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MDPI

Comparative life cycle environmental impact assessments of fruit and vegetable waste valorization in a Mediterranean market

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Supplementary material

1. Landfill disposal (LC) inventory data

Landfill stage: This section is shown in *section 2.2.1* in the paper. The IPCC method, developed for solid waste disposal (SWDS), was used to calculate the amount of methane emitted at the landfill [1, 2]. Among the three described levels for assessing CH_4 emissions from SWDS, this study used the Tier 1 FOD method, which mainly uses default activity data and parameters, for determining methane emissions at the landfill [2]. Methane emissions from SWDS during a single year can be estimated with Equation 1 (Eq. 1). Methane is generated due to the decomposition of organic matter under anaerobic conditions. Some of the generated methane is oxidised in the SWDS cover or can be recovered for energy or flaring. The amount of methane emitted from SWDS can be calculates as:

$$CH_4\ \text{Emissions} = \left[\sum_x CH_4\text{generated}_{x,T} - R_T\right] \cdot (1 - OX_T) \qquad \text{(Eq. 1)}$$

where CH_4 emissions is the CH_4 emitted in year T, expressed in Gg; T is the inventory year; X is the waste category or type/material; R_T is the recovered CH_4 in year T, expressed in Gg; OX_T is the oxidation factor in year T, expressed in fraction.

The base for the calculation of methane generation is the amount of degradable organic carbon (DOC) as defined in Equation 2 (Eq. 2).

$$DDOC_m = W \cdot DOC \cdot DOC_F \cdot MCF \qquad \text{(Eq. 2)}$$

where $DDOC_m$ is the mass of decomposable DOC deposited, expressed in Gg; W is the amount of waste deposited in the landfill per year, expressed in Gg; DOC is degradable organic carbon in a year of deposition, expressed in Gg C/Gg waste; DOC_F corresponds to a fraction of DOC that decomposes under anaerobic conditions expressed in fraction; MCF is the CH_4 correction factor for aerobic decomposition in the year of deposition, expressed in fraction.

Therefore, to determine the methane quantity generated from the waste that can be decomposed, the fraction of CH_4 contained in the generated landfill gas is multiplied by the quotient of the molecular weights CH_4/C (Eq. 3).

$$CH_4generated_T = DDOC_m \cdot F \cdot \frac{16}{12} \qquad (Eq. 3)$$

where CH_4 $generated_T$ is the amount of CH_4 generated from decomposable material; $DDOC_m$ is the mass of decomposable DOC deposited, expressed in Gg; F is the fraction of CH_4, by volume, ingenerated landfill gas, expressed in fraction; 16/12 is the molecular weight ratio CH_4/C.

The emission factors and parameters were chosen according to the recommended default value:

- The amount of waste deposited in the landfill per year (W) was 1.64 Gg FVW per year.
- The DOC value was 0.070 Gg per Gg FVW.
- The recommended default value chosen for DOC_F was 0.7 [2], assuming that the waste for which this assessment is being developed is considered a highly decomposable waste since it belongs to food waste.
- The MCF accounts for the fact that, for a given amount of waste, unmanaged SWDS produce less CH4 than managed anaerobic SWDS. Of all the MCF values assigned, it has been considered that the MCF that best fits the conditions of the landfill studied is 0.5 [2], since it corresponds to a semi-aerobic managed solid waste landfill site [3].
- The CH_4 fraction (F) value in the landfill gas was recommended to be 0.5 [2].
- The oxidation factor (OX) reflects the amount of CH_4 oxidised in the soil or other waste material. The amount of methane oxidised in the soil was unknown, so the value was assumed to be zero.
- At the Al Ghabawi landfill, as reported by Hadjidimoulas [3], 75% of the methane generated is therefore recovered. The methane generated per year was 0.027 Gg CH_4 and the methane emissions were 18.3 kg CH_4/d.

References

[1] IPCC, in: H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, K. Tanabe (Eds.), 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the Natioanl Greenhouse Gas Inventories Programme, Published: IGES, Japan, 2006.
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[3] C. Hadjidimoulas, Methane Gas Emissions: Methods of Improving the Efficiency of the Biggest Landfill Gas Waste to Energy Project in the Middle East Installed in Amman, Jordan, Open Access Library Journal 5(8) (2018) 1-35.

Table S1. Environmental impacts result for all impacts categories assessed using the ReCiPe 2016 Midpoint (H) method for landfill disposal.

							Avoid impact
Impact category	**Total**	**FV**	**WCT**	**Transport**	**Cells**	**Electricity, mix**	**Electricity, mix**
Global warming (kg CO_2 eq)	645.66	0.00	141.2	45.69	586.91	1.24	-129.47
Stratospheric ozone depletion (kg CFC11 eq)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ionizing radiation (kBq Co-60 eq)	1.51	0.00	1.20	0.40	0.00	0.18	-0.27
Ozone formation, Human health (kg NOx eq)	0.04	0.00	0.07	0.12	0.00	0.00	-0.15
Fine particulate matter formation (kg PM2.5 eq)	0.03	0.00	0.05	0.03	0.00	0.00	-0.06
Ozone formation, terrestrial ecosystem (kg NO_x eq)	0.01	0.00	0.07	0.12	0.00	0.00	-0.15
Terrestrial acidification (kg SO_2 eq)	0.07	0.00	0.15	0.09	0.00	0.01	-0.18
Freshwater eutrophication (kg P eq)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Marine eutrophication (kg N eq)	2.93	0.00	0.00	0.00	0.00	0.00	0.00
Terrestrial ecotoxicity (kg 1,4-DBC)	579.01	0.00	28.89	600.10	0.00	0.37	-80.35
Freshwater ecotoxicity (kg 1,4-DBC)	0.23	0.00	0.14	0.13	0.00	0.00	-0.04
Marine ecotoxicity (kg 1,4-DBC)	0.60	0.00	0.23	0.48	0.00	0.00	-0.10
Human carcinogenic toxicity (kg 1,4-DBC)	0.03	0.00	0.09	0.04	0.00	0.00	-0.09
Human non-carcinogenic toxicity (kg 1,4-DBC)	12.19	0.00	4.81	9.47	0.00	0.03	-2.11
Land use (m^2a crop eq)	0.55	0.00	0.59	0.20	0.00	0.00	-0.24
Mineral resource scarcity (Kg Cu eq)	0.01	0.00	0.01	0.00	0.00	0.00	0.00
Fossil resource scarcity (Kg oil eq)	7.92	0.00	44.61	14.86	0.00	0.21	-51.76
Water consumption (m^3)	-0.23	0.00	0.00	0.00	0.00	0.00	-0.23

Table S2. Environmental impacts result for all impacts categories assessed using the ReCiPe 2016 Midpoint (H) method for AD and composting plant.

					Avoid impact		
Impact category	**Total**	**FVW**	**Turning**	**Transport**	**Compost**	**Liquid biofertiliser**	**Electricity, mix**
Global warming (kg CO_2 eq)	-1436.08	0.00	3.48	11.18	-560.43	-239.01	-618.33
Stratospheric ozone depletion (kg CFC11 eq)	-0.02	0.00	0.00	8.21	-0.01	-0.01	0.00
Ionizing radiation (kBq Co-60 eq)	-5.49	0.00	0.03	0.10	-2.90	-1.24	-1.30
Ozone formation, Human health (kg NOx eq)	-2.27	0.00	0.04	0.03	-1.09	-0.47	-0.71
Fine particulate matter formation (kg PM2.5 eq)	-0.86	0.00	0.21	0.01	-0.55	-0.27	-0.27
Ozone formation, terrestrial ecosystem (kg NO_x eq)	-2.29	0.00	0.04	0.03	-1.10	-0.47	-0.72
Terrestrial acidification (kg SO_2 eq)	-2.19	0.00	1.68	0.02	-2.05	-0.87	-0.85
Freshwater eutrophication (kg P eq)	-0.03	0.00	0.00	0.00	-0.02	-0.01	0.00
Marine eutrophication (kg N eq)	-0.02	0.00	0.00	0.00	-0.01	-0.01	0.00
Terrestrial ecotoxicity (kg 1,4-DBC)	-1456.94	0.00	4.54	146.69	-822.45	-350.75	-386.60
Freshwater ecotoxicity (kg 1,4-DBC)	-9.34	0.00	0.01	0.03	-6.19	-2.64	-0.18
Marine ecotoxicity (kg 1,4-DBC)	-12.85	0.00	0.01	0.12	-8.40	-3.58	-0.50
Human carcinogenic toxicity (kg 1,4-DBC)	-3.60	0.00	0.00	0.01	-2.13	-0.91	-0.44
Human non-carcinogenic toxicity (kg 1,4-DBC)	-367.33	0.00	17.78	2.31	-254.00	-108.32	-10.16
Land use (m^2a crop eq)	-129.72	0.00	0.02	0.05	-86.60	-36.93	-1.16
Mineral resource scarcity (Kg Cu eq)	-2.15	0.00	0.00	0.00	-1.45	-0.62	0.00
Fossil resource scarcity (Kg oil eq)	-353.59	0.00	1.11	3.63	-73.59	-31.38	-249.03
Water consumption (m^3)	-8.25	0.00	0.00	0.00	-4.80	-2.05	-1.13