Lifecycle Assessment of Plastic Recycling Systems Supporting the Development of PLACES

Background

The Circulate Initiative has developed an open-sourced prototype GHG calculator to track the environmental impact of plastic waste management and recycling solutions that prevent plastic pollution in India and Indonesia. PLACES - Plastic Lifecycle Assessment Calculator for the Environment and Society, is based on the findings of a scientific paper published by Circulate Capital and the Singapore Institute of Manufacturing Technology (SIMTech), a unit of Singapore's Agency for Science, Technology and Research (A*STAR) in the Journal of Resources, Conservation and Recycling.[1] This white paper summarizes the research approach, methodology, assumptions, and key findings from the research conducted by Circulate Capital and SIMTech.

This note has been prepared by The Circulate Initiative to provide the users of PLACES an overview of the research approach, assumptions, and findings from the Life Cycle Assessment (LCA) study which forms the basis for the calculator.

Approach

PLACES was developed with the Life Cycle Assessment (LCA) methodology based on the ISO 14040/44 guidelines.[2,3] The study is contextualized to waste management practices in India and Indonesia including end-of-life (EOL) fates for plastic waste in each country.

Methodology

The following section of the note provides an overview of the research methodology adopted for the LCA study.

LCA studies consist of four steps – 1) Goal and Scope Definition, 2) Life Cycle Inventory Analysis, 3) Life Cycle Impact Analysis and 4) Life Cycle Interpretation.

1. Goal and Scope definition

The goal of PLACES is to quantify the environmental impact of key plastic waste EOL treatment in India and Indonesia, which can be used to provide recommendations to policymakers and investors to focus their efforts towards EOL fates that can help to reduce environmental impact.

The key plastic wastes covered in this study are High-Density Polyethylene (HDPE), Low-Density Polyethylene (LDPE), Polypropylene (PP) and Polyethylene Terephthalate (PET), which account for a majority of plastic waste in India and Indonesia. In addition, the 'generic' category reflects all mixed plastic waste materials based on the status-quo composition for the country. The scope of this study

[1] Neo, E. R. K. *et al.* Life cycle assessment of plastic waste end-of-life for India and Indonesia. *Resour. Conserv. Recycl.* 174, 105774 (2021).
[2] ISO. ISO 14044 Environmental Management — Life Cycle Assessment — Requirements and Guidelines. (2006).
[3] ISO. ISO 14040 Environmental Management — Life Cycle Assessment — Principles and Framework. (2006).

includes downstream waste plastic treatment, from plastic waste generation to disposal or processing. This includes the collection of plastic waste and processing of plastic waste.

2. Life Cycle Inventory Analysis

This step involves the collection of relevant data. Data relating to the plastic waste EOL fates in the two countries were obtained from best available official reports from governmental organisations, ministries, and various industry sources. Certain assumptions were also considered for the calculation and analysis (see the 'Key Assumptions' section). The environmental impact factors were sourced from the Ecoinvent V3.6 database.

3. Life Cycle Impact Assessment

This step involves the selection of relevant environment impact categories. The calculator includes three different environmental impact categories – Carbon footprint, Energy consumption and Water consumption. Carbon footprint and water consumption are based on midpoint impact categories from ReCiPe V1.13 using the hierarchist approach[4] (climate change and water depletion respectively) while energy consumption is based on the cumulative energy demand model.

These impact categories were chosen as they represent key considerations in dealing with plastic waste. Carbon footprint provides an understanding of the impact on global warming, while energy and water represent key resources for emerging countries such as India and Indonesia.

4. Life Cycle Interpretation

This step involves the interpretation of findings from the LCA study. Two separate LCA system models are considered – Attributional LCA (ALCA) and Consequential LCA (CLCA).[5] ALCA studies the portion of environmental impact that should be attributed to the technology and is aligned with the GHG Protocol. On the other hand, CLCA allows the audience to understand the change in environmental impact as a consequence of the change in technology mix. For instance, the avoided production of plastics due to an increase in recycling is considered in CLCA and not in ALCA.

[4] RIVM. ReCiPe 2016 v1.1. 201 (2017).
[5] Ekvall, T. Attributional and consequential life cycle assessment. *Sustain. Assess. 21st century* 395, 1–22 (2020).

Key Assumptions

To fill any gaps in the data collected, various assumptions were considered which are detailed in the table below. The following section of this note highlights the key assumptions that were considered for the LCA study.

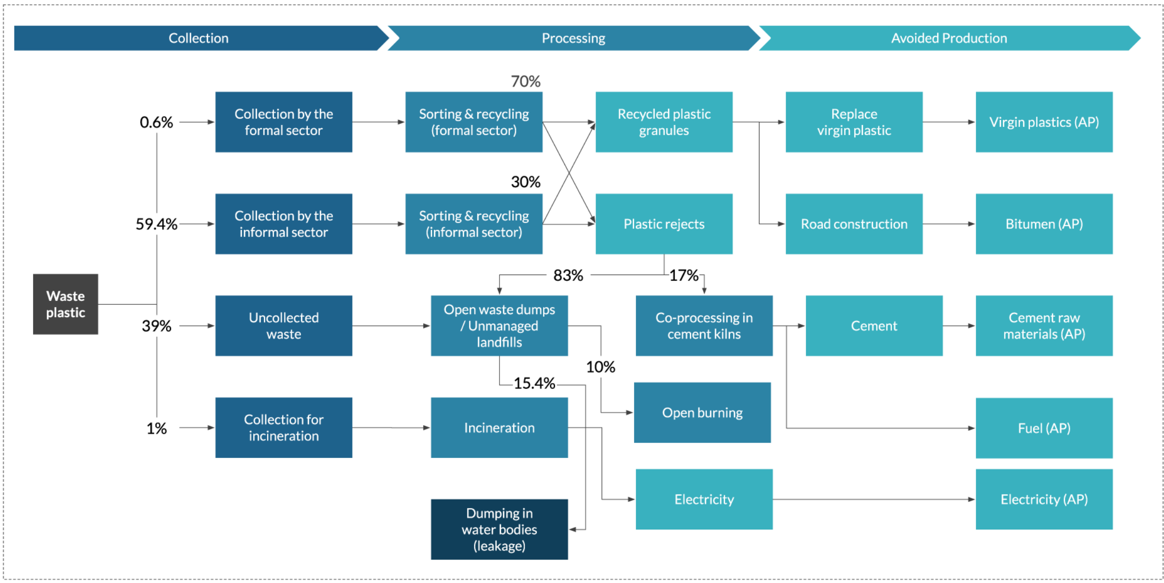
Life cycle stage	India	Indonesia
Plastic Waste End-of-Life	• No imported plastic waste. • Recycling rate of 95% for rigid plastic and 40% for flexible plastic. • For cement kilns, the only source of plastic waste is plastic waste rejected from recycling. • All dumpsites in India are assumed to be open dumps. • 10% of waste plastic in open dumps are openly burnt. • Dumping in water bodies modelled as leakage to water bodies.	• Recycling rate for individual plastics estimated from the breakdown of plastic types received by a recycler. • Dumping in water bodies modelled as leakage to water bodies . • Share and fate of imported waste plastic is the same as locally generated waste plastic.
Average Transport Distance	• 5 km for informal collection • 15 km for formal collection • 15 km to open dumps • 30 km to WTE plants • 50 km to recycling facilities	• Average transport distance of 20 km between all facilities. • Transport distance between UK and Indonesia (15,755 km) taken as the average import distance.
Avoided Production	**Recycling** • Recycled plastic has a 50% replacement ratio to virgin plastics • Recycled plastic has a 100% replacement ratio to bitumen in road construction **Co-processing in Cement Kilns** • Plastic waste has a 10% replacement to limestone • Calorific values of plastic waste used to determine replacement of coal as fuel	

System Boundaries

The following section reflects the system boundaries that were considered for India and Indonesia.

Figure 1: *System Boundary for India*

Modelled System Boundary for India: Existing Waste Management (Default EOL fates)

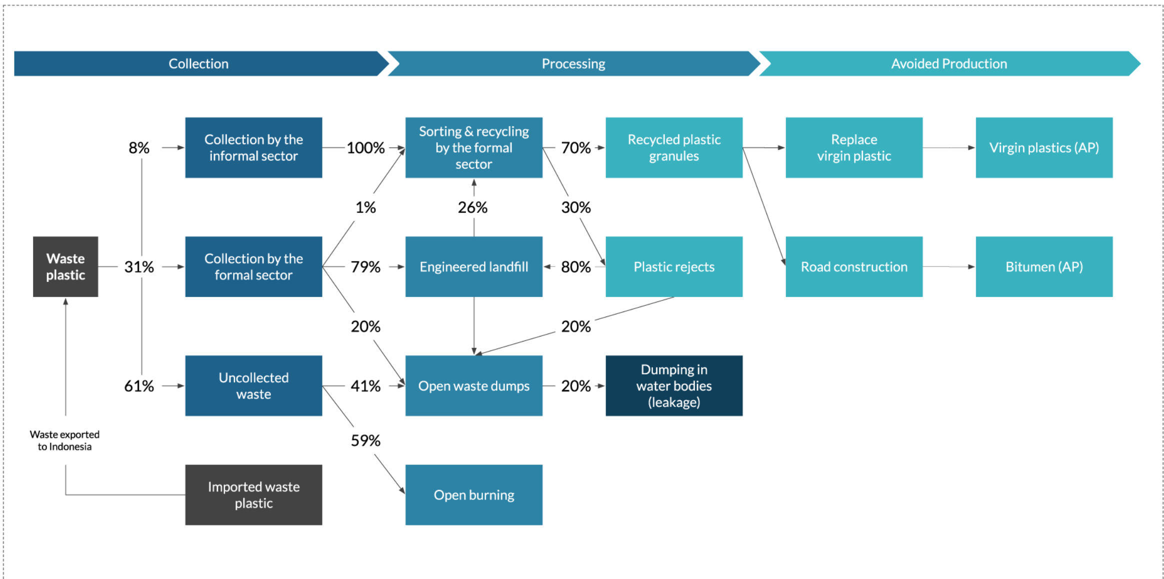


Modified diagram. Original from Singapore Institute of Manufacturing Technology

thecirculateinitiative.org/ghg-calculator

Figure 2: *System Boundary for Indonesia*

Modelled System Boundary for Indonesia: Existing Waste Management (Default EOL fates)



Modified diagram. Original from Singapore Institute of Manufacturing Technology

thecirculateinitiative.org/ghg-calculator

Key Findings

The following section of this note summarises the key findings from the LCA analysis.

Finding 1: Environmental Impact of Plastic Waste Collection, Processing and Avoided Production

Without avoided production, the carbon footprint per kg of waste plastic collection and processing is approximately three times higher in Indonesia when compared to India. This is primarily due to the higher contribution from more prevalent open burning in Indonesia. Recycling has the potential to offset the environmental impact due to savings from the avoided production of resources. However, as Indonesia has only a 10% recycling rate, the weaker recycling efforts are only able to offset water and energy consumption, but insufficient to offset the carbon footprint.

Figure 3: *Carbon Footprint of Plastic Waste Collection, Processing and Avoided Production in India and Indonesia*

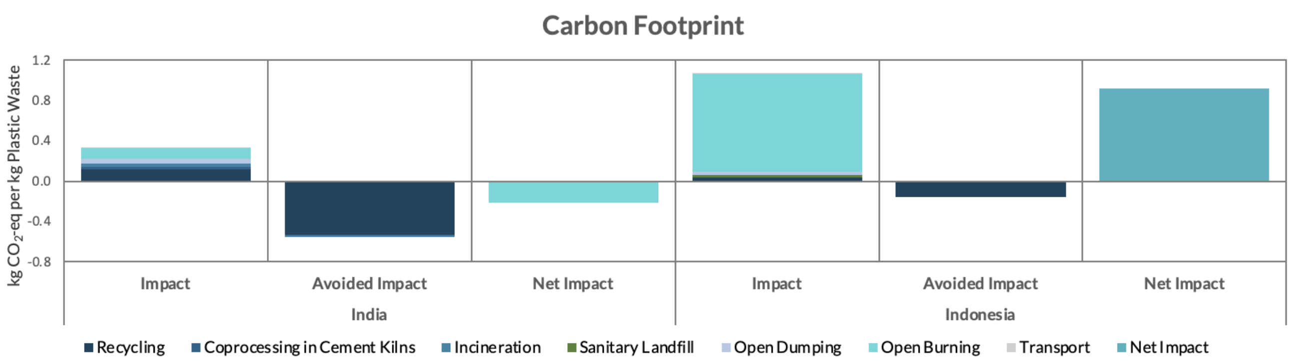


Figure 4: *Energy Consumption of Plastic Waste Collection, Processing and Avoided Production in India and Indonesia*

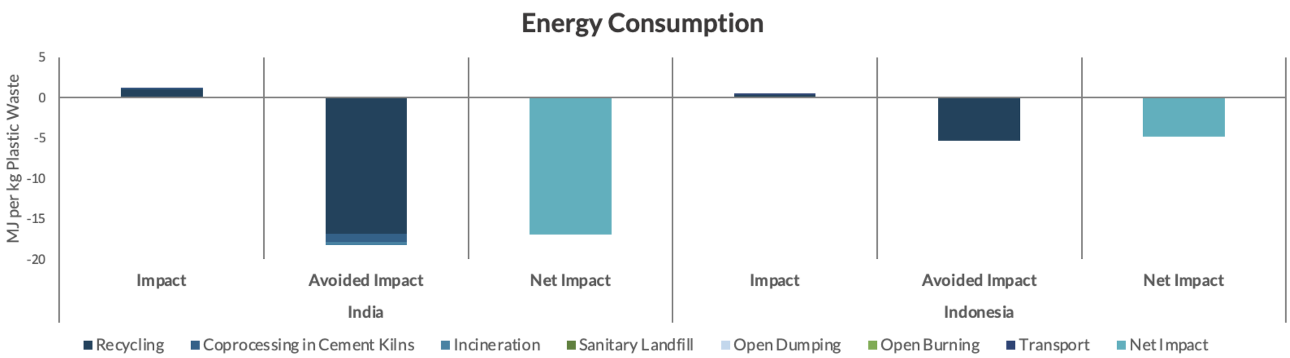
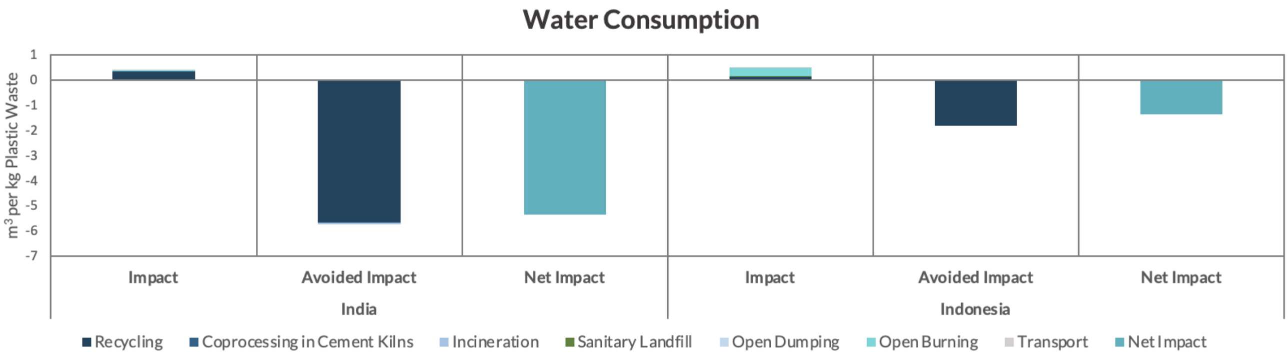


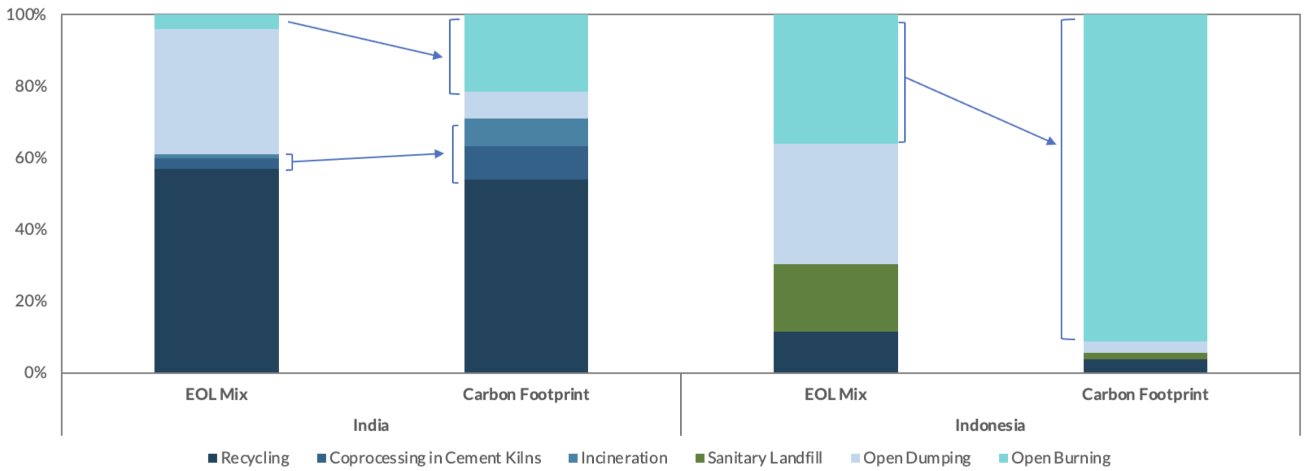
Figure 5: *Water Consumption of Plastic Waste Collection, Processing and Avoided Production in India and Indonesia*



Finding 2: Hotspot Analysis of Plastic Waste Collection and Processing

Open burning, incineration, and co-processing at cement kilns are carbon footprint hotspots for India, accounting for 8% of plastic waste EOL but contributing to 38% of total carbon footprint. In Indonesia, open burning is the sole carbon footprint hotspot, accounting for 36% of plastic waste EOL, but contributes to 91% of the total carbon footprint.

Figure 6: *Hotspot Analysis of Plastic Waste Collection and Processing in India and Indonesia*



Finding 3: Environmental Impact of Plastic Waste End-of-Life Fates

Recycling has the lowest environmental net impact as compared to other end-of-life fates. Open dumping and sanitary landfill have lower carbon footprints as compared to open burning, incineration, and co-processing in cement kilns since it does not involve any burning of plastic waste. However, there are trade-offs in other impacts, such as human toxicity and urban land occupation. Open burning has the highest carbon footprint on a per kilogram basis. Incineration has a very high carbon footprint, but it is partially offset by the avoided production of electricity.

Figure 7: *Environmental Impact of Plastic Waste End-of-Life Fates in India*

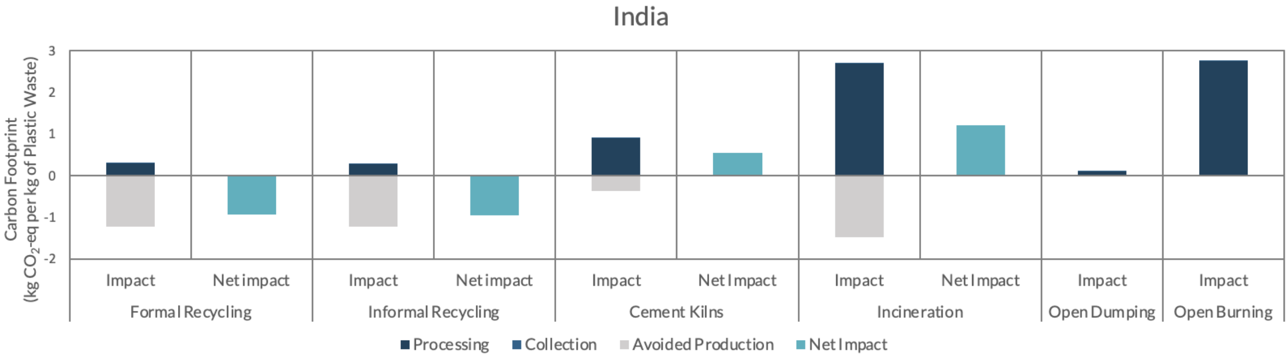
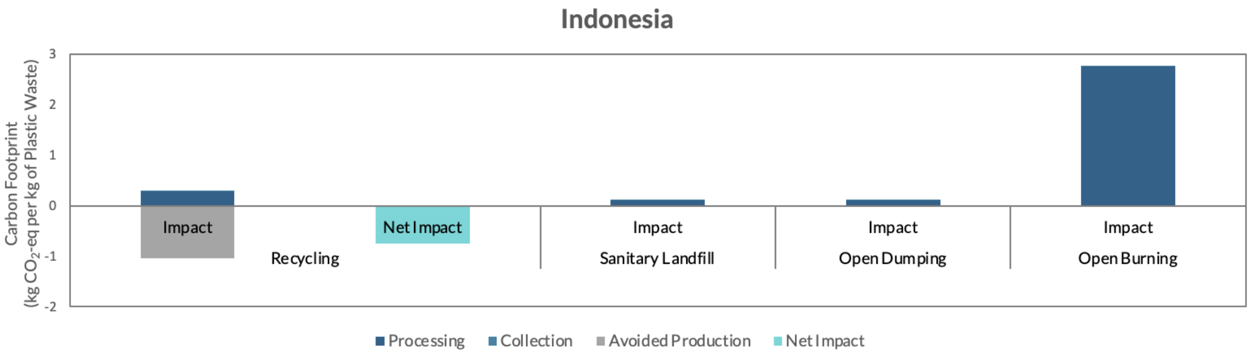


Figure 8: *Environmental Impact of Plastic Waste End-of-Life Fates in Indonesia*



Conclusion

In this study, the LCA of plastic waste end-of-life treatment in both India and Indonesia was studied. The results showed that the carbon footprint, energy consumption, and water consumption associated with plastic waste treatment in India is lower when compared to Indonesia. This can primarily be attributed to less mismanagement of plastic waste in India, with significantly higher recycling rates and lower open burning activities.

The results of this study can help to inform future investment decisions towards plastic waste management, encouraging further recycling to reduce the mismanagement of plastic waste in both India and Indonesia.

For a full list of sources consulted for the Life Cycle Assessment study, please click this link.