PLASTIC WASTE MAKERS INDEX 2023

Basis of Preparation

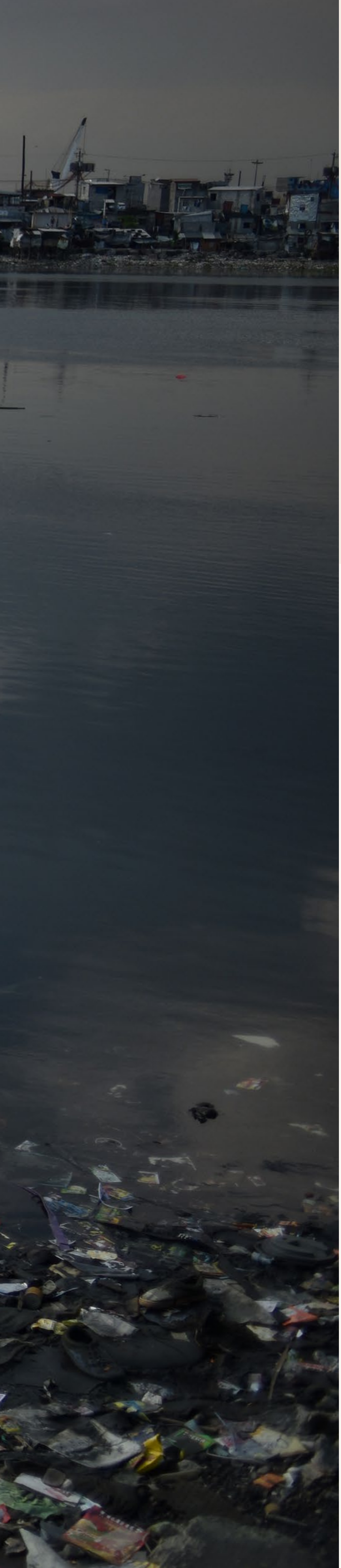
Authors

Dominic Charles and Laurent Kimman,
Minderoo Foundation

Sarah Laidler, Lawrence Campbell and Carl Sorensen,
Carbon Trust

Correspondence to: dcharles@minderoo.org

A landfill site in Kyrgyzstan where rubbish, including plastic waste, can be seen burning. With greenhouse gas emissions across the plastic lifecycle being measured for the latest edition of the Plastic Waste Makers Index, the plastic waste dilemma is not only a pollution one but also a climate one. Photo credit: Collab Media via Getty Images.



CONTENTS

Children trying to catch small fish with a sheet of plastic near their house in a community near Manila Bay in Manila, Philippines. Photo credit: Jes Aznar via Getty Images.

STEERING COMMITTEE, ANALYTICAL PARTNERS AND DATA PROVIDERS

1.1 Steering Committee

A steering committee of eight experts, reflecting knowledge and experience of the plastics industry, trade economics, supply chain analytics and with broad geographic scope, was assembled to jointly review and refine the methodology developed for The Plastic Waste Makers Index in 2021 (**Figure 1**). From June to November 2022, the Steering Committee participated in four virtual workshops.

The primary objective of the Steering Committee was to challenge the analysis and assumptions made in the modelling and endorse the resulting estimates. To achieve these objectives, the Steering Committee was given mandate to review and, where necessary, recommend changes to the methodology.

The Steering Committee also offered guidance on the relevant insights of the analysis and suggestions to improve its impact. It did not, however, formally endorse any opinions and implications derived from the work.

Table 1: Composition of the Steering Committee.

Name	Affiliation	Title
Prof. Sam Fankhauser (Chair)	University of Oxford and Grantham Research Institute on Climate Change, London School of Economics	Professor of Climate Economics and Policy
Prof. Ambuj Sagar	Indian Institute of Technology, Delhi	Head of School of Public Policy
Mark Barnaba AM	Fortescue Metals Group; Minderoo Foundation	Deputy Chairman; Co-Chair, No Plastic Waste
Dr Tony Worby	Minderoo Foundation	Director, Planet Portfolio & Flourishing Oceans
John Willis	Planet Tracker	Head of Research
Toby Gardner	Stockholm Environment Institute	Senior Research Fellow and Director, Trase
Steve Jenkins	Wood Mackenzie	VP, Consulting
Lakshmi Poti	Laudes India LLP	Sr. Programme Manager, Materials
Mark Spicer (Observer)	KPMG	Partner, ESG and Responsible Investment

An aerial view of Tagarete River, contaminated with garbage, plastic recipients, bottles and toxic waste. Photo credit: Gaston Brito Miserocchi/Stringer via Getty Images.

1.2 Analytical Partners

Wood Mackenzie is an energy research consultancy that empowers strategic decision-making in global natural resources with quality data, analysis and advice. It supported the analyses of single-use plastics material flows and greenhouse gas emissions (Sections 3 and 4).

Carbon Trust is consultancy that helps companies and organisations measure and reduce their carbon footprint. It supported the analysis of greenhouse gas emission estimates and footprinting (Section 4).

Profundo is an independent not-for-profit company which aims to make a practical contribution to a sustainable world and social justice with profound and fact-based research and advice. It supported the analysis of calculating the revenue from polymers bound for single-use plastic waste (Section 6.1).

1.3 Data Providers and Sources

Bloomberg delivers business and financial information, news and insight. Its data was used to inform the group revenue calculations (Section 6).

Nexant provides software, consulting and energy services, including capacity, supply, demand and trade-flow projections, profitability and price forecasts, value chain and end use analysis. Its data was used to inform the single-use plastic revenue calculations (Section 6.1).

Orbis, a Bureau van Dijk product, is a resource for entity data with information on close to 400 million companies. Its data was used to inform the group revenue calculations (Section 6).

Refinitiv provides financial software and risk solutions – delivering news, information and analytics. Its data was used to inform the group revenue calculations (Section 6).

UN Comtrade is a repository of official international trade statistics and relevant analytical tables. Its data was used to inform the material flow analysis (Sections 3.5, 3.7 and 3.8).

Wood Mackenzie is an energy research consultancy that empowers strategic decision-making in global natural resources with quality data, analysis and advice. Its data was used to inform the material flow analysis (Sections 3.4 and 3.6).

World Integrated Trade Solution is software developed by the World Bank in collaboration with the United Nations Conference on Trade and Development (UNCTAD), which allows users to access and retrieve information on trade and tariffs. Its data was used to inform the material flow analysis (Section 3.8).

ANALYTICAL COMPONENTS

The Plastic Waste Makers Index report comprises of three components, namely:

This document outlines the steps taken to complete each analysis. It can be read independently of the Our Approach section in the report Plastic Waste Makers Index 2023.

1. **Material Flow Analysis**
2. **Greenhouse Gas Footprinting**
3. **Circularity Assessment**

A woman working exposes herself to fumes and smoke from burning plastic bags. Most plastic is not recycled, and open-burning is a common method for 'managing' plastic pollution in high-leakage countries. Photo credit: Andrew Holbrooke/Corbis via Getty Images.

MATERIAL FLOW ANALYSIS

A senior citizen collects abandoned plastic bags for sale at a market in Chongqing Municipality, China. The Chinese Government has announced a nationwide ban on stores distributing free ultra-thin plastic bags in 2008. Photo credit: China Photos via Getty Images.

3.1 Introduction

The purpose of this analysis is to develop a comprehensive and representative model of the global flows of single-use plastics, from the production of polymers in primary form through to generation of single-use plastic waste.

Material flows approach

Several earlier studies model the total volume of plastic in global municipal solid waste streams (MSW-P). In these cases, the volume of MSW-P is estimated looking only at one point in the plastics life-cycle – the "end", or point of disposal.[1,2,3,4] Estimates are made by combining country-level data on total waste generation per capita with data on the plastic proportion of the waste.

Estimates of per capita waste generation are generally reported nationally, although methodologies and consistency differ country to country.[5] Estimates of the share of plastic in MSW are more problematic: derived from sampling, they are limited in number, frequency, and require aggregating a patchwork of primary sources to report at a global level.[6] As a result, several studies present MSW-P estimates at the regional or archetype level to avoid false precision of extrapolating to individual country estimates.[7,8]

By contrast, in our model we take a whole life-cycle – or material flow – approach to estimating single-use plastic content in MSW (which we estimate make up around two-thirds of total MSW-P, the balance being primarily durable household goods and textiles).[9] We track the flow of single-use plastic materials through their lifecycle – from polymer form to finished goods to waste – and estimate where they are produced, converted, consumed and disposed. The results provide estimated volumes of single-use plastic in MSW with country-level granularity.

A similar methodology was conceived by the US EPA in the 1970s (and in use ever since) – and recent research has produced regional estimates for the EU[10] – but, to our knowledge, this approach has never been applied on a global scale, nor tracked material flows starting from individual production assets.[11]

To estimate the contribution to single-use plastic waste from all polymer producers operating globally, the integrated model follows a supply-chain approach. There are six modules in the integrated model, aligning with the key supply chain steps. The structure and objective of the integrated model is to maintain visibility over in-scope materials as they flow from source to waste, considering the following six steps:

1.	Production as Polymers	Section 3.4
2.	International trade of polymers in primary form	Section 3.5
3.	Conversion of polymers into rigid and flexible single-use plastic	Section 3.6
4.	International trade of single-use plastics in bulk	Section 3.7
5.	International trade in single-use plastics in finished goods	Section 3.8
6.	Resulting volume of single-use plastics in Municipal Solid Waste (MSW)	Section 3.9

The methodology applied in modules 1-6 is described in detail in the following sections. A high-level description of the key questions answered by each module, scope, limitations, volumes and key data sources is provided below in Figure 1 below.

Figure 1: Overview of the model, key questions, scope and limitations

Material flow	Polymer production	Polymer trade	Conversion	Single-use plastic trade in bulk	Trade of single-use plastics in finished goods	Single-use plastics in MSW
Key questions	Who produces what resin where?	What are the trade relations between producer and converter countries?	How is polymer converted to single-use plastic products?	How are packaging and products traded internationally?	What % of single-use plastic is traded and what are the trade patterns?	How much single-use plastic is in every country and what is its composition?
Scope	Estimated 2021 production volumes for all relevant assets worldwide	Estimate trade volumes using UN Comtrade	Focus on top 6 polymers contributing 90%+ to single-use plastics in MSW	Map 90%+ of trade in global plastic packaging from UN Comtrade data	Use Consumer Products to map 95%+ of trade of products on single-use plastics	Country-level and format specific estimations of single-use plastic in MSW
Limitations	Asset capacity known, utilisation rates estimated at country-level	Mass balance approach to polymer trade	Excluding 10+ polymers that account for 10% of plastics in MSW	Assumptions made around polymer and converted packaging and finished goods		Excluding textiles, durable consumer products and other non-fast moving plastics
Estimated volumes, MMT	~220	~90	~120	~40	~30	~120

3.2 Scope of the analysis

"Single-use plastics"

We focus on "single use plastics" as the key unit of analysis. We define "single-use plastics" as those usage categories with the shortest lifespan – typically 3-6 months comprising mostly of Plastic Packaging, plus single-use Consumer & Institutional Products.[12]

Material composition of single-use plastics

The fate of single use plastic waste as it passes through any waste management system – whether it is collected, recycled, landfilled, burned or leaks into the environment – differs depending on its material composition: principally, whether the packaging or product is rigid, flexible or multi-layer/multi-material plastic.[13] We have consolidated flexibles and multi-layer/multi-material plastics into a single category, which all have the property of flexibles.

To estimate the share of rigids vs. flexibles in single use plastic waste, we analyse how packaging and products are produced: i.e., we infer composition based on the polymer type and the conversion process used, and track both format and polymer composition throughout the value chain.

Production sources

By tracking the transformation of single-use plastics from polymers, via conversion processes, into packaging and products, we are also able to estimate the source of waste volumes. We link in additional analysis of where polymers are produced, by whom, and in what quantities, to provide estimates, not just of the source country of plastic polymer production, but also the source producer – i.e., specific assets of polymer producers.

Lifespan

Given the estimated short lifecycle of single-use plastics,[14] we make the simplifying assumption that the total volume of polymer produced in a single calendar year is – within the same calendar year – also traded, converted into packaging and products, traded as packaging and consumer products, traded as a constituent of finished goods and disposed. This is, in effect, a material flows model (and not a stocks model) and we make no adjustments for existing stocks or build-up of inventory.

The original methodology from Version 1 was reviewed and updated, and analysis completed, between March and November 2022. For consistency and based on data availability, in all cases, we use data for calendar year 2021 for Version 2.

3.3 In-scope polymers

Overview

In 2021, an estimated 402 million tonnes of polymer – across 14 discrete polymer types – were converted into a similar volume of plastic products. This global total can be disaggregated into estimated volumes of per industrial sector use, for each polymer and for 100+ individual countries.

Across all polymers, we estimated the total volume of single-use plastics to be approximately 139 million metric tonnes (MMT), comprising 135 MMT of Packaging and 4 MMT of single-use Consumer & Institutional Products (**Figure 2**). The remaining 262 MMT are used by other industrial sectors, which are considered to be non-single use, such as Textiles (73 MMT), Building and Construction (67 MMT), Transportation (13 MMT), Electrical/Electronics (15 MMT) or Other (94 MMT; including durable Consumer & Institutional Products; **Figure 2**).

The subsequent analysis focuses on Packaging and Consumer & Institutional Products (P&CI) only, with the remaining "non-single use" categories excluded from further analysis.

To prioritise which polymers would be in-scope for detailed analysis – i.e., tracking volumes from source asset of production, through polymer trade, into converted products – we analysed the polymer composition of P&CI and estimated which polymers contribute materially to P&CI and thus to single-use plastic waste.

Based on the analysis of the polymer composition of single-use plastics, six polymers (PP, HDPE, LDPE, LLDPE, PET, PS [new for Version 2]) were included as in-scope for the end-to-end analysis of material flows, composition and sources, as summarised in Figure 3 – hereafter, referred to as "Single-use Plastic Polymers". These polymers represent 93%, or 129 MMT, of total single-use plastic volumes in 2021. The out-of-scope polymers (e.g., PVC, PA/66/EPS) make up the remaining 10 MMT of single-use plastic volumes.

3.4 Polymer Production

We have estimated 2021 output volumes for all production facilities (hereafter, described as "assets") producing in-scope polymers.[15] The database includes 1,400 individual single-use plastic polymer assets globally, with asset names and the location (country and region). Each asset was designated as producing one of the in-scope polymers at a given annual capacity (in thousand tonnes). Where an asset can produce multiple in-scope polymers, these assets are described as having "swing" capacity. In absence of data detailing the exact output of these "swing capacity" assets for each polymer, the total in-scope capacity was divided equally between the in-scope polymers.

The operator and owner of each asset is captured. Where an asset is jointly owned by two or more companies, the asset is listed multiple times (once for each owner), with the percentage ownership share recorded against each asset record. Production capacity of each asset/owner combination was calculated as the product of total (nameplate) capacity of each asset and ownership percentage. Production capacity of each asset owner was multiplied by an estimated region and polymer specific asset utilisation rate to calculate actual production attributable to any specific asset and owner.

A single operating utilisation rate was estimated for all assets producing a given polymer in each region. There are eight regions (Africa, Asia, Europe, Latin America and the Caribbean, Middle East, North America, Oceania, Russia and the Caspian); and six in-scope polymers (HDPE, LDPE, LLDPE, PP, PET, PS); resulting in 40 operating utilisation rate assumptions.

Figure 2: Consumption of plastic polymers by industrial use sector (MMT, 2021)

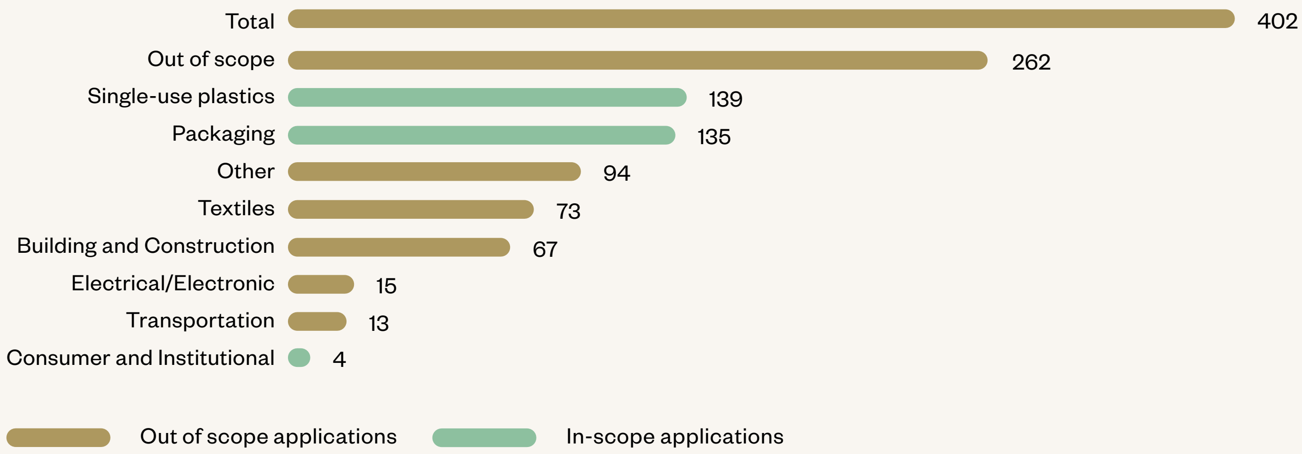
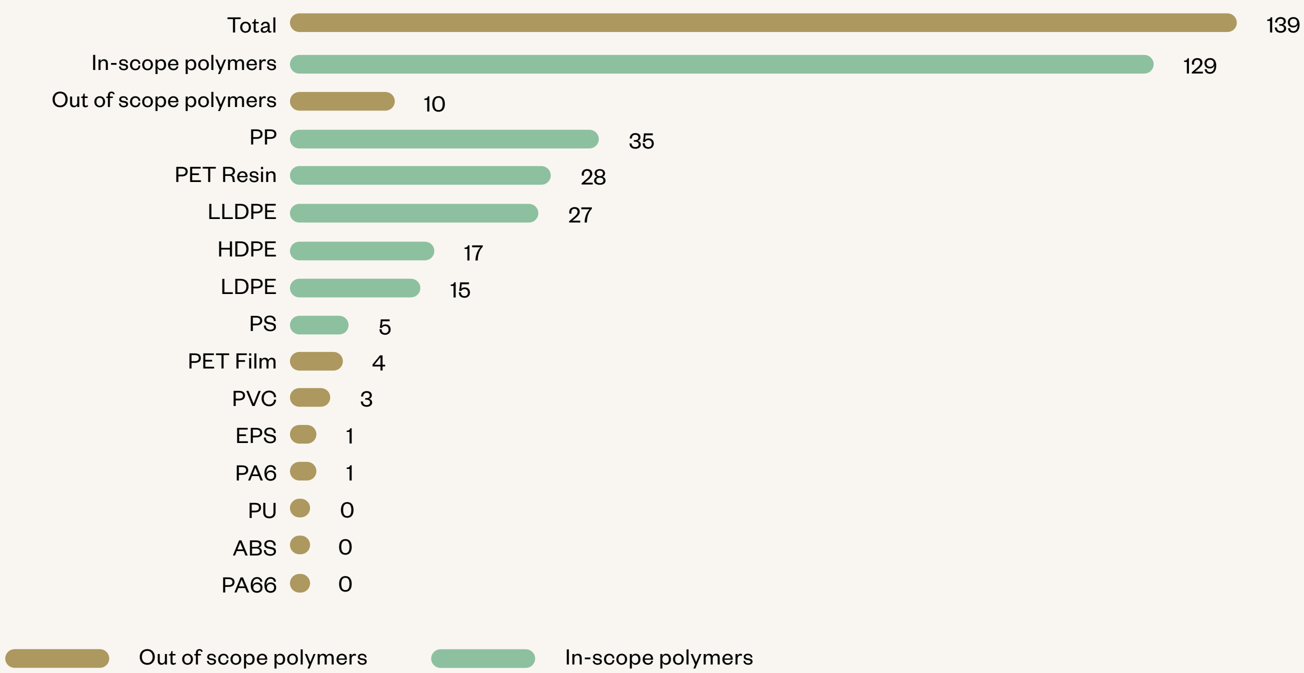


Figure 3: Polymer composition of single-use plastics category (MMT, 2021)



Source: Minderoo analysis

Table 2: An illustrative sample of the production model

ID	Asset Name	Polymer	Region	Country	Operator	Owner	Owner (%)	Capacity (kt)	Op Rate (%)	Production (kt)
2	Asset A	LDPE	North America	Canada	Local Company A	Parent Company A	100	35	84	29
4	Asset B	LLDPE	North America	Canada	Local Company B	Parent Company B	100	180	86	155
5	Asset C	LLDPE	North America	Canada	Local Company C	Parent Company C	100	250	86	215
6	Asset D	LLDPE	North America	Canada	Local Company D	Parent Company D	100	455	86	391
7	Asset E	HDPE	North America	Canada	Local Company E	Parent Company E	100	455	93	421

The output of this module is a detailed view of the volumes of in-scope polymers produced by different operators and owners in every country, or aggregated regions (Table 2). The outputs of this module are used as inputs in the Polymer Trade module.

3.5 Polymer Trade

After production, polymers are either converted domestically or traded internationally. To model the trade of polymers and track the flow of polymers from source to destination countries, we combined the outputs from the Polymer Production module with bilateral trade data at the country-level from Wood Mackenzie and UN Comtrade.[16] To simulate how primary polymers flow from production either to domestic consumption or export trade, we evaluated three different possible modelling variants:

1. **Domestic first:** Under this paradigm, exports are primarily served by domestic production. Domestic production that is not exported, and imports serve domestic consumption. Domestic consumption in this paradigm is calculated as the sum of residual domestic volumes, production minus exports, and imports.

2. **Import first:** In this approach, exports are primarily served by imports, whereas domestic production primarily serves domestic consumption. If imports surpass exports, the residual amounts are consumed domestically. Equally, if imports fall short to satisfy export demand, the gap is served by domestic consumption. Domestic consumption in this paradigm is calculated as the sum of residual imported volumes (imports minus exports) and the sum of domestic volumes (domestic production minus exports if total exports surpass imports).

3. **Pooled:** Imports and domestic consumption are pooled and serve exports and domestic consumption according to their relative weight. Domestic consumption in this paradigm is calculated as the sum of domestic production and imports, minus the exported volumes.

The analysis pursued the “domestic first logic” to model the trade of polymers, for the following rationale: as plastics are a high volume, low margin commodity, business logistic costs matter – discounting the viability of “imports first” and “pooled approach”. Furthermore, an “imports first” paradigm results in an illogical scenario where most imported plastic is re-exported immediately – creating a never-ending flow of material.

Following the “domestic first logic”, we modelled the trade of polymers based on the volume produced in each country, by asset and polymer, as well as by polymer-specific trade matrices provided by Wood Mackenzie, and based on UN Comtrade data. These matrices detail, for each in-scope polymer, the volumes traded by any country to any other country. Our model did not consider re-exports, as the data quality was insufficient to draw robust conclusions on whose polymers are re-exported.

Finally, while in most cases the calculated net polymer position of each country aligned with the Wood Mackenzie country-level conversion demand, in a few cases there was some meaningful deviation (>+10%). Differences can be explained by some combination of inaccuracies in the trade data, re-exports, stocks and inventory. To account for these differences, we proceeded with the lower value and are therefore more conservative in our estimation of net polymer position in certain countries. The impact on global in-scope polymer volumes is <10% (118 MMT vs. 129 MMT).

We followed a mass-balance approach to model the trade of polymers – assets export per their market share – acknowledging that this introduces the assumption that all assets (within a country and per polymer) share the same export rate.[a] Secondly, the mass-balance approach also implies that assets follow the same trade patterns of countries.[b]

Based on the production data and the trade matrices, we determined:

1. **The export share of each country:** The polymer-specific export share for each country was calculated by dividing the total polymer exports of country x by the total polymer production volumes of country x.

$$\text{Export share (\%)} = \frac{\text{Exports (Country x, Polymer y)}}{\text{Production (Country x, Polymer y)}}$$

2. **The country production market share of each asset:** The markets share of each asset in each country was calculated by dividing the total output of polymer by a specific asset by the total production that polymer in the country.

$$\text{Market share (Asset x, Country y; Polymer z)} = \frac{\text{Market share (Asset x, Country y; Polymer z)}}{\text{Total Production (Asset x, Country y, Polymer z)}}$$

3. **The absolute volume, and relative share, exported to each country, for each asset and by polymer:** Based on the polymer trade grids, the countries' export orientation and the asset's market share we calculated the exports of all assets:

   Total Exports (Country x, Polymer y):
   1,000 tonnes – 100%

   Exports to country a: 100 tonnes – 10%

   Exports to country b: 400 tonnes – 40%

   Exports to country n: 500 tonnes – 50%

4. **For each asset, the exported volumes and the volumes that are converted domestically:** Based on the countries' export share (eq.1), the assets' market share in country, and the trade grids, we calculated i) how much of an asset's production is exported, ii) where it is exported to, and iii) the residual amounts serving domestic consumption:

   Exported volumes (Asset x, Country y, Polymer z) = Production* Market Share* Export Share

   Domestic volumes (Asset x,Country y,Polymer z) = Production-Export Volumes

5. **The contribution of a polymer producer in Country A for polymers exported to country B:** We calculated the contribution (in tons) of each asset in different countries by multiplying the total volume of polymers exported by that asset with the % share going to the respective country:

   Responsibility (Asset x, Polymer y, Country n) = Exported Volume * % of Exports to Country (n)

6. **A net polymer position in each country, by polymer, for each asset:**
   Net resin (Country x, Polymer y) = Production-Exports + Imports

The outputs of this module are an estimated contribution of each asset to the polymer-specific net polymer position of each country – or taking polymer trade into account, who is the original polymer producer of the different polymers in any given country.
The outputs of this module are used in the Conversion module to estimate how much of each asset's contribution to the net polymer volumes in each country is converted into single-use plastics.

a. If country A produces 1000 HDPE and exports 500 (50%), c.p., all HDPE producers in country A export 50% of their production

b. If country A exports 1000 HDPE, 500 to China, 300 to Indonesia and 200 to Singapore, the 50% of the HDPE exports of an asset located in country A are destined for China, 30% to Indonesia and 20% to Singapore.

3.6 Conversion into Rigid and Flexible Single-Use Plastics

The output of the Polymer Trade module is an estimated net polymer volume for each in-scope polymer, in each country for every asset. This Conversion module estimates the share of polymer volumes converted into single-use plastics – and those that are transformed into other out-of-scope product categories, as well as the proportions of rigid versus flexible formats.

Detailed methodology to estimate single-use plastics

The methodology to estimate single-use plastics, and polymer composition, was informed by three types of datasets:

1. **Typology of industrial uses of plastics:** describing what products are used by which industrial sectors and their format.[17]

2. **Plastic application data:** describing the volumes of products produced by different processes and thereby enabling the matching of polymers to conversion processes and industrial sectors, described by data from the American Chemistry Council (ACC), Wood Mackenzie (WM), and Plastics Europe (PE).

3. **Country-level conversion demand by polymer and process:** estimation of the volume of polymers converted by different processes in 191 countries, based on Wood Mackenzie's 2021 country-level polymer analysis.

Together, these three datasets allow us to calculate:

1. The total conversion output of 191 countries.

2. How much plastics, in which format, are used by the different industrial sectors across all 191 countries.

3. The polymer split of all conversion outputs, and thereby the polymer split of products in the different industrial sectors and by format.

4. Calculate relative share of contribution to single-use plastics on a company level. **Plastic usage by different industrial sectors**

For each polymer, we estimate what share is converted into each of eight plastic product categories by industrial sector, represented in Table 3 below:

Table 3: Plastic product categories by industrial sector

Category	Example Products
Packaging	• Plastic bottles for beverages, water, carbonated soft drinks or other liquid food products, including caps and closures. • Plastic bottles for non-food liquids, including household detergents, personal care products. • Plastic containers in the shape of pots, tubs and trays, including rigid food and grocery containers. • Industrial containers such as crates and totes and non-categorised rigid packaging. • Laminated paper and aluminium packaging materials. • Plastic bags for carrying small items. • Thin plastic packaging films. • Sachets and multilayer flexible plastic packaging commonly used for food and consumer product retail sales.
Single-use Consumer & Institutional Products	• Rigid health and hygiene (e.g., applicators). • Flexible health and hygiene (e.g., diapers).
Transportation	• Motor vehicles and their parts (including autos, trucks, buses, motorcycles and bicycles), railroad equipment, travel trailers, campers, golf carts, snowmobiles, aircraft, military vehicles, ships, boats and recreational vehicles.
Building & Construction	• Pipe, conduit and fittings (including drainage, irrigation, plumbing fixtures and septic tanks), siding, flooring, carpeting, insulation materials, panels, doors, windows, skylights, bathroom units, furniture, gratings and railings, coatings, adhesives and sealants.
Electrical/ Electronic	• Home and industrial appliances (including electrical and industrial equipment), wire and cable coverings, communications equipment, resistors, magnetic tape and batteries.
Industrial Machinery	• Engine and turbine parts, farm and garden machinery, construction and related equipment, fishing and marine supplies, machine tools, ordnance and firearms, fishing and marine supplies, and chemical process equipment.
Textiles	• Woven fabric for apparel, footwear.
Other	• Major categories represented include agriculture, large industrial containers, bedding. • Durable Consumer & Institutional Products (e.g., homewares, furniture).

Plastic segmentation data

The methodology for mapping polymer volumes to product categories by industrial sector was informed by published plastic application segmentation data from three sources:

1. **American Chemistry Council ("ACC")** – application segmentation for HDPE, LLDPE, LDPE, PP, PS, EPS, and PVC.[18]
2. **Plastic Europe** – application segmentation for ABS, PA6/66, PU.[19]
3. **Wood Mackenzie** – application segmentation for PET.

The application segmentation data from the above three sources was used to construct a series of mapping matrices to link each polymer's country-level volume to the defined product categories by industrial sector. In some cases, the outputs of conversion processes can be used by different sectors and the importance of these sectors varies between economies. To account for these differences, we have included the GDP composition as a factor influencing classification of outputs volumes produced into industrial sectors. The re-categorised country-level volume data was then aggregated into a regional and global view of plastic volumes. The high-level overview of the methodology is illustrated in Figure 4.

To construct the matrices and estimate country-level production of single-use plastics a series of mapping and transformation processes were undertaken, as illustrated in Figure 3 above and described in detail on the following page.

1.1 Industry Application Mapping Matrices – HDPE/LLDPE/LDPE/PP

Wood Mackenzie segments HDPE, LLDPE, LDPE, and PP country-level demand volumes by the conversion processes. These segmentations are mapped into product categories by industrial sector segments by referencing the American Chemistry Council Plastics Industry Producers' Statistics (ACC PIPS) for HDPE, LLDPE, LDPE, and PP. The ACC PIPS statistical reports provide application breakdowns of plastic polymer sales (by weight) for each conversion process employed.

For each plastic, the percentage of each application falling under a particular conversion process was calculated, and each application was allocated to a product category by industrial use based on the application description. For example, the percentage of HDPE film consumed for food packaging is given by the formula:

$$\text{\% HDPE Film Consumed for Food Packaging} = \frac{\text{HDPE Food Packaging Film}}{\text{Total HDPE Film}} = 15.95\%$$

For the conversion processes for which ACC PIPS statistical report application breakdowns are not available, the allocation to product category by industrial use was done:

4. directly if the implied application is considered obvious (i.e. fibre extrusion, cable/wire extrusion), or
5. informed by the US GDP composition by industry if the conversion process was known to be utilised in multiple application categories (i.e. HDPE, LDPE, LLDPE sheet extrusion).

The rationale and assumptions made for each allocation from ACC PIPS are documented in Industry Application Mapping Matrices – HDPE/LLDPE/LDPE/PP in the endnotes.[20]

An example of the mapping matrices for HDPE is shown in Figure 5.

Figure 4: Overview of the methodology to determine in-scope polymers

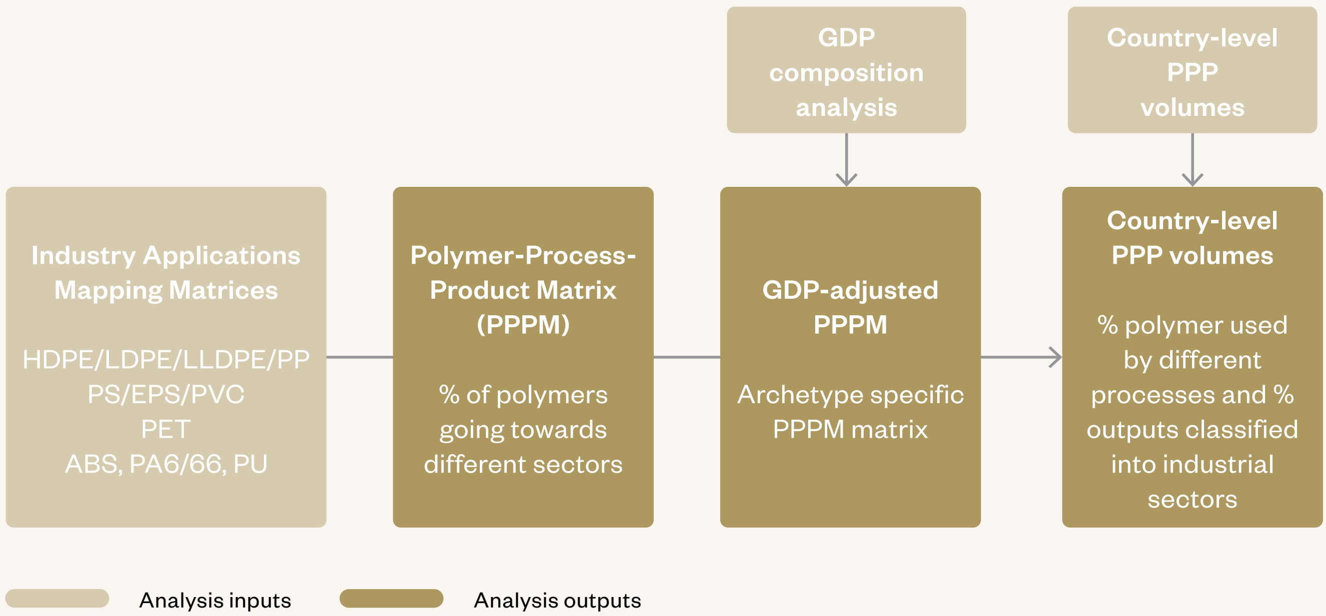


Figure 5: Example of mapping matrices for HDPE

<table>
<tr><th>Polymer</th><th>Applications</th><th>Volumes (tons, %)</th><th>Process</th><th>Sector</th><th>Format</th></tr>
<tr><td rowspan="11">HDPE</td><td>Packaging film</td><td>100 (5%)</td><td rowspan="3">Film extrusion (37.5%)</td><td rowspan="5">Packaging (60%)</td><td rowspan="6">Flexible (55%)</td></tr>
<tr><td>Non-food film</td><td>600 (30%)</td></tr>
<tr><td>Retail bags</td><td>50 (2.5%)</td></tr>
<tr><td>Food bottles</td><td>50 (2.5%)</td><td rowspan="2">Blow moulding (7.5%)</td></tr>
<tr><td>Household products</td><td>100 (5%)</td></tr>
<tr><td>Cosmetics</td><td>10 (0.5%)</td><td rowspan="4">Injection moulding (30%)</td><td>C&I (10%)</td></tr>
<tr><td>Tubs, containers</td><td>90 (4.5%)</td><td>Transportation (10%)</td><td rowspan="5">Rigid (45%)</td></tr>
<tr><td>Caps, closures</td><td>200 (10%)</td><td rowspan="3">Construction (20%)</td></tr>
<tr><td>Auto parts</td><td>300 (15%)</td></tr>
<tr><td>Pipes</td><td>300 (15%)</td><td>Pipe extrusion (15%)</td></tr>
<tr><td>Drums</td><td>200 (10%)</td><td>Rotation mould (10%)</td><td>Other</td></tr>
</table>

1.2 Industry Application Mapping Matrices – PS/EPS/PVC

Wood Mackenzie reports PS, EPS and PVC country-level demand as aggregated volumes, and further segmentation into application categories are informed by ACC PIPS statistical reports for PS, EPS and PVC. These reports provide application breakdowns of plastic polymer sales (by weight) for each plastic, and these applications are allocated product categories by industrial use based on their description. The rationale and assumptions made for each allocation from ACC are documented in Industry Application Mapping Matrices – PS/EPS/PVC in the endnotes.[21]

1.3 Industry Application Mapping Matrices – PET

Wood Mackenzie reports PET resin country-level demand by application categories, i.e. country level-conversion of PET into end applications such as water bottles, toiletries or cosmetics. Hence, these volumes are directly allocated to product categories by industrial use based on their description. The application breakdown for PET fibre and PET film are informed by Wood Mackenzie industry analysis and are also directly allocated to product categories by industrial use based on their description, e.g. country level demand for automotive PET filament. The rationale and assumptions made for each allocation are documented in the Industry Application Mapping Matrices – PET in the Endnotes.

1.4 Industry Application Mapping Matrices – ABS, PA6/66, PU

Wood Mackenzie reports ABS, PA6/66 and PU country-level demand as aggregated volumes, and further segmentation into application categories are informed by Plastics Europe application segmentations for these three polymers. The Plastic Europe[c] application segmentations are then allocated to product categories by industrial use based on their description.
The rationale and assumptions made for each allocation are documented in Industry Application Mapping Matrices – ABS, PA6/66, PU in the Endnotes.

Step 1:
Synthesis in a matrix
After the categorisation of polymer-to-product conversion volumes using the matrices described above, the percentage breakdown for each polymer – by conversion process, application or both – are used to synthesise a Polymer-Process-Product Matrix (PPPM) as illustrated in Table 4.

Step Two:
GDP sensitivity analysis
The outputs of some conversion processes are used by different industrial sectors, e.g., film extruded products can be used either for packaging or for agricultural applications, and the relevance of these industrial sectors differs between economies. To account for these differences, we formulated six economy archetypes – US, China, high-income countries, upper-middle income countries, lower-middle income countries and low-income countries, following the World Bank classification – analysed the relative economic importance of the sectors using plastics and constructed GDP-adjusted Polymer-Product-Product Matrices (PPP Matrices).

Step 3:
Application of Mapping Matrices to Country-Level Demand
The GDP-adjusted PPP-Matrix was then applied to Wood Mackenzie's 2021 country-level polymer demand data to convert all demand data into product categories. An example of this mapping for one country is shown in Table 5. The country-level mapped plastic demand was then further aggregated to provide a regional and global view of plastic demand for product categories by industrial use.

Table 4: Archetype matrix of polymer-to-product conversion

		Packaging		CI		Transportation		...	
Polymer	**Process**	**Rigid**	**Flex**	**Rigid**	**Flex**	**Rigid**	**Flex**	**Rigid**	**Flex**
HDPE	Flim extrusion	0%	75%	0%	20%	0%	0%	0%	5%
	Sheet extrusion	60%	0%	10%	0%	20%	0%	10%	0%
	Injection	70%	0%	10%	0%	20%	0%	0%	0%
	Pipe extr.	0%	0%	0%	0%	0%	0%	100%	0%
	...	20%	10%	5%	20%	10%	15%	10%	0%
LDPE	Flim extrusion	0%	40%	0%	20%	0%	30%	0%	10%
	Sheet extrusion	35%	0%	0%	0%	10%	0%	55%	0%
	Injection	0%	0%	0%	50%	0%	0%	0%	50%
	Pipe extr.	0%	0%	0%	0%	20%	0%	80%	0%
	...	0%	0%	10%	0%	0%	10%	0%	80%
...	...	0%	35%	7%	13%	5%	20%	8%	2%

Table 5: Illustrative example of archetype matrix applied to Wood Mackenzie country-level polymer conversion volumes data

				Packaging		CI		Transportation		...	
Country	**Polymer**	**Process**	**Demand (kt)**	**Rigid**	**Flex**	**Rigid**	**Flex**	**Rigid**	**Flex**	**Rigid**	**Flex**
China	HDPE	Film extrusion	200	0	150	0	40	0	0	0	10
		Sheet extrusion	500	300	0	50	0	100	0	50	0
		Injection	400	280	0	40	0	80	0	0	0
		Pipe extr.	100	0	0	0	0	0	0	100	0
		...	200	40	20	10	40	20	30	20	0
	LDPE	Film extrusion	100	0	40	0	20	0	30	0	10
		Sheet extrusion	700	250	0	0	0	70	0	380	0
		Injection	200	0	0	0	100	0	0	0	100
		Pipe extr.	10	0	0	0	0	4	0	16	0
		...	100	0	0	10	0	0	10	0	80
	..	...	100	0	35	7	13	5	20	8	2

c. Plastics Europe is a pan European association of plastic manufacturers, providing regular industry reports and analysis.

The mapping of polymers to processes and products, in combination with the country-level demand per process and polymers, enables the estimation of the polymer composition of the converted products, as well as of the industrial sectors that use these products.

In other words, based on this analysis, for each country we know the share of each polymer converted to single-use vs non-single use plastics.

For each individual line of the PPP Matrices described above, the output of the polymer-to-product categorisation is also designated as a Rigid or Flexible.[22]

Additionally, by applying a mass balance approach, the source assets of these single-use plastic volumes are estimated. The calculation used is:

Post conversion responsibility =

Net resin (asset x, polymer y, country z)

*% polymer converted to Fast- Moving Plastics

*% (rigids/flexibles)

An illustrative sample of the outputs is shown in Table 6. For example, Asset #5 exports 210kt of LLDPE, of which 180kt is exported to the United States. The United States has a conversion rate of 78.3% for single-use plastics, meaning it converts 141kt (= 78.3% * 180kt) of Asset #5's LLDPE into single-use plastics. Similarly, 5kt of Asset #5's LLDPE is converted in-country in Canada, which has a conversion rate of 79% for single-use plastics, equating to 4kt of in-scope polymer. Using this methodology across the globe, we calculate that Asset #5 has 169kt of LLDPE volumes converted into in-scope polymers, of which the majority (168.48kt) is in flexible formats.

Table 6: An illustrative sample of the outputs

Asset Name	Polymer	Owner Name	Country	Production	Export	Domestic	In-scope	Rigids	Flexibles
4	LLDPE	Company A	Canada	155	151	3.6	121.65	0.34	121.30
5	LLDPE	Company B	Canada	215	210	5.1	168.95	0.48	168.48
6	LLDPE	Company C	Canada	391	382	9.2	307.50	0.87	306.63

The degree of uncertainty or error introduced by applying this approach is driven by the relative share of each polymer converted into single-use plastics versus other product categories by industrial sector. For example, 100% of PET resin is estimated to be converted into single-use plastics, suggesting a perfect correlation between source inputs and outputs. On the other hand, approximately 40% of HDPE is converted into single-use plastics, meaning three-fifths of the global HDPE is bound for out-of-scope plastics. Thus, in the absence of more detailed data that provides insight over the destination of specific source polymer, we assumed that all polymer producers share proportionate accountability for the resulting volumes of single-use plastics.

The output of this Conversion module is an estimated contribution of each asset to the volumes of single-use plastics converted in every country.

3.7 Bulk Packaging Trade

Post conversion, packaging material is either transformed domestically into finished products or traded internationally. Out of the 118 MMT of in-scope polymers converted into single-use packaging, our analysis of the packaging trade reveals that an estimated 39 MMT of in-scope packaging are traded globally, impacting the contribution of each polymer producer, and 79 MMT are transformed domestically into finished goods.

In the absence of transparency on a conversion level – whose polymers are converted into which products and which ones are traded – we again employ a mass-balance approach to model the trade of plastics in the form of packaging.

The modelling of the packaging trade is based on the following steps:

1. **Identification of product categories that encompass in-scope plastic packaging material.**

- We evaluated a list of 37 UN Comtrade HS 6-digit codes and their product descriptors and characterised the products by:
  - Whether the product is likely to be transformed into single-use plastics
  - Whether it is likely composed of in-scope polymers

- This analysis resulted in 18 product categories that fulfil both criteria and that were classified as in-scope for further analysis, as detailed in Table 7 below. The results of this analysis were tested and refined with industry experts.

2. In-scope products were further mapped against their polymer composition and format and the associated conversion processes (**Table 7**). While many categories do not explicitly define the format or the polymer composition, the chosen categories cover over 95% of the total traded packaging and thus are assumed to be representative of all packaging trade.

3. For each of these product categories, a country-to-country trade grid was built based on public-access UN Comtrade data, covering 90%+ of the traded volumes. For each of the 18 identified product categories, these trade grids detail the total volume exported and imported for 200+ countries, the source country of imports as well as the destination of exports. It is important to note that, for only a few countries, the trade volumes were perceived as outliers and were manually deleted from the trade grids. The methodology for identifying the outliers was where very small trade countries (e.g., Trinidad and Tobago) were supposedly trading vast quantities of packaging goods (e.g., in the billions) which is comparable to China or US trade volumes. We conducted a manual check of the trade volumes downloaded from UN Comtrade and identified the outliers, and deleted their volumes as this would skew the trade flow.

Figure 6: In-scope products mapping against polymer composition, format the associated process type

Product & Description		Process							
6 Digital Code	**Product**	**Film Extrusion**	**Sheet Extrusion**	**Extrusion Coating**	**Blow Moulding**	**Injection Moulding**	**Raffia**	**PET Conversion**	**PS Conversion**
391910	Plastics; plates, sheets, film, foil, tape, strip, other flat shapes thereof, self-adhesive, in rolls of a width not exceeding 20cm	X	X						
391990	Plastics; plates, sheets, film, foil, tape, strip, other flat shapes thereof, self-adhesive, other than in rolls of a width not exceeding 20cm	X	X						
392010	Plastics; plates, sheets, film, foil and strip, of polymers of ethylene, non-cellular and not reinforced, laminated, supported or similarly combined with other materials	X	X						
392020	Plastics; of polymers of propylene, plates, sheets, film, foil and strip, non-cellular and not reinforced, laminated, supported or similarly combined with other materials	X	X						
392030	Plastics; of polymers of styrene, plates, sheets, film, foil and strip, non-cellular and not reinforced, laminated, supported or similarly combined with other materials								X
392062	Plastics; plates, sheets, film, foil and strip, of polyethylene terephthalate, non-cellular and not reinforced, laminated, supported or similarly combined with other materials							X	
392111	Plates, sheets, film, foil and strip, of cellular polymers of styrene, unworked or merely surface-worked or merely cut into squares or rectangles (excluding self-adhesive products, floor, wall and ceiling coverings of heading 3918 and sterile surgical or dental adhesion barriers of subheading 3006.10.30)								X
392119	Plates, sheets, film, foil and strip, of cellular plastic, unworked or merely surface-worked or merely cut into squares or rectangles (excludingthose of polymers of styrene, vinyl chloride, polyurethanes and regenerated cellulose, self-adhesive products, floor, wall and ceiling coverings of heading 3918 and sterile surgical or dental adhesion barriers of subheading 3006.10.30)	X	X						
392190	Plates, sheets, film, foil and strip, of plastics, reinforced, laminated, supported or similarly combined with other materials, unworked or merely surface-worked or merely cut into squares or rectangles (excluding of cellular plastic; self-adhesive products, floor, wall and ceiling coverings of heading 3918)	X	X						
392310	Plastics; boxes, cases, crates and similar articles for the conveyance or packing of goods			X	X	X			
392321	Ethylene polymers; sacks and bags (including cones), for the conveyance or packing of goods	X							
392329	Plastics; sacks and bags (including cones), for the conveyance or packing of goods, of plastics other than ethylene polymers	X							
392330	Plastics; carboys, bottles, flasks and similar articles, for the conveyance or packing of goods				X	X			
392340	Plastics; spools, cops, bobbins and similar supports, for the conveyance or packing of goods				X	X			
392350	Plastics; stoppers, lids, caps and other closures, for the conveyance or packing of goods				X	X			
392390	Plastics; articles for the conveyance or packing of goods n.e.s. in heading no. 3923	X	X		X	X			
392410	Plastics; tableware and kitchenware				X	X			
392490	Plastics; household and toilet articles				X	X			

4. Based on the conversion process mapping of the in-scope packaging categories, as well as the known polymer split of these conversion processes, we estimated the polymer and format composition of traded packaging, for all countries and in-scope products.

   By doing so, we can translate and express packaging trade grids into polymer and format specific trade grids. This process entails several steps:

- As categories include outputs of several processes, e.g., Product 391910 could be either sheet of film extruded outputs, for each country/product, we estimated the relative share of these processes:

$$\text{Product A (Process 1, Country x)} = \frac{\text{Output Process 1 (Country x)}}{\text{Output Process 1 (Country x)} + \text{Output Process n (County x)}}$$

- Product A (Country x) = 100% - Process 1 = 50% - Process 2 = 20% - Process n = i
- We calculated the absolute contribution of each process to the traded volumes, multiplying the traded volumes by their relative process split Process contribution (ktons, Process x, Country y, Product z) = Traded volumes traded* Process Share
- Once the relative and absolute contribution of each process to the traded products was established, we use the country specific polymer composition of each process, calculated from the conversion model, to derive the polymer composition of the traded products:

  Polymer 1 (Product x, Country y) =

  % Polymer 1 (Process z)*

  % Process z (Product x)*

  Volume (Product x)
- As conversion processes are typically associated with specific packaging formats – e.g., all extruded film is flexible whereas all blow moulded products are rigids[d] – we were able to determine the share of each polymer going towards rigid versus flexible formats within that product category. Thus, we disaggregated the products into two format categories – rigid versus flexible – which were further subdivided by the five-in-scope polymers, resulting in 10 format/polymer vectors for each product, e.g., "Product 391910 – RigidPP" or "Product 391910 – FlexibleLLDPE".

5. The resulting format-polymer vectors were combined with the country-to-country trade matrices for all 18 in-scope products, modelling the trade of packaging expressed as format-polymer vectors. The trade matrix of one product is now expressed in 10 format-product matrices.

6. In the sub-final step, the format-polymer-matrices for all 18 product categories were combined into single format-polymer trade matrices (one for each format-polymer combination, e.g., FlexiblePP)

$$\sum \text{(Format (x), Polymer (y))} = \sum_{\text{Product (n)}}^{\text{Product (i)}} \text{Format (x), Polymer (y)}$$

The format-polymer trade matrices were then combined with the output of the conversion model, the contribution of rigid and flexible single-use plastics of each polymer producer in every country. For example, if a producer is responsible for 10% of rigid PP in a country A, which exports rigid PP to country B, company A's net contribution in country A would decrease by 10% and increase by the exported amount in country B.

Whereas the overall contribution of single-use packaging stayed the same for each polymer producer, it shifted between countries, according to the trade flows of in-scope packaging material between these countries. For example, China and Germany are large net exporters of packaging material, therefore a polymer producer's contribution to single-use plastic waste in these countries would decrease because of the trade and increase in the importing countries.

d. See 'Conversion' for the mapping of polymers to processes, sectors and formats

3.8 Finished Goods Trade

Once single-use plastics are formed into final products – e.g., filled, used as wrapping, or as single-use products in their own right – these finished goods can be either consumed domestically or traded internationally. As with the trade of bulk packaging, a polymer producer's final contribution to single-use plastic waste is impacted by the trade of finished goods – decreasing in exporting countries and increasing in countries that import goods containing plastics attributable to the polymer producer. Given that asset-level attribution is only possible up until the point of conversion, we applied again a mass-balance approach to model the trade of finished goods and its impact on polymer producer contribution to single-use plastic waste.

Identification of value chain archetypes for single-use plastic products

To model the trade of finished goods and the single-use plastic used within them, we evaluated archetypical single-use plastic product value chains, their trade patterns and intensities and the impact on country-level estimates of single-use plastic waste generation.

From a comprehensive study of 23 global value chains by the McKinsey Global Institute[23], four value chains were selected as the most relevant and representative archetypes for single-use plastic products (**Figure 13**).[e] The same study analysed each value chain from World Input-Output Tables to compute a Trade intensity – gross exports / gross output (%) – in other words, the proportion of finished goods that are exported.

Single-use plastics are found in the majority of finished goods in these four value chains. We acknowledge that the share of plastic in finished goods, by both weight and value, will vary between the value chains – e.g., a higher share of weight and value in a single-use plastic bottle (in the Food & Beverage value chain) versus the film wrapping for a smartphone (in the Computer & Electronics value chain). However, given a lack of available data detailing the share of plastic across or within these value chains – and an analysis beyond the scope of this project to compile – we made the simplifying assumption that the plastic share, by weight and value, in each value chain is constant. Therefore, we calculated the weighted average trade intensity, across the globally traded volumes of these four value chains, as a proxy for the trade intensity of the volume of single-use plastic in finished goods (**Table 8**).

Table 7: Single-use plastic product value chains, trade intensities and globally traded volumes

Product Category	Trade intensity (%)(9)	Globally traded volumes ($bn)
Food & Beverages	13%	880
Plastics & Rubber	23%	192
Furniture & Other manufacturing	25%	244
Computer & Electronics	48%	596
Combined	**26% weighted average**	

e. The trade intensity describes how much of an output is traded internationally, and in turn the plastic used as packaging within these products. In other words, if 13% of all F&B outputs are traded internationally, 13% of the packaging used in F&B is traded too (9).

We then modelled the dynamics of the trade in finished goods using one super-archetype product grouping: Consumer Goods, as defined by UN Comtrade Product Group "SoP3" (and accessed via the World Bank Integrated Trade Tool),[25] which combines more than 1,523 individual product categories – including all the product categories in the four value chains selected previously.

Calculation of country-level trade intensities and traded volumes

The overall trade intensity describes how much of the total output is traded on average. However, some countries participate more in trade than others, impacting both volumes traded as single-use plastics and the country-level trade intensity. To calculate the volumes traded by each country, we estimated:

1. The total amount of single-use plastics traded as finished goods:
   - The total volume of single-use plastics post conversion is 118 MMT.
   - A trade intensity of 26% implies that ~31 MMT of single-use plastics are traded internationally in the form of finished goods.
2. A country-level traded volumes and trade intensity, calculated by:
   - The individual countries' trade participation, i.e., the countries' share of the global traded volumes in Consumer Goods (as defined by UN Comtrade). For example, China contributes approximately 16% to the global exports of consumer goods, and imports 6.3% of all traded consumer goods.
   - The ratio between single-use plastics in-country post packaging trade and single-use plastics traded as finished goods. Given the paucity of data on re-exports, the country-level trade intensity was capped at 100%, meaning no country can export more plastic in finished goods than there is single-use plastics in country post packaging trade.[f]

Compilation of trade matrices

To analyse the trade flows of finished goods between countries, identify net exporter and importers, as well as the destinations, respectively the source of trade, again a country-to-country trade matrix was built based on World Bank's Integrated Trade Tool database.[26]

The trade matrices include detailed accounts of the top 25 importers and exporters, and their trade partners, covering 95%+ of the global traded value of Consumer Products.[g] As plastic contents in the trade of Consumer Products cannot be differentiated by format or polymer, the same trade intensity (trade over outputs) was used for all single use plastics in traded consumer goods.

To test the robustness of the analysis, we conducted a sensitivity analysis to estimate the impact of using different trade intensities on national MSW volumes and triangulated the results with prior studies and secondary literature.

Estimation of the impact of finished goods trade on polymer producer contributions to single-use plastic waste

The country-level trade intensities (describing how much leaves the country) in combination with the trade grids (describing where single-use plastics as finished goods is traded to) were used to compute the impact of the trade of finished goods on polymer producer contributions to single-use plastic waste:

1. We modelled all trade relationships between countries that collectively represent 95% of the traded volumes. In this model, 71 countries collectively represented 95%+ of the traded volumes and therefore we included the top 5,041 top trade relationships (71*71) in the analysis. Trade to and from countries that are not within the top 71 was not included in the model.
2. In combination with the country-level trade intensities, these detailed trade matrices describe the absolute flow of single-use plastics between these countries.
3. Based on the relative market share of each asset (n=1,400) in each country, we computed the impact on polymer producer contribution to single-use plastic waste. For example:
   - Contribution in country X post packaging trade: 100
   - Country level trade intensity: 30%
   - Relative importance of partner countries
   - Country A – 80%
   - Country B – 20%
   - Impact of trade on contribution:
   - Country X: – 100 * (1-30%) = 70
   - Country A: 100 * 30% * 80% = 24
   - Country B: 100 * 30% * 20%= 6
4. By computing both trade from countries as well as trade to countries, the model estimates the impact of the finished goods trade on polymer producer contribution to single-use plastic waste in each of the countries and a new estimation of net contribution post finished goods trade.

f. The impact of this assumption on overall results is limited, as it applies to few countries only, e.g., Netherlands, Belgium or Singapore, which are all characterised by relatively small populations and relatively large plastics production and trading hubs.

g. If a country A is in the top 25 importers or exporters, the detailed trade account with the countries' trade partners is included in the matrix, e.g., also the volumes country A trades with a country that is not within the top 25. This approach excludes volumes that are traded between countries that are neither within the top 25 importers nor exporters.

3.9 Estimates of Single-Use Plastic Waste

As described above, estimates of single-use plastic waste volumes at the country level – in addition to company-level contributions – are one of the outputs of this analysis. We triangulated the results of our analysis with previous country level estimations to ensure the robustness of our results and classify our study within a wider stream of research on plastics.[27, 28, 29] They can be used as the baseline to inform granular waste management and plastic pollution models.

Single-use plastic waste estimates by country are calculated by taking the post-conversion volume (Section 3.6), adding net Packaging Trade (Section 3.7) and adding net Finished Goods Trade (Section 3.8). Calculations were done separately for Rigids and Flexible, which then provide a combined total volume.

The same calculation is performed at the asset level to track single-use plastic waste volumes back to production sources. Source single-use plastic waste volumes for each asset in each country were summed to express a global single-use plastic waste volume for every production asset. Hence, for each polymer producer, we can reconcile total contribution to single-use plastic waste across every country, and compare these volumes to the total volumes of plastic produced, plastics converted and total single-use plastic waste. The calculation for “rolling up” from individual production assets (n=1,400) to a global total for each polymer producer/company is described in Section 7: Producer Definition. New for this edition, once we “rolled up” to the polymer producer, we included the recycled feedstock used by polymer producers based on their recycling capacity, and netted this off the total single-use plastic waste generation figure to calculate net single-use plastic waste contribution. As an example, if Company A has a total single-use plastic waste footprint of 5 MMT, and also produces 1 MMT of recycled plastic, then their net contribution to single-use plastic waste is 4 MMT.

An illustrative sample of the outputs is provided in Table 9 below.

Table 8: An illustrative sample of the outputs of total single-use plastic waste

ID	Polymer	Asset	Country	Flex MSW single-use plastic waste	Rigid single-use plastic waste	Total single-use plastic waste
4	LLDPE	Asset A	Canada	123.9	0.3	124.2
27	HDPE	Asset B	United States	35.7	90.3	126.0
151	HDPE	Asset C	Argentina	25.6	44.1	69.7
470	LDPE	Asset D	Belgium	112.5	22.4	134.9

3.10 Confidence levels and uncertainties

Country-level estimates of single-use plastics across production, polymer trade, conversion and packaging trade have a high confidence levels: by which we mean that data sources are credible, triangulated and calculation methodologies are proven. We expect the vast majority of results to be within a narrow margin of error (**Figure 7**).

The assumption on finished goods trade intensity introduces some uncertainty about the final country-level single-use plastic waste estimates. We take the trade intensity of four value chains as a proxy for all single-use plastics. These value chains have trade intensities ranging from 13% to 48%, and each will have different proportions of plastic as a share of total product value and weight. Estimating the total volume of single-use plastics in each of these global value chains, and calculating the weighted average trade intensity, would be a refinement to our simplifying assumption. However, such an analysis was beyond the scope of this report.

Producer-level estimates of single-use plastics production have high confidence levels. Confidence levels around polymer trade vary according to whether the producer has an export-led business model or is domestic sales-led. Confidence in the producer conversion estimates is high for producers of PET resin, where the proportions of polymers going into in-scope applications is 100%. This proportion is lower for other in-scope polymers (73% of PS; 71% of LLDPE; 66% of LDPE; 42% of PP; 39% of HDPE), and it is theoretically possible that any single producer of these polymers in any country may be actively engaged in long-term supply to out-of-scope applications accounting for all their output.

We apply a mass balance calculation: a “fair” representation of on-the-ground reality, all other things being equal. Some degree of disclosures on these matters are made by individual companies;[30] we actively encourage greater disclosure by producers in the spirit of transparency and intend to update our analysis in response.

3.11 Re-basing 2019

In order to make a like-for-like comparison for the single-use plastic waste footprint with the Plastic Waste Makers Index 2021 edition, we had to re-base 2019 numbers for the following:

- Added polystyrene (PS) to in-scope polymers.
- Added recycled feedstock – i.e., netted off post-consumer plastic waste recycled by the company from the total single-use plastic waste figure for that company.

As such, we updated the following 2019 material flow models to account for the re-basing:

- Polymer production.
- Polymer trade.
- Conversion into single-use rigid and flexible plastics.
- Single-use plastic waste footprint

Figure 7: Summary of data confidence and uncertainty

Module	**Confidence** (Credible or triangulated data sources and robust/proven methodology)	**Uncertainty** (Variance within data, single source, or new methodology)	**Relative impact on results**
Resin Production	High confidence in accuracy asset-level production capacities	Some uncertainties around asset-specific operating production rates	High
Resin Trade	• High confidence in the identified trade patterns at the country level and by polymers • High confidence for assets in markets with low trade volumes or high market shares	• **High uncertainty for assets in diverse, export oriented markets** • ‘Domestic first’ vs ‘mass balance logic’ for re-exports has low uncertainty”	
Conversion	• High confidence in conversion demand at country and process level (+-5%) • High confidence in the classification of in/out of scope applications for most polymers (<5%)	• Some uncertainty in the classification of in/out of scope applications, for some specific polymers (HDPE/PP) excl. USA • Some uncertainty around composition of product groups, e.g. ‘films, sheets or foil of polyethylene’	
Packaging Trade	High confidence in representative packaging product categories and trade grids (+-10%)	Low uncertainty around composition of product groups, e.g. ‘films, sheets or foil of polyethylene’	
Finished Goods Trade		**High uncertainty on ‘weighted’ trade intensity of plastic in packaging and CI**	Low

GREENHOUSE GAS FOOTPRINTING

4.1 Introduction

Minderoo Foundation approached Carbon Trust to calculate the emissions of the total of global single use plastic production in 2021 attributed to the producers of the plastic polymers.

Minderoo and Carbon Trust agreed that the project approach consist of the development of a carbon calculator to express the emissions amount associated with each plastic producer in tonnes CO_2e.

This methodology is a custom endeavour and unique in the carbon accounting industry. To achieve a reasonable of level trust in the provided figures where possible, relevant published literature benchmarked against as a method to confirm rational findings.

The analysis and calculation are dependent on many assumptions and limitations such as (but not limited to) region, extraction method, equipment, polymer use, fuel use, transportation and end of life. These assumptions were presented and agreed with Minderoo in a supporting steering committee. Wood Mackenzie provided key data from their databases on the chemical industry, which has notably been used to estimate energy use for the emissions from cradle-to-polymer.

The results produced from the methodology are a reasonable estimate of cradle-to-grave GHG emissions for single-use plastic waste from different polymer producers; but is only ever a reasonable estimate. The analytical team sees the benefit of the producers footprinted to calculate their own emissions and disclose these for use by customers to ensure a more accurate representation of GHG emissions by product by company.

The analysis has looked at single-use plastics made up of six polymers: HDPE, LDPE, LLDPE, PP, PET and PS. The GHG emissions calculations have included the consideration of the mechanical recycling of PET. Due to the limited scale of on par recycled content for the other five polymers, these are not included in this report.

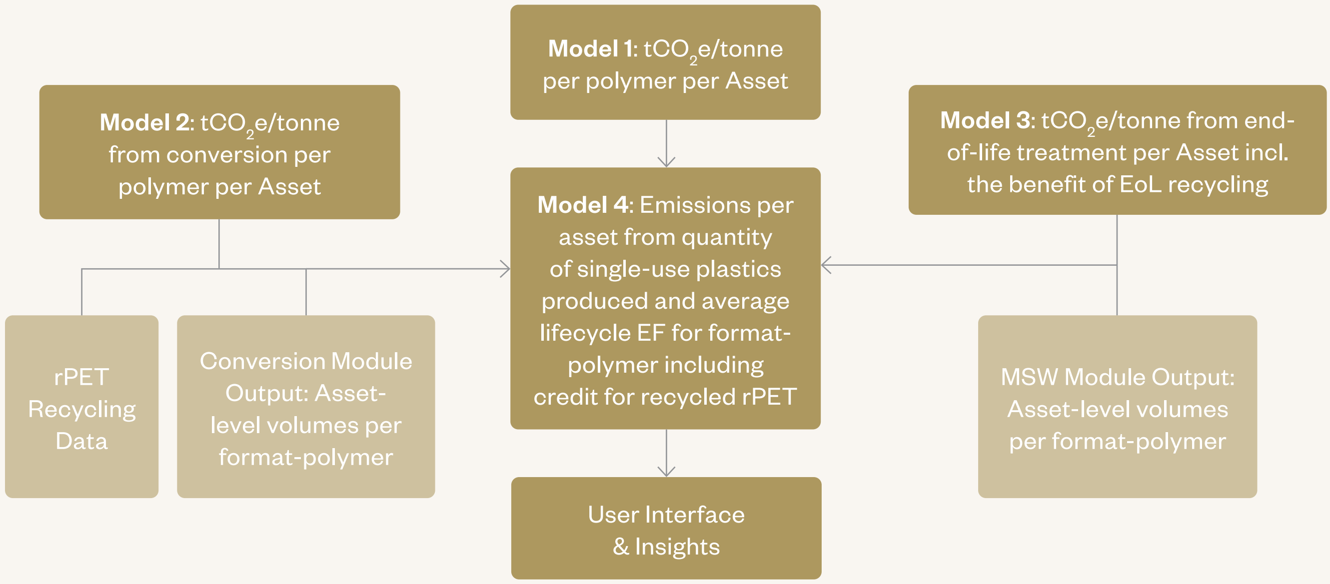
••

A refinery complex. Most lifecycle emissions from single-use plastics are produced by the oil and gas and petrochemical industries in the "upstream" part. Photo credit: Scott Barbour via Getty Images

4.2 Model overview

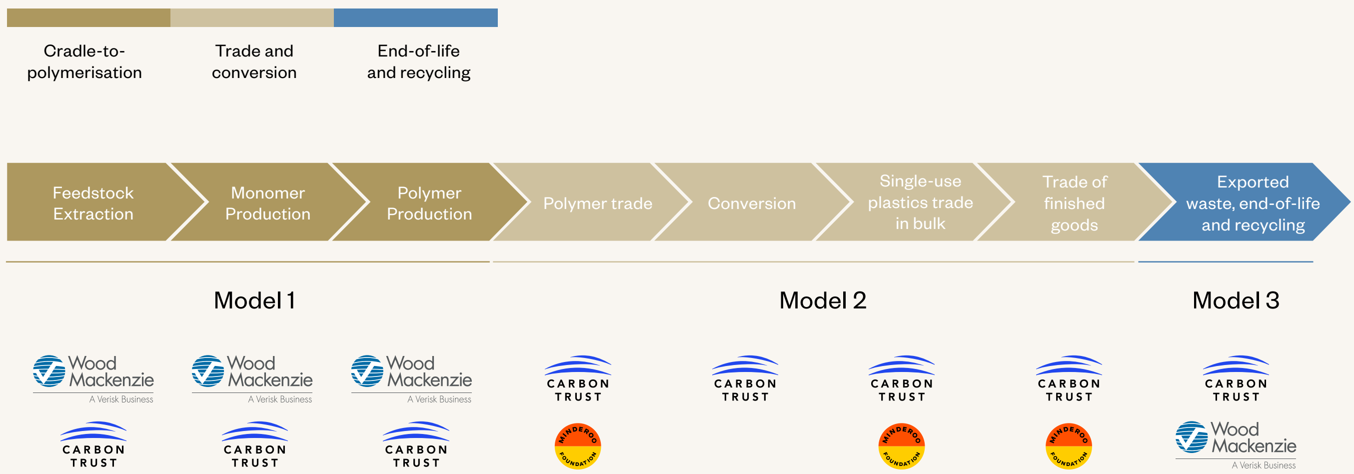
To build the cradle-to-grave footprint of single-use plastics, four Excel models were built with separate purposes to reduce the complexity of the model. That has been outlined in the figure below.

Figure 8: Models built to show the cradle-to-grave footprint of single-use plastics



4.2.1 Overall process and ownership

Figure 9: Overall process and ownership of the greenhouse gas footprinting



4.2.2 Baselining approach

This methodology was seen as unique in its field, and to ensure our approach was reasonable, we devised an expected value chain using research relevant to each stage of the value chain. Where a specific example was not available, we used comparisons from Carbon Trust's body of knowledge. This established a baseline hypothesis for the contribution for each lifecycle stage in line with our completed results.

Table 9: Estimated % contribution of greenhouse gas footprint for plastic production, trade and stages

Value Chain stage	Estimated % contribution	Source
Feedstock and Monomer production	30-50%	EcoInvent EF database
Polymer production	15-20%	Nature (2019)
Polymer trade	0-2%	Carbon Trust Estimate*
Conversion incl. Losses	15-30%	Nature (2019,2022)
Bulk packaging trade	0-2%	Carbon Trust Estimate*
Finished goods trade	0-1%	Carbon Trust Estimate*
Waste trade	0-1%	Carbon Trust Estimate*
End of life	2-10%	Nature (2019,2022)

*Definition of Carbon Trust estimate: This is an indicating average gauged by similar bulk transportation and similar product footprints to arrive at this average.

4.3 Feedstock Extraction, Monomer Production, Polymer Production (Model 1)

4.3.1 Model objectives

- Determine the Scope 1 and 2 GHG emissions from the Assets that produce in-scope polymers.
- Calculate the embodied carbon (upstream Scope 3) of the monomers that the Assets use.
- Calculate the GHG emissions such that the calculations are as specific to each individual Asset as possible.

4.3.2 Model approach

General Approach

The cradle-to-polymer footprint is done in three stages: feedstock extraction and refining, monomer production and polymerisation. Below we have outlined the process for feedstock, monomer production and polymerisation for each polymer.

This is translated to a mapping of activities linked to the outputs and factors applicable to calculate the emissions linked to each polymer from cradle-to-gate. The footprint is calculated from the emissions from the water, electric power, steam and thermal energy required for monomer production and polymerisation. For combustion for thermal energy, the efficiency is assumed constant at 90% for all fuels. For combustion for steam energy, the assumed global efficiency is 70% for coal and 80% for gas and fuel oil. These are factored into the regional emission factors. The combustion efficiencies are the proportion of useful heat to total heat. The second emissions source in cradle-to-polymerisation is process emissions. This is where losses in the chemical processes are flared, thereby also generating emissions.

Since there is a small loss in each chemical process, the feedstock and monomer formation emissions are uplifted to account for this loss before the monomer enters the asset. The mapping below illustrates the main data points used from feedstock to polymer.

*Definition of Carbon Trust estimate: This is an indicating average gauged by similar bulk transportation and similar product footprints to arrive at this average.

Figure 10: Process for feedstock, monomer production and polymerisation for six selected polymers

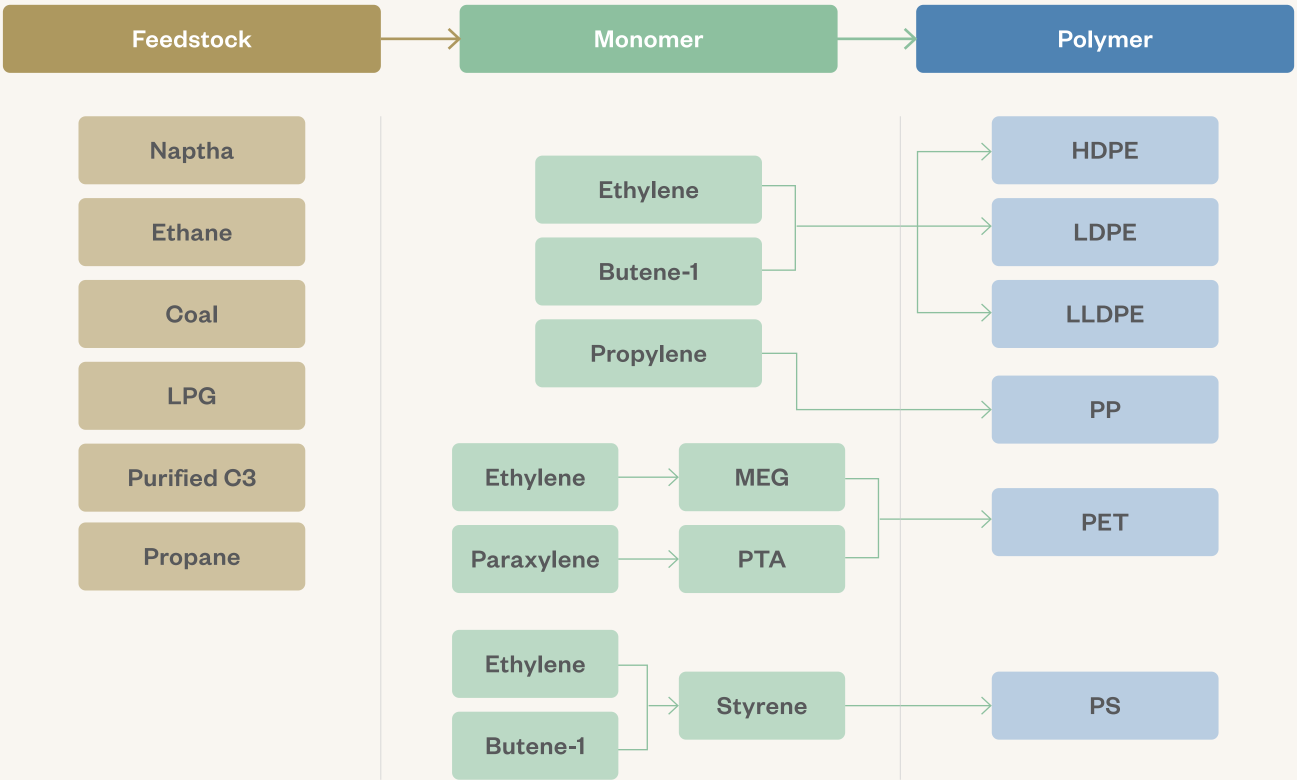
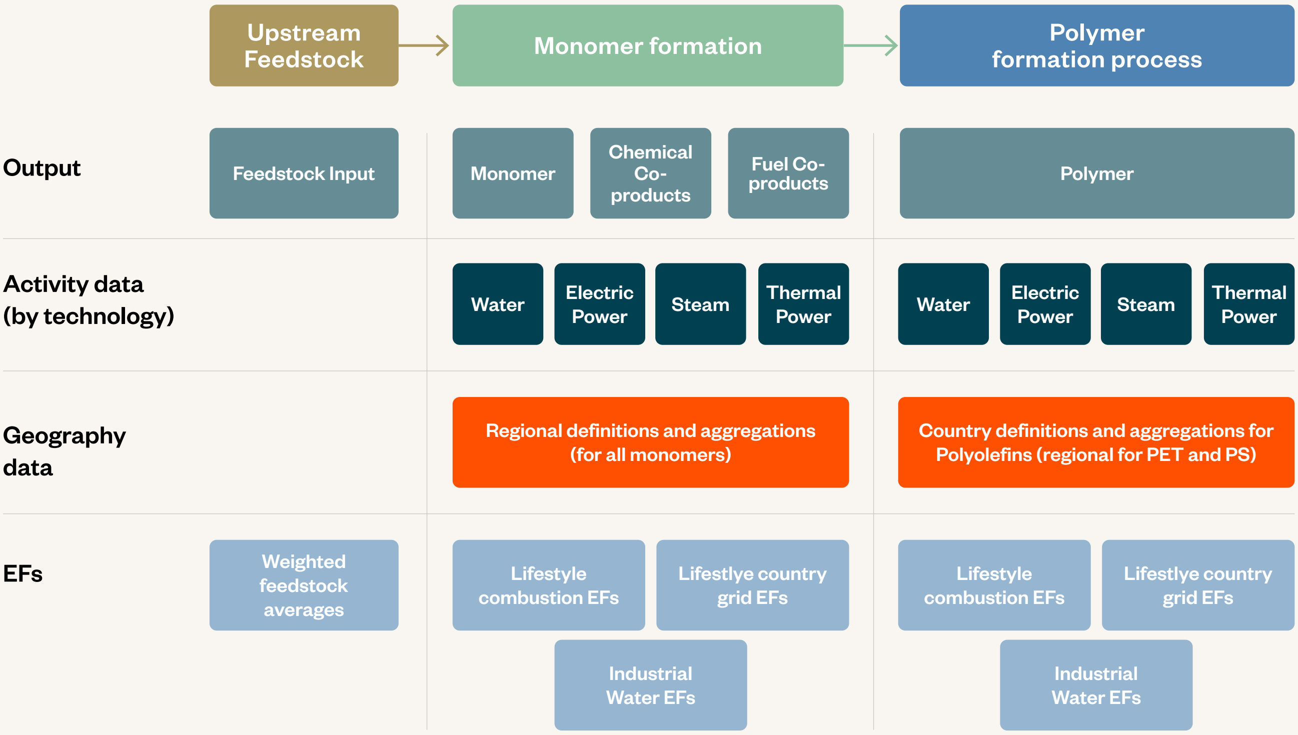


Figure 11: Mapping the main data points that illustrate the feedstock-to-polymer process



1. Polypropylene and polyethylene

Feedstock

For each region, a pre-provided feedstock emission factor that covers GHG emissions from extraction to the point of entering the monomer production plant is used. This is based on a calculation of the average feedstock mix used in monomer production plants in each asset's region. For propylene, the feedstock mix is weighted by that region's monomer production mix of propane dehydrogenation, refinery purification and steam cracking. For ethylene production, it is assumed that assets source it exclusively from steam cracking. The exception to these regional averages is assets that use the coal-to-olefin production route. These are assumed to exclusively use the coal-to-olefin technology and therefore use only coal as a feedstock. Hence, the feedstock emission factor in this instance is only from coal extraction.

Monomer production

For each region, an average monomer production emission profile is used. This profile is an average view of the energy and utility used for monomer production in that region. The profile also calculates the quantity of monomer yielded compared to the quantity of other chemicals (chemical co-products). To calculate energy and utility use for monomer production, a mass allocation approach is used. This allocates the energy and utility requirements proportionately to the mass of the different outputs produced through the monomer production technologies (e.g., steam cracking). The mass allocation only includes the co-products that are sold externally from the plant and not the co-products that are either used for further refining in the plant or fed back into the burner as additional fuel.

A comparison with emissions allocation by economic value was carried out and it was found that such approach could lead to significant regional differences as the prices of steam cracker outputs vary by region. The shortcoming of this approach would consequently be that GHG accounting would become dependent on regional fluctuations in the market value of chemicals. This would inhibit an inter-regional carbon intensity comparison.

The assumptions around how co-product fuels are used for ethylene and propylene are based on these principles:

- Ethane is assumed to always be combusted. This is because ethane is only a by-product of propane dehydrogenation (PDH) and is assumed that PDH plants have no use for ethane and do not produce it in sufficient quantities for it to have economic value.
- Methane is less valuable than hydrogen as a co-product and hence as a general principle it has been assumed that waste methane is more likely to be burned than hydrogen. Methane yield is weighted by the proportion of plants found in the European Commission (EC) study to use methane for fuel (as opposed to flaring it).
- Fuel oil is assumed to be combusted next (if an energy demand remains). This is again because hydrogen has the highest value so it is assumed to be used last as fuel.
- Hydrogen is used to cover any residual energy requirement. Similarly to methane, the proportion of hydrogen used for fuel is weighted by the average proportion of plants found in the European Commission (EC) study to use hydrogen for fuel (as opposed to flaring it, selling it or using it for hydrogenation processes).

For thermal energy produced with the co-product mentioned above, the assumptions around the emission factors are the following: combusting hydrogen is assumed to have zero emissions. When methane, ethane or fuel oil are combusted on site, the only emissions are the direct combustion emissions, e.g., the cradle-to-combustion is removed. The residual thermal energy not met with co-product chemicals is assumed to be a mix of natural gas and fuel oil following the industrial fuel mix in that region and is footprinted including combustion and cradle-to-combustion emissions. The monomer production emission factors for electricity and steam are a regional weighted average with weightings based on the proportion of monomer production in each country.

Assets in China that follow the coal-to-olefin/methanol-to-olefin route where olefins are produced through coal-based feedstock are assumed to derive thermal energy exclusively from coal. This assumption means that assets using this technology are far more emissions intensive than any other polyolefin-producing asset.

2. Polymerisation

Polypropylene and polyethylene consider calculations for all energy and utility inputs. This includes the full breakout of the different types of thermal heat production. These are then matched to the weighted regional emissions factors for steam and electricity, a global water factor, and the emissions factor for fuels mentioned above. All emissions factors are full lifecycle. For butene that is used in PE production, cradle-to-monomer emission factors from EcoInvent are used.

Polymerisation emission calculations for assets using coal-to-olefin technologies are calculated based on a generic polymer emission profile. Hence, these assets all have the same polymerisation emissions intensity, regardless of whether a PE asset produces HDPE, LLDPE or LDPE. This is an assumption based on expert interviews with the understanding this approach is more representative.

For non-Asia coal assets, the polymerisation inputs and process emissions are linked to the exact polymer produced for PE assets and the polymerisation technology used for PP. These are then footprinted based on the country grid emissions factor of the asset, a standard water factor and regional industrial fuel mix for steam generation.

The final cradle-to-polymer emissions are calculated by multiplying the cradle-to-polymer emissions intensity for the asset's production with the asset's production volume.

3. Polystyrene and PET

Cradle-to-monomer

For polystyrene and PET, a single emission factor was applied to the production of the monomers (styrene, mineral oil MEG and PTA) from the extraction of feedstock up until monomer production. These emission factors were sourced from EcoInvent. The emission factors were regional and were allocated based on a geographic specificity principle, where a regional emissions factor is assumed to more accurate than a global one, such that more geographically granular, regional emissions factors are used when possible.

Monomer trade

Across the six polymers footprinted, MEG, PTA and styrene are the only inputs into polymerisation that are assumed to be traded. This is because these chemicals are less volatile than ethylene and propylene. The trade matrix for MEG, PTA and styrene is built from Wood Mackenzie data that comes from the Global Trade Tracker. Hence, the cradle-to-monomer emissions factor for an asset depends on the trade patterns of the region it is located in. Each polymer producer is assumed to trade in the same way as its region.

4. Polystyrene

For polystyrene, asset-level data was not available for PS production within this study. Hence, a generic industry average for general purpose PS production is used. This means that all assets use the same monomer quantities and energy and utilities per tonne of PS produced.

The emission factors used for PS are the following: for water, we have used a global average based on an emissions factor for industrial water supply and treatment; for electricity, the country lifecycle grid factor is used; for thermal energy, the emission factor is a weighted average of thermal energy production based on the regional industrial mix of the asset's region. Steam is also footprinted with a weighted emissions factor by the regional industrial mix and is assumed to be high-pressure steam at 42 bars.

The results for PS assets are calculated based on the estimate of the production volume of PS assets. This multiplied by the asset's emissions intensity (based solely on carbon intensity of energy for the country and region) gives the total emissions for 2021 for the asset in question.

4.3.3 Assumptions and limitations summary

Feedstock extraction and refining

The lack of traceability into different grades of feedstock and different extraction technologies used to generate the feedstock that go into monomer production mean a global emission factor average is used for the emissions from extraction up until the gate of the monomer production plant.

Monomer production

Monomers output from steam crackers are often mixed in petrochemical industry park pipelines for distribution to downstream derivatives producers. Additionally, each asset has changing feedstock over time. It is hence argued based on expert interviews that using a regional/ sub-regional average yield and energy requirement provides the most representative data.

Polymerisation

The main limitation is that the efficiency of energy conversion is not modelled beyond the technology used by the asset. This is due to the availability of data in the public domain. A secondary limitation is that it is not possible to ascertain the exact carbon intensity of the assets used; the best proxy available is the grid mix and industrial heat mix for its country of location.

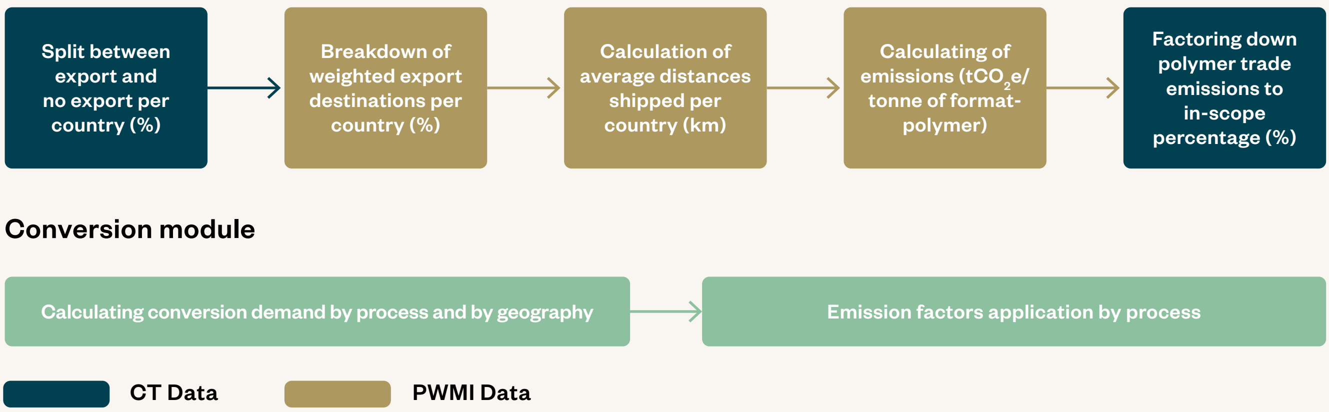
4.4 Polymer trade, conversion, bulk trade and finished products trade (Model 2)

4.4.1 Objectives

- Determine the GHG emissions from the conversion process per process and per geography.
- Determine the GHG emissions from the trade modules per polymer and per format-polymer, where trade includes the emissions associated with the logistics when the respective polymers leave the country.
- Calculate the emissions such that the calculations are aligned with the PWMI conversion module that tracks volumes.

4.4.2 Model approach

Figure 12: Trade Modules (Polymer Trade, Bulk Packaging, Finished Goods Trade)



Polymer trade, bulk packaging and finished goods trade

The mass of each phase was first divided by the material not assumed to have left the country and traded based on country specific demand and that exported.

Each country's relevant trade partners were defined by Minderoo supplied data where the trade matrix.

Each source country has an average distance calculated based on each traded country and sea freight emissions factor applied to resultant average distance the trade matrices were based on the data provided by Minderoo.

Each source country had an export emission assigned to is based on the average by using Carbon Trust's freight calculator the average distance factor creating a country specific trade factor per kg CO_2e/kg product was applied to determine the relevant trade emissions.

Example: 1 MMT of polymer traded from US to China. XX kg CO_2e/kg is multiplied by mass of the transported material.

The allocation approach for polymer and bulk packaging uses the polymer type to allocate back to the producing asset. With finished goods trade the polymer allocation is lost, meaning it is allocated back by absolute mass proportion produced by the asset.

Example: For every 1 MMT of polymer produced by Asset X, 2% of the total is traded through bulk packaging. So, 2% of the total trade emissions is attributed back to the polymer producing asset.

Conversion

Though the demand for each conversion process was split by country, the data available by a conversion plant was not available and an industry average had to be used. The following global EF considered the inputs as water, fuel electricity and heat and outputs of volatile organic compounds (VOCs) and other organics from the process.

For each conversion process, a global average for each process was used. There were cases where the process name did not match the exact process named. When this occurred the average emissions factor of a similar or analogous process was used or the average of the conversion process.

The total of all in-scope conversion emissions were attributed back the relevant polymer producing asset using the type of polymer and the percentage of the total polymer mass the asset had produced in proportion for the year.

4.4.3 Main assumptions and limitations

Trade

- It is assumed that goods are moved a fixed average distance dependent on the country. For each country a distance proxy for the truck/rail factory-to-port distance part of shipping has been used.

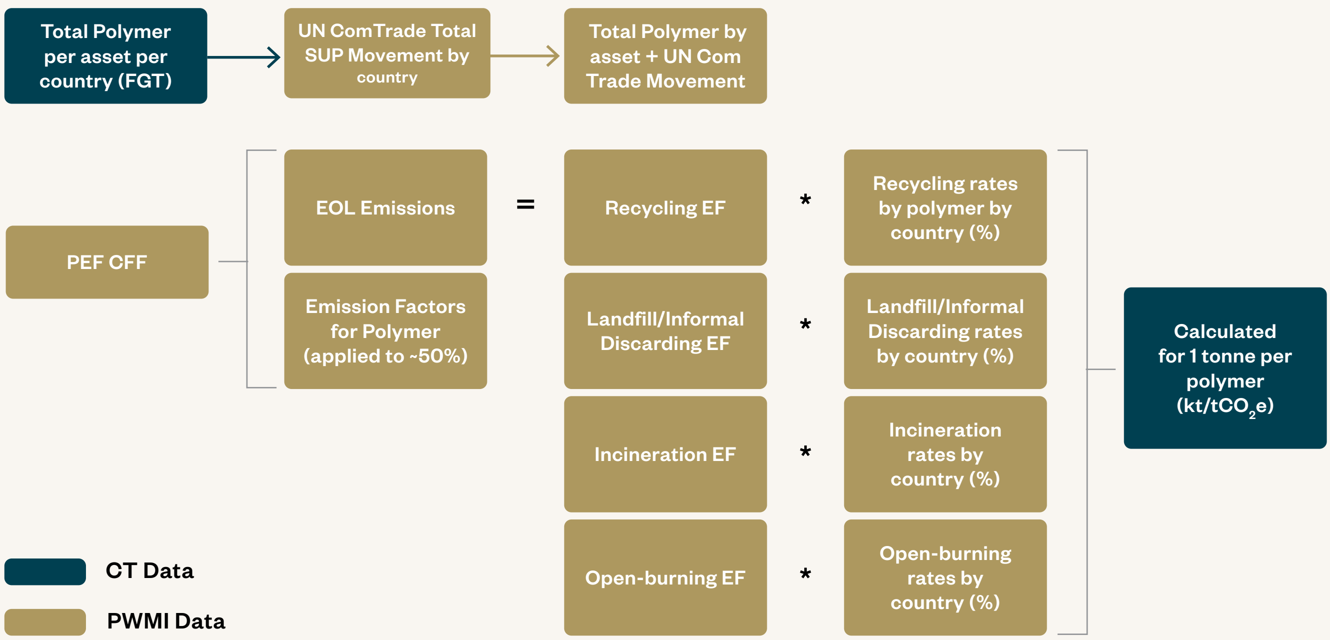
Conversion

- The data used is not at an asset level for conversion only by process.
- The traceability or availability of data on the process efficiencies, each process efficiency is assumed to be a global constant.

4.5 Exported waste, EOL, and recycling (Model 3)

4.5.1 Model approach

Figure 13: Model approach for calculating emissions within Model 3.



Within Model 3, Carbon Trust calculated emissions associated with each in-scope polymer per 1 tonne, this is then applied on an asset level. With data sources for recycling rates for each polymer by country (as provided by Wood Mackenzie), Carbon Trust further extrapolated the remaining end-of-life rates for landfill, incineration, open burning and leakage. These non-recycling rates have been modified based on the previous percentage to match each polymer.

Recycling is not assumed to be in a closed asset system, e.g., where a company ensures its PET production are recycled at end-of-life and then uses that as rPET input. Instead, it is assumed that companies source PET bales on the open market for recycling. This assumption means that the end-of-life recycling credit in Model 3 is applied equally for each polymer in each country regardless of which asset is attributed responsibility for production.

Emission factors for each have been calculated based on the research by Zheng and Suh[31] (2019) for each end-of-life route. Emission factors for end of life do not vary by country, recycling technology or polymer.

Carbon Trust also used UN Comtrade data to account for how waste is imported and exported. This data has been derived from data on "plastic waste". In order to obtain a comparison for single-use plastic, the import/export values have been scaled by an estimation of in-scope single-use plastics as a share of global plastics production.

The sum of the total finished goods of flexible and rigid per asset per country was assumed to be their final place of use. This combines with the waste that is made in the country to account for non-traded finished goods.

The assumption that one third of all plastic wasted is single-use sourced from the PWMI 2021 report was applied to UN Comtrade data to obtain single-use plastic traded waste. The waste being moved around from the top eight exporting countries represents over 75% of total exports of plastic waste, and therefore only the top eight exporters of plastic waste are looked at.

Using the assumption Afghanistan export to Australia in plastic we would move whatever percentage of plastic was moved of the total exported waste per the amount of polymer.

Example: If Afghanistan export 40% to Australia we would move 40% of the total polymer from asset 1 in Afghanistan to Australia.

To reconcile non-recycling rates where polymer supplied information didn't match country recycling rates the supplied recycling rate was applied at the country level then re-calculated landfill/leakage/incineration/open burn were readjusted in equal proportion to account f or new recycling rate figure.

Example: If 4% of HDPE is recycled in Albania, the original non-recycled rates would be to make up the 96% in the same proportions.

The calculated emissions tonne per tonne CO_2e (t/t CO_2e) applying the recycling and non-recycling rates to 1 tonne to work out the volume then applied the emission factors. Emission factors were sourced from the Nature paper and calculated the same way as before we then used the t/t CO_2e and proportioned by polymer back to the asset.

4.6 Results and analysis and recycling credit (Model 4)

4.6.1 Objectives

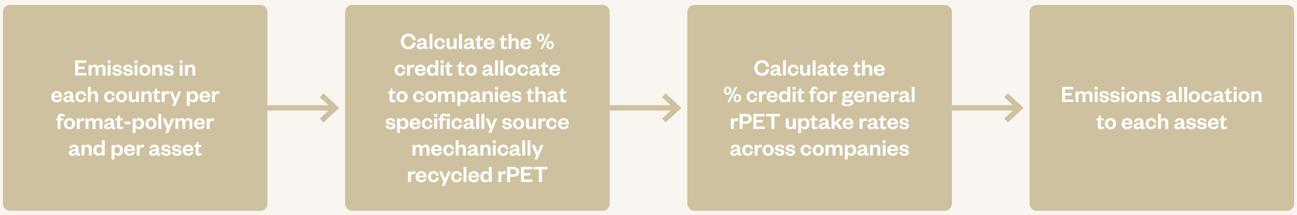
- Scale the emissions from Model 1 per asset based on the proportion of plastic output that becomes in-scope single-use plastic
- Allocate emissions from Model 2 and Model 3 to each individual asset by geography, polymer(s) produced and volume
- Structure outputs such that they can be used to create graphical insights for the report.

4.7 Modelling approach

Figure 14: Modelling approach for emissions allocation across all Models.

Emissions allocation from Model 1

Emissions allocation from Model 2 and Model 3



Model 1, Model 2, Model 3: Emissions input

These results from the sourced models are combined at an asset level and can be consolidated to producer level based on the data on ownership.

1. Producer Data: Asset ownership

The Producer Data sheet is copied from PWMI's producer aggregation model. It contains the ownership structure of every Asset including the Assets that are owned in joint venture structures with up to four owners.

2. Allocating Asset ownership

The Assets are matched to their owners based on the Producer Data input. Responsibility for each Asset's lifecycle emissions and in-scope production volume is calculated by multiplying these by each owner's ownership percentage. By aggregating by producer, the emissions and in-scope volume can be calculated across the Asset pool.

3. Recycled content allocation

The benefit of using rPET works in two steps in the calculations: specific companies with known capacity of procuring rPET for their plastic conversion facilities get credit for this distributed across all of their assets. Hence, this is a concrete benefit calculated for these companies that invest in rPET. However, there is also rPET that is not sourced by companies that also own PET production facilities (e.g., converters that do not own polymer production facilities). To account for this benefit in the value chain, every PET producer gets a small benefit from the general use of rPET in the value chain.

A similar approach would be followed for all other polymers in scope if rates and mass volumes were deemed non de minimis.

4. Overall recycling methodology

In PWMI, the Assets are the building blocks of the models. Production tonnage and emissions are allocated to each Asset, which are then allocated to the producers that own the Assets. Allocating recycled content consequently also has to be done at Asset-level for the impact of recycled content to be captured in the results. The only recycled content included in the model is mechanically recycled PET (rPET) and has been confirmed by Minderoo and the PWMI data to be 2 MMT. Of this 2 MMT, 0.6 MMT is producer specific and allocated to producers such as Indorama Ventures and Far Eastern New Century.

5. Benefit from recycling

The benefit (or credit) from recycling is the displaced emissions from producing virgin PET and end-of-life treatment such as incineration minus the emissions associated with recycling. The recycling benefit must be split between the company whose products are recycled at end-of-life, and those using this recyclate, it cannot be double counted. Under PEF CFF for plastics, 50% of the credit is allocated to company whose products are recycled and 50% to the company that uses recyclate.

6. rPET volumes

The volume of rPET is inputted in two ways: rPET that is not producer-specific and rPET that is producer-specific. Producer-specific in this context means the rPET is sourced by a specific company (a producer) that owns Assets. In these cases, the recycling credit can be allocated to the specific Assets that the producer owns. If the rPET is not producer-specific, then the credit for using recyclate is distributed across all PET assets proportionally to the volume that they produce.

7. Consolidated: rPET volumes

In the rPET Production Volume column, rPET volume is allocated to PET-producing Assets in two parts:

1. rPET that is not petchem-specific, i.e., rPET sourced by converters who do not own any of the Assets, is assumed to displace virgin PET proportionately to an Asset's share of global virgin PET production.
2. rPET that is petchem-specific, i.e., rPET volume purchased by companies that also own PET-producing Assets, is allocated only to those companies. The way this is done is to allocate a company's rPET volume to every Asset proportionally to the Asset's production volume as a share of the company's total PET production.

Example: An Asset that produces 0.3 MMT of in-scope PET. If a producer owns a third of that Asset and produces 10 MMT of PET in total, then that Asset is 1% of the producer's PET volume. If the producer sources 0.1 MMT of rPET then it is assumed that 1% of that Asset's volume will be from rPET. This is then added on to the general non-petchem-specific rPET volume from which every PET-producing Asset benefits to give the total rPET volume for each Asset.

8. Consolidated: rPET

Crediting the emissions with recycling, the rPET volume is multiplied by the PEF CFF credit allocation (50% to user of recyclate) and then by the upstream recycling credit, which is the difference between that PET asset's average cradle-to-polymer emissions intensity and the rPET recycling emission factor. It is therefore the key assumption that demand is constant and hence that the rPET volumes are displacing virgin production by the Assets. The rPET recycling emission factor is global. The credit from recycling is allocated as part of Model 3 and is hence part of the Model 3 emissions input into this model.

4.8 Main assumptions and limitations

For the results within model 4, assumptions and limitations are drawn from the sourced models with the addition of.

Recycled Content Assumptions

It is assumed that recycling has no implications for the emissions from other value chain stages, so the emissions from trade and conversion are assumed constant regardless of rPET recyclate.

Chemical recycling has been set to zero for the purposes of emission calculations.

4.9 Greenhouse gas footprinting: detailed assumptions and uncertainty factors

To provide an idea of uncertainty of the results a percent uncertainty has been applied based on the product footprinting approach called DQI (Data Quality Indicator) or data quality approach for Materiality and Emission Factors certainty. For each Life Cycle Stage, we have modelled each uncertainty in these terms weighting the assumptions and uncertainties in quantified terms.

Figure 15: Assumptions and uncertainty factors

4.9.1 Full model assumptions and limitations

Model 1:

Feedstock Assumptions

Aspect	Assumption
Emissions from feedstock extraction and refinery	Emissions from feedstock extraction and refining are based on a global average for each feedstock.
Upstream Feedstock breakdown used per asset (% naphtha, % ethane etc.)	The feedstock breakdown is provided at a regional level rather than at country or asset level.

Monomer Production Assumptions

Aspect	Assumption
Energy required to convert feedstock into monomer	It is assumed that the energy demand is constant based on the feedstock and technology. As this is given by a chemical process, the variability will likely be quite low. The energy required is determined also by the split of feedstock.
Emission factors for energy	Emission factors for monomer production have been aggregated into regional emission factors for electric, thermal and steam energy. This means that on aggregate, the data should be representative for a region but there may be variation by asset that is not being captured.
Assumptions around the energy conversion efficiency (% - useful energy/energy input)	Each process has an implicit assumption of efficiency for each energy type. Since the actual average efficiency will depend on all the sites that produce monomers for a region, there may be considerable differences beyond just the technology and region. Hence, it is assumed that each asset sources monomers that have been produced with regionally representative energy efficiencies.
Combustion emission factors for each fuel source (kgCO_2e/unit)	Global lifecycle EFs are used for coal, fuel oil, and other fuels. The WTT component of the EF is assumed to be globally representative, similar to the assumption around the emissions from the extraction of feedstock for monomerisation.
Non-energy input demand	It is assumed that the non-energy input is constant based on the feedstock and technology used.
Yields and losses (%)	It is assumed losses are insignificant and only depend on the choice of technology. All losses are flared.

••
A worker sorts out used nylon fishing nets at a warehouse in France that is specialised in the recycling and sale of plastic from nylon fishing nets. Photo credit: Fred Tanneau/AFP via Getty Images.

Polymer Production Assumptions

Aspect	Assumption
Technology route breakdown	The technology used for polymer production is asset-level for PP, PE and PET and regional for PS.
Energy required to convert monomer into polymer	The energy demand for polymerisation is process-specific and industry average. As a chemical process, the demand side of the energy requirement is probably stable.
Assumption around the sources of the energy required for polymerisation (e.g., coal, grid elec, etc)	The emission factors are country-level, rather than asset-level due to data limitations, as it is not possible to ascertain the energy mix used on site (particularly if assets use energy on site or from a local industrial energy supply). Instead, the best proxy is to use country-level data.
Assumptions around the energy conversion efficiency of the Asset (% - useful energy/ energy input)	Data is not available to determine efficiency of the Asset, e.g. data on upgrades, retrofits, scraps, etc. Hence, a general efficiency is embedded for each technology.
Combustion emission factors for each fuel source (kgCO_2e/unit)	Global lifecycle EFs are used for coal, fuel oil, and other fuels. The WTT component of the EF is assumed to be globally representative, similar to the assumption around the emissions from the extraction of feedstock for monomerisation.
Demand from any other non-energy input such as water	The technology used for polymer production is asset-level for PP, PE and PET and regional for PS. As a chemical process, the demand side of the energy requirement is assumed stable.
Yield	Losses are always assumed to be flared. Losses vary by technology used for polymer production which is asset-level for PP, PE and PET, but regional for PS.
Monomer trade	Each monomer supply chain is assumed to follow overall trade patterns for region in question. Hence, it is assumed that all Assets that produce PET for instance in a certain regions source PTA and MEG from around the world proportionately to overall trade patterns for that region. The traded monomers are assumed to be PX, PTA, MEG, and styrene. Ethylene and propylene are typically co-located with their downstream derivatives and hence not traded.

Model 2:

Aspect	Assumption
Assumption around the sources of the energy required for conversion	The emission factor is global and included within the conversion emissions factor but will not account for intra-country differences in the carbon intensity of energy as data.
Losses in conversion	Losses are assumed to be small and to be constant by each conversion process.
Trade distances	Average trade distances are calculated based on specific geographic points in each country and based on the PWMI trade matrices.
Transport type breakdowns	The breakdown in transport types is based on general assumptions between shipping/rail/ truck. The materiality of trade is very low.

Model 3:

Aspect	Assumption
Waste Exports - Shipping	Country level export data is applied proportionally for the polymer quantities by assets factored by the quantity of single-use waste compared to all plastic waste
Waste Trade - Domestic	CT developed a proxy for per country to apply to a % proportion of polymers sold in country (not exported)
Recycling Rates	Country level data on recycling rates are assumed to be accurate and include considerations of collection of the plastic waste.

4.9.2 Data references

Baselining approach

- Nature, 2019: Strategies to reduce the global carbon footprint of plastics, Nature Climate Change
- Nature Sustainability, 2022: Growing environmental footprint of plastics driven by coal combustion, Nature Sustainability
- OECD, 2022: Executive summary, Global Plastics Outlook: Policy Scenarios to 2060, OECD iLibrary (oecd-ilibrary.org)

Model 1:

- Wood Mackenzie supplied emission factors
- Strategies to reduce the global carbon footprint of plastics (2019)
- BEIS 2021 Greenhouse gas reporting: conversion factors 2021 - GOV.UK (www.gov.uk)
- IEA Emissions Factors 2021 - Data product - IEA
- PWMI Supplied data
- EcoInvent 3.8
- Academic Literature:
  - Z. Gholami, F. Gholami, Z. Tišler, and M. Vakili, 'A Review on the Production of Light Olefins Using Steam Cracking of Hydrocarbons', Energies, vol. 14, no. 23, p. 8190, Dec. 2021, doi: 10.3390/en14238190.
  - S. Madival, R. Auras, S. P. Singh, and R. Narayan, 'Assessment of the environmental profile of PLA, PET and PS clamshell containers using LCA methodology', Journal of Cleaner Production, vol. 17, no. 13, pp. 1183–1194, Sep. 2009, doi: 10.1016/j.jclepro.2009.03.015.
  - B. Young, T. R. Hawkins, C. Chiquelin, P. Sun, U. R. Gracida-Alvarez, and A. Elgowainy, 'Environmental life cycle assessment of olefins and by-product hydrogen from steam cracking of natural gas liquids, naphtha, and gas oil', Journal of Cleaner Production, vol. 359, p. 131884, Jul. 2022, doi: 10.1016/j.jclepro.2022.131884.
  - M. S. Masnadi et al., 'Global carbon intensity of crude oil production', U.S. Department of Energy Office of Scientific and Technical Information, 2018. [Online]. Available: https://www.osti.gov/pages/servlets/purl/1485127
  - I. D. Posen, P. Jaramillo, A. E. Landis, and W. M. Griffin, 'Greenhouse gas mitigation for U.S. plastics production: energy first, feedstocks later', Environ. Res. Lett., vol. 12, no. 3, p. 034024, Mar. 2017, doi: 10.1088/1748-9326/aa60a7.

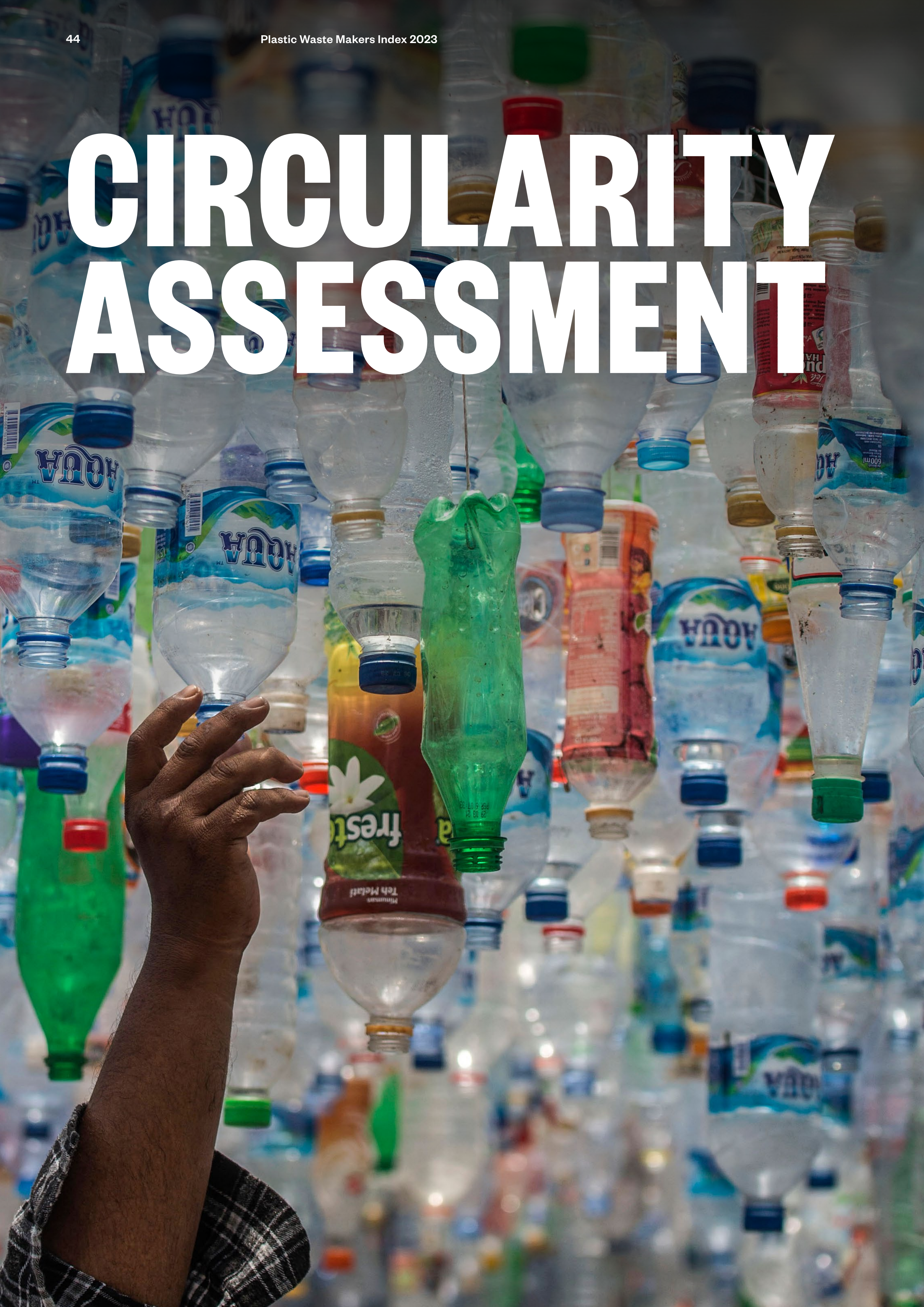
Model 2:

- EcoInvent 3.8
- PWMI Supplied data
- Carbon Trust proprietary transport emissions calculator

Model 3:

- PWMI Supplied data
- Wood Mackenzie Supplied Recycling Rates
- UN Comtrade Data

CIRCULARITY ASSESSMENT



5.1 Introduction

One output from the Material Flow Analysis is the estimated contribution to single-use plastic waste by each polymer producer. Complementary to this, we believe it is important to acknowledge whether and how these producers are responding to this problem. We have therefore conducted a Circularity Assessment (CA) to capture their response to the plastic waste problem through the adoption of circular economy principles and practices.

A circular economy is restorative and regenerative by design. This means materials constantly flow around a "closed loop" system, rather than a "linear" system. In the case of plastic, this means simultaneously keeping the value of plastics in the economy, without leakage into the natural environment.

Minderoo's Circularity Assessment aims to capture and rank the efforts of the world's largest producers of single-use plastics to embrace circular economy principles and, thereby, reduce their accountability for plastic pollution. The purpose of this exercise is to equip all stakeholders with an understanding of how producers of plastic polymers are responding to the plastic waste problem and, in turn, encourage greater commitment, engagement and progress.

A description of the methodology applied in the CA exercise is described in the following sections. The structure of the analysis is carried out in the following steps:

- Scope of the analysis.
- Approach to the Circularity Assessment.
- Conducting the Circularity Assessment.
- Partnering with the University of Oxford and Indian Institute of Technology, Delhi.
- Scoring and weighting.

An Indonesian activist from ECOTON (Ecological Observation and Wetlands Conservation) prepares an installation made with used plastic, including 4,444 bottles, collected from the river in Gresik, East Java, to raise public awareness of plastic waste in rivers and oceans. Photo credit: Juni Kriswanto/AFP via Getty Images.

5.2 Scope of the analysis

Scope

For this assessment, we have focused on the top 50 producers of single-use plastics (based on their 2021 production of the six in-scope polymers, as defined in the MFA), who collectively account for approximately 75% of global production. The exercise was designed to be undertaken "outside-in"– i.e., desk-based research based on public reports – and made specific to plastic polymer producers.

More than 40 of the top 50 producers are publicly listed companies, for whom disclosure of non-financial information (such as ESG topics) through sustainability and integrated reports is widely adopted. As a result, we assumed sufficient information to be available to assess producers' efforts to transition to circular models of productivity in response to the single-use plastic waste problem.

Investor Working Group

For the Circularity Assessment in Version 1 of The Plastic Waste Makers Index, we designed a set of questions based on Ellen MacArthur Foundation's (EMF) Circulytics survey. For Version 2, to strengthen the use-case of the Circularity Assessment benchmark, we engaged a number of investors and banks that are at the forefront of ESG investments to help refine the assessment criteria. We held one-on-one calls with seven financial institutions with a combined AUM of more than USD 6 trillion who provided technical input and expertise. We then held a roundtable discussion with the members of the Investor Working Group and played backed the feedback received from the one-on-ones as well as presented the refinements to the Circularity Assessment criteria for any final comments.

The outcome of our engagement with the Investor Working Group was a refined survey that includes the same five qualitative questions (Enablers) as last time on strategy, targets, infrastructure, customer engagement and supply engagement, along with four new questions on target ambition, risk management, management compensation and board oversight. On target ambition, we look ahead and account for the targets disclosed on recycled content made by the petchem industry and assessed the ambition level of these targets relative to virgin polymers production. We then categorised the nine questions into five themes: strategy, targets, infrastructure, external engagement and governance.

In addition, the two quantitative questions (Outcomes) in the survey remain unchanged, which assess the proportion of a company's inputs and outputs sourced from recycled, or other sustainable circular feedstocks, versus from linear fossil-fuels.

In Figure 16, we outline the eleven questions and highlight the updates. Together, these questions are intended to provide an indicative measure of the extent to which polymer producers are committed to and actively addressing the challenge of plastic pollution through transitioning to a more circular business model.

Figure 16: Question and answer grids used in Circularity Assessment of single-use plastic polymer producers (developed from EMF's Circulytics survey and the Minderoo Investor Working Group)

1A	**Is the company's strategy aligned with becoming more circular? Note: this covers both group strategy and sustainability strategy**
	1. No relevant mentions of circular economy for plastics
	2. Relevant concepts of circular economy principles for plastics are "loosely" mentioned
	3. Circular economy principles for plastics were specifically mentioned as part of the strategic priorities and/or as part of the group's core strategy pillars.
1B	**Does the company's organisational risk management include risks and opportunities related to the transition to a circular economy, and the risks of staying in a linear economy?**
	1. No
	2. Yes for some parts of the organisation
	3. Yes for majority of organisation
	4. Yes for entire organisation
2A	**Does the company have measurable circular economy targets?**
	1. No targets
	2. Targets are being developed either for a relevant concept (e.g. materials circulation) or circular economy explicitly
	3. Targets developed on overall organisation level, but are not SMART targets
	4. SMART targets developed on organisation level
	5. SMART targets developed on organisation level and further down on sub-unit (e.g. business unit or region) level
2B	**What is the circularity target (as a percentage of virgin production)?**
	1. No targets by 2025 or 2030
	2. 5-year target (e.g., by 2025)?
	3. 10-year target (e.g., by 2030)?
3	**To what extent does the company have suitable infrastructure in place to support a circular business model?**
	1. No plans in place to reconfigure existing or configure new infrastructure to support a circular business model
	2. Companies that are in the process of developing pilot plant projects or are investing in R&D to minimize plastic waste
	3. Capital expenditure plan has been reviewed and/or new infrastructure has been designed to prepare the shift to a circular business model
	4. Reconfiguration of existing infrastructure or development of new infrastructure have started in order to support a circular business model
	5. All infrastructure is suitable for circular business models
4A	**To what extent does the company engage with suppliers to increase sourcing based on circular economy principles?**
	1. No interactions involving circular economy as a topic
	2. Ad-hoc interactions involving circular economy as a topic
	3. Ongoing programme with one or more of the top five suppliers by mass using circular economy principles
	4. Ongoing programme with all of the top five suppliers by mass using circular economy principles
	5. Supplier requirements based on circular economy principles, as specified in contracts, are in place with all of your top five suppliers by mass
4B	**To what extent does the company engage with customers on advancing circular economy topics?**
	1. No interactions involving circular economy as a topic
	2. Ad-hoc interactions involving circular economy as a topic
	3. Ad-hoc interactions involving circular economy as a topic AND a plan in development for an ongoing programme using circular economy principles (e.g. collaboration in communicating the benefits of products and services based on circular economy principles)
	4. Ongoing programme using circular economy principles with any customer
	5. Ongoing programme using circular economy principles with the majority of customers
5A	**To what extent is management compensation linked to circular business model initiatives (strategies/commitments/progress)?**
	1. No compensation is linked to circular business model initiatives
	2. Share of management compensation is linked to circular business model initiatives
	3. Share of management compensation is linked specifically to circular business model initiatives for plastics
5B	**Does the company provide evidence of oversight and responsibility for circularity commitments at Board level?**
	1. There is no evidence of sustainability oversight at board level
	2. There is a Board committee with sustainability in its mandate along with other business critical functions (e.g., Audit & Risk)
	3. There is a Board committee dedicated specifically to sustainability
	4. There is a Board committee dedicated specifically to circularity
6	**For materials (renewable and non-renewable) suitable for the technical cycle, what % of the materials inflow (physical material that comes into the company's manufacturing processes) is:**
	• Non-virgin (including reused and recycled products and materials)
7	**What % (by mass) of the total outflow of materials (renewable and non-renewable) suitable for the technical cycle is materials processing waste or by-products that go to landfill or incineration or downcycled (and are therefore not closed-loop)?**

5.3 Conducting the Circularity assessment

We partnered with PhD and MBA candidates from the University of Oxford and the Indian Institute of Technology, Delhi, to conduct the assessment. Three students conducted the assessment and answered questions one to five through desk-based research and publicly available information. The research focused on reviewing annual reports, sustainability reports, and company press releases. In instances where a company has multiple subsidiaries, they focused the analysis on group-level reporting. A source was included to each answer in the underlying model, which outlines the report and page number or link to a press release or website page.

It is important to note for these questions that they assessed a company's response to the plastic waste problem specifically, using circular economy principles. There were several instances where companies have disclosed information and outlined commitments to reduce greenhouse gas emissions, energy consumption, water consumption, and waste produced at site, but fell short of mentioning any commitments or targets relating to plastic leakage specifically. While we are encouraged by the level of commitment by many polymer producers to reduce their impact on climate issues, this exercise was scored solely on a company's performance with respect to circular practices related to plastics.

Questions 6 and 7 were answered with reference to the Material Flows Analysis section and other publicly available data sources.

Below is a table outlining the eleven questions split across five themes and the scoring associated for each answer. For a definition of terms used when applying the answer grid, see Section 6 – Definitions: Circularity Assessment.

Question 1 (a): Is the company's strategy aligned with becoming more circular?

This question focused on the group's overall strategy as well as its sustainability strategy.

- Where there was no mention of circular economy principles for plastic waste in either strategy, then the company received a score of 0%.
- Where relevant concepts of circular economy principles for plastic waste were "loosely" mentioned, i.e. where a company seeks to play an important role in the circular economy for plastics, then the company received a score of 50%.
- The company only received a score of 100% where we believed circular economy principles for plastics were specifically mentioned as part of the strategic priorities and/or as part of the group's core strategy pillars.

Question 1 (b): Does the company's organisational risk management include risks and opportunities related to the transition to a circular economy, and the risks of staying in a linear economy?

This question focused on the group's risk management against the risks and opportunities presented with the linear and circular economy.

- Where there was no mention of risk management procedures or materiality frameworks, then the company received a score of 0%.
- Where there was risk management procedures and frameworks for some parts of the organisation, then the company received a score of 33%.
- Where there was risk management procedures and frameworks for the majority of the organisation, then the company received a score of 67%.
- Where there was risk management procedures and frameworks for the entire organisation, then the company received a score of 100%.

Question 2 (a): Does the company have measurable circular economy targets?

This question focused on the group's development and disclosure of SMART circular economy targets for plastics: Specific (clearly defined), Measurable (expressed with a number), Achievable (ambitious but not unrealistic), Relevant (the target talks about circular economy concepts) and Time-bound (there's a deadline to achieve it).

- Where no targets on circular economy principles for plastics were mentioned, then the company received a score of 0%.
- Companies that had targets at an organisational level but were not SMART targets received a score of 50%, e.g. double the company's PET bottle recycling rate, without a specific time frame given.
- Companies that had SMART targets at the organisation level and sub-unit level received a score of 100%.

Question 2 (b): What is the circularity target (as a percentage of virgin production)?

This question focused on measuring the ambition of the SMART targets based on a timeframe and as a share of the company's total virgin production. We only factored in 5- or 10-year targets that were clear and unambiguous on circular plastics, i.e, volume or share of plastic polymers produced from recycled waste or polymers made from alternative materials that are genuinely sustainable sourced and biodegradable (e.g., in marine environment).

- Where there were no SMART targets, then the company received a score of 0%.
- Where there was a 5-year target (e.g., by 2025 or 2026), then this was taken as a share of total virgin

production. Given this is more ambitious than a 10-year target, we adjusted the scoring by 2.5x to bring it in-line with a 10-year target.

- Where there was a 10-year target (e.g., by 2030), then this was taken as a share of total virgin production.
- Where a company had both a 5-year and 10-year target then the average was taken.

Question 3: To what extent does the company have suitable infrastructure in place to support a circular business model?

This question focuses on infrastructure that supports circular economy principles for plastics.

- Companies received a score of 0% where there were no plans to reconfigure or develop infrastructure that supported circular economy principles for plastics.
- Companies that are in the process of developing pilot plant projects or are investing in R&D to minimise plastic waste received a score of 25% or 50% depending on the stage and timeline.
- Companies received a score of 75% if new or existing infrastructure has been configured or designed to support circular economy principles for plastics, e.g. building a plant to produce PET from post-consumer waste.
- Companies received a score of 100% if all infrastructure is already suitable for circular business models for plastics.

Question 4 (a): To what extent does the company engage with suppliers to increase sourcing based on circular economy principles?

- To score a company based on their engagement with suppliers, which, to increase sourcing based on circular economy principles, we looked at joint venture agreement and partnerships. In our view, this includes engagement with waste management and recycling companies. e.g., recycling initiatives with suppliers for increasing recycled content into the polymer production process. Where there was no evidence of interactions with suppliers on circularity for plastics, then the company received a score of 0%.
- Where we came across evidence of ad-hoc interactions with suppliers plus a plan in development with one supplier then the company received a score between 40-60%.
- Where ongoing programmes with all suppliers, as specified in contracts, was in place for all of their top five suppliers, then the company received a score of 100%.
- We intentionally did not include a question on company membership with circular economy related initiatives as we do not believe we are in a position to make a judgement on the effectiveness of these initiatives. That said, where companies are members of circular economy related initiatives (e.g., Alliance to End Plastic Waste), we gave companies the benefit of the doubt and the company received a score of at least 20% for Question 4.

Question 4 (b): To what extent does the company engage with customers on advancing circular economy topics?

To score a company based on their engagement with customers, we took a similar view to Question 4 (a).

- Where there was no evidence of interactions with customers on circularity for plastics, then the company received a score of 0%.
- Where we came across evidence of ad-hoc interactions with customers plus a plan in development with one customer then the company received a score of 50%.
- Where ongoing programmes with the majority of customers was in place then the company received a score of 100%.

Question 5 (a): To what extent is management compensation linked to circular business model initiatives (strategies/commitments/progress)?

This question looks at the level of accountability for management based on the level to which circular business model initiatives is linked to their compensation.

- Where no compensation is linked, then the company received a score of 0%.
- Where a share of compensation is linked to circular business model initiatives, then the company received a score of 50%.
- Where a share of compensation is linked to circular business model initiatives specifically for plastics, then the company received a score of 100%.

Question 5 (b): Does the company provide evidence of oversight and responsibility for circularity commitments at Board level?

This question looks at the level of board oversight and responsibility for circularity commitments, and specifically looked at the board committees.

- Where there is no evidence of sustainability oversight at board level, then the company received a score of 0%.
- Where there is a Board committee with sustainability in its mandate along with other business critical functions (e.g., Audit & Risk), then the company received a score of 33%.
- Where there is a Board committee dedicated specifically to sustainability, then the company received a score of 67%.

- Where there is a Board committee dedicated specifically to circularity, then the company received a score of 100%.

Question 6: For materials (renewable and non-renewable) suitable for the technical cycle, what % of your materials inflow (physical material that comes into your manufacturing processes) is non-virgin (including reused and recycled products and materials)

To calculate the percentage of materials inflow that are non-virgin, i.e. materials that have been previously used such as recycled products, we considered the recycling capacity of polymer producers.

Detailed data on recycling capacity at a company level was available mechanical recycling of PET and polyolefins, as well as for chemical/advanced recycling of in-scope polymers.

To calculate the recycled input capacity for polymer producers, we used Wood Mackenzie's recycling capacity database for polymer producers operating or in partnership with recycling facilities for PET, polyolefins, polystyrene and chemical recycling.

Regarding PET, and given that PET fibre is out-of-scope (textiles are not considered as single-use plastics), we only considered rPET capacities for bottle-to-bottle as these were considered single-use plastic applications, similar to those under our scope in the Material Flow Analysis. The below formula was used to calculate the materials inflow percentage of non-virgin materials for a company:

$$\text{Non-virgin material inputs (\%)} = \frac{\text{Recycled production (kt)}}{\text{Total polymer produciton (kt)}}$$

Question 7: What % (by mass) of your total outflow of materials (renewable and non-renewable) suitable for the technical cycle is materials processing waste or by-products that go to landfill or incineration (and are therefore not recirculated)?

Question 6 estimates the percentage of non-virgin plastic feedstock flowing into the production cycle, which is ultimately controlled by the company and hence we use company-level production capacity rates.

Question 7, on the other hand, estimates the percentage of plastic flowing out of the production cycle that is not recycled in the country where the plastic eventually ends up. We therefore account for country-level recycling rates for Question 7.

To calculate the percentage material outflows, we used global recycling rates for PP, PS, HDPE, LDPE, and LLDPE at a country level, where possible.

- The European Commission has recycling rates for the 27 countries in the EU for PP, HDPE, and LDPE/LLDPE.[32]

- OECD provided recycling rates for PP, HDPE, and LDPE/LLDPE for the US and Japan.[33]

- Where recycling rates for individual countries was not found, we used the global recycling rates for PP and PE, which are 2% and 4%, respectively, as sourced by Wood Mackenzie. This, in our view, is acceptable as recycling rates in countries outside of EU, Japan, and US are not likely to have recycling rates materially higher than the global rates.

Regarding PET, we used Wood Mackenzie's global supply and demand model for rPET bottle food-contact consumption. Wood Mackenzie developed a supply and demand model for rPET for every country of the world that has PET demand exceeding three thousand tonnes and for countries which have production facilities. Trade flows for the plastic waste trade are also included in the model, however, for the purpose of simplicity, we have not considered trade flows into our analysis as they represent less than two percent of global PET bottle consumption.

1. To calculate the PET recycling rate in-country, we used the following formula

$$\text{PET recycling rate (\%)} = \frac{\text{rPET food grade consumption (kt)}}{\text{Total PET production (kt)}}$$

2. These country recycling rates for PP, PS, PE, and PET were then applied to our SUP model at the individual asset level, for both rigids and flexible plastics. The SUP model is generated in the Material Flow Analysis (section 3.9) and estimates what percentage the single-use plastic waste produced by each asset ends up where, on a country-by-country basis. This method considers the recycling rates of each country where the percentage of waste produced by each asset ends up.
We use the formula below.

$$\text{SUP of asset x recycled in country y} = \text{SUP of asset x in country y} \times \text{recycling rate of country y}$$

3. We then summed up the total SUP recycled for an asset in each country to calculate the total SUP recycled for a polymer producer. We then divided this number by the total SUP production to estimate the percentage of materials outflow that ends up as waste.

$$\text{Materials outflow recycled (\%)} = \frac{\text{Total SUP recycled (kt)}}{\text{Total SUP production (kt)}}$$

4. Question 7 is asking for the percentage of materials outflow that is not recirculated and hence we must carry out an additional step, as per the formula below.

$$\text{Materials outflow not recycled (\%)} = 1 - \text{Materials outflow recycled (\%)}$$

Triangulation of assessment

Three researchers conducted the assessment for questions one to five independently (questions one to five were answered via desk-based research) for the top 50 producers over the course of five weeks in August/September 2022.

A project team meeting between Minderoo and the researchers was held to discuss the results. After comparing the results, there were approximately 30 scores (out of 500) that had a difference in scores of more than 1 point. A discussion was then had on these large discrepancies and source documentation reviewed again by the project team, with a final score determined by the project team lead. Where there was a difference of 1 point between the scores, an average of three scores was taken.

5.4 Scoring and weighting

To create an overall score, the five Enabler themes were together given the same weighting as the two Outcome scores, thus giving an equal importance to commitments, policies and practices, as to achievement of circular business.

Each of the five themes in Enablers were assigned equal weighting, i.e., 10%. Compared to last time this meant that some questions were assigned a lower weighting as new questions were added, which is the case for strategic priorities, target disclosure, customer engagement and supplier engagement (each now worth 5% versus 10% last time). (**Figure 17**).

This time round, we also recalibrate our scoring for the Outcomes. On Question 6, we take a more realistic approach and recalibrate scoring so that companies with a 50% or more recycled content achieve an A grade, which is based on preliminary EU 2025 target of 50% recycled content for packaging. On Question 7, we excluded country-level PET recycling rates for downcycling and only included on par (bottle-to-bottle) recycling rates for PET.

Finally, we also recalibrate our weighting for Outcomes – we place greater weighting on efforts by petchems to source post-consumer plastic waste as a feedstock as this is ultimately in their control, and companies doing good today in a challenging circular plastics system deserve credit. (**Figure 18**).

Percentage scores were also converted into a letter score from A-E – A score of 'A' implies a fully circular business model or practice, while a score of 'E' implies a fully linear business model or practice. (Table 10).

Figure 17: Refinements and overall scoring weighting

2019: Enablers

10% Strategy

10% Targets

10% Infrastructure

10% Supplier Engagement

10% Customer Engagement

Outcomes

25% % Recycled inflows

25% % Recycled outflows

5 questions

1. Strategy
2. Targets
3. Infrastructure
4. Supplier engagement
5. Customer engagement

2021: Enablers

10% Strategy

10% Targets

10% Infrastructure

10% External Engagement

10% Governance

Outcomes

33% % Recycled inflows

17% % Recycled outflows

9 questions

1. Strategy
   A. Strategic priorities
   B. Risk management
2. Targets
   A. Target disclosure
   B. Target ambition
3. Infrastructure
4. External engagement
   A. Supplier
   B. Customer
5. Governance
   A. Compensation
   B. Board oversight

Figure 18: Changes and rationale to Outcomes methodology.

	Current Methodology	Concerns	Changes
Question 6: % recycled inflows	• Companies are scored from 'A' to 'E' based on recycled content of 0-100% (recycled polymer production as a share of total polymer production	• Companies that are doing good are not being fairly rewarded – i.e., recycled content of 90% or more only achieves an 'A' grade, which is unrealistic	• Recalibrate scoring – recycled content of 50% or more achieves an 'A' Grade (based on preliminary EU 2025 target of 50% recycled content for packaging)
Question 7: % recycled outflows	• For PET producers, we apply country-level PET flake recycling rates, which includes closed-loop and downcycling	• Companies are achieving a high grade where countries have high PET flake to fibre recycling rates, i.e., downcycling	• Apply closed-loop bottle-to-bottle recycling rates only
Weighting of Q6 & Q7	• 50% weighting for Q6 • 50% weighting for Q7	• Companies have more control over feedstock inputs (Q6) and far less control over what happens to product at end of life (Q7) • Giving equal weight to both feels like insufficient credit for individual efforts of companies (Q6) versus collective effort (Q7)	• 67% weighting for Q6 • 33% Weighting for Q7

Table 10: Conversion of percentage scores into grade scores.

Lower limit	Upper limit	Letter
88.89	100	A
77.78	88.89	A-
66.67	77.78	B
55.56	66.67	B-
44.44	55.56	C
33.33	44.44	C-
22.22	33.33	D
11.11	22.22	D-
0	11.11	E

Bales of recyclable materials at a facility. Photo credit: AzmanL via Getty Images.

VALUE AT RISK

The extent of potential financial losses within a company and financial portfolio based on their exposure to single-use plastic waste – which are outlined in earlier sections – is difficult to quantify. As such, we have developed a methodology that provides some guidance on the magnitude of risk facing petchems.

At a high level, we have identified which petchems are more or less at risk based on two indicators: (i) their share of group revenue from single-use plastics; and (ii) the potential for negative impact from policy headwinds on single-use plastics revenue based on their primary export markets.

A view of the beach of the coastal town of Zouk Mosbeh, north of Beirut, covered with garbage and waste that washed and piled along the shore after stormy weather. Photo credit: Joseph Eid/AFP via Getty Images.

6.1 Calculating single-use plastics polymer revenue

Most producers of single-use plastic polymer are part of diversified oil & gas and/or (petro)chemical companies with multiple business units and streams of revenue – of which single-use plastics is only one. In general, their parent companies do not split out and report results for business units that map to our definition (i.e., the production of the six in-scope polymers defined in the MFA); and even where there is consistency at the reported level, there is no public market valuation of the relevant business unit.

Estimating polymer producers' revenues from single-use plastics

We took the contribution to SUP waste from each in-scope production asset, in tonnes, and then estimated the revenue of the SUP at the individual asset level following three steps:

1. Each of the 1,400 assets were mapped to country, sub-region and regions.
2. Average 2021 Polymer prices in USD for each country, sub-region, and region (where available) were sourced from Nexant.
3. Production volume from each asset was multiplied by relevant average polymer price for the relevant country (or sub-region, or region, where not available).

The output of this analysis is therefore an estimated revenue figure for each asset. An illustrative example can be seen in the table below.

Table 11: Example of asset-level estimated revenue generated from SUP

Asset ID	Polymer	Operator	Producer	Country	Sub-Region	Region	2021 SUP (kt)	2021 Revenue (USDm)
2	LDPE	Local company A	Company A	Canada	North America	Americasv	24.8	37
4	LLDPE	Local company B	Company B	Canada	North America	Americas	124.2	160
5	LLDPE	Local company C	Company C	Canada	North America	Americas	172.5	222
6	LLDPE	Local company D	Company D	Canada	North America	Americas	314.0	405

The revenue figures at the asset level were then aggregated to estimate the SUP revenue figures at the producer level. 1,400 in-scope polymer production assets are operated by nearly 500 unique local companies, which are in turn owned by over 300 unique global producers.

6.2 Estimating negative impacts from policy headwinds

We estimate the negative impact on single-use plastics revenue based on two things: (i) primary sales market exposure for petchem selling their polymers; and (ii) a judgement on the policy headwinds in place in those sales markets, which we have split into three buckets:

- **Prohibitive regulation**, e.g., bans, which we think has a low impact on virgin polymer demand as bans tend to be on the fringes and target only a specific product, but impact on total plastic volume is minor;
- **Economic**, e.g., taxes, levies, which achieves a medium score as it incentivises users to adapt but effectiveness depends on implementation and historically it has done little to impact recycled market share, as we have seen in Europe; and
- **Standards**, e.g., recycled content, which we think has a high impact as it forces sector-level change and provides incentives recycled resins upstream.
  Bringing this together we assign an overall high, medium, and low numerical score for the different policies based on how effective they are at reducing demand for virgin polymers. This is highlighted below.

Figure 19: Estimated negative impact on single-use plastics revenue

i Primary sales market exposure; and

Exposure to sales markets per producer = % of resin converted in each of 8 regions

X

ii Weighted average impact of policy headwinds in their primary sales markets
Each region is assigned a score based on impact of policy headwinds...

Policy headwinds	Impact on virgin polymer demand	Rationale	Score
• **Prohibitive regulation,** e.g., bans	• **Low**	• Typically targets only a marginal sub-segment of specific products, e.g., straws or bags, and does not always factor in the environmental impact of alternatives	1
• **Economic,** e.g., taxes, levies, EPR	• **Medium**	• Incentivises users and producers to adapt their behaviour, but effectiveness is dependent on implementation and historically has done little to impact recycled vs virgin market share, e.g., in Europe	2
• **Standards,** e.g., minimum recycled content targets	• **High**	• Forces sector-level change and provides incentives for recycled resins upstream in direct correlation with ambition level of targets and timeline	3

Using PEW/Duke University 2022 Annual Trends in Plastic Policy: A Brief[34] we assign a policy score to each region and then calculate a weighted average score based on where the petchem sells their polymers across eight regions and assign a high, medium or low risk rating to each region based on the following ranges for weighted average scores:

- Less than 1.5 is low
- Between 1.5 and 2.0 is medium
- More than 2.0 is high

As an example, we can go through Company A, which exports 40% of their polymer to North America, 23% to Europe and so on. Each region is assigned a policy score, e.g., Europe scores a 3 given they are implementing minimum recycled content standards, which will have a high impact on virgin polymer demand. We then calculate a value for each region based on export share and policy score and calculate a weighted average score. In the case of Company A, it receives a weight average score of 2.0 and hence is medium risk rated.

Figure 20: Value calculations for each region based on their export share and policy score

	Export share	Policy score[1]	Value
North America	40%	2	0.8
Europe	23%	3	0.7
China	10%	1	0.1
Asia (ex. China)	11%	2	0.2
Africa	2%	1	0.0
Latin America	12%	1	0.1
Middle East	3%	1	0.0
Oceania	0%	1	0.0

X =

= **weighted score of 2.0 (medium)**

DEFINITIONS

Acronyms

ACC PIPS	American Chemistry Council Plastics Industry Producers' Statistics
C&I	Consumer & Institutional
CA	Circularity Assessment
EMF	Ellen MacArthur Foundation
EPA	Environmental Protection Agency
ESG	Environmental, Social and Governance
EU	European Union
F&O	Financing & Ownership
GDP	Gross Domestic Product
GHG	Greenhouse Gas
HDPE	High-Density Polyethylene
IPO	Initial Public Offering
LDPE	Low-Density Polyethylene
LLDPE	Linear Low-Density Polyethylene
MFA	Material Flow Analysis
MMT	Million Metric Ton
MSW	Municipal Solid Waste
MSW-P	Municipal Solid Waste Plastic
OECD	Organisation for Economic Co-operation and Development
PA	Polyamide
PET	Polyethylene Terephthalate
PP	Polypropylene
PPPM	Polymer-Process-Product Matrix
PS	Polystyrene
PU	Polyurethane
PVC	Polyvinyl Chloride
rPET	Recycled Polyethylene Terephthalate
SMART	Specific, Measurable, Achievable, Relevant, and Time-Bound
SUP	Single-Use Plastic
UN	United Nations
US	United States
USD	United States Dollar
WM	Wood Mackenzie

Producer definition

Below we outline Minderoo's definition of a producer and the link between assets, operators, and owners.

Assets: Wood Mackenzie provided a global asset production database of in-scope polymers (PP, HDPE, LDPE, LLDPE, PS and PET Resin) for 2021. The database comprises of 1,400 unique asset names, with a combined total production of in-scope polymers of 230MMT. An asset is a production site where hydrocarbons are converted into plastic polymers.

Operator: The assets are operated across 500 unique operator names, which has also been provided by Wood Mackenzie. Operators are locally-incorporated companies that run the assets.

Owner: Wood Mackenzie also provided the ownership structure of the operators. Profundo then verified, and corrected, where necessary, the ownership structure of the operators, using Orbis as the source.

Producer: Our definition of a producer is detailed below. The definition of a polymer producer is any company that either:

i) directly owns 100% of an operator, or

ii) directly part-owns multiple operators.

In addition, financial institutions are not considered to be polymer producers. The financial institutions stake in an operator is assigned to the operator itself, who, as a result, is therefore considered to be a producer. Furthermore, where a non-financial organisation partly owns one operator only, their stake is therefore also assigned to the operator itself.

As an example of (i), Dow owns 100% of Dow Chemical Canada (an operator) and is therefore considered a producer.

As an example of (ii), Mesaieed Petrochemical Company has a 49% stake in Qatar Chemical Company Ltd. - (Q-Chem) and a 49% stake in Qatar Chemical Company II Ltd. - (Q-Chem II). Mesaieed directly part-owns multiple operators and therefore is considered a producer.

On the contrary, Pushineh Polymer Industrial Group only part-owns one operator, its 36% stake in Laleh Petrochemical Company, and hence is not considered a polymer producer. Pushineh's 36% stake is therefore assigned to the operator, Laleh Petrochemical Company, who in turn is considered a producer.

Similarly, Justice Shares Broker directly part-owns multiple operators e.g. 15% in Ilam Petrochemical Company and 30% in Marun Petrochemical Company. However, given that Justice Shares Broker is considered a financial institution, we assign its stakes to the operators, who in turn are considered to be producers.

Circularity Assessment

Below is a definition list, which, in parts, has been lifted from the EMF's Circulytics survey[35].

Question 1 – Strategy and risk

Circular economy principles:

- Design out waste and pollution
- Keep products and materials in use

Strategy:

- The current strategy of your company for a 5-year (or similar) period.

Strategic priorities:

- The next level of detail within the overall strategy, usually 3-5 priorities in total.

Question 2 – Targets

Measurable circular economy targets:

- Targets that are quantifiable (i.e. target is expressed with a number) and have a clear deadline i.e. limited by a date). SMART target defined below.

SMART targets:

- Refers to targets that are Specific (clearly defined), Measurable (expressed with a number), Achievable (ambitious but not unrealistic), Relevant (the target talks about circular economy concepts) and Time-bound (there is a deadline to achieve it).

Question 3 – Infrastructure

Infrastructure:

All PPE assets (property, plant, and equipment). The physical infrastructure with a use period of one year or more that allows for circular way of doing business. For a petrochemical company this could be: waste collection; sorting; recycling (mechanical + chemical); re-design for recyclability/biodegradability; alternative circular materials Note: The infrastructure does not necessarily need to be purpose built. Existing infrastructure is acceptable if it is capable of supporting a circular way of doing business.

Questions 4 – External engagement

Suppliers:

Any company you procure from (can be more than one step upstream).

Ongoing programme:

Regular engagement with relevant stakeholders oriented around a formal agreement between parties to realise pre-defined objectives.

Customers:

Any company or individual you sell, lease, or rent to (can be more than one step downstream).

Question 5 – Governance

Compensation:

Discipline of determining a director/management pay and benefits.

Board:

An executive committee that jointly supervises the activities of an organisation.

Management committee:

Group of people who are held accountable for the activities of the organisation.

Questions 6 & 7 – Input and output

Materials (renewable and non-renewable) suitable for the technical cycle:

That can be used, reused/redistributed, maintained/prolonged, refurbished/remanufactured, or recycled. This includes all non-renewable materials such as metals, plastics, and synthetic chemicals, as well as renewable materials that are designed to be part of the technical cycle, such as wood and cotton. Note that this category also includes materials of biological origin that are used as reactants in chemical processes (e.g. vegetable oil for plastics) and that form the basis of another materials or products that behave as technical material (e.g. pulp for paper).

Non-virgin:

Material that has been previously used, including reused, refurbished, repaired, remanufactured, and recycled products, components, and materials.

Renewable:

Material that can be continually replenished.

Materials sourced from regeneratively managed resources:

Materials grown in ways that improve whole ecosystems, including by increasing soil health and carbon content, water quality, and biodiversity. The concept goes beyond retaining the status quo of natural systems and extends to improving their health and capacity to regenerate themselves.

Material sourced from sustainably managed resources:

The material was grown in a way that preserves the ecosystem status quo without degrading it further, but falls short of being regenerative. Sustainable sourcing is considered a transition stage towards a regenerative way of managing renewable materials sourcing.

By-products:

An inevitable secondary result of materials processing, while recognising all byproducts can be feedstock for another production.

Waste:

Unwanted or unusable materials or substances, while recognising all waste can be feedstock for another production.

Renewable energy sources:

Energy (electricity, heat, and fuel) is renewable if it is:

- Non-biomass based renewable sources:
  - Solar
  - Wind
  - Hydro (land-based, tidal, and wave)
  - Geothermal
- Biomass based energy that is 1) from a regeneratively/sustainably grown source and derived from residues and/or by-products when using virgin material, or 2) processed from by-products/waste streams. This excludes incineration for energy recovery, except when all the following conditions are met:
  - Other end of life options for the material, besides landfill, has been demonstrably exhausted;
  - The material is from a biological source;
  - The biological material is demonstrably traceable to a source of renewable and regenerative production;
  - The biological material is completely uncontaminated by technical materials, (including coatings, preservatives, and fillers except when these are demonstrably inert and non-toxic), and other biological materials which do not adhere to these restrictions;
  - Energy recovery is optimised to extract the maximum practical net energy content from the material and is usefully employed to displace non-renewable alternatives;

  The by-products of the energy recovery are themselves 100% biologically beneficial (e.g. as a soil conditioner), and are not detrimental to the ecosystems to which they are introduced.

ENDNOTES

1. Ryberg M et al. 2018, Mapping of global plastics value chain and plastics losses to the environment, United Nations Environment Programme. Available from: https://wedocs.unep.org/handle/20.500.11822/26745

2. Lebreton L et al. 2019, Future scenarios of global plastic waste generation and disposal, Palgrave Commun. 5, pp. 1–11. Available from: https://doi.org/10.1057/s41599-018-0212-7

3. Lau W et al. 2020, Evaluating scenarios toward zero plastic pollution, Science Vol. 369, Issue 6510, pp. 1455-1461. Available from: https://science.sciencemag.org/content/369/6510/1455/tab-e-letters [8 January 2021]

4. Jambeck J et al. 2015, Plastic waste inputs from land into the ocean, Science, vol. 347, no. 6223, pp. 768-771. Available from: https://science.sciencemag.org/content/347/6223/768

5. Kaza et al. 2018, What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050, World Bank. Available from: https://openknowledge.worldbank.org/handle/10986/30317 [8 January 2021]

6. Ibid.

7. Lau et al. 2020, Evaluating scenarios toward zero plastic pollution.

8. Ryberg et al. 2018, Mapping of global plastics value chain.

9. Environmental Protection Agency 2021, National Overview: Facts and Figures on Materials, Wastes and Recycling, United States Government. Available from: https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/national-overview-facts-and-figures-materials [8 January 2021]

10. Hsu W.-T. et al. 2020, How circular are plastics in the EU?: MFA of plastics in the EU and pathways to circularity, Cleaner Environmental Systems. Available from: https://doi.org/10.1016/j.cesys.2020.100004.

11. Smith F 1975, A Solid Waste Estimation Procedure: Material Flows Approach., U.S. Environmental Protection Agency (SW-147). Available from: https://nepis.epa.gov/Exe/ZyPDF.cgi/2000QPOD.PDF?Dockey=2000QPOD.PDF [8 January 2021]

12. R. Geyer, J.R. Jambeck, and K.L. Law 2017, Production, Use, and Fate of All Plastics Ever Made, Science Advances, vol. 3, no. 7. Available from: https://dx.doi.org/10.1126/sciadv.1700782. [8 January 2021]

13. Lau et al. 2020, Evaluating scenarios toward zero plastic pollution.

14. Geyer et al. 2017 , Production, Use, and Fate of All Plastics

15. Ibid.

16. International Trade Centre 2021, Trade statistics for international business development. Available from: https://www.trademap.org/Index.aspx

17. Lau et al. 2020, Supplementary Materials for an Integrated global model and scenario analyis of plastic pollution. Science (80-.). 369, 1255–1461. Available from: https://science.sciencemag.org/content/suppl/2020/07/22/science.aba9475.DC1

18. American Chemistry Council 2020, Plastics 101, American Chemistry Council. Available from: https://plastics.americanchemistry.com/Plastics-101/ [8 January 2021]

19. Plastics Europe 2019, Plastics – the facts 2019, Plastics Europe. Available from: https://www.plasticseurope.org/en/resources/publications/1804-plastics-facts-2019

20. Ibid.

21. Ibid.

22. Lau et al. 2020, Evaluating scenarios toward zero plastic pollution.

23. Lund S et al. 2019, Globalization in transition: the future of trade and value chains, McKinsey Global Institute. Available from: https://www.mckinsey.com/featured-insights/innovation-and-growth/globalization-in-transition-the-future-of-trade-and-value-chains

24. Ibid.

25. World Bank Integrated Trade Solution 2021, International merchandise trade, tariff and non-tariff measures data. Available from: https://wits.worldbank.org/

26. To be advised

27. Jambeck J et al. 2015, Plastic waste inputs from land into the ocean

28. Ryberg M et al. 2018, Mapping of global plastics value chain

29. Kaza et al. 2018, What a Waste 2.0

30. Formosa Plastics Corporation 2019, Annual Report, pp. 169. Available from: http://www.fpc.com.tw/fpcwuploads/files/2019_1301_20200610.pdf

31. Zheng, J., Suh, S. Strategies to reduce the global carbon footprint of plastics. Nat. Clim. Chang. 9, 374–378 (2019). https://doi.org/10.1038/s41558-019-0459-z

32. Circular Plastics Alliance 2020, Plastic Packaging Collection and Sorting, European Commission, pp. 10. Available from: https://ec.europa.eu/docsroom/documents/43694 [8 January 2021]

33. OECD 2020, Improving Markets for Recycled Plastics: Trends, Prospects and Policy Responses, OECD. Available from: https://read.oecd-ilibrary.org/environment/improving-markets-for-recycled-plastics/summary-of-polymer-specific-data-from-oecd-questionnaire-responses_9789264301016-20-en#page1 [8 January 2021]

34. PEW/Duke University 2022. Annual Trends in Plastic Policy: A Brief. Available from: https://nicholasinstitute.duke.edu/sites/default/files/publications/Annual-Trends-in-Plastics-Policy-A-Brief_2.pdf [25 September 2021]

35. Ellen MacArthur Foundation 2020, Circulytics method introduction, Ellen MacArthur Foundation. Available from: https://www.ellenmacarthurfoundation.org/assets/downloads/circulytics-method-introduction.pdf [8 January 2021]