PLACES

Plastic Lifecycle Assessment Calculator for the Environment and Society

Lifecycle Assessment of Plastic Recycling Systems in India, Indonesia, Malaysia, the Philippines, Thailand, and Vietnam Supporting the Development of PLACES: Summary Report

The Circulate Initiative

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PLACES

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Background

The Circulate Initiative, in collaboration with the Singapore Institute of Manufacturing Technology (SIMTech), a research institute of the Agency for Science, Technology and Research (A*STAR), developed an open-access greenhouse gas (GHG) calculator, the Plastic Lifecycle Assessment Calculator for the Environment and Society (PLACES) to track the environmental impact of plastic waste management and recycling solutions in India and five countries in Southeast Asia.

This note is 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 LCA methodology based on the ISO 14040[1]/14044[2] guidelines. The study is contextualized to waste management practices, including end-of-life (EOL) fates for plastic waste in each country.

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[1] ISO - *ISO 14040 Environmental Management — Life Cycle Assessment — Requirements and Guidelines (2006).*

[2] ISO - *ISO 14044 Environmental Management — Life Cycle Assessment — Principles and Framework (2006).*

Methodology

The following section 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 Assessment, and 4) Interpretation.

1. Goal and Scope Definition

The goal of PLACES is to quantify the environmental impact of key plastic waste EOL treatment in India, Indonesia, Malaysia, the Philippines, Thailand, and Vietnam. The findings from the analysis can be used to provide recommendations to policymakers and investors to focus their efforts towards plastic waste management practices that reduce environmental impact.

The key plastic waste types covered in this study are High-Density Polyethylene (HDPE), Low-Density Polyethylene (LDPE), Polypropylene (PP), and Polyethylene Terephthalate (PET), which account for most of the plastic waste in each country. In addition, the "Generic" plastic waste category accounts for all mixed plastic materials based on status quo composition for the country. As a result, all plastic waste materials are considered in this study. The scope of this study includes downstream plastic waste 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 six countries were obtained from the best available official reports from governmental organizations and non-governmental organizations (NGOs), and consultations with various industry sources. Certain assumptions were also considered for the calculation and analysis (see the "Key Assumptions" section). The system boundaries constructed were peer reviewed by local country experts in plastics, waste management, and the circular economy. The environmental impact factors were sourced from the Ecoinvent V3.9 database.

3. Life Cycle Impact Assessment

This step involves the selection of relevant environmental impact categories. The calculator includes three different environmental impact categories: carbon footprint, energy consumption, and water consumption. The environmental impact factors for carbon footprint are based on the Intergovernmental Panel on Climate Change (IPCC) 2021 model (climate change, GWP100), those for energy consumption are based on the Cumulative Energy Demand model, while those for water consumption are based on the midpoint impact category from ReCiPe 2016 V1.03 (water use).

These three 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 included in the study.

4. 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). ALCA studies the portion of environmental impact that should be attributed to the technology and is aligned with the GHG Protocol. CLCA, on the other hand, allows the users 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.

Key Assumptions

To fill any gaps in the data collected, various assumptions were considered, which are detailed in the table below. Where data sources were available to support the data collected, they are not listed.

	Plastic Waste End-of-Life	Transport Distance
India	• The proportion of plastic waste recycled by informal and formal sectors for each polymer type is assumed to be 99% informal, 1% formal. • All landfills and dumpsites are assumed to be open dumps due to the lack of landfills operating under sanitary conditions in India.[3] • 10% of plastic waste in open dumps are openly burnt.[4]	• Local transport distance[5]: ○ 5 km between collection and informal sorting ○ 15 km between collection and formal sorting ○ 50 km between sorting facility and recycling plant ○ 15 km between collection and open dumps ○ 30 km between collection and waste-to-energy (WTE) plants • For uncollected waste, it is assumed that no transport is involved. • India is assumed to have no imported plastic waste as import of plastic waste has been banned since August 2019.
Indonesia	• The recycling rate for each plastic type is estimated from the breakdown of plastic types received by plastics aggregators. • The EOL fates for recycling rejects are weighted to the three other EOL fates (Sanitary Landfill, Open Dumps, and Open Burning).	• Local transport distance[6]: ○ 20 km between collection and all facilities • For uncollected waste, it is assumed that no transport is involved. • While import volumes are negligible in comparison to the domestic plastic waste generated, the transport distance (8,325km)[7] between the top plastic waste import partner, the Marshall Islands (55% of imports)[8], and Indonesia is taken as the distance traveled by plastic waste imports. Plastic waste is assumed to be shipped from the largest port in each country (based on the cargo volume handled) in the year of reference - Majuro in Marshall Islands and Tanjung Priok in Indonesia respectively.[9] Sea transport is assumed.

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[3] Kapur-Bakshi, S., Kaur, M., and Gautam, S. - *Circular Economy for Plastics in India: A Roadmap* (2021).
[4] Kumari, K., et al. - *Emission from open burning of municipal solid waste in India* (2019).
[5] Neo E. R. K., et al. - *Life cycle assessment of plastic waste end-of-life for India and Indonesia* (2021).
[6] Ibid.
[7] Ports.com *(n.d.)*.
[8] UN Comtrade Database (2020).
[9] World Shipping Council - *The Top 50 Container Ports* (n.d.).

<table>
<tr><th></th><th>Plastic Waste End-of-Life</th><th>Transport Distance</th></tr>
<tr><td>Malaysia</td><td>Each polymer's EOL fates are assumed to follow the same proportions as the EOL fates for all plastics in Malaysia, except the polymer-specific recycling rate.[10]
The recycling rate for "Other plastics" is assumed to be the average of the "Other plastics" recycling rates of Thailand, the Philippines, and Vietnam.
The EOL fates for recycling rejects are weighted to the four other EOL fates (Sanitary Landfill, Incineration, Open Dumps, and Open Burning) for Malaysia.</td><td>Local transport distances are assumed to be the same transport distances for the respective EOL fates in Vietnam, due to a similar proportion of collected waste streams of incineration and sanitary landfills:
60 km between collection and recycling plant
50 km between collection and sanitary or unsanitary landfills
60 km between collection and incineration plant
The transport distance (18,359 km)[11] between the top three plastic waste import partners (similar in proportion), the USA, Japan, and Germany, and Malaysia is taken as the average distance traveled by plastic waste imports to Malaysia. Plastic waste is assumed to be shipped from the largest port in each country (based on the cargo volume handled) in the year of reference - Los Angeles (USA), Tokyo (Japan), and Hamburg (Germany) to Klang (Malaysia).[12] Sea transport is assumed.
For uncollected waste, it is assumed that no transport is involved.</td></tr>
<tr><td>Philippines</td><td>The plastic waste EOL fates and proportion for each EOL fate were assumed to follow that of packaging waste.[13]</td><td>Transport distance to recycling and co-processing at cement kilns in the Philippines is assumed to be the same as transport distance for recycling in Vietnam (60 km), due to similar collection rates and urban-to-rural disparity in collection rates.
Transport for recycling is assumed to be entirely by land. Based on consultations with local experts, most recycling plants in the Philippines are situated on the main island of Luzon.
The transport distance (33,673 km)[14] between the top plastic waste import partner – the USA (40% of imports)[15] – and the Philippines is taken as the average distance traveled by plastic waste imports. Plastic waste is assumed to be shipped from the largest port in each country (based on the cargo volume handled) in the year of reference - Los Angeles and Manila ports respectively.[16] Sea transport is assumed.
For uncollected waste, it is assumed that no transport is involved.</td></tr>
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[10] World Bank - *Market Study for Malaysia: Plastics Circularity Opportunities and Barriers* (2021).
[11] Ports.com *(n.d.)*.
[12] World Shipping Council - The Top 50 Container Ports (n.d.).
[13] WWF Philippines - *EPR Scheme Assessment for Plastic Packaging Waste in the Philippines* (2020).
[14] Ports.com *(n.d.)*.
[15] UN Comtrade Database (2020).
[16] World Shipping Council - *The Top 50 Container Ports* (n.d.).

	Plastic Waste End-of-Life	Transport Distance
Thailand	• The formal and informal collection rates of total recycled plastic waste are assumed to be the same as those of packaging plastic waste (85.9% of plastic waste collected is through the formal sector, 14.1% through the informal sector).[17] All informally collected plastic waste is assumed to be for recycling. • The EOL fates for recycling rejects are weighted to the four other EOL fates (Sanitary Landfill, Incineration with Waste-to-Energy, Open Dumps, Open Burning) for Thailand.	• The transport distance (7,319 km)[18] between the top plastic waste import partner, Japan, and Thailand is taken as the average distance traveled by plastic waste imports. Plastic waste is assumed to be shipped from the largest port in each country (based on the cargo volume handled) in the year of reference - Tokyo and Bangkok ports respectively.[19] Sea transport is assumed. • For uncollected waste, it is assumed that no transport is involved.
Vietnam	• The proportion of plastic waste recycled by informal and formal sectors for each polymer type is assumed to follow the national figures of 2018 (33% is collected through the formal sector, 67% through informal collection).[20] All informally collected plastic waste is assumed to be for recycling. • The incineration rate of formally collected plastic waste is assumed to be the same as the incineration rate for municipal solid waste (13% of collected plastic waste).[21] • The national average of the proportion of all landfills being sanitary or unsanitary (open dumps) is assumed to be the same as urban areas (31% of landfills in Vietnam are sanitary, 69% unsanitary).[22] • The open dump rate of formally collected plastic waste excludes an unknown quantity of waste disposed of at unverified dumpsites, which is included under "Uncollected", as defined by the data source.[23] • The EOL fate for recycling rejects is weighted to the four other EOL fates (Sanitary Landfill, Incineration, Open Dumps, Open Burning) for Vietnam.	• The transport distances from collection to landfills, recycling, and incineration for Vietnam are assumed to be the same as Hanoi.[24] These are: ○ 60 km between collection and recycling plant ○ 50 km between collection and sanitary or unsanitary landfills ○ 60 km between collection and incineration plant • The transport distance (5,712 km)[25] between the top plastic waste import partner, Japan, and Vietnam is taken as the average distance traveled by plastic waste imports. Plastic waste is assumed to be shipped from the largest port in each country (based on the cargo volume handled) in the year of reference – Tokyo and Ho Chi Minh ports respectively.[26] Sea transport is assumed. • For uncollected waste, it is assumed that no transport is involved.

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[17] WWF Thailand - *Scaling Up Circular Strategies to Achieve Zero Plastic Waste in Thailand* (2020).
[18] Ports.com *(n.d.)*.
[19] World Shipping Council - *The Top 50 Container Ports* (n.d.).
[20] IUCN, EA and QUANTIS - *National guidance for plastic pollution hotspotting and shaping action. Final report for Vietnam (2020).*
[21] Salhofer, S., et al. - *Plastic Recycling Practices in Vietnam and Related Hazards for Health and the Environment (2021).*
[22] Phuong N. H. - *The legal, policy and institutional frameworks governing marine plastics in Viet Nam (2020).*
[23] IUCN, EA and QUANTIS - *National guidance for plastic pollution hotspotting and shaping action. Final report for Vietnam (2020).*
[24] Thanh, H., Yabar, H., Higano Y., and Mizunoya, T. - *Potential of Greenhouse Gas Emissions Reduction Associated with Municipal Solid Waste Management in Hanoi City, Vietnam (2015).*
[25] Ports.com *(n.d.)*.
[26] World Shipping Council - *The Top 50 Container Ports (n.d.).*

For avoided production, in all countries where applicable:

- Recycled plastic is assumed to have a 50% replacement ratio to virgin plastics.
- Recycled plastic is assumed to have a 100% replacement ratio to bitumen, when used in road construction.
- For the use of plastic waste to replace coal as fuel in cement kilns, the calorific values of each plastic waste type were used to determine the replacement ratio of coal.[27, 28]

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[27] Zhang, H., Themelis, N. J., and Bourtsalas, A. - *Environmental impact assessment of emissions from non-recycled plastic-to-energy processes (2021).*
[28] Wasilewski, R., and Siudyga, T. - *Energy recovery from waste plastics (2013).*

System Boundaries

The following section reflects the system boundaries that were considered for each country.

Figure 1: System Boundary for India

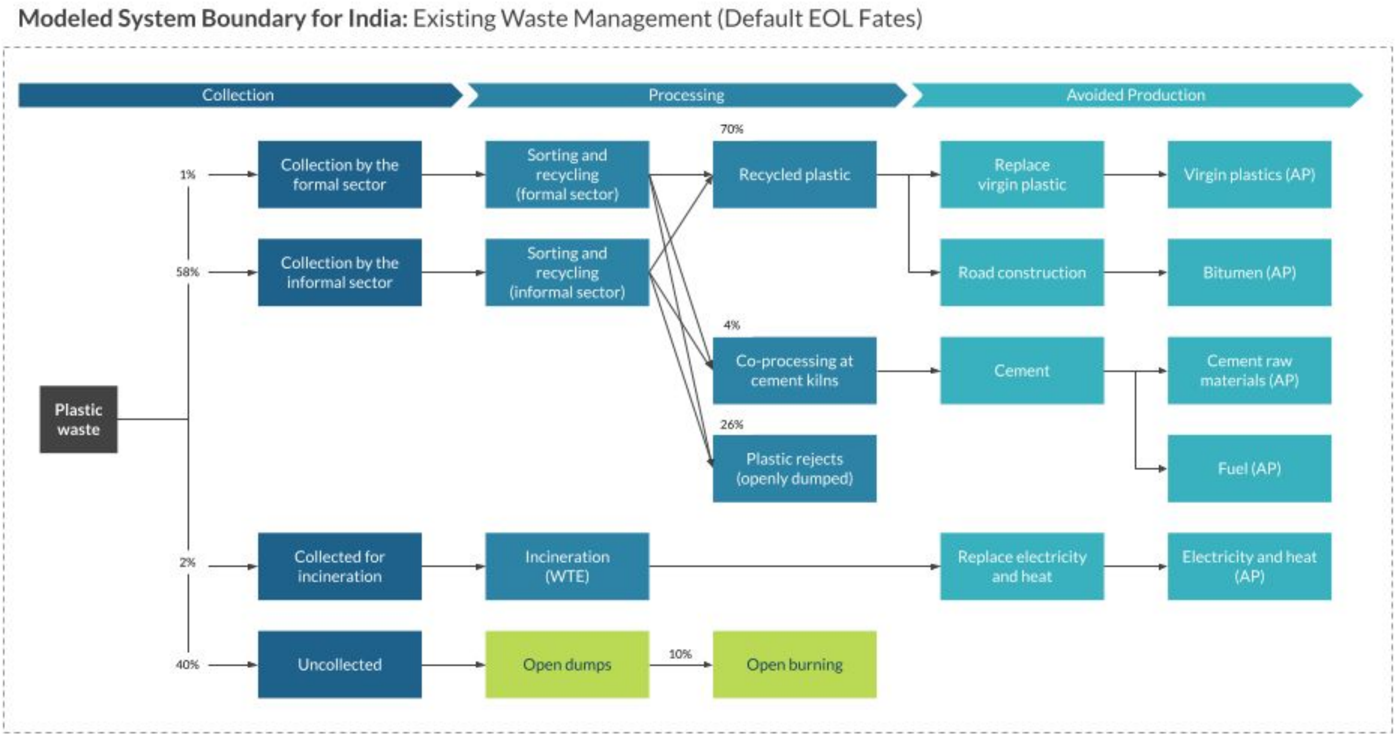


Figure 2: System Boundary for Indonesia

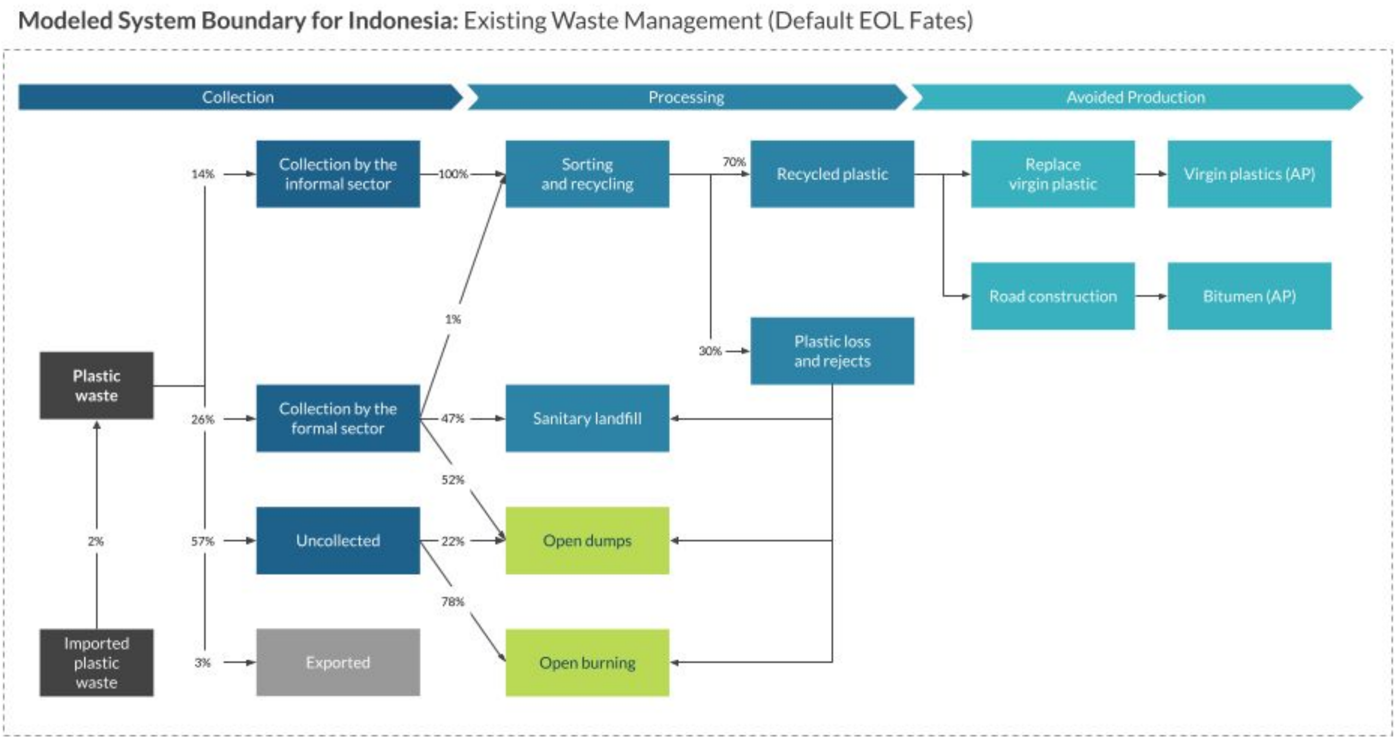


Figure 3: System Boundary for Malaysia

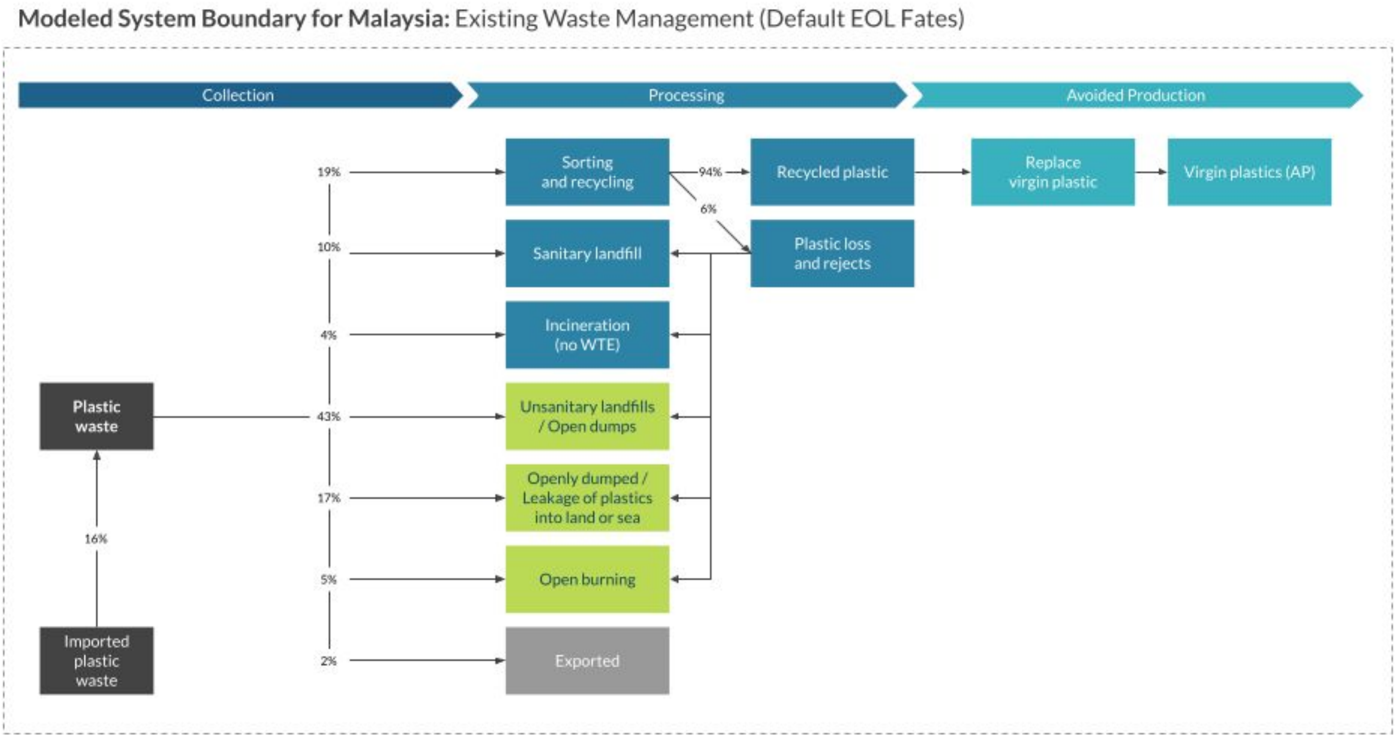


Figure 4: System Boundary for the Philippines

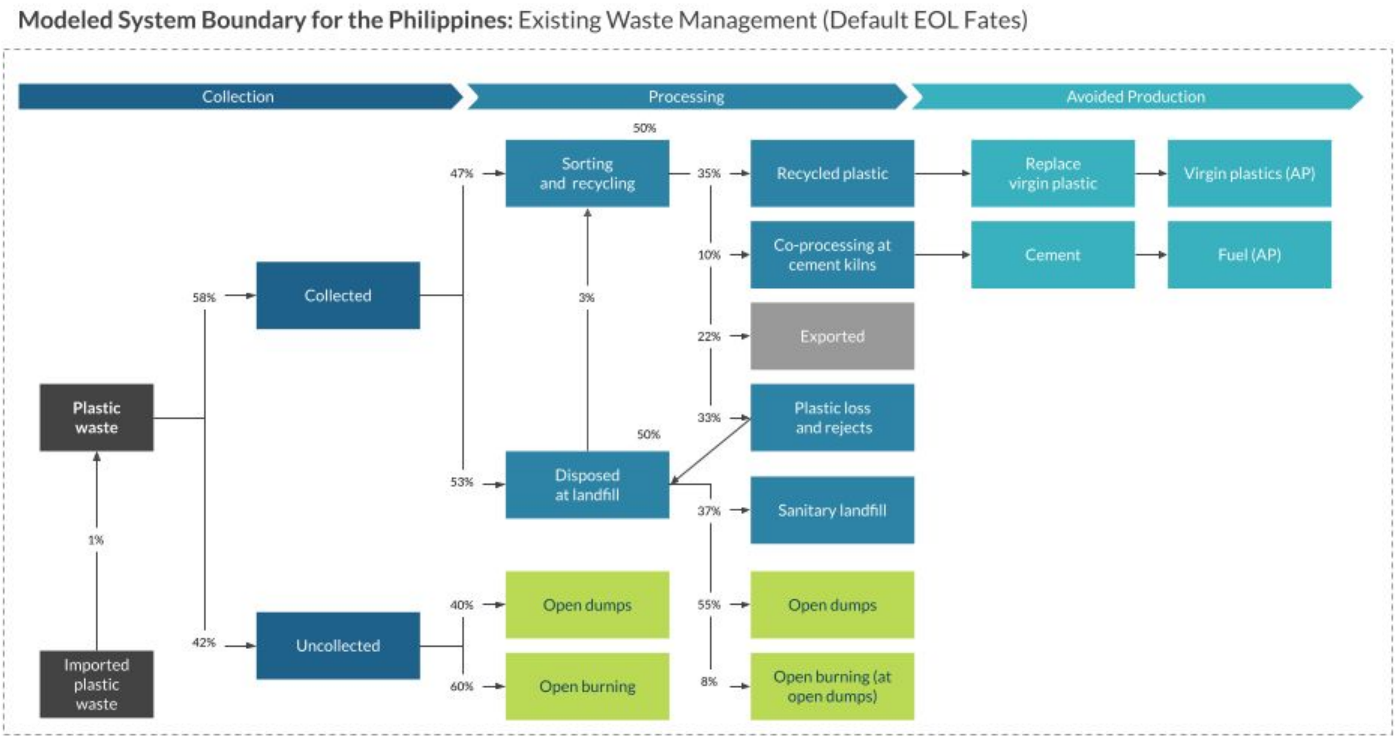


Figure 5: System Boundary for Thailand

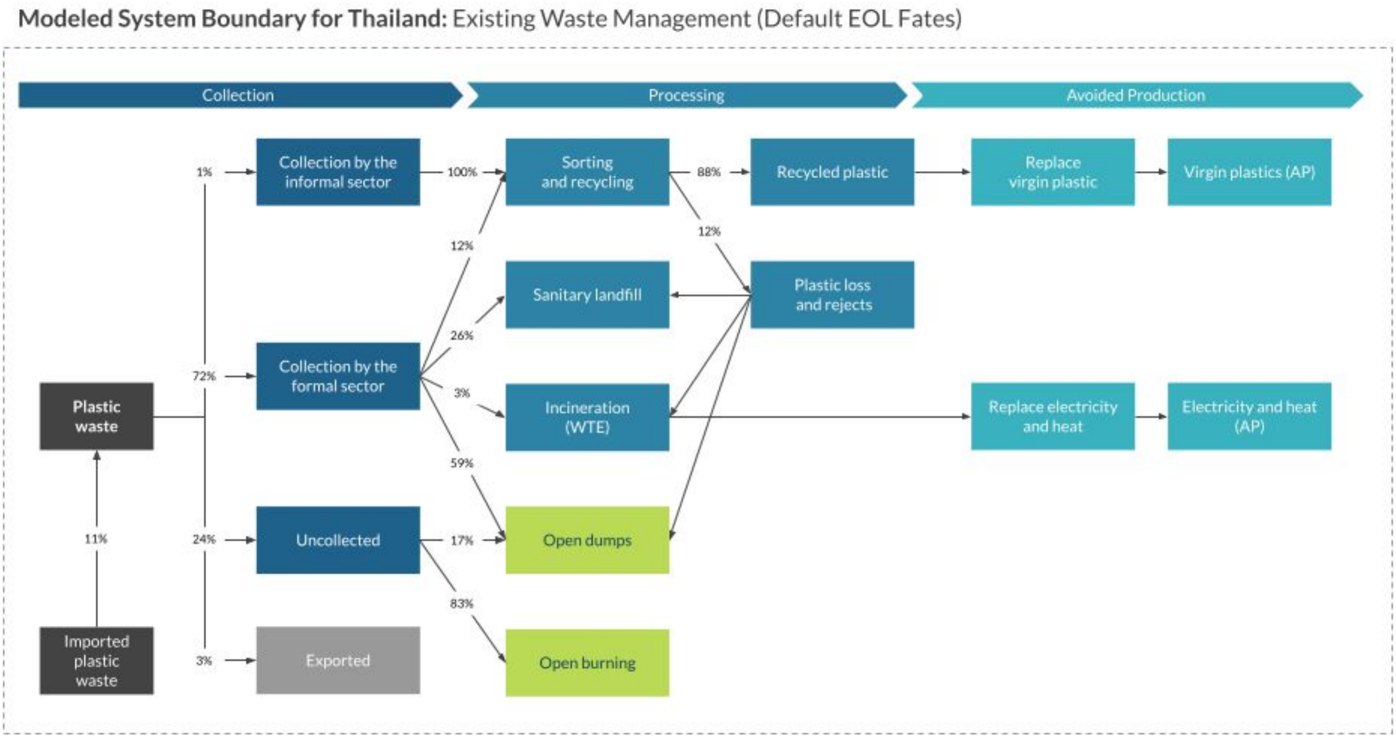
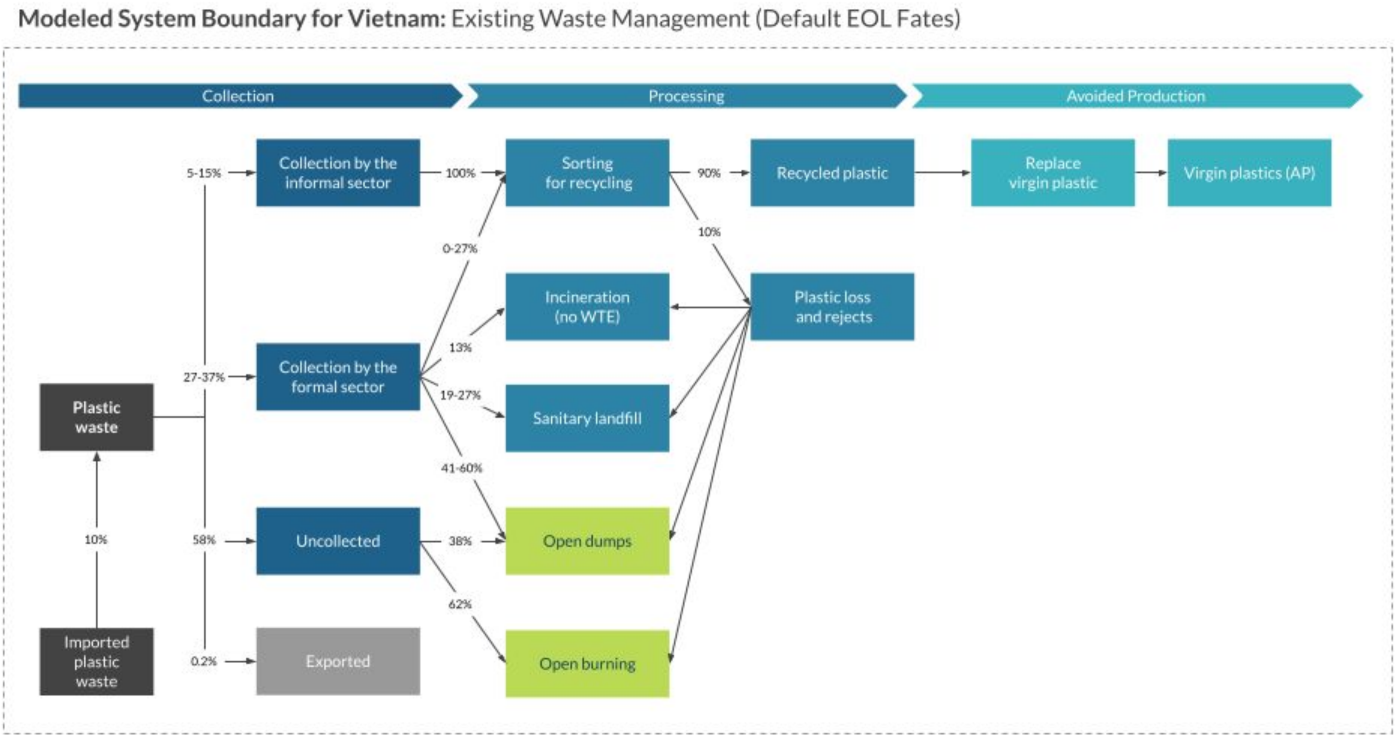


Figure 6: System Boundary for Vietnam



After reviewing the system boundary with local experts in Vietnam, the general sentiment was that the 5% informal collection rate obtained from data sources currently available does not accurately reflect the local realities for the whole of Vietnam. Where the collection of all recyclables is carried out by the informal sector (as identified through expert consultations), the informal collection rate goes up to 15%.

Due to the uncertainty around the informal collection rate and its knock-on effect on other numbers in the system boundary, each affected number is represented using a range in the case of Vietnam. However, a sensitivity analysis on the extremes of these ranges revealed that the effect on the results of the LCA analysis is not significant. Hence, the LCA calculations in the study utilize the original informal collection rate of 5% in the LCA model.

It must be noted that the LCA study is limited by the current data that is available on the material flows. The system boundary and LCA results can be updated at a later date when more reliable data on the material flows are available.

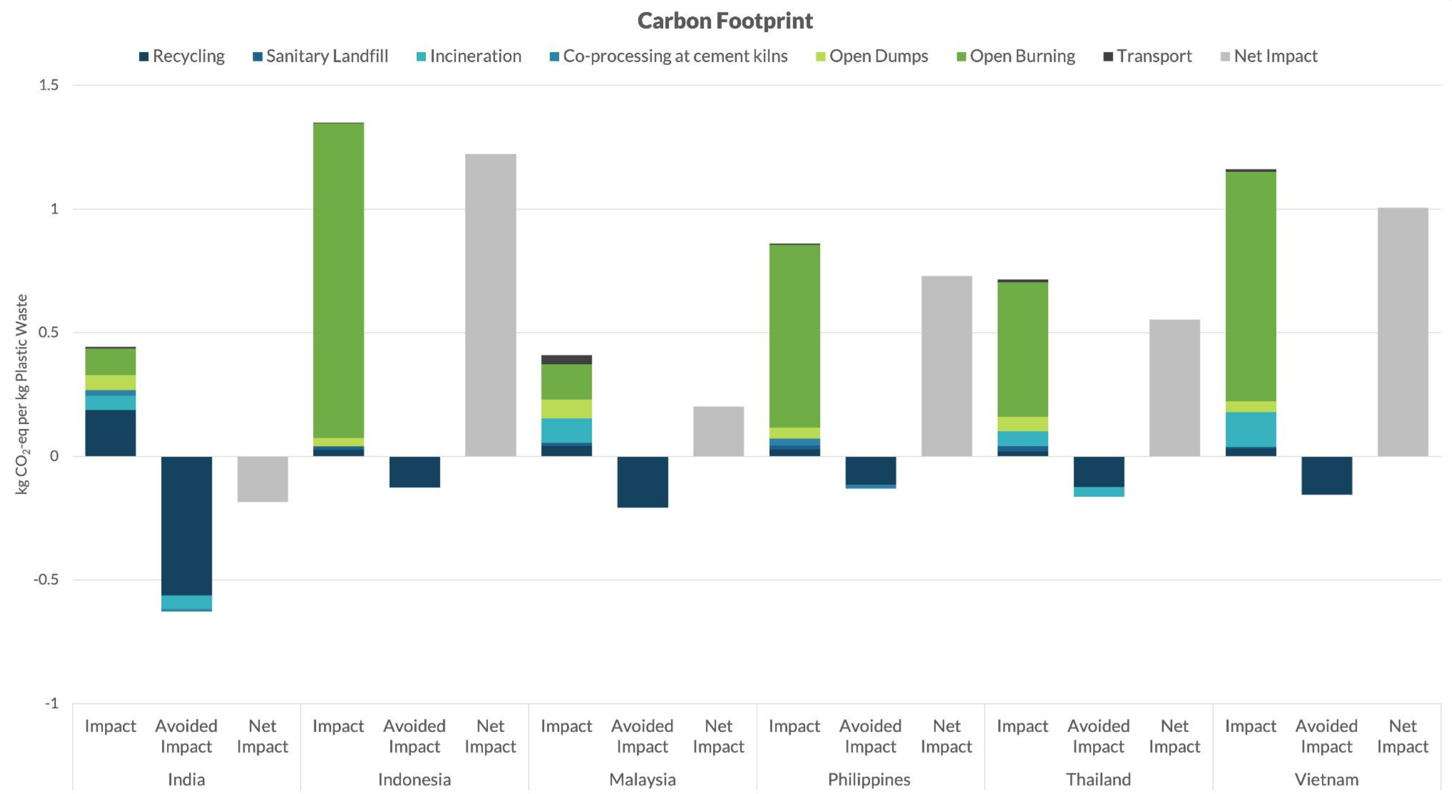
Key Findings

Finding 1: Environmental Impact of Plastic Waste Across the Six Countries

Indonesia has the highest carbon footprint per kg of plastic waste treated due to a high open burning rate (48%).[29, 30] This is followed by Vietnam, the Philippines, Thailand, Malaysia, and India. When avoided impacts are considered, all the impact indicators for the six countries decreased.

Recycling has the potential to offset the environmental impacts (i.e., carbon footprint, energy consumption, and water consumption) due to savings from the avoided production of virgin plastics. India has a negative net impact, primarily due to the highest rate of plastics recycling (41%) among the six countries and the resulting avoided production of virgin plastics.

Figure 7: Carbon Footprint of Plastic Waste Collection, Processing, and Avoided Production in India, Indonesia, Malaysia, the Philippines, Thailand, and Vietnam



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[29] World Economic Forum - *Radically Reducing Plastic Pollution in Indonesia: A Multistakeholder Action Plan (2020).*
[30] World Bank - *Plastic Waste Discharges from Rivers and Coastlines in Indonesia (2021).*

Figure 8: Energy Consumption of Plastic Waste Collection, Processing, and Avoided Production in India, Indonesia, Malaysia, the Philippines, Thailand, and Vietnam

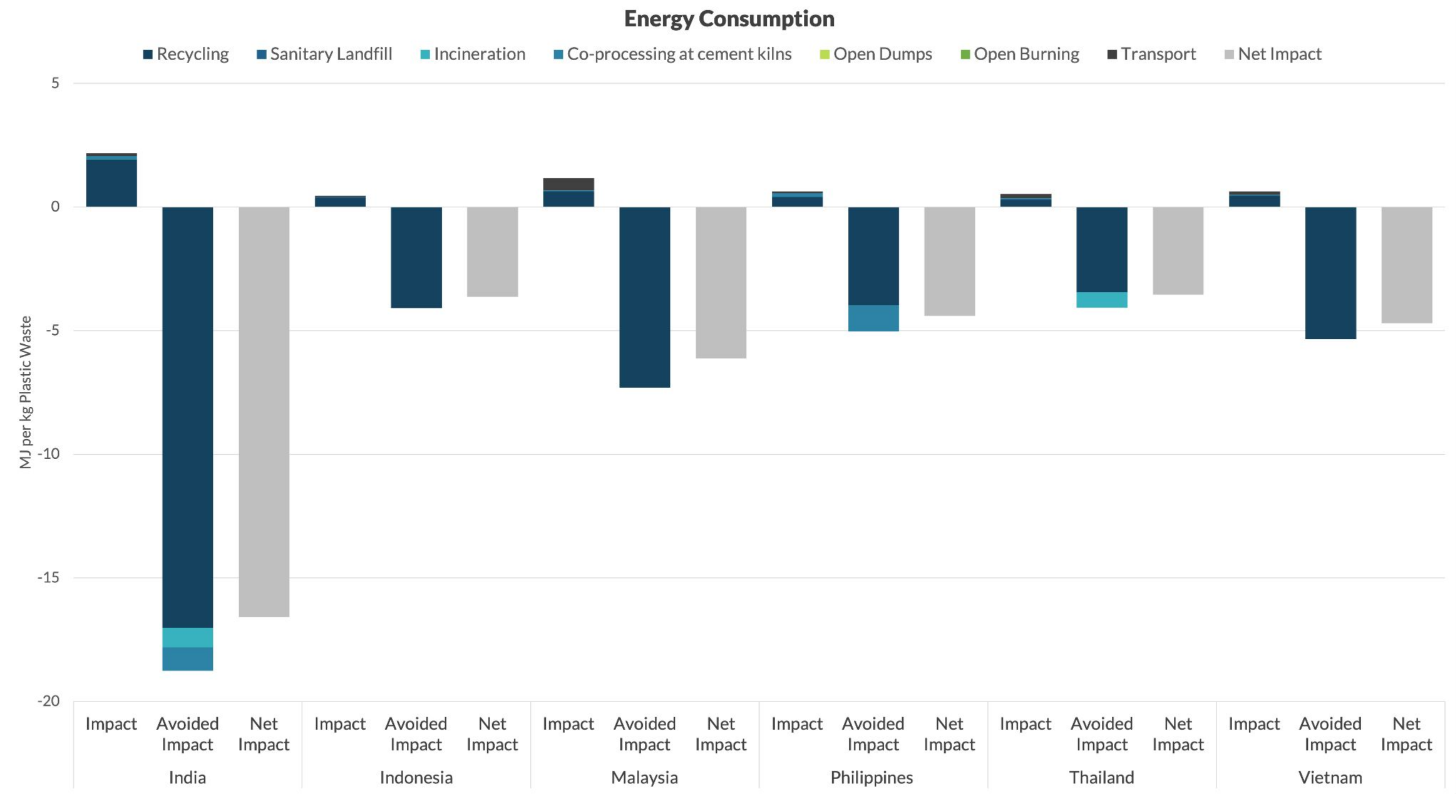
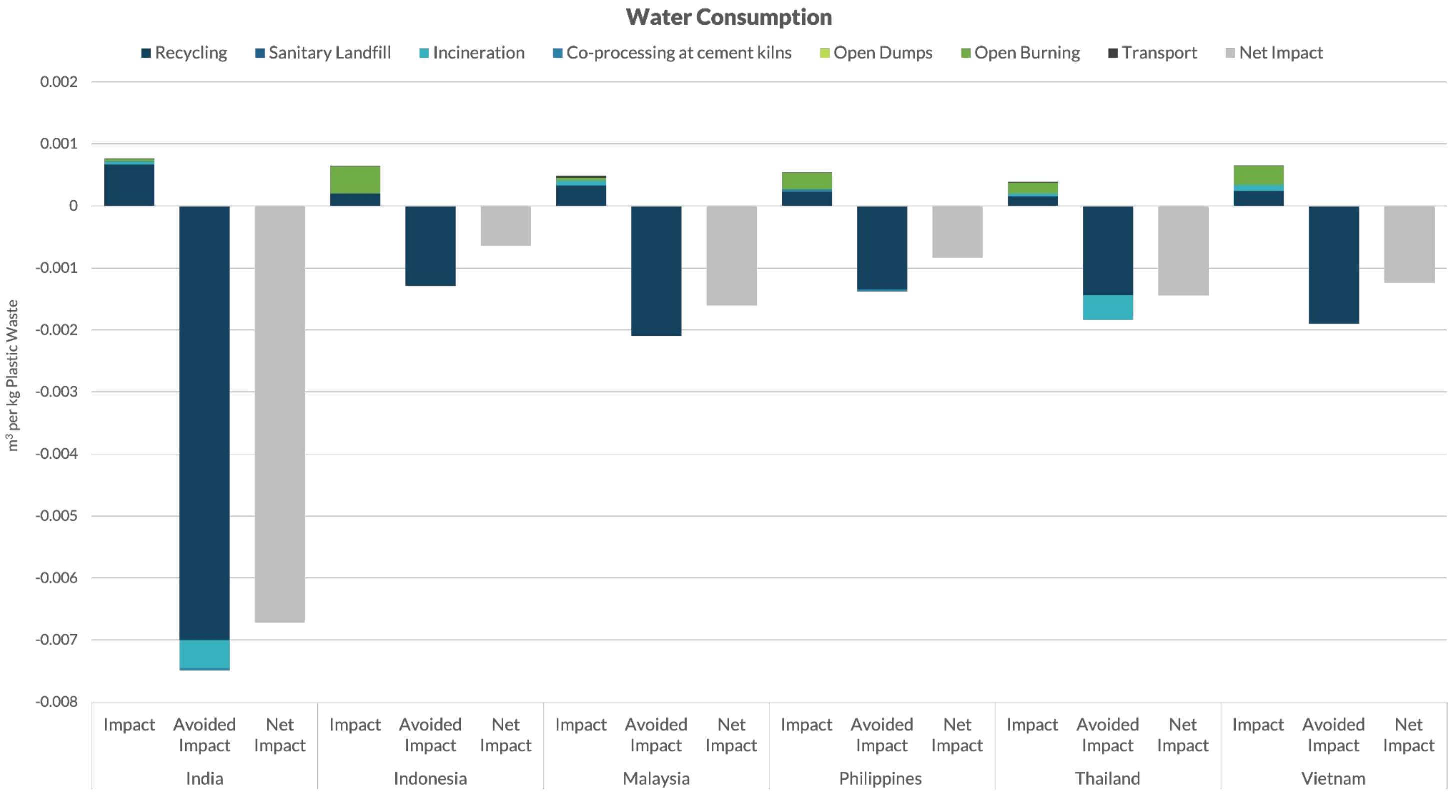


Figure 9: Water Consumption of Plastic Waste Collection, Processing, and Avoided Production in India, Indonesia, Malaysia, the Philippines, Thailand, and Vietnam

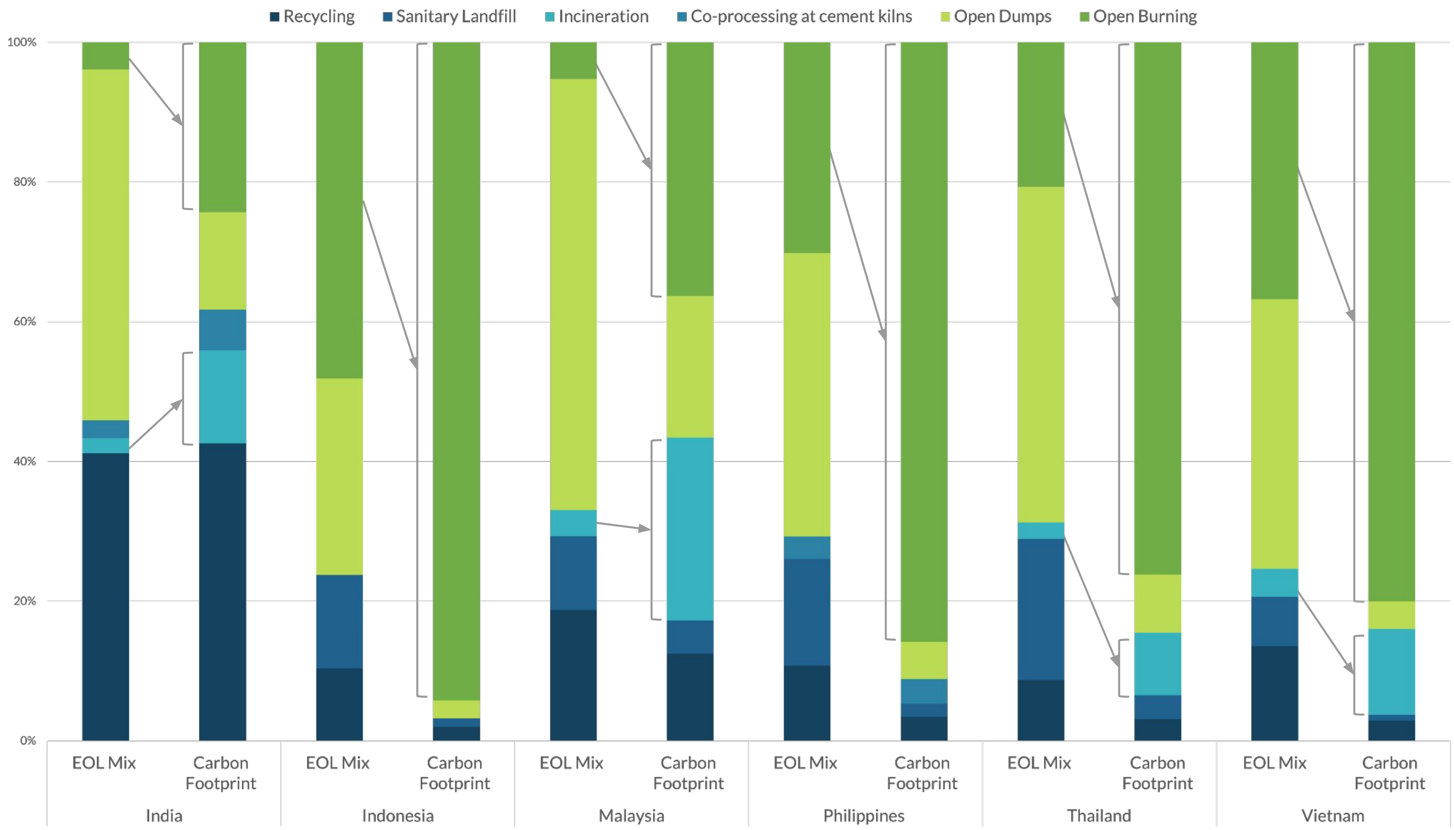


Finding 2: Hotspot Analysis of Plastic Waste Collection and Processing

Open burning and incineration of plastic waste are carbon footprint hotspots in India, Malaysia, Thailand, and Vietnam. They account for 4% (India), 9% (Malaysia), 23% (Thailand), and 41% (Vietnam) of plastic waste EOL share but contribute 38% (India), 62% (Malaysia), 85% (Thailand), and 92% (Vietnam) of total carbon footprint, respectively.

In Indonesia and the Philippines, open burning is the sole carbon footprint hotspot. Open burning accounts for 48% (Indonesia) and 30% (the Philippines) of plastic waste EOL and contributes 94% (Indonesia) and 86% (the Philippines) of total carbon footprint, respectively.

Figure 10: Hotspot Analysis of Plastic Waste Collection and Processing in India, Indonesia, Malaysia, the Philippines, Thailand, and Vietnam



Finding 3: Carbon Footprint of Plastic Waste End-of-Life Fates

Recycling has the lowest net impact of the carbon footprint per kg of plastic waste among the various EOL fates. Open burning, incineration, and co-processing at cement kilns have the highest carbon footprint ("Impact") as they involve the burning of plastic waste. In India and Thailand, the incineration of plastic waste generates electricity and heat, which replaces the electricity and heat generated from the burning of fossil fuels, hence resulting in a lower net impact. Similarly, in the Philippines, the avoided production of coal partially offsets the impact of co-processing of plastic waste at cement kilns.

Figure 11: Carbon Footprint of Plastic Waste End-of-Life Fates in India

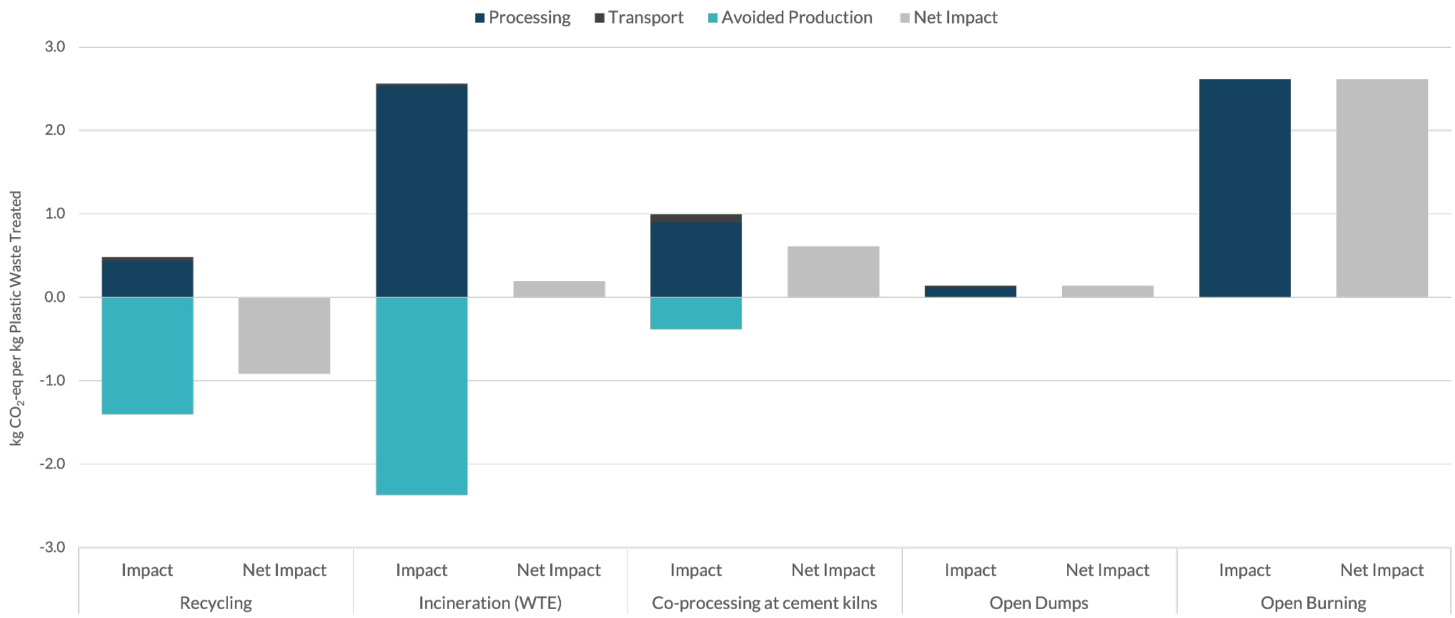


Figure 12: Carbon Footprint of Plastic Waste End-of-Life Fates in Indonesia

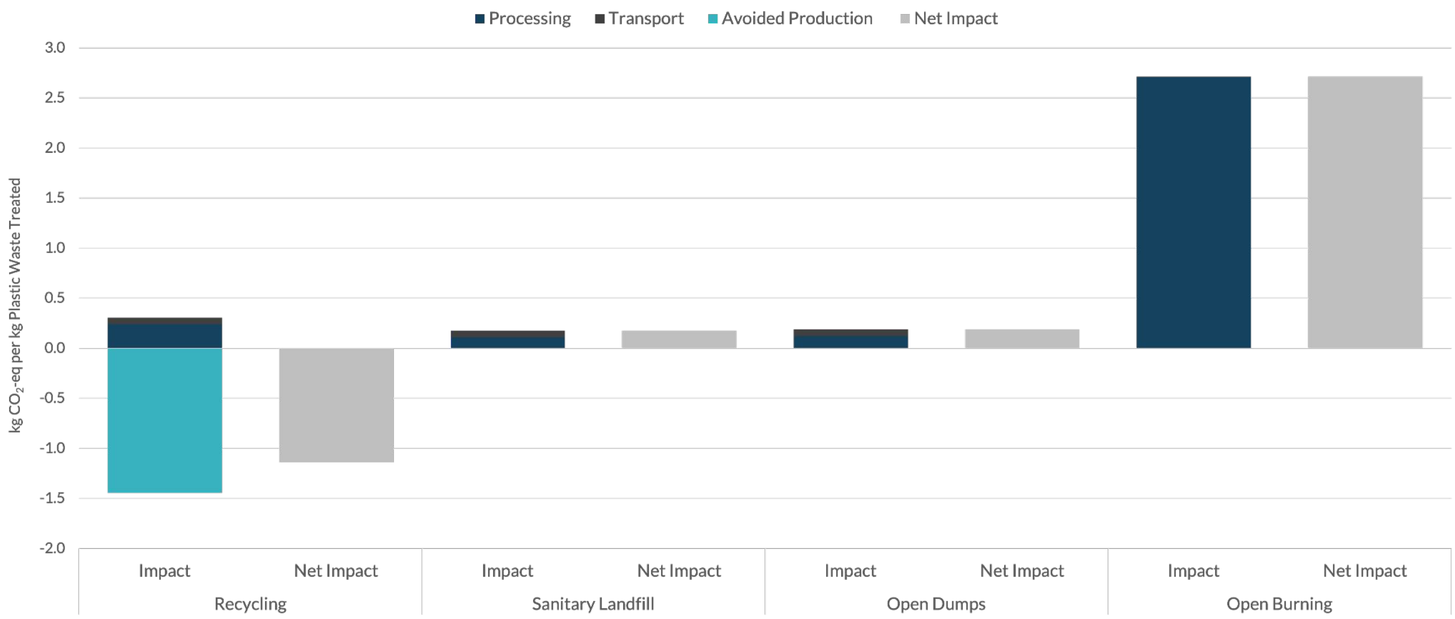


Figure 13: Carbon Footprint of Plastic Waste End-of-Life Fates in Malaysia

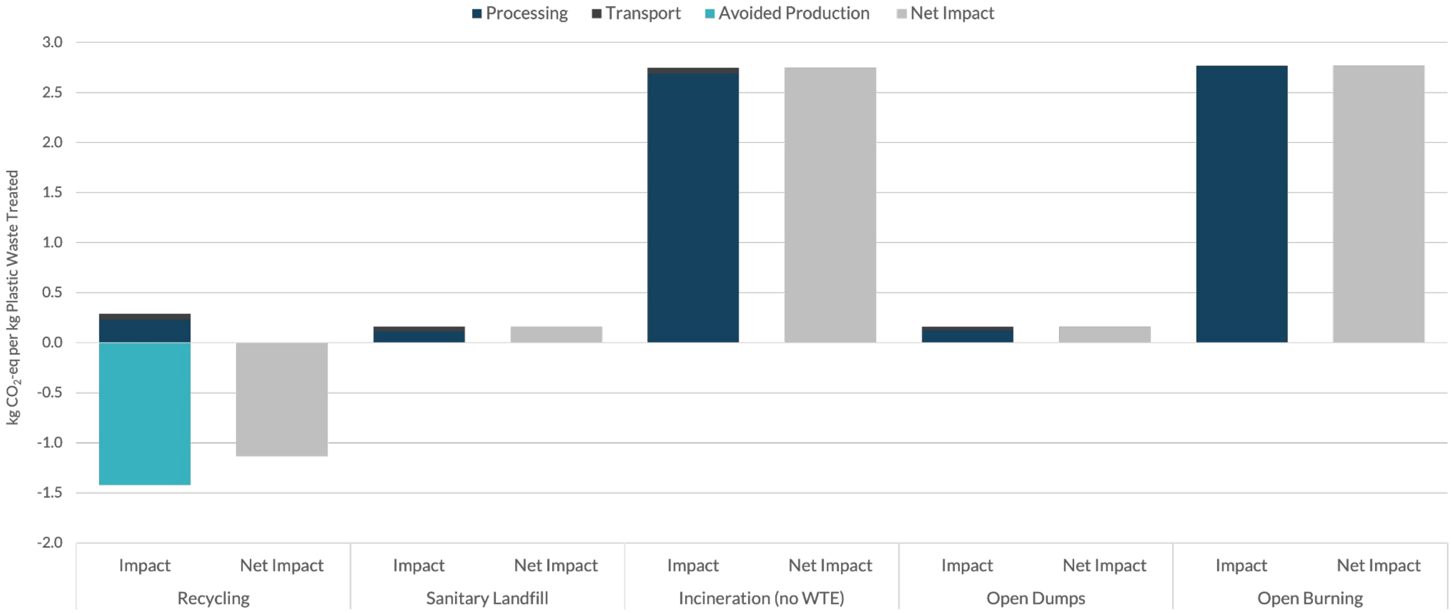


Figure 14: Carbon Footprint of Plastic Waste End-of-Life Fates in the Philippines

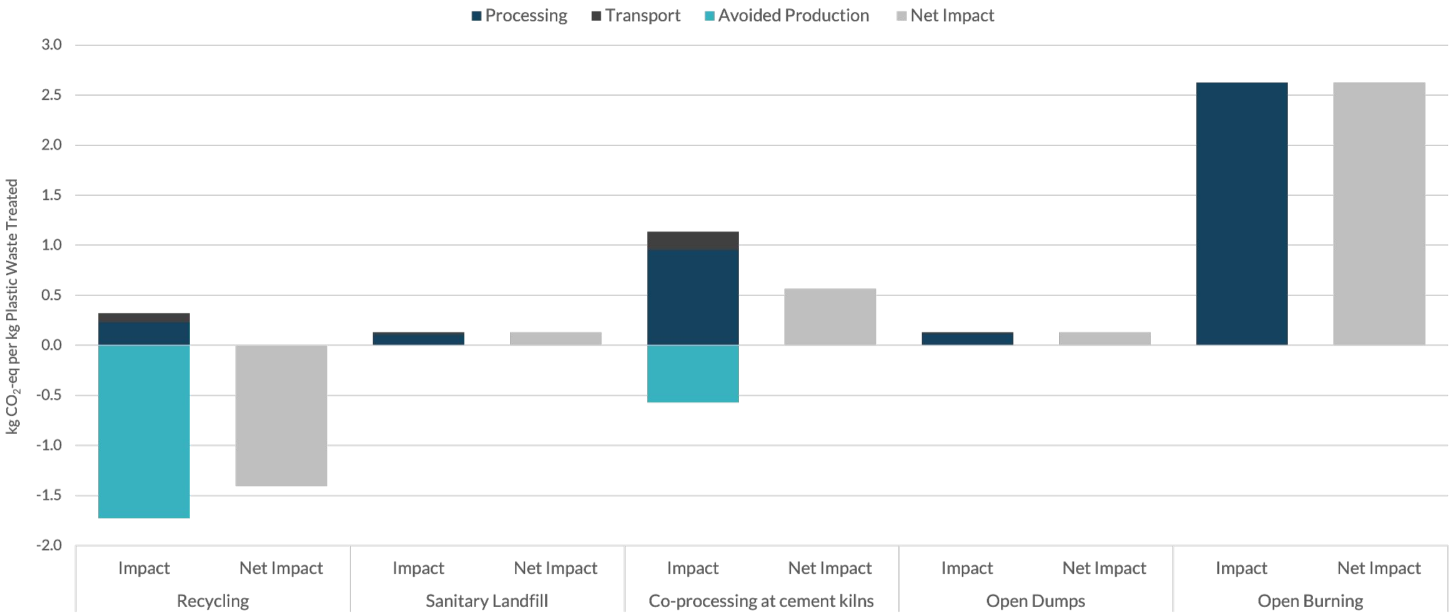


Figure 15: Carbon Footprint of Plastic Waste End-of-Life Fates in Thailand

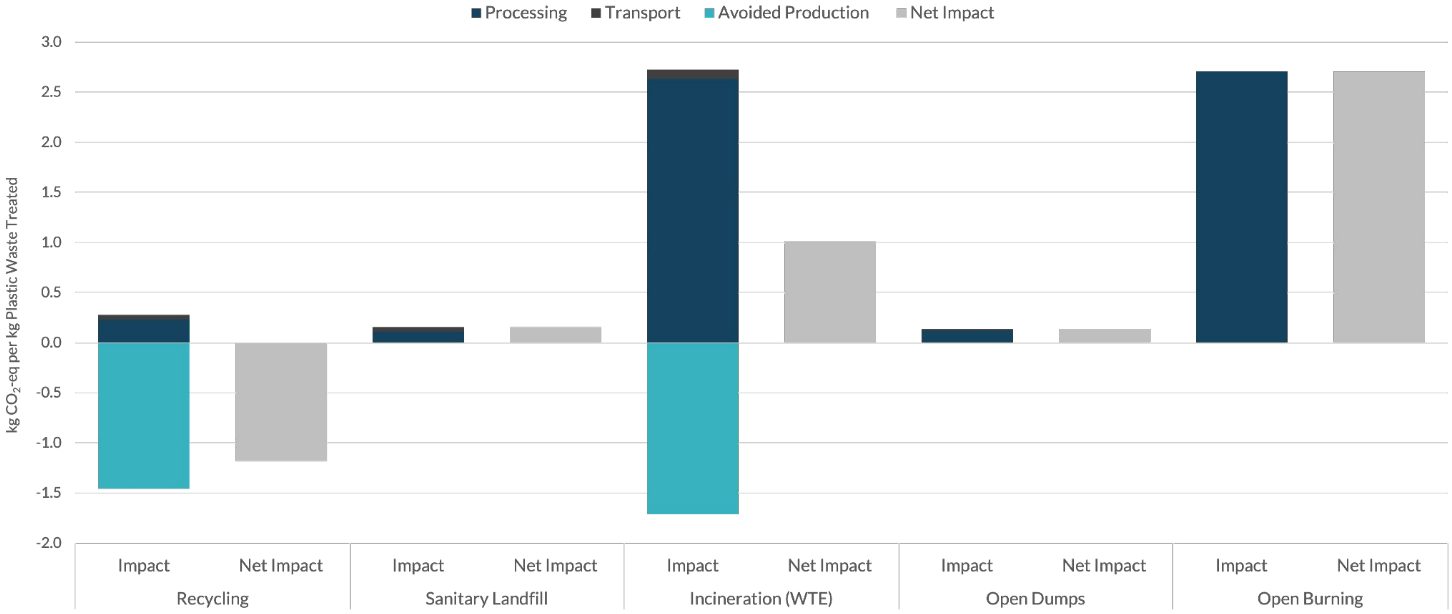
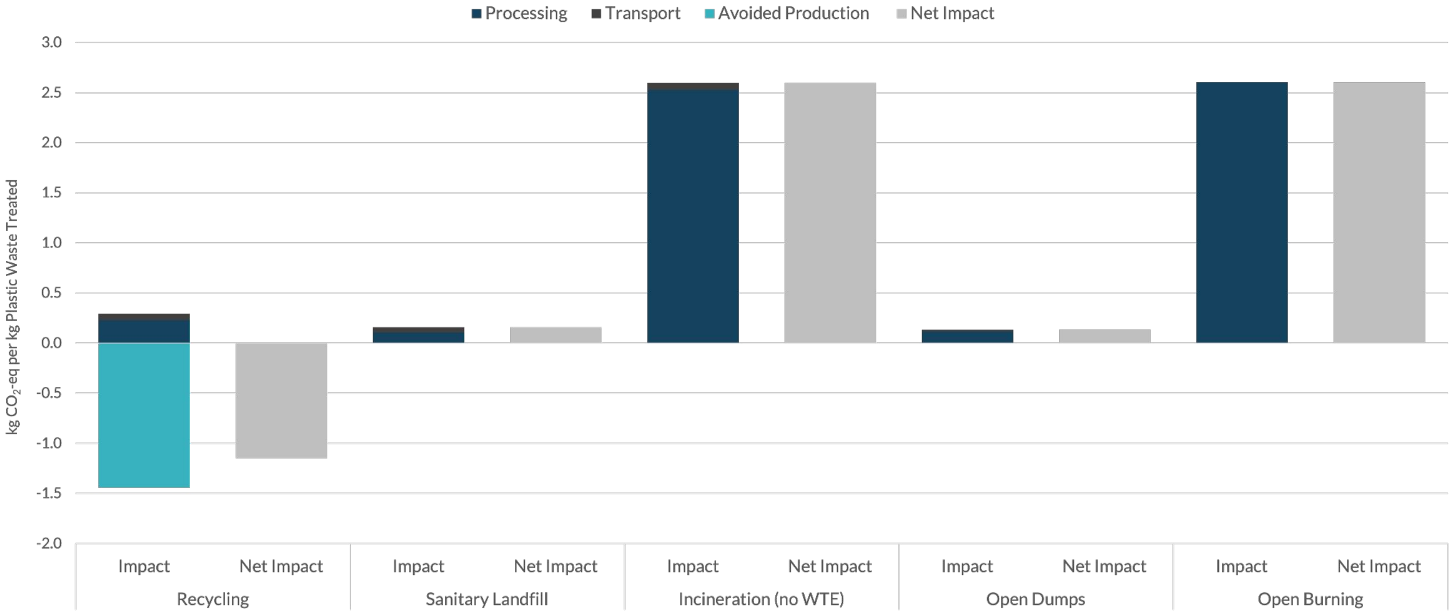


Figure 16: Carbon Footprint of Plastic Waste End-of-Life Fates in Vietnam



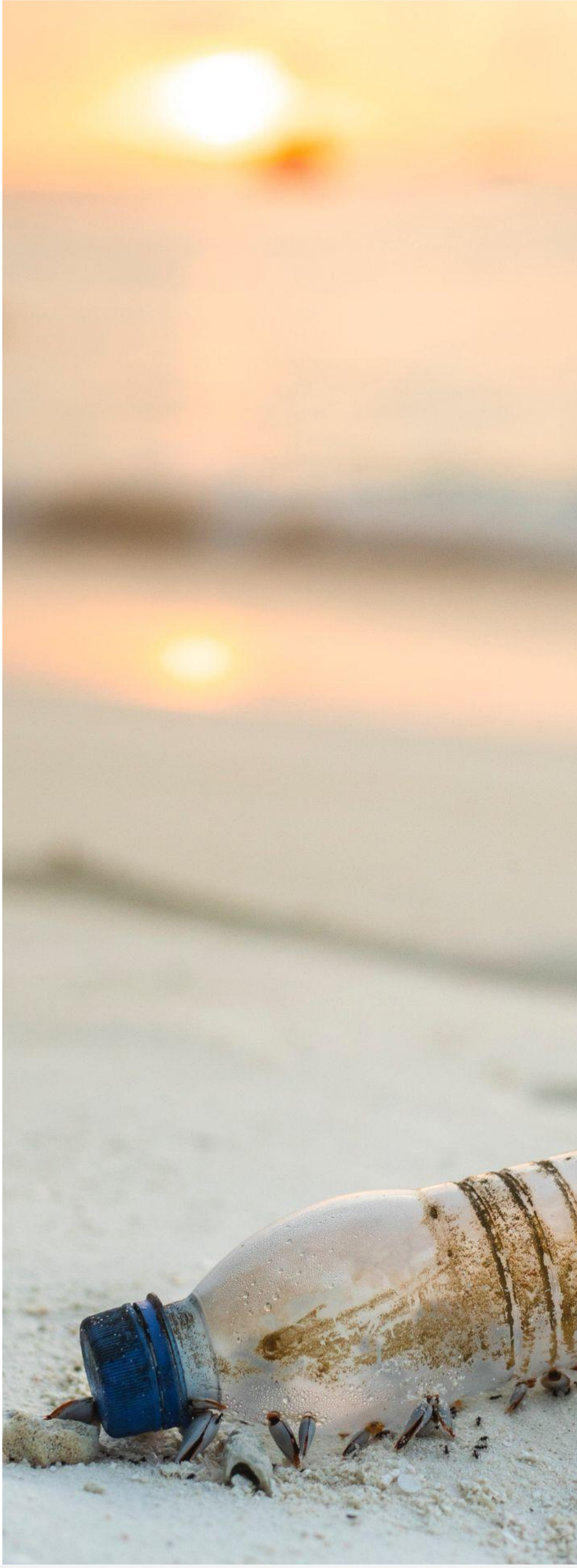
Conclusion

In this study, the LCA of plastic waste EOL treatment in India, Indonesia, Malaysia, the Philippines, Thailand, and Vietnam was studied. The results showed that when avoided production is not considered, the carbon footprint associated with plastic waste treatment per kg of plastic waste generated is the highest in Indonesia. This can primarily be attributed to a higher rate of open burning of plastic waste in Indonesia.

When avoided production is considered, the carbon footprint associated with plastic waste treatment per kg of plastic waste generated is the highest in Indonesia as well, followed by Vietnam, the Philippines, Thailand, Malaysia, and India. The relatively lower net impact in Thailand and Malaysia can be attributed to energy recovery at incineration facilities present in Thailand and to the relatively higher recycling rate and lower open burning activities in Malaysia. India has a negative net impact, primarily due to the high rate of plastics recycling and the resulting avoided production of virgin plastics.

The results of this study can help to inform future investment decisions around plastic waste management, encouraging further recycling to reduce the mismanagement of plastic waste in these countries.

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



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