

DEISO RESEARCH

Environmental impacts of open dumping, uncontrolled landfilling and open burning of municipal solid waste in developing countries

A life cycle assessment by income level and climate zone

Dr. Mahdi Ikhlayel

DEISO Research · DEISO LLC, Tokyo, Japan

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KEY FINDINGS

What the study found

- **Open burning** — human toxicity is about 77% of the weighted impact in every income group and both climates, with freshwater aquatic ecotoxicity at about 21%. Per tonne, open burning gives 2,080–2,170 kg 1,4-DB-eq of human toxicity potential.
- **Open dumps and uncontrolled landfills, humid climate** — freshwater aquatic ecotoxicity (about 60%) and eutrophication (about 30%) dominate, because heavy metals leave the site through water.
- **Open dumps and uncontrolled landfills, arid climate** — human toxicity leads at about 60%, followed by freshwater aquatic ecotoxicity at about 35%; emissions go mainly to soil, with about 8% to air.
- **Global warming** — dumping one tonne gives 432–520 kg CO₂-eq including biogenic carbon (333–399 kg excluding it), more than twice the 196 kg of open burning, and it rises with income level.
- **Heavy metals** — lead and zinc are the largest metal emissions; lead to water is the highest in every case.
- **Waste fractions** — metals cause the highest impacts, plastic drives eutrophication and ecotoxicity, and glass has the lowest impact.

ABSTRACT

Abstract

This life cycle assessment estimates the potential environmental impacts of disposing of municipal solid waste (MSW) in developing countries. It covers waste from three economies — low-income, lower-middle-income and upper-middle-income — in two climate zones, arid and humid, and three disposal methods: uncontrolled (unsanitary) landfilling, open dumping and open burning. Five impact categories are assessed with the CML 2001 method: acidification potential (AP), eutrophication potential (EP), freshwater aquatic ecotoxicity potential (FAETP), global warming potential (GWP) and human toxicity potential (HTP). The study gives a baseline for the environmental cost of poor waste handling, and shows how that cost changes with climate, income level and waste composition.

Keywords: waste management; uncontrolled landfills; open dumps; open burning; environmental impacts; developing countries; life cycle assessment; heavy metals

BACKGROUND

Waste disposal in developing countries

The world generated an estimated 2.01 billion tonnes of municipal solid waste in 2016, and that figure is projected to reach 3.40 billion tonnes by 2050 ([Kaza et al., 2018](#)). Disposal practice divides sharply by income:

about 93% of waste is dumped in low-income countries, against 2% in high-income countries ([Kaza et al., 2018](#)). Collection gaps, limited budgets and weak enforcement keep open dumping and open burning in place across much of Africa, Asia and Latin America ([Guerrero et al., 2013](#); [Ferronato & Torretta, 2019](#)).

Each of these practices moves pollutants into a different part of the environment. Dumps and uncontrolled landfills release leachate to soil and water and landfill gas to air. Open burning releases trace gases, particulate matter and hazardous air pollutants that are largely missing from national emission inventories ([Wiedinmyer et al., 2014](#)). Life cycle assessment has been applied widely to solid waste management ([Laurent et al., 2014](#)), and earlier work has used uncontrolled disposal as the baseline against which better systems for developing countries are designed ([Ikhlaiel, 2018b](#)). What is missing is a consistent picture of how the impacts of the disposal practices themselves shift with income level and climate.

OBJECTIVE AND SCOPE

Objective, research questions and scope

The study assesses the environmental impacts of MSW disposal in developing countries across three economies and, for each, an arid and a humid climate. It looks at uncontrolled (unsanitary) landfilling, open dumping and open burning, because they are widely practised in many developing countries. The evaluation is built to show the impacts of these practices, how each contributes to environmental degradation, and which environmental issue is most pressing for a given economy and climate.

Three research questions guide the work:

- 1 Do the environmental impacts differ from one economy to another?
- 2 Do climate conditions influence those impacts?
- 3 How does waste composition affect each impact category?

The study does not rank individual countries. A ranking would need accurate data on each country's whole waste management system — collection schemes, transport distances and energy, the share and composition of waste openly burned, and the size of informal recycling — and those data are either unavailable or do not exist.

METHOD

Method

Life cycle assessment and system boundaries

The assessment follows the life cycle assessment framework of ISO 14040 and ISO 14044 ([ISO, 2006a](#); [ISO, 2006b](#)). The following were kept outside the system boundary: waste collection from the point of generation to the disposal site or a transfer station; transport to a landfill or dump; informal recycling; other treatment such as composting and formal pilot projects; and the energy used to handle waste at disposal sites. The results therefore represent the potential emissions and impacts of the disposal step itself. Countries are grouped as low-income, lower-middle-income and upper-middle-income following the World Bank classification ([World Bank, 2016](#)).

Functional unit

The functional unit is 1 tonne of MSW disposed of by uncontrolled landfilling, open dumping or open burning in a developing country, defined by its economic level and climate.

Inventory analysis

Emissions to air, water and soil were estimated for each disposal method, economy, climate and waste composition. Inventories for uncontrolled landfills and open dumps came from the waste-specific and climate-specific model of [Doka \(2016a\)](#); inventories for open burning came from the waste-specific model of [Doka \(2016b\)](#). Both models were run for the waste of each economy, for arid and humid conditions, and for 1 tonne of each single waste type. The climate inputs were mean annual temperature, mean annual precipitation and mean actual evapotranspiration. The methane correction factor follows the IPCC guidelines ([IPCC, 2006](#)). Energy used at disposal sites was outside the scope, so no energy data were needed.

CALCULATION METHOD

All inventory and impact calculations in this study were built and run in Microsoft Excel.

Waste composition data came from the World Bank ([Hoornweg & Bhada-Tata, 2012](#)) and cover organic, paper, plastic, metals, glass and “other” waste. The source does not define “other” waste, and many countries do not report it. In this study it was taken as rubber, textiles, wood and a hazardous e-waste portion mixed with MSW, at 25% each, based on fractions reported for developing countries ([Guerrero et al., 2013](#); [Wilson et al., 2015](#)). E-waste in many developing countries is collected and disposed of together with MSW ([Ikhlayel, 2017](#); [Ikhlayel, 2018a](#)).

Table 1. Parameters used in the study.

Parameter	Value	Source
Waste composition, low income (organic / paper / plastic / glass / metals / other)	64 / 5 / 8 / 3 / 3 / 17%	Hoornweg & Bhada-Tata, 2012
Waste composition, lower-middle income	59 / 9 / 12 / 3 / 2 / 15%	Hoornweg & Bhada-Tata, 2012
Waste composition, upper-middle income	54 / 14 / 11 / 5 / 3 / 13%	Hoornweg & Bhada-Tata, 2012
Make-up of “other waste”	Rubber, textiles, wood and e-waste, 25% each	Assumption; see Guerrero et al., 2013 , Wilson et al., 2015
Climate inputs per zone	Mean annual temperature, mean annual precipitation, mean actual evapotranspiration for an arid and a humid zone	Hijmans et al., 2005 ; Mu et al., 2011
Methane correction factor (MCF)	0.6, the default for uncategorised disposal sites	IPCC, 2006
Metal fraction burned in open burning	10%	Assumption
Landfill height / open-dump height	20 m / 10 m	Assumption
Landfill operating time	30 years	Assumption
Definitions of uncontrolled landfill, open dump and open burning	As used in the inventory models	Doka, 2016a ; Doka, 2016b ; Hoornweg & Bhada-Tata, 2012

Life cycle impact assessment

Several impact assessment methods exist, including ILCD, IMPACT 2002+ and ReCiPe. The CML 2001 method ([Guinée, 2002](#)) was used at midpoint level because it is widely applied to municipal solid waste management. Five categories were evaluated: acidification potential (AP), eutrophication potential (EP), freshwater aquatic ecotoxicity potential (FAETP), global warming potential over 100 years (GWP) and human toxicity potential (HTP).

RESULTS

Results and discussion

Impact profile by disposal method

Open burning produces a near-identical profile in both climates and all three economies. Human toxicity is the largest share, at about 77% on average, followed by freshwater aquatic ecotoxicity at about 21%; eutrophication makes up most of the remainder.

For open dumps and uncontrolled landfills the profile depends on climate. In humid conditions freshwater aquatic ecotoxicity is the largest share, at about 60% on average, followed by eutrophication at about 30% and human toxicity at about 10%. In arid conditions human toxicity leads at about 60% and freshwater aquatic ecotoxicity follows at about 35%. Leaving those two categories aside, eutrophication is the largest remaining impact in the humid climate and global warming in the arid one. Acidification is noticeable in the arid climate and negligible in the humid one; global warming is similar in both.



Figure 1. Share of weighted environmental impacts of MSW disposal by uncontrolled landfill, open dump and open burning, for three economies in arid and humid climates. Values redrawn from the original analysis.

By economy, human toxicity from open burning changes little, from 2,080 to 2,170 kg 1,4-DB-eq per tonne in both climates. With open dumping and uncontrolled landfilling, freshwater aquatic ecotoxicity is the main concern for low-income countries in humid conditions, while human toxicity is the main contributor in arid conditions. In lower-middle-income countries with humid conditions, freshwater aquatic ecotoxicity and eutrophication are both significant, and human toxicity is the most severe impact under arid conditions. Upper-middle-income countries follow the lower-middle-income pattern in arid conditions; in humid conditions freshwater aquatic ecotoxicity and human toxicity are the most severe. Table 2 gives the characterised results per tonne.

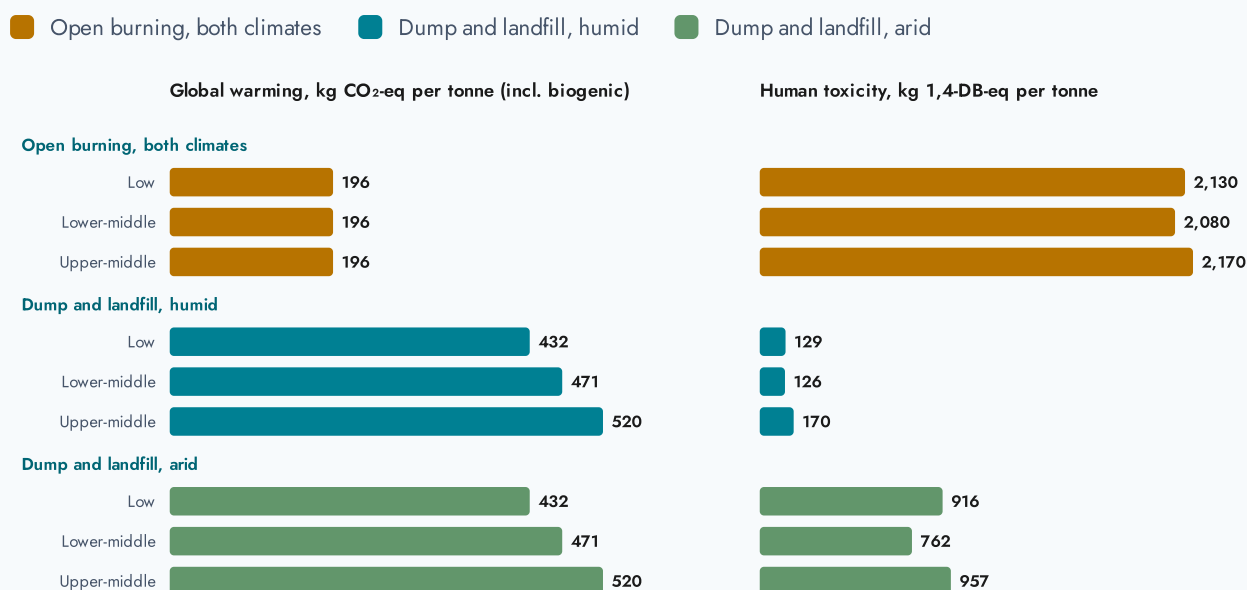


Table 2 in chart form. Global warming and human toxicity potential per tonne of MSW, from Table 2. Dumps and uncontrolled landfills carry the larger climate burden; open burning carries by far the larger human toxicity burden.

Table 2. CML 2001 characterised impacts per tonne of MSW disposed of, by disposal method, climate and economy. Open-burning results do not vary with climate, and open dumps and uncontrolled landfills give identical results in this model, so those rows are combined.

Disposal method	Climate	Income group	AP (kg SO ₂ -eq)	EP (kg PO ₄ -eq)	FAETP (kg 1,4-DB-eq)	GWP incl. biogenic (kg CO ₂ -eq)	GWP excl. biogenic (kg CO ₂ -eq)	HTP (kg 1,4-DB-eq)
Open burning	Arid and humid	Low	0.405	4.88	573	196	188	2,130
Open burning	Arid and humid	Lower-middle	0.405	4.56	419	196	189	2,080
Open burning	Arid and humid	Upper-middle	0.405	4.20	572	196	188	2,170
Open dump and uncontrolled landfill	Humid	Low	0.437	34.2	1,150	432	333	129
Open dump and uncontrolled landfill	Humid	Lower-middle	0.411	38.4	832	471	363	126
Open dump and uncontrolled landfill	Humid	Upper-middle	0.378	37.2	1,150	520	399	170
Open dump and uncontrolled landfill	Arid	Low	0.818	2.98	557	432	333	916
Open dump and uncontrolled landfill	Arid	Lower-middle	0.840	2.79	403	471	363	762

Disposal method	Climate	Income group	AP (kg SO ₂ -eq)	EP (kg PO ₄ -eq)	FAETP (kg 1,4-DB-eq)	GWP incl. biogenic (kg CO ₂ -eq)	GWP excl. biogenic (kg CO ₂ -eq)	HTP (kg 1,4-DB-eq)
Open dump and uncontrolled landfill	Arid	Upper-middle	0.763	2.56	556	520	399	957

Heavy-metal emissions

The main heavy-metal emissions are antimony, arsenic, cadmium, chromium, chromium (VI), cobalt, lead, manganese, mercury, nickel, selenium, silver, tin, titanium, vanadium and zinc. Lead and zinc are the most significant. Compared with other metals on the same emission path, lead emissions to water are the highest in every case, and higher in the arid climate than in the humid one; lead is also significant in soil and slight in air. Zinc emissions are significant to air, followed by soil. Figure 2 shows the mix of the remaining metals in each case.

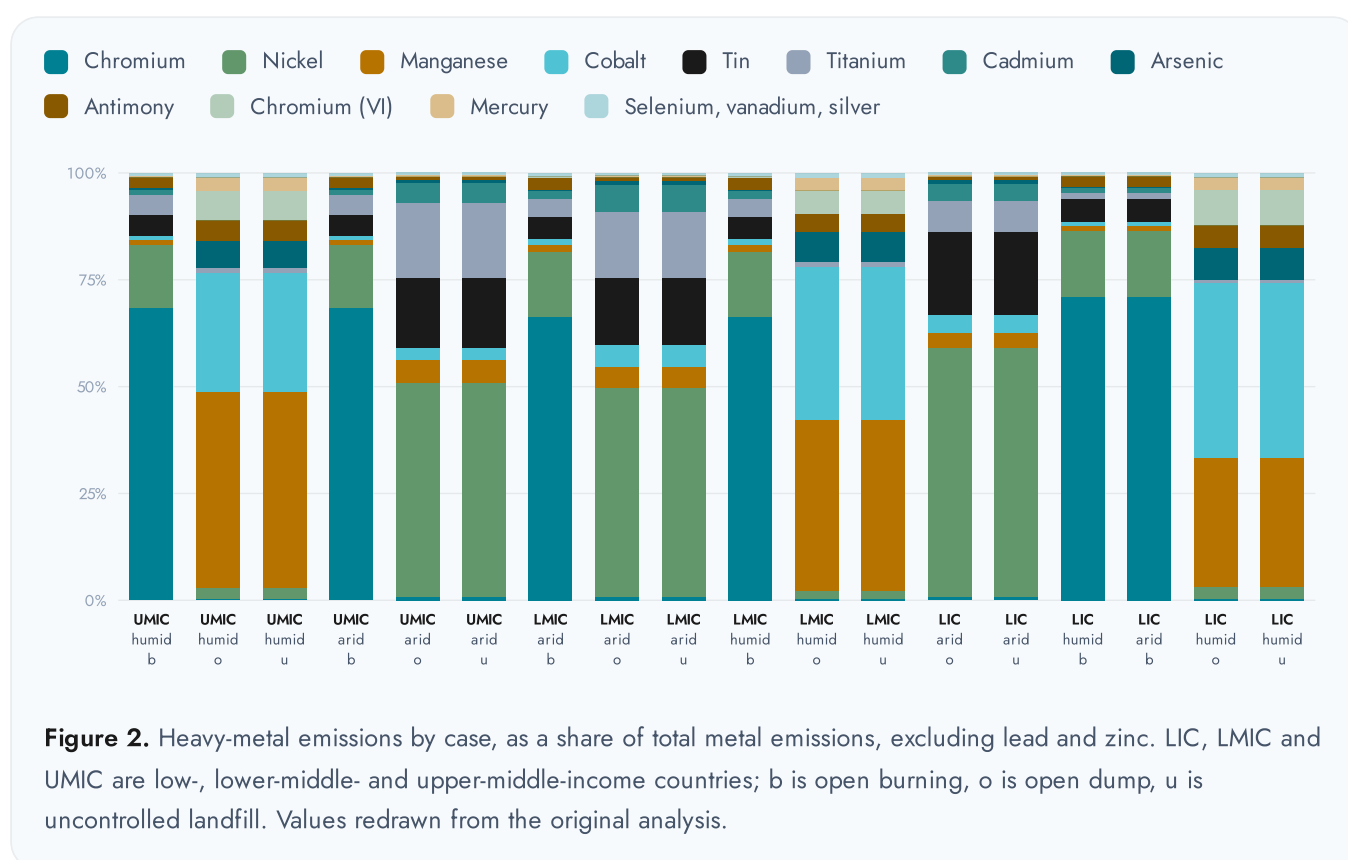


Figure 3 shows where those emissions go. In the humid climate the fate of heavy metals from dumps and uncontrolled landfills is almost entirely water, while in the arid climate it is soil, at about 90%, and air, at about 8%. Open burning sends metal emissions to soil in every case. Across the elements examined, metal presence in soil is significant compared with air, and the same holds for emissions overall, regardless of economy and disposal method.

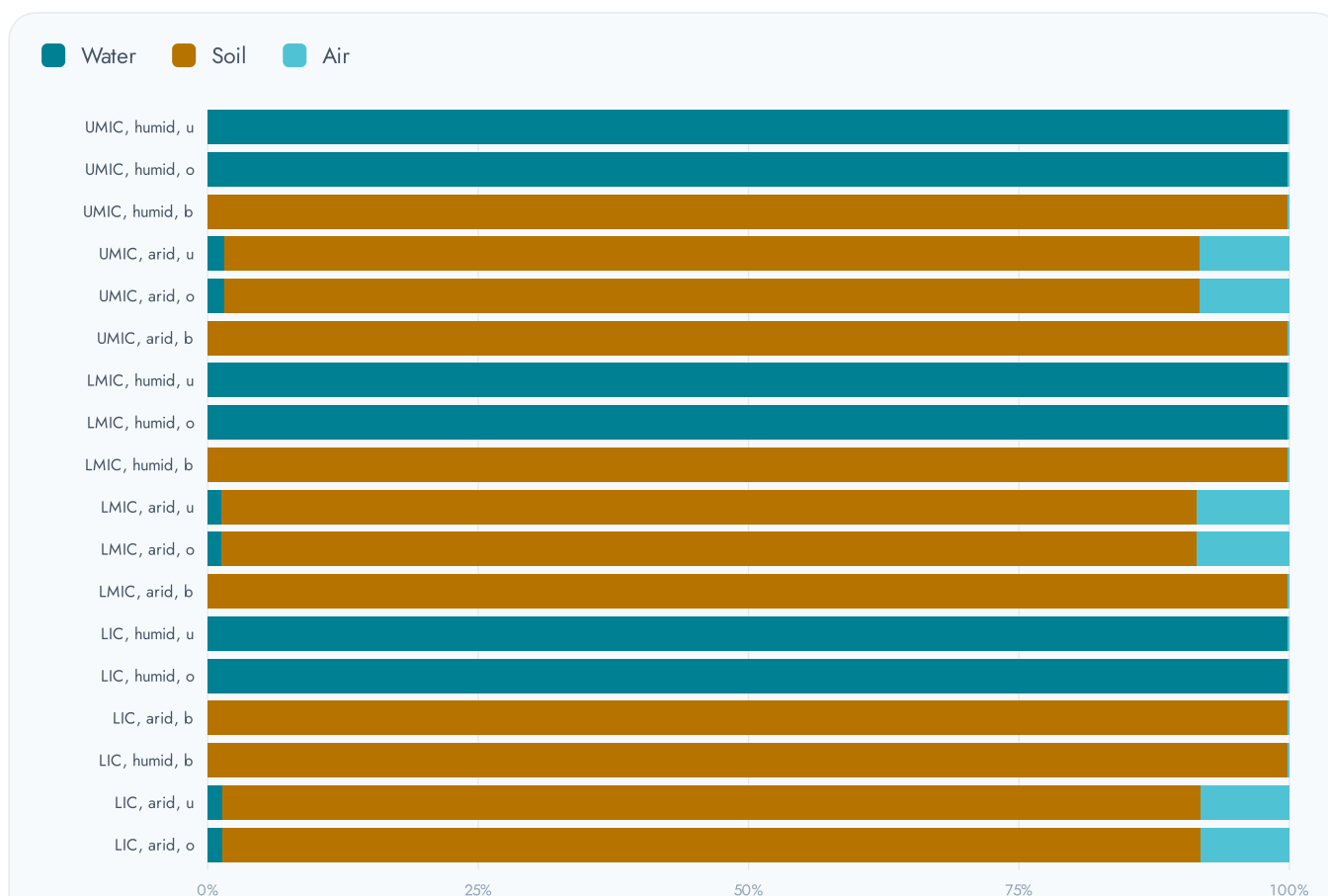


Figure 3. Share of heavy-metal emissions to water, soil and air by case. Abbreviations as in Figure 2. Values redrawn from the original analysis.

Impacts by economy and climate

Figure 4 aggregates the weighted impacts by economy and climate. Human toxicity is more significant in arid conditions, highest in upper-middle-income countries (21.6%). Global warming is highest in upper-middle-income countries in both climates (18.0%). Freshwater aquatic ecotoxicity is significant in humid conditions, at 23.1% for both low-income and upper-middle-income countries, and lowest for lower-middle-income countries in arid conditions (9.9%). Eutrophication is significant in humid conditions, particularly in lower-middle-income (30.8%), upper-middle-income (29.8%) and low-income (27.9%) countries. Acidification is higher in arid conditions, at 21.4% for lower-middle-income and 21.0% for low-income countries.

	LIC arid	LIC humid	LMIC arid	LMIC humid	UMIC arid	UMIC humid
Acidification	21.02%	13.11%	21.42%	12.63%	19.89%	11.94%
Eutrophication	4.11%	27.86%	3.86%	30.83%	3.55%	29.79%
Freshwater aquatic ecotoxicity	13.56%	23.11%	9.87%	16.80%	13.56%	23.11%
Global warming	15.42%	15.41%	16.57%	16.57%	18.02%	18.02%
Human toxicity	20.98%	12.65%	19.10%	12.35%	21.62%	13.30%

Figure 4. Aggregated and weighted environmental impacts by economy and climate. Each value is the share of that economy-climate case within the impact category, so each row sums to 100%. Darker cells mark larger shares.

Impacts by waste type

To isolate the effect of composition, 1 tonne of each waste type — organic, paper, plastic, glass, metals and other waste — from low-income countries was modelled through open dumping and uncontrolled landfilling in both climates. The worst impacts come from the disposal of metals, in both climates. The next worst come from plastic, other waste and paper in the humid climate. Glass has the lowest impacts in both climates.

Each fraction points to a particular concern: metals to human toxicity and freshwater aquatic ecotoxicity; paper to human toxicity; plastic to eutrophication and freshwater aquatic ecotoxicity; organic waste to global warming, human toxicity and freshwater aquatic ecotoxicity; glass to human toxicity and freshwater aquatic ecotoxicity; and other waste to eutrophication, freshwater aquatic ecotoxicity and human toxicity. These findings agree with the results for whole waste compositions.

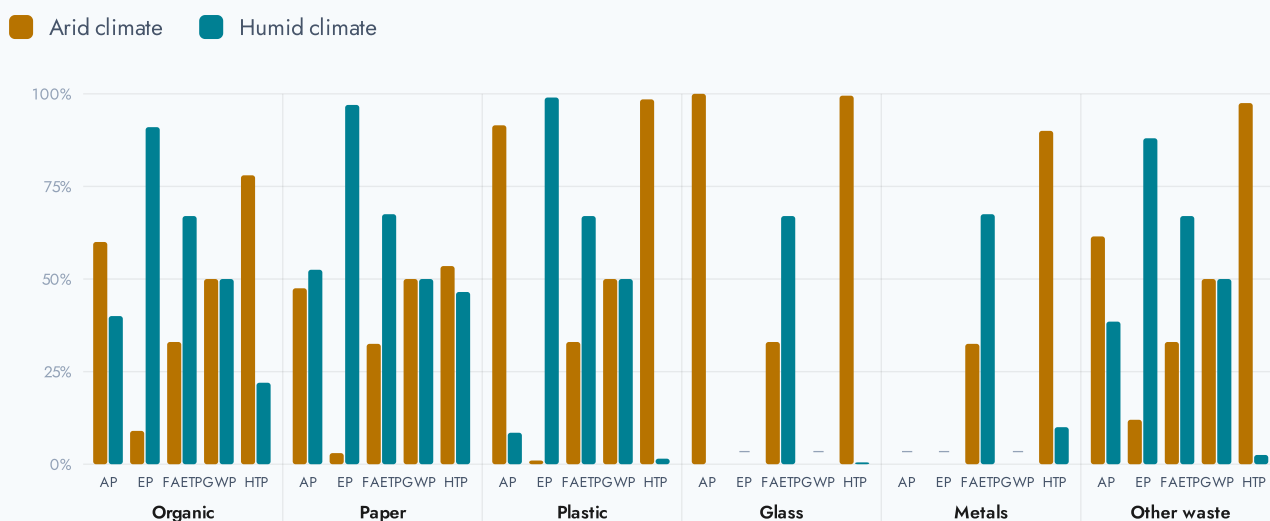


Figure 5. Split of each impact category between arid and humid climates for 1 tonne of each waste type disposed of in open dumps and uncontrolled landfills (both methods give identical results). A dash marks a category with no contribution from that fraction. Values redrawn from the original analysis.

UNCERTAINTY

Sensitivity and Monte Carlo analysis

The sensitivity analysis used waste disposal in low-income countries with arid conditions, through uncontrolled landfills and open dumps, for a composition of 64% organic, 5% paper, 8% plastic, 3% glass, 3% metals and 17% other waste ([Hoornweg & Bhada-Tata, 2012](#)). Each fraction was varied by one standard deviation of -50% and $+50\%$. The overall results do not change, but the analysis shows which inputs carry influence: the metals fraction and the organic fraction have the strongest effect, and glass and other waste also move the results in some cases.

Table 3. Results of the sensitivity analysis.

Case	Organic	Paper	Plastic	Glass	Metals	Other waste
1 – SD	–2.7%	–0.7%	–1.7%	–29.3%	–13.2%	–2.4%
1 + SD	2.7%	0.7%	1.7%	29.3%	13.2%	2.4%
2 – SD	–1.2%	–0.5%	–0.9%	–7.3%	–35.9%	–4.4%
2 + SD	1.2%	0.5%	0.9%	7.3%	35.9%	4.4%
3 – SD	–9.0%	–0.5%	–7.4%	–13.0%	0.0%	–20.1%
3 + SD	9.0%	0.5%	7.4%	13.0%	0.0%	20.1%
4 – SD	–33.0%	–9.2%	–1.1%	0.0%	0.0%	–6.8%

Case	Organic	Paper	Plastic	Glass	Metals	Other waste
4 + SD	33.0%	9.2%	1.1%	0.0%	0.0%	6.8%
5 – SD	–14.3%	–1.3%	–1.7%	0.0%	0.0%	–32.7%
5 + SD	14.3%	1.3%	1.7%	0.0%	0.0%	32.7%

	Case 1	Case 2	Case 3	Case 4	Case 5
Organic	±2.7%	±1.2%	±9%	±33%	±14.3%
Paper	±0.7%	±0.5%	±0.5%	±9.2%	±1.3%
Plastic	±1.7%	±0.9%	±7.4%	±1.1%	±1.7%
Glass	±29.3%	±7.3%	±13%	0%	0%
Metals	±13.2%	±35.9%	0%	0%	0%
Other waste	±2.4%	±4.4%	±20.1%	±6.8%	±32.7%

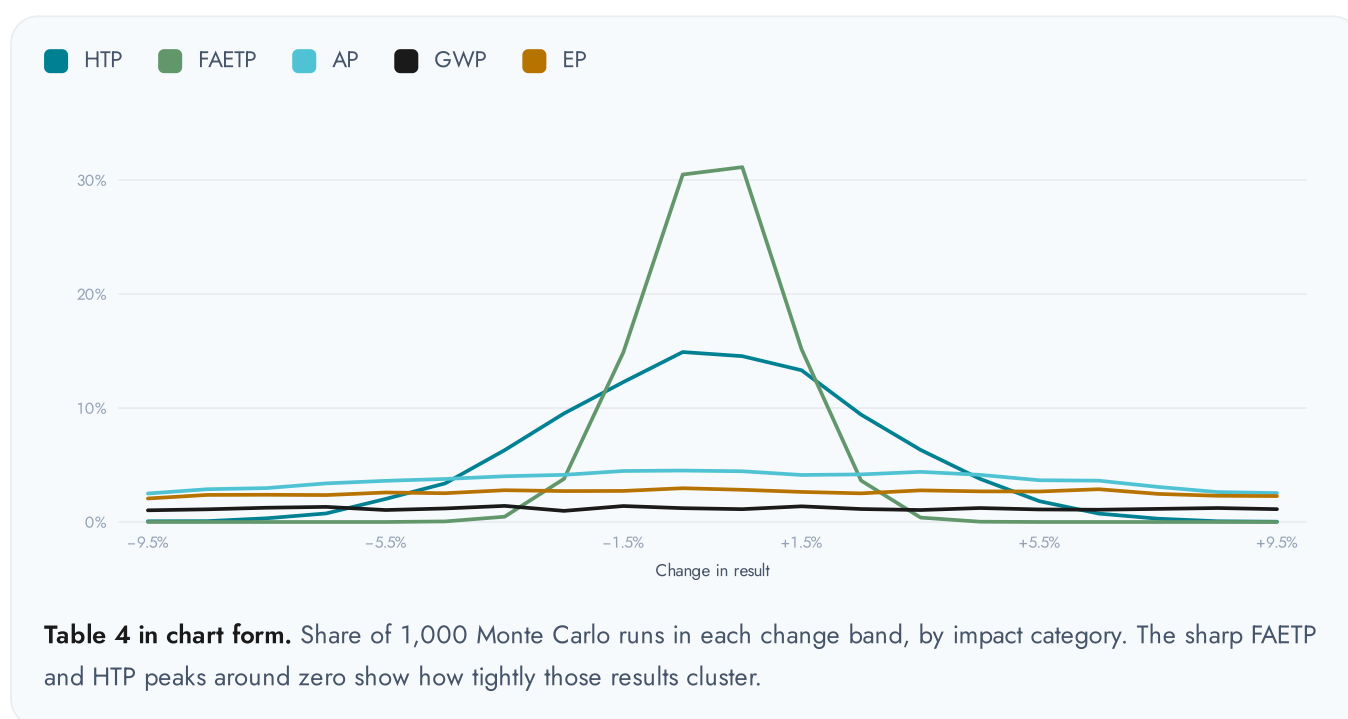
Table 3 in chart form. Size of the change in result for ± 1 standard deviation in each waste fraction, by case. Darker cells mark larger changes.

Uncertainty was tested with a Monte Carlo analysis of 1,000 runs with randomly generated parameters. Table 4 lists, for each impact category, the share of runs that changed the result by a given amount. Freshwater aquatic ecotoxicity results cluster tightly: about 62% of runs changed the result by no more than $\pm 0.5\%$, about 92% by no more than $\pm 1.5\%$, and none by more than $\pm 4.5\%$. Human toxicity spreads a little wider, with about 74% of runs within $\pm 2.5\%$. For acidification, global warming and eutrophication, no single change band holds more than 5% of runs. All recorded changes stay within $\pm 9.5\%$ of the base result, so the results are stable.

Table 4. Monte Carlo analysis: share of 1,000 runs, by change in result and impact category.

Change in result	HTP	FAETP	AP	GWP	EP
–9.5%	0.06%	0%	2.5%	1.03%	2.06%
–8.5%	0.07%	0%	2.88%	1.11%	2.37%
–7.5%	0.33%	0%	2.98%	1.25%	2.39%
–6.5%	0.75%	0%	3.39%	1.33%	2.36%
–5.5%	2.03%	0%	3.61%	1.05%	2.59%
–4.5%	3.39%	0.05%	3.78%	1.19%	2.53%
–3.5%	6.3%	0.46%	4.01%	1.41%	2.79%

Change in result	HTP	FAETP	AP	GWP	EP
-2.5%	9.53%	3.79%	4.14%	0.97%	2.71%
-1.5%	12.28%	14.87%	4.48%	1.4%	2.73%
-0.5%	14.91%	30.49%	4.51%	1.21%	2.96%
+0.5%	14.55%	31.14%	4.45%	1.12%	2.83%
+1.5%	13.31%	15.15%	4.12%	1.37%	2.64%
+2.5%	9.43%	3.64%	4.18%	1.14%	2.51%
+3.5%	6.32%	0.39%	4.4%	1.05%	2.78%
+4.5%	3.79%	0.02%	4.14%	1.23%	2.69%
+5.5%	1.83%	0%	3.66%	1.1%	2.68%
+6.5%	0.74%	0%	3.62%	1.07%	2.87%
+7.5%	0.29%	0%	3.07%	1.15%	2.46%
+8.5%	0.06%	0%	2.63%	1.23%	2.3%
+9.5%	0.03%	0%	2.54%	1.13%	2.27%



CONCLUSION

Conclusion and implications

All three disposal practices damage the environment, but not in the same way. The answer to the first research question is yes, though less than expected: income level shifts the size of individual impacts by a few percentage points, while the ranking of concerns stays much the same. The answer to the second is strongly yes: for dumps and uncontrolled landfills, climate decides whether the main burden falls on freshwater ecosystems or on human health. The answer to the third is that a few fractions — metals above all, then plastic and organic waste — carry most of the impact.

What this study adds

- **One consistent comparison** — three income groups, two climates, three disposal methods and six waste fractions are assessed per tonne with the same models and impact method, instead of one city or one country at a time.
- **Climate outweighs income** — for dumps and uncontrolled landfills, moving from an arid to a humid climate changes which impact dominates, while moving between income groups changes impact shares by only a few percentage points.
- **The mechanism behind the climate effect** — heavy-metal emissions are traced to their receiving medium: water in humid climates, soil and air in arid ones.
- **Fraction-level priorities** — metals, plastic and organic waste are identified as the fractions that carry most of the impact, which points to where separation pays off first.

Three practical priorities follow from the results:

- **End open burning first** — its human toxicity burden is the highest in absolute terms and does not ease with income level or climate.
- **Match site controls to climate** — in humid regions, leachate containment protects water; in arid regions, cover and soil protection limit metal exposure.
- **Keep metals and e-waste out of mixed waste** — the metals fraction drives human toxicity and ecotoxicity and is among the most influential inputs in the sensitivity analysis.

LIMITATIONS

- Collection, transport, informal recycling and site energy are outside the system boundary.
- Open dumps and uncontrolled landfills share the same inventory model and parameters here, so they give identical results.

- Waste composition data date from 2012; Figures 1 to 5 show weighted shares, while Table 2 gives absolute characterised results.

QUESTIONS

Frequently asked questions

Which waste disposal method has the highest human toxicity impact in developing countries?

Open burning. In this study it carries about 77% of the weighted impact as human toxicity in every income group and climate, and its characterised human toxicity potential is 2,080 to 2,170 kg 1,4-DB-eq per tonne of waste, against 126 to 957 kg for open dumps and uncontrolled landfills.

How does climate change the environmental impact of open dumps and uncontrolled landfills?

In humid climates heavy metals leave the site mostly through water, so freshwater aquatic ecotoxicity (about 60% of the weighted impact) and eutrophication (about 30%) dominate. In arid climates emissions go mainly to soil and air, and human toxicity leads at about 60%, followed by freshwater aquatic ecotoxicity at about 35%.

What is the carbon footprint of open dumping one tonne of municipal solid waste?

Between 432 and 520 kg CO₂-eq per tonne including biogenic carbon, or 333 to 399 kg CO₂-eq excluding it, rising with income level. Open burning of the same tonne gives about 196 kg CO₂-eq including biogenic carbon.

Which waste fractions cause the most environmental impact when dumped?

Metals, through human toxicity and freshwater aquatic ecotoxicity. Plastic raises eutrophication and ecotoxicity, organic waste contributes to global warming, human toxicity and ecotoxicity, and glass has the lowest impact of the fractions studied.

Can DEISO run a life cycle assessment of a waste management system?

Yes. DEISO runs life cycle assessments of waste collection, treatment and disposal systems, from inventory modelling through scenario comparison to reporting. Requests go through the DEISO quotation form.

CITATION

How to cite this study

Researchers are welcome to cite this study, and the full study is available as a [PDF](#). Please credit Dr. Mahdi Ikhlayel as the author and DEISO Research as the publisher, using one of the formats below; the online version is published on dei.so.

APA 7

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