%	-9.4%	-11.3%	-2.2%	-4.7%	-6.4%	-8.1%
Marine eutrophication	-0.1%	-0.1%	-0.2%	-0.2%	-0.1%	-0.1%	-0.1%	-0.1%
Freshwater ecotoxicity	-9.0%	-14.7%	-17.3%	-19.3%	-5.2%	-8.8%	-10.5%	-11.9%
Mineral, fossil & renewable resource depletion	-2.6%	-4.2%	-4.9%	-5.5%	-1.6%	-2.7%	-3.3%	-3.7%
CED	-3.6%	-6.7%	-8.5%	-10.0%	-2.2%	-4.3%	-5.6%	-6.9%
Water depletion	-4.6%	-8.6%	-10.7%	-12.6%	-2.9%	-5.9%	-7.8%	-9.8%

[1] Impact category with the highest impact reduction compared to the baseline situation.

Sensitivity on the Substitution Ratio between Secondary and Primary PP Granulate

Table S23. Percent change of the impacts and water consumption associated with the whole RPCs life cycle, according to the different values of the substitution ratio between secondary and primary PP granulate. Considering for example the first column, the percent change is calculated as: Δ% = [IMPACT $_{\text{ratio 1:1}}$ – IMPACT $_{\text{ratio 1:0.66}}$] / IMPACT $_{\text{ratio 1:0.66}}$, keeping constant the type of scenario (W1-RE1) and the number of uses (*n*= 20). The impact changes are reported for 20, 50, 80, and 125 rotations.

Scenario W1-RE1	**Scenario W2-RE2**

	n = 20	50	80	125	20	50	80	125
Climate change	-21.7%	-16.8%	-14.3%	-12.3%	-23.4%	-19.1%	-16.7%	-14.5%
Ozone depletion	-0.2%	-0.3%	-0.3%	-0.3%	-0.2%	-0.3%	-0.3%	-0.3%
Human toxicity, non-cancer effects	-2.1%	-1.6%	-1.4%	-1.2%	-2.2%	-1.8%	-1.5%	-1.4%
Human toxicity, cancer effects	-14.7%	-12.2%	-10.7%	-9.5%	-15.8%	-13.8%	-12.5%	-11.3%
Particulate matter	-22.2%	-17.4%	-14.9%	-12.9%	-24.0%	-19.9%	-17.5%	-15.4%
Photochemical ozone formation	-29.3%	-23.5%	-20.4%	-17.8%	-30.9%	-25.6%	-22.6%	-19.9%
Acidification	-18.9%	-15.3%	-13.4%	-11.8%	-20.2%	-17.3%	-15.6%	-13.9%
Terrestrial eutrophication	-20.9%	-16.4%	-14.1%	-12.3%	-22.1%	-18.0%	-15.7%	-13.8%
Freshwater eutrophication	-2.4%	-2.1%	-2.0%	-1.8%	-2.6%	-2.4%	-2.3%	-2.2%
Marine eutrophication	-18.7%	-14.2%	-12.1%	-10.4%	-20.3%	-16.2%	-14.0%	-12.2%
Freshwater ecotoxicity	-5.2%	-3.8%	-3.2%	-2.7%	-5.4%	-4.0%	-3.3%	-2.8%
Mineral, fossil & renewable resource depletion	-1.7%	-1.5%	-1.3%	-1.3%	-1.8%	-1.6%	-1.5%	-1.4%
CED	-33.3%	-27.6%	-24.4%	-21.6%	-35.3%	-30.8%	-27.9%	-25.2%
Water depletion	-14.2%	-11.7%	-10.3%	-9.1%	-15.7%	-14.0%	-13.0%	-11.9%

Table S24. Impact indicators and water resources consumption associated with the life cycle of 100 single use plastic crates when the substitution ratio between the secondary and primary granulate is 1:1 by mass. The percent change is calculated as: $\Delta\% = [IMPACT_{ratio\ 1:1} - IMPACT_{ratio\ 1:0.66}] / IMPACT_{ratio\ 1:0.66}$.

		Total value	Δ%
Climate change	kg CO_2 eq	91.12	-28%
Ozone depletion	kg CFC-11 eq	1.09E-05	0%
Human toxicity, non-cancer effects	CTUh	1.61E-05	-2%
Human toxicity, cancer effects	CTUh	4.36E-06	-18%
Particulate matter	kg $PM_{2.5}$ eq	0.035	-29%
Photochemical ozone formation	kg NMVOC eq	2.29E-01	-37%

Acidification	mol_c H^+ eq	4.46E-01	-23%
Terrestrial eutrophication	mol_c N eq	6.96E-01	-27%
Freshwater eutrophication	kg P eq	4.23E-02	-3%
Marine eutrophication	kg N eq	7.11E-02	-25%
Freshwater ecotoxicity	CTUe	695.87	-7%
Mineral, fossil & renewable resource depletion	kg Sb eq	2.04E-03	-2%
CED	MJ	2065.87	-40%
Water depletion	m^3 water	1.38	-17%

resources

MDPI

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