

Supplementary Materials

COVID-19 induced Changes in Residual Municipal Waste Management in Provincial Territories of the Marche Region (Italy): Flow Analysis and Environmental Assessment

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Supplementary Material Accompanying Section 2.3.2

Table S1. Mass balances of the aerobic biostabilisation MBTs in provincial territories PT_{PU} and PT_{MC}.

Output (% RMW)	EWC [16]	PT _{PU}	PT _{MC}
os-RMW	19 12 12	78.1	69.1
Metal	19 12 02	0.0	0.03
bios-OFRMW	19 05 03	13.3	25.4
Leachate	19 07 03	0.0	2.775
Aqueous liquid waste	16 10 02	0.0	0.245
Process losses	-	8.6	2.45
Total	-	100	100
us-OFRMW	19 05 01	21.9	30.9

Table S2. EE consumption for the MT steps expressed per tonne of incoming RMW.

Phase	Specific EE Consumption (kWh t RMW ⁻¹)
Bland shredding	10.33
Hammer shredding	11.74
Conveyor belt	0.10
Magnetic separation	0.56
Sieving by rotating trommel	0.70
Conveyor belt, os-RMW	0.19
Conveyor belt, us-OFRMW	0.19
Total	23.81

Table S3. EE and material consumptions for the aerobic biological treatment steps expressed per tonne of incoming us-OFRMW*.

Type of Consumption	Value	Unit
Water consumption	37.80	L t us-OFRMW ⁻¹
EE consumption	18.60	kWh t us-OFRMW ⁻¹
Diesel consumption	0.96	L t us-OFRMW ⁻¹
Diesel consumption ¹	0.81	kg t us-OFRMW ⁻¹

¹ Based on the assumed diesel density of 846 kg m⁻³ [56].

* The consequential consumptions per tonne of RMW (FU) were derived according to the following expression:

$$Consumption [x \text{ t RMW}^{-1}] = \frac{Consumption [x \text{ t us-OFRMW}^{-1}] * us-OFRMW [t \text{ year}^{-1}]}{RMW [t \text{ year}^{-1}]} \quad (S1)$$

Table S4. Air emissions after biofiltration from the aerobic biological treatment steps expressed per tonne of incoming us-OFRMW*.

Component	(kg t us-OFRMW ⁻¹)
CO ₂	8.40E-01
CH ₄	1.15E+00
N ₂ O	1.30E-01
NH ₃	5.58E-03
VOCs	2.10E-01
H ₂ S	6.14E-04

* The consequential emissions per tonne of RMW (FU) were derived according to the following expression:

$$Emission [kg t RMW^{-1}] = \frac{Emission [kg t us-OFRMW^{-1}] * us-OFRMW [t year^{-1}]}{RMW [t year^{-1}]} \quad (S2)$$

Table S5. EE and water consumptions for landfilling expressed per tonne of deposited waste*.

Type of Consumption	Value	Unit
EE consumption	1.704	kWh t deposited waste ⁻¹
Water consumption	0.00965	m ³ t deposited waste ⁻¹
Water consumption ¹	9.65	kg t deposited waste ⁻¹

¹ Based on the water density of 1000 kg m⁻³ [56].

* The consequential consumptions per tonne of RMW (FU) were derived according to the following expression:

$$Consumption [x t RMW^{-1}] = \frac{Consumption [x t deposited waste^{-1}] * deposited waste [t year^{-1}]}{RMW [t year^{-1}]} \quad (S3)$$

where (see Figure 2):

- deposited waste (Pre-COVID-19 scenario) = bios-OFRMW + os-RMW

- deposited waste (COVID-19 scenario) = bios-OFRMW + os-RMW + RMW_{NO-COVID-19}.

Table S6. Leachate productions in landfilling expressed per tonne of deposited waste*.

	PT _{PU}			PT _{MC}	Unit
	Upper Coastal Landfill	Lower Coastal Landfill	Inland landfill		
Leachate production	0.152	0.337	6.036	-	m ³ t deposited waste ⁻¹
Leachate production	0.153 ¹	0.340 ¹	6.084 ¹	0.0558	t t deposited waste ⁻¹

¹ Based on the assumed leachate density of 1.008 t m⁻³ [51].

* The consequential productions per tonne of RMW (FU) were derived according to the following expression:

$$Production [t t RMW^{-1}] = \frac{Production [t t deposited waste^{-1}] * deposited waste [t year^{-1}]}{RMW [t year^{-1}]} \quad (S4)$$

where (see Figure 2):

- deposited waste (Pre-COVID-19 scenario) = bios-OFRMW + os-RMW

- deposited waste (COVID-19 scenario) = bios-OFRMW + os-RMW + RMW_{NO-COVID-19}.

Table S7. Representative BMPs and physico-chemical characteristics of bios-OFRMW, residual organic fraction in os-RMW, and organic fraction in RMW for provincial territories PT_{PU} and PT_{MC}.

	PT _{PU}	PT _{MC}
<i>bios-OFRMW</i>		
BMP (NmL CH ₄ gVS ⁻¹ - Volatile Solids ⁻¹)	143.4	143.4
VS (% TS - Total Solids)	49.67	60.01
TS (% FM - Fresh Matter)	74.81	62.56
<i>residual organic fraction in os-RMW¹</i>		
BMP (NmL CH ₄ gVS ⁻¹)	272.0	272.0
VS (% TS)	66.77	66.77
TS (% FM)	56.32	56.32
<i>organic fraction in RMW²</i>		
BMP (NmL CH ₄ gVS ⁻¹)	445.6	445.6
VS (% TS)	46.33	61.23
TS (% FM)	57.34	58.59

¹ Compositional level (by mass) of residual organic fraction in os-RMW: 30.7%.

² Compositional level (by mass) of organic fraction in RMW: 36.2% in PT_{PU}, 24.9% in PT_{MC}.

Table S8. LFG compositions for the controlled landfills in provincial territories PT_{PU} and PT_{MC} (NA = not available).

Component	PT _{PU} upper coastal landfill	PT _{PU} lower coastal landfill	PT _{PU} inland landfill	PT _{MC}
CH ₄ (% by vol)	51.05	38.40	45.75	45.07
CO ₂ (% by vol)	33.18	27.50	33.69	31.46
H ₂ S (% by vol)	5.50 ¹	0.01	0.01	0.01
HCl (mg Nm ⁻³)	NA	0.76	0.07	0.42
HF (mg Nm ⁻³)	NA	0.32	0.23	0.28
SO ₂ (mg Nm ⁻³)	NA	57.00	864.70	460.85
CO (mg Nm ⁻³)	9.50	NA	NA	9.50 ²
NH ₃ (mg Nm ⁻³)	15.16	38.15	0.97	18.09

¹ In terms of mg Nm⁻³.

² Assumed equal to PT_{PU} - upper coastal landfill.

Table S9. Exhaust gas compositions from ICEs for the controlled landfills in provincial territories PT_{PU} and PT_{MC}.

	PT _{PU} upper coastal landfill	PT _{PU} lower coastal landfill	PT _{PU} inland landfill	PT _{MC}	Unit
PM	0.08	0.11	0.05	0.08	mg Nm ⁻³
NO ₂	368	384	352	368	mg Nm ⁻³
CO	164.5	236	93	164.5	mg Nm ⁻³
TOC	89	123	55	89	mg Nm ⁻³
SO ₂	62.5	80	45	62.5	mg Nm ⁻³
HCl	0.77	1.165	0.38	0.77	mg Nm ⁻³
HF	0.29	0.43	0.15	0.29	mg Nm ⁻³
Exhaust gas flow rate	3053	4389	1716	3053	Nm ³ h ⁻¹
Operating h ¹	8100	8100	8100	8100	h year ⁻¹

¹ Assumption from the permit on Integration Pollution Prevention and Control of the lower coastal controlled landfill in provincial territory PT_{PU} [55].

Table S10. Basic consumption data for the considered WtE plant*.

Type of Consumption	Value	Unit
<i>Diesel</i>		
Generating sets	2820.00	L year ⁻¹
Transport	1410.00	L year ⁻¹
<i>Methane</i>		
Ignition and post-combustion	538,943.00	Nm ³ year ⁻¹
<i>Water</i>		
Industrial use	24,178.00	m ³ year ⁻¹
Civil use	6000.00	m ³ year ⁻¹
Steam cycle	20,463.00	m ³ year ⁻¹
Quenching of ash	7852.00	m ³ year ⁻¹
<i>EE</i>		
Self-consumption	15,222.10	MWh year ⁻¹
EE from grid	1143.70	MWh year ⁻¹
<i>Chemicals¹</i>		
NaOH	0.40	t year ⁻¹
NaClO	0.30	t year ⁻¹

¹ Necessary for demineralization of water used in the steam cycle.

* Treated waste: 137,316.65 t year⁻¹.

Table S11. Elemental compositions for relevant waste material fractions.

Material Fraction	Elemental Composition (% dry basis)								Moisture (% FM)
	C	H	O	S	N	Cl	F	Ash	
Paper/cardboard	45.55	4.31	43.77	0.03	0.10	0.40	0.01	4.90	26.67
Organic	50.85	6.42	39.51	0.04	1.37	0.34	0.00	2.94	69.61
Green	47.83	8.73	53.83	0.02	1.33	0.37	0.00	6.30	48.89
Plastic	70.21	12.16	12.25	0.09	0.69	0.85	0.01	2.58	4.67
Metal	0.51	0.78	6.01	0.00	0.10	0.00	0.00	76.96	5.00
Wood	53.11	7.63	43.86	0.10	0.16	0.28	0.00	0.83	16.92
Glass	0.51	0.10	0.72	0.00	0.10	0.00	0.00	95.15	0.00
Textile	39.76	7.19	30.94	0.12	4.17	0.47	0.01	19.35	7.78

Table S12. Compositional characteristics (expressly in terms of the material fractions in Table S11) for the RMW in provincial territories PT_{PU} and PT_{MC}.

Material Fraction	PT _{PU} (%)	PT _{MC} (%)
Paper/cardboard	14.40	24.60
Organic	31.82	30.04
Green	11.40	2.80
Plastic	24.83	24.20
Metal	4.02	4.87
Wood	3.56	5.78
Glass	2.80	2.70
Textile	7.17	5.01

Table S13. Elemental compositions of the RMW in provincial territories PT_{PU} and PT_{MC}*.

RMW	Elemental Composition (% FM)								
	C	H	O	S	N	Cl	F	Ash	Moisture
PT _{PU}	33.36	5.20	18.07	0.04	0.67	0.34	0.005	8.70	34.08
PT _{MC}	34.16	5.03	18.93	0.04	0.53	0.34	0.005	8.91	31.58

* Determination based on derivation (from Table S11) of the elemental compositions on FM basis for relevant material fractions, and consequential combination with the respective compositional characteristics in Table S12.

Table S14. LHV of the RMW in provincial territories PT_{PU} and PT_{MC} and consequential EE productions by thermal treatment per tonne of input waste.

	PT _{PU}	PT _{MC}	Unit
LHV	13,542.47	13,521.21	kJ kg ⁻¹
Gross EE production ¹	902.83	901.41	kWh t ⁻¹
Self-consumption ²	0.11	0.11	MWh t ⁻¹
Net EE production	0.79	0.79	MWh t ⁻¹

¹ Derived according to the following expression:

$$Gross\ EE\ [kWh\ t^{-1}] = \frac{LHV_{RMW}[kJ\ kg^{-1}] * 0.24 * 1000\ [kg\ t^{-1}]}{3600\ [kJ\ kWh^{-1}]} \quad (S5)$$

² Derivable from Table S10.

Table S15. Basic output data (flue gas and residues) for the considered WtE plant.

Output	To Disposal	To Recovery	Univocal	Unit
Flue gas ¹	-	-	728,987,708	m ³ year ⁻¹
BA	2.16E-04	1.94E-01 ²	-	t t input waste ⁻¹
Inert from BA	4.48E-02 ⁴	1.46E-01 ³	-	t t input waste ⁻¹
Metal from BA	-	3.16E-03	-	t t input waste ⁻¹
FA + APCR	-	-	4.81E-02	t t input waste ⁻¹
Aqueous liquid waste ⁵	-	-	4.48E-03	t t input waste ⁻¹

¹ According to: flue gas hourly rate 95,511 m³ h⁻¹, operating hours 7632.5 h year⁻¹.

² Assumption on EE consumption for BA treatment: 4 kWh t BA⁻¹ [41,62].

³ According to the specific inert recovery from BA equal to 751 kg t BA⁻¹ [62].

⁴ According to the following expression:

$$Inert_{disposal} = BA_{recovery} - (Inert_{recovery} + Metal_{from\ BA}) \quad (S6)$$

⁵ Identified by EWCs 16 10 02 and 19 01 06* [29].

Table S16. Basic output data on chemical consumptions (for FGC) and air emissions for the considered WtE plant.

	Value	Unit
<i>Chemicals</i>		
NaHCO ₃	950.48	t year ⁻¹
Ca(OH) ₂	1172.44	t year ⁻¹

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High efficiency Ca(OH) ₂	227.04	t year ⁻¹
Activated carbon	60.00	t year ⁻¹
NH ₃	354.56	t year ⁻¹
<i>Emissions</i>		
CO	9.47	mg Nm ⁻³
NO _x	56.85	mg Nm ⁻³
N ₂ O	2.24	mg Nm ⁻³
SO _x	1.63	mg Nm ⁻³
PM	0.45	mg Nm ⁻³
HCl	2.28	mg Nm ⁻³
HF	0.05	mg Nm ⁻³
TOC	0.91	mg Nm ⁻³
NH ₃	0.38	mg Nm ⁻³
Hg	0.12	µg Nm ⁻³
Cd+Ti	0.25	µg Nm ⁻³
Metals	1.60	µg Nm ⁻³
PAH	0.028	µg Nm ⁻³
PCDD/F	0.001	µg Nm ⁻³
PCB-DL	0.00022	µg Nm ⁻³

Table S17. Assumptions and resulting values of non-renewable CO₂ emissions from thermal treatment of RMW in provincial territories PT_{PU} and PT_{MC}.

Assumptions [62]			
- CO₂ emissions calculated from elemental compositions of RMW material fractions in provincial territories PT_{PU} and PT_{MC}, considering the stoichiometric oxidation ratio of 3.67 (44/12) g CO₂ g C⁻¹ - Carbon contents of RMW material fractions as plastic (C: 16.61% in PT_{PU}, 16.19% in PT_{MC}), metal (C: 0.02% in PT_{PU} and PT_{MC}), glass (C: 0.01% in PT_{PU} and PT_{MC}), and half of textile (C: 2.63% in PT_{PU}, 1.84% in PT_{MC}) considered of non-renewable origin			
Resulting values			
	PT _{PU}	PT _{MC}	Unit
Non-renewable C	0.1796	0.1715	kg kg RMW ⁻¹
Non-renewable CO ₂ emissions	659	629	kg t RMW ⁻¹

Supplementary Material Accompanying Section 3.1.2

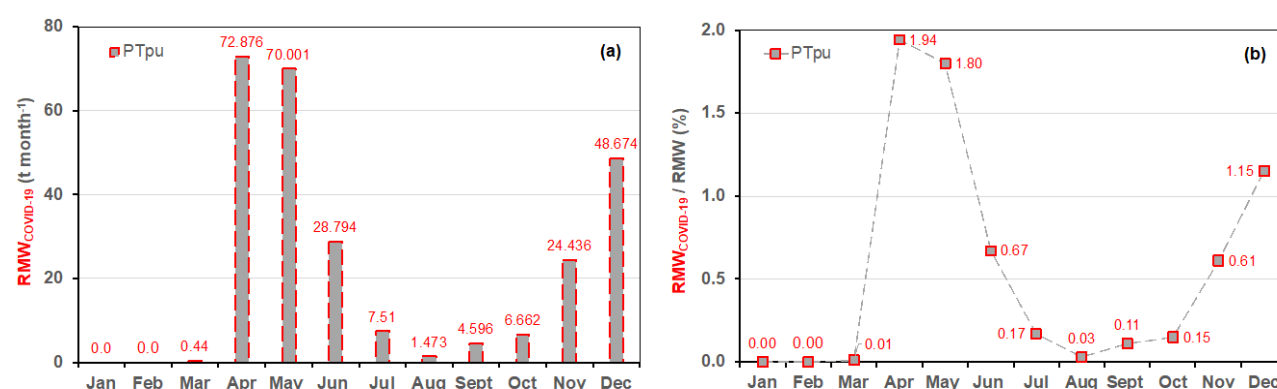


Figure S1. COVID-19 scenario (2020), provincial territory PT_{PU}: resulting monthly amounts of RMW_{COVID-19} (a) and percentage ratios of RMW_{COVID-19} to overall RMW (b).

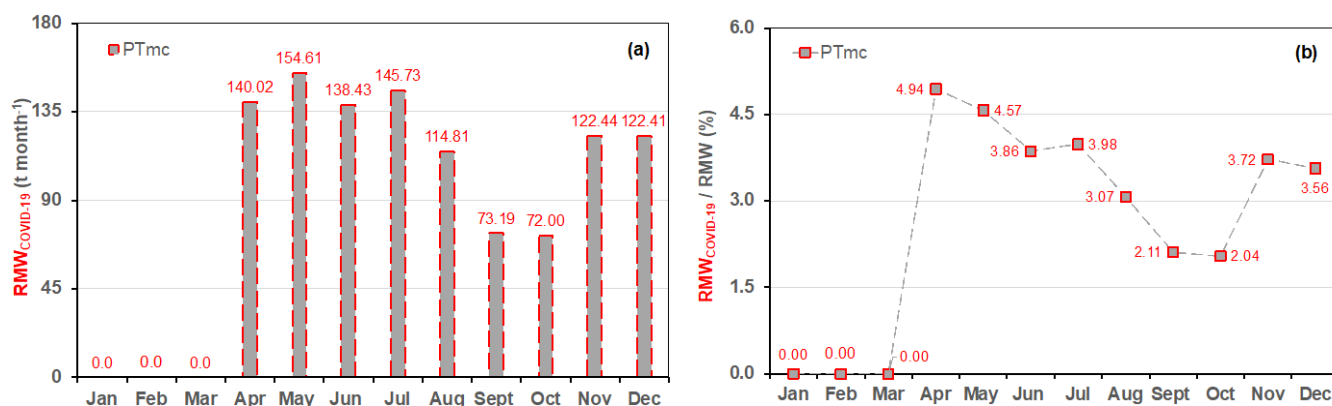


Figure S2. COVID-19 scenario (2020), provincial territory PTMC: resulting monthly amounts of $RMW_{COVID-19}$ (a) and percentage ratios of $RMW_{COVID-19}$ to overall RMW (b).

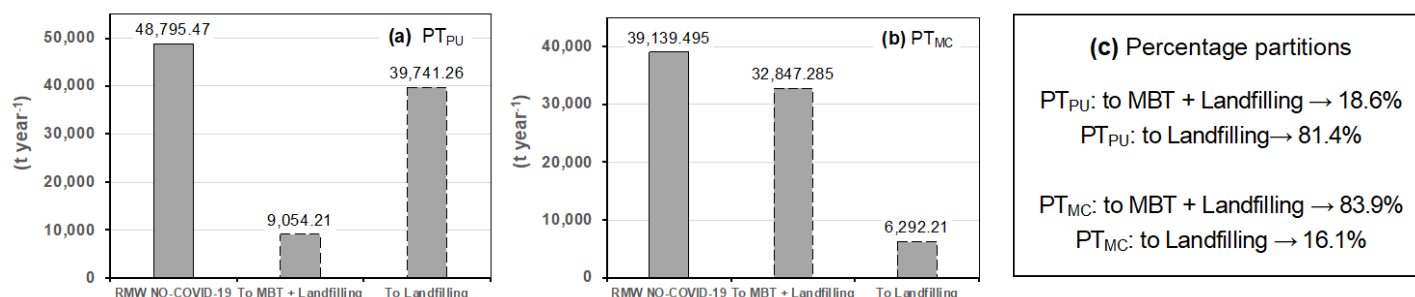


Figure S3. COVID-19 scenario (2020): resulting amounts of $RMW_{NO-COVID-19}$ yearly addressed to alternative management practices (see Figure 2) in provincial territories PT_{PU} (a) and PT_{MC} (b) and percentage partitions (c).

Supplementary Material Accompanying Section 3.2.1

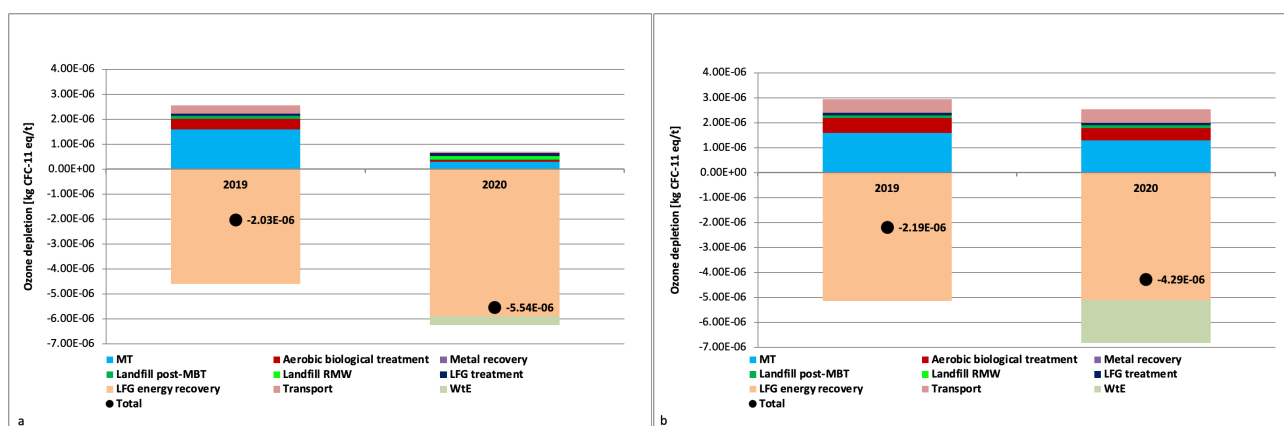


Figure S4. Contribution of process units of RMW management for 2019 (Pre-COVID-19 scenario) and 2020 (COVID-19 scenario) to ozone depletion (OD) for provincial territories PT_{PU} (a) and PT_{MC} (b). The dots (Total) display the resulting values of the indicator in Table 6.

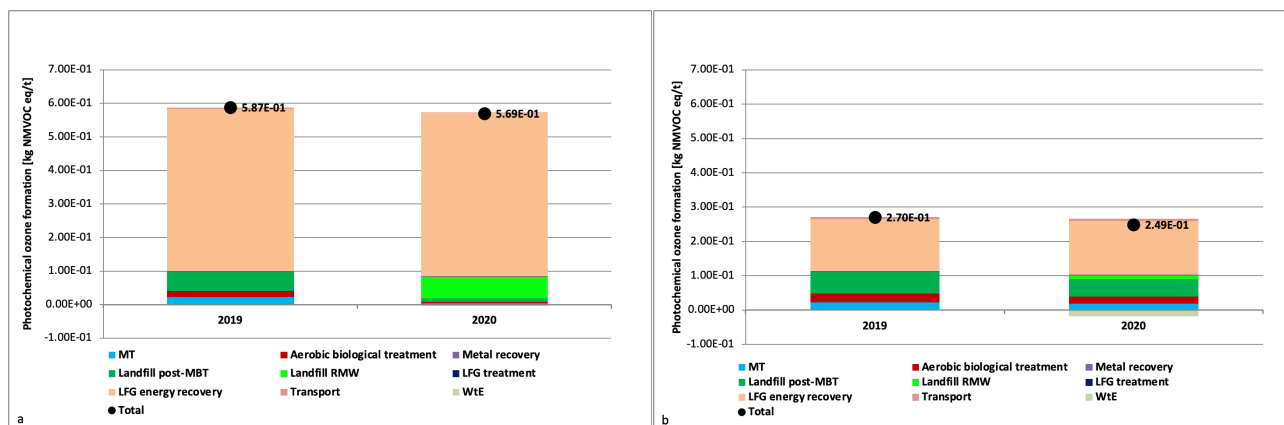


Figure S5. Contribution of process units of RMW management for 2019 (Pre-COVID-19 scenario) and 2020 (COVID-19 scenario) to photochemical ozone formation (POF) for provincial territories PT_{PU} (a) and PT_{MC} (b). The dots (Total) display the resulting values of the indicator in Table 6.

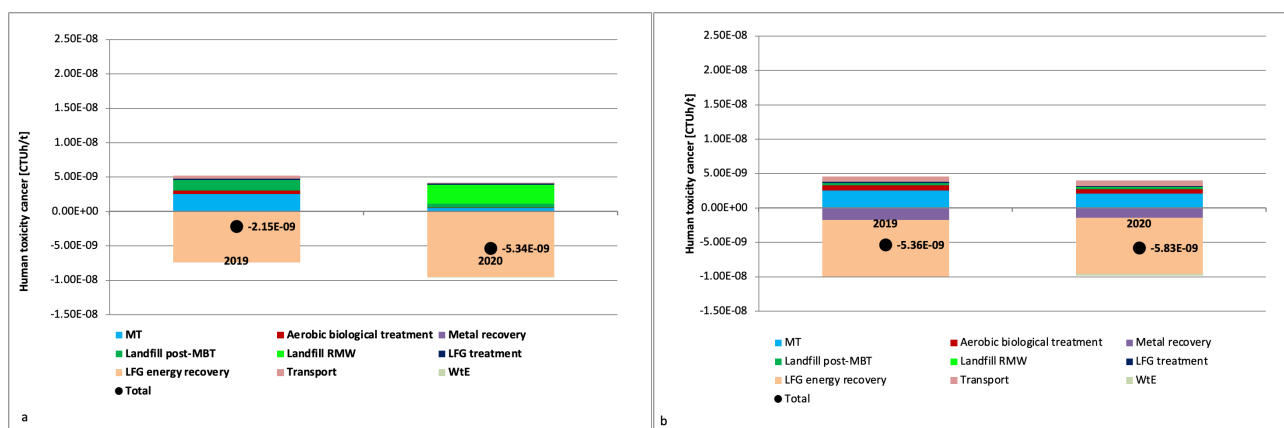


Figure S6. Contribution of process units of RMW management for 2019 (Pre-COVID-19 scenario) and 2020 (COVID-19 scenario) to human toxicity, cancer (HTc) for provincial territories PT_{PU} (a) and PT_{MC} (b). The dots (Total) display the resulting values of the indicator in Table 6.

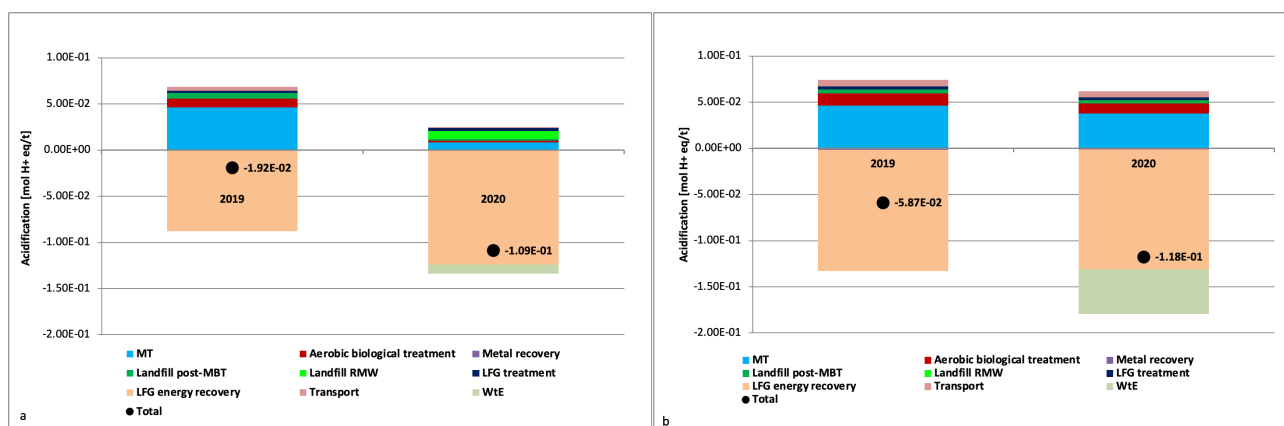


Figure S7. Contribution of process units of RMW management for 2019 (Pre-COVID-19 scenario) and 2020 (COVID-19 scenario) to acidification (A) for provincial territories PT_{PU} (a) and PT_{MC} (b). The dots (Total) display the resulting values of the indicator in Table 6.

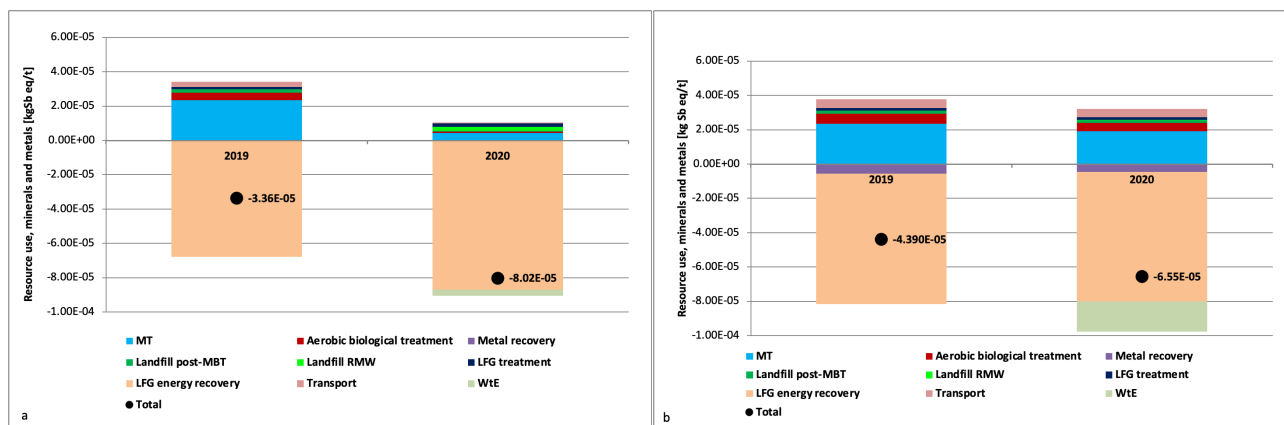


Figure S8. Contribution of process units of RMW management for 2019 (Pre-COVID-19 scenario) and 2020 (COVID-19 scenario) to resource use, mineral and metals (Rumm) for provincial territories PT_{PU} (a) and PT_{MC} (b). The dots (Total) display the resulting values of the indicator in Table 6.

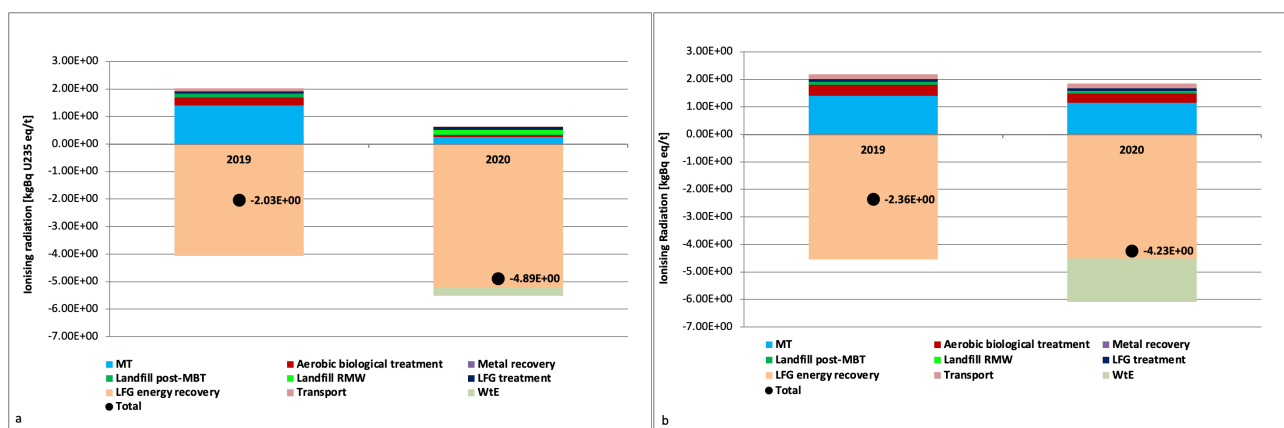


Figure S9. Contribution of process units of RMW management for 2019 (Pre-COVID-19 scenario) and 2020 (COVID-19 scenario) to ionising radiation (IR) for provincial territories PT_{PU} (a) and PT_{MC} (b). The dots (Total) display the resulting values of the indicator in Table 6.

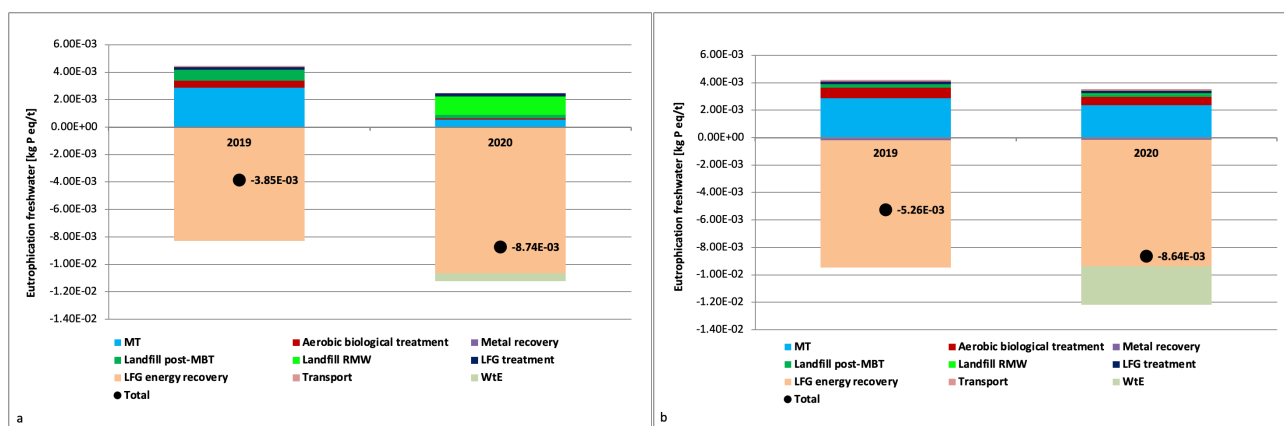


Figure S10. Contribution of process units of RMW management for 2019 (Pre-COVID-19 scenario) and 2020 (COVID-19 scenario) to eutrophication, freshwater (Ef) for provincial territories PT_{PU} (a) and PT_{MC} (b). The dots (Total) display the resulting values of the indicator in Table 6.

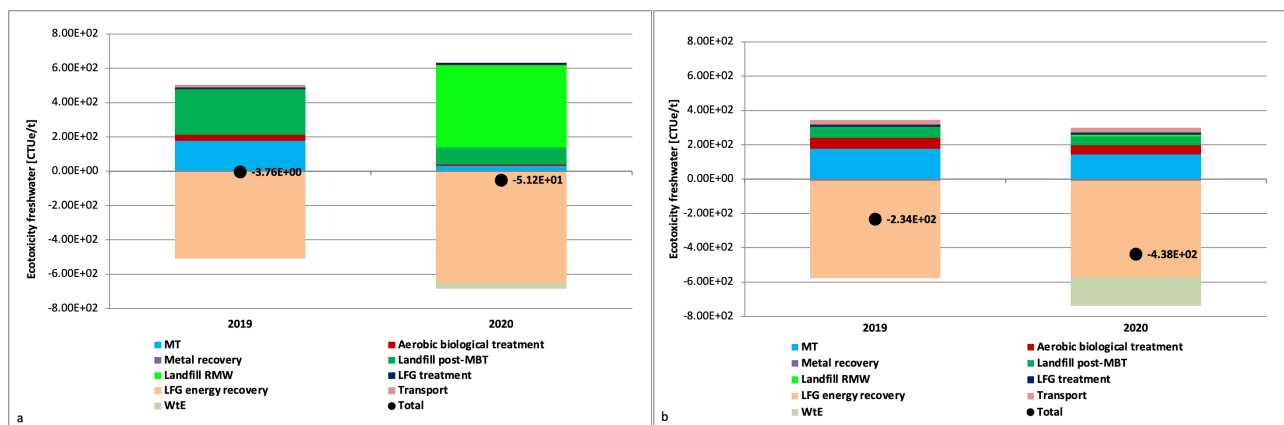


Figure S11. Contribution of process units of RMW management for 2019 (Pre-COVID-19 scenario) and 2020 (COVID-19 scenario) to ecotoxicity, freshwater (ETf) for provincial territories PT_{PU} (a) and PT_{MC} (b). The dots (Total) display the resulting values of the indicator in Table 6.

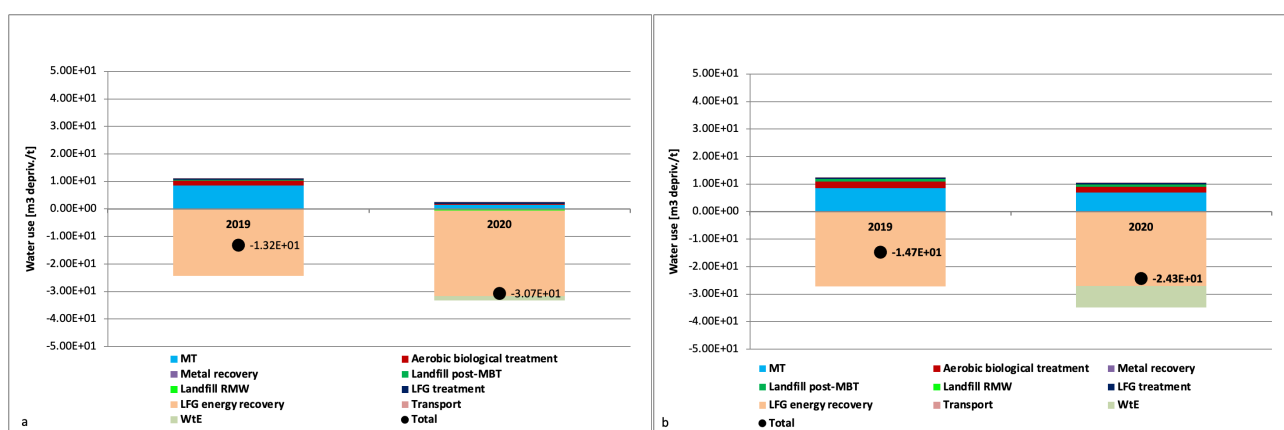


Figure S12. Contribution of process units of RMW management for 2019 (Pre-COVID-19 scenario) and 2020 (COVID-19 scenario) to water use (WU) for provincial territories PT_{PU} (a) and PT_{MC} (b). The dots (Total) display the resulting values of the indicator in Table 6.

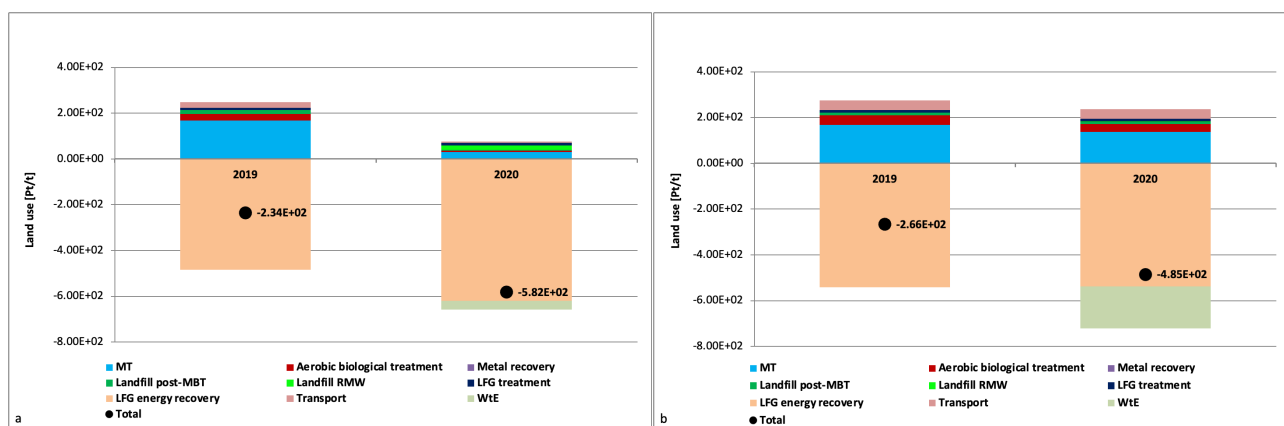


Figure S13. Contribution of process units of RMW management for 2019 (Pre-COVID-19 scenario) and 2020 (COVID-19 scenario) to land use (LU) for provincial territories PT_{PU} (a) and PT_{MC} (b). The dots (Total) display the resulting values of the indicator in Table 6.

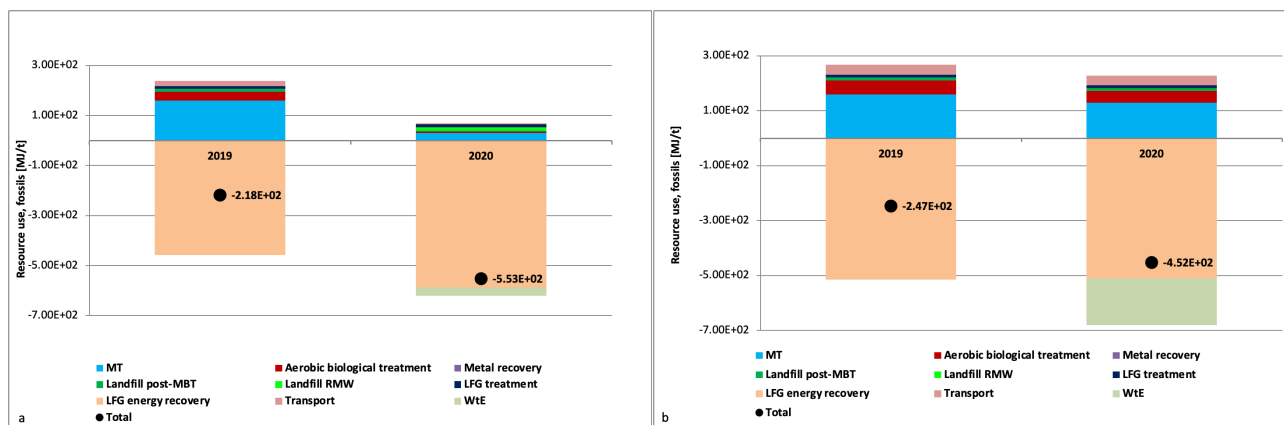


Figure S14. Contribution of process units of RMW management for 2019 (Pre-COVID-19 scenario) and 2020 (COVID-19 scenario) to resource use, fossils (RUF) for provincial territories PT_{PU} (a) and PT_{MC} (b). The dots (Total) display the resulting values of the indicator in Table 6.

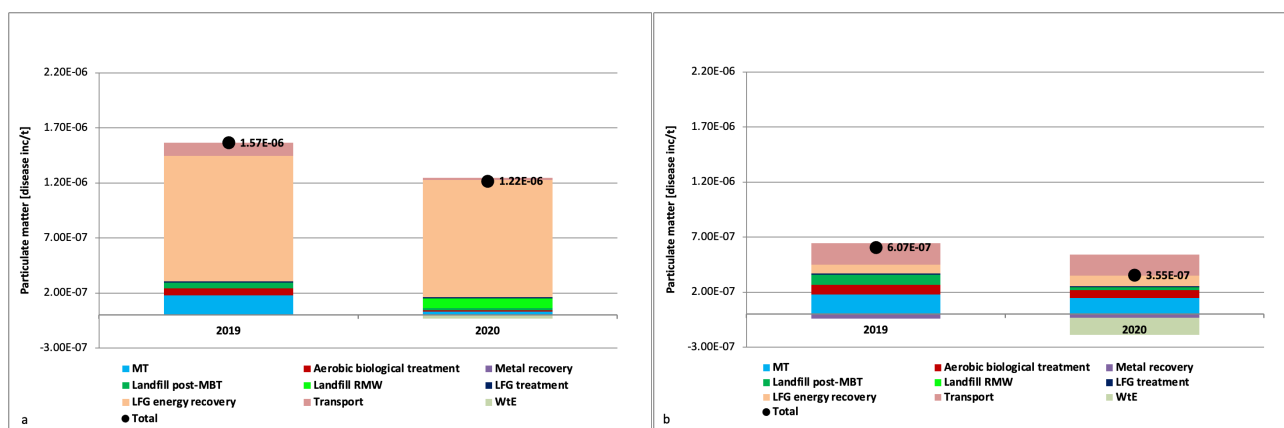


Figure S15. Contribution of process units of RMW management for 2019 (Pre-COVID-19 scenario) and 2020 (COVID-19 scenario) to particulate matter (PM) for provincial territories PT_{PU} (a) and PT_{MC} (b). The dots (Total) display the resulting values of the indicator in Table 6.

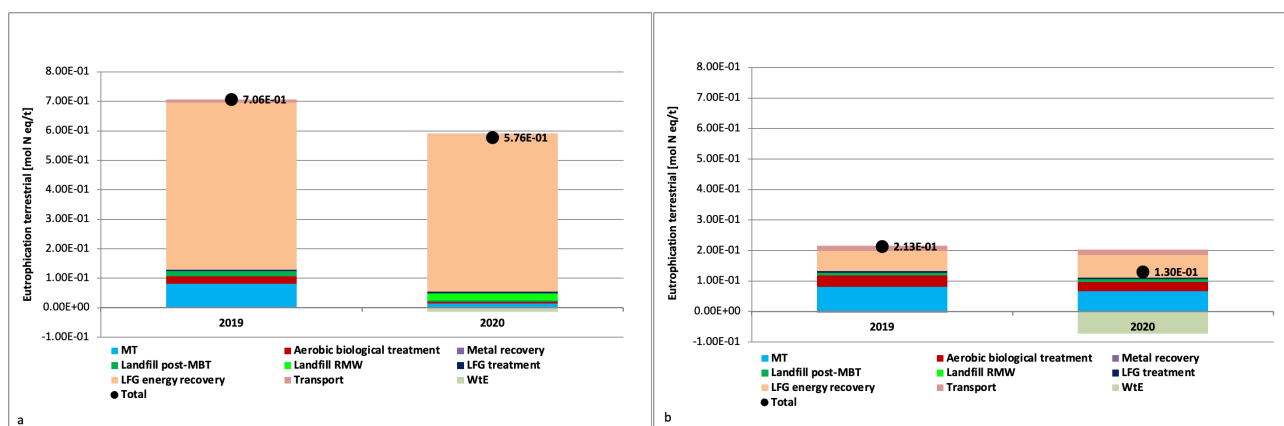


Figure S16. Contribution of process units of RMW management for 2019 (Pre-COVID-19 scenario) and 2020 (COVID-19 scenario) to eutrophication, terrestrial (Et) for provincial territories PT_{PU} (a) and PT_{MC} (b). The dots (Total) display the resulting values of the indicator in Table 6.