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Material flow analysis of plastics in Australia: Towards a circular economy of polymers

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ABSTRACT

Plastic is a critical material in Australia, widely used across industries for its versatility and cost-effectiveness. However, the growing volume of plastic waste, amounting to 3201 kt in 2020–21, poses significant environmental challenges. Only 13 % of plastic waste was recycled, while 81 % was sent to landfill, 1 % energy recovery and 5 % exported. This study examines the lifecycle of plastics in Australia, including production, consumption, waste generation, and recycling practices. Employing Material Flow Analysis (MFA) combined with Environmentally Extended Input-Output (EEIO) analysis, we trace the flows of major plastic types, identify systemic inefficiencies and reginal disparities in recycling. Results show that 77 % of the 1280 kt of virgin polymers consumed were imported, with polyethylene (HDPE and LDPE) being the most common type, followed by PVC and PP. The manufacturing and construction sectors together account for 84 % of total plastic consumption. Regional patterns vary considerably. New South Wales and Victoria report the highest plastic use, reflecting population size, while recycling rates differ widely. South Australia achieves a 20 % recycling rate, whereas the Australian Capital Territory recycles only 0.1 % locally due to the absence of recycling facilities. Of the total plastic waste recycled, 46 % was reprocessed domestically, and the remainder exported, highlighting gaps in local recycling infrastructure. These findings underscore the urgent need to improve Australia's recycling capacity and practices. Strengthening domestic infrastructure is essential for mitigating environmental impacts and advancing towards a circular economy of plastics.

1. Introduction

Plastic is a versatile and widely used material, valued for its durability, lightweight properties, and affordability. However, its extensive use has contributed to a mounting environmental crisis: plastic pollution. Global life-cycle greenhouse gas (GHG) emissions from plastics are estimated at approximately 1.7 Gt CO_2e yr^{-1}, surpassing emissions from the global aviation sector (Rikhter et al., 2022). Global plastic production has grown markedly, from 299 million tonnes (Mt) in 2013 (Geyer et al., 2017; Ritchie et al., 2023; Stegmann et al., 2022) to 400 Mt in 2022 (Plastics Europe, 2023). If current trends continue, annual global plastic production is projected to reach 590 Mt by 2050 (IEA, 2022).

The Global Plastics Outlook OECD (2022) reports that 350 Mt of plastic waste are generated annually (Ritchie et al., 2023). Managing this growing waste stream poses substantial environmental and human health risks (Abbasi et al., 2023; Di et al., 2021; Heller et al., 2020; Jang et al., 2020). Despite global efforts to mitigate plastic pollution, projections suggest that the growth in plastic waste will outpace mitigation efforts (Borrelle et al., 2020).

In 2019, only 9 % of global plastic waste was recycled, 19 % was incinerated, and nearly 50 % was disposed of in landfills (OECD, 2022; Ritchie et al., 2023). In the United States, less than 8 % of plastic waste is recycled, with most ending up in landfills (Heller et al., 2020). By contrast, the European Union reported a significantly higher average

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recycling rate of 32.5 %, reflecting differences in disposal costs and policy frameworks (Chawla et al., 2022). Norway exhibits mixed performance: although 25 % of plastic waste is sorted for recycling only 9 % of recyclates are utilized domestically. Nevertheless, Norway has set ambitious targets to recycle 50 % of plastic packaging by 2025 and 55 % by 2030 (The Norwegian Ministries, 2022).

Recent material flow analyses highlight challenges in plastic circularity across regions and sectors. In India, only 13 % of 15.5 million metric tons (Mt) of plastic waste was recycled in 2018–19, despite production of 19.3 Mt, mainly used in packaging, textiles, and construction (Emami et al., 2024). In the EU, 37 Mt of plastic waste from 73 Mt of consumption in 2016 was largely not returned to production (Hsu et al., 2021). Portugal shows low circularity in plastic packaging, with just 11 % recycled input (Gonçalves et al., 2024). In Germany, surgical hospitals use 531 g of polymers per patient daily, mainly polypropylene (45 %) and latex (25 %), highlighting sector-specific challenges (Ivanović et al., 2022).

In Australia, plastic waste has a very low recovery rate, around 15 %, with the majority (84 %) sent directly to landfill (ABS, 2020). More recent estimates indicate that the recycling rate for plastic waste was 14 % in 2021, based on a multi-regional Waste Input-Output model (Fry and Schandl, 2024). Regional differences in recycling practices reflect not only cultural and historical differences in environmental stewardship, but also the presence of specific industries within each region. Addressing these variations is critical for transitioning to a circular economy and achieving sustainable materials management (Ackerman and Levin, 2023).

Globally, governments are using regulatory and economic instruments to promote plastics circularity. The European Union's *Single-Use Plastics Directive* and proposed *Packaging and Packaging Waste Regulation* establish bans on problematic items, mandatory recycled-content targets, and extended producer responsibility (EPR) schemes (European Commission 2017; Geng et al., 2019). Similar EPR systems in Canada, Japan, and South Korea make producers financially accountable for collection and recycling, often using eco-modulated fees to reward design for recyclability (OECD, 2022). Economic levers such as landfill levies and recycled-content mandates, alongside sustainable procurement, are helping create markets for secondary plastics.

Despite these efforts, persistently low recycling rates in many countries are attributed to inadequate infrastructure and high costs (Murti et al., 2022). Moreover, multilayer plastic packaging made up of different material layers provides valuable benefits for product storage but presents significant challenges for recycling (Rezvanian et al., 2025; Seier et al., 2024). Plastics such as polystyrene (PS) and polyvinyl chloride (PVC) are especially problematic in packaging due to recycling inefficiencies and contamination risks and should be phased out of packaging use (Novakovic et al., 2023). PVC remains widely used in construction, where legacy additives like lead pose ongoing challenges. Studies have found high lead concentrations in older PVC materials and project continued presence in end-of-life products without stricter recycling controls (Hahladakis et al., 2018; Schmidt et al., 2024; Turner and Filella, 2021). Continued low recycling rates highlight the need to transition to more recyclable materials like PET, PP, HDPE, and LDPE, alongside improved packaging design (Novakovic et al., 2023; Seier et al., 2024). South Korea recycles only 13.5 % of plastic packaging waste from households, despite having EPR policies. Strengthening regulations and upgrading recycling systems are essential to reduce environmental and climate impacts and advance a circular economy (Jang et al., 2020). The Netherlands and Taiwan similarly provide effective models for strengthening plastic recycling infrastructure and advancing circular economy policy (Calisto Friant et al., 2022; Lai and Lee, 2022; Wu et al., 2021).

However, large-scale progress in addressing plastic pollution remains limited, prompting negotiations for a Global Plastics Treaty at the United Nations Environment Assembly in March 2022 (Dreyer et al., 2024). The UN Plastics Treaty Nature (2024) underscores the urgency of reducing plastic production and consumption, promoting sustainable product design, and strengthening recycling and waste management systems. Anchored in circular economy principles, the treaty aims to minimise waste, extend the lifespan of plastic products, and foster innovation in eco-friendly alternatives to conventional plastics (Velenturf and Purnell, 2021).

Understanding recycling rates for specific polymer types, such as polyethylene terephthalate (PET), high-density polyethylene (HDPE), and PVC, is critical for identifying materials with high recovery potential and those requiring targeted interventions. Yet, reliable data on plastic usage across sectors and polymer specific recycling rates remains scarce (Lau et al., 2020). Such data gaps hinder the development of effective, targeted strategies to address plastic waste. Without detailed insights into plastic flows within industries such as packaging, construction, automotive, and consumer goods, designing robust recycling programs and policies remains challenging.

Australia's approach follows the same direction but relies more on voluntary and co-regulatory mechanisms. Key instruments include the *National Waste Policy* (DCCEEW 2024a), *Recycling and Waste Reduction Act* 2020 (DCCEEW, 2021), and *National Plastics Plan* (DAWE, 2021), complemented by state-level single-use plastics bans and container deposit schemes (Gelling, 2023). While these provide a strong framework, Australia has yet to implement a mandatory national EPR or recycled-content standard, though recent consultations signal movement toward stronger, nationally consistent measures (DCCEEW, 2024b).

Hossain, et al. (2022) compiled data on the use of major plastic types across states in Australia, identified key waste sources, and explored challenges and opportunities in transitioning to a circular economy. However, their analysis excluded materials such as rubber and textiles and offered limited insight into inter-state plastic flows. Understanding these flows is vital for uncovering regional patterns in plastic consumption, recycling, and waste management, which are crucial for developing effective, region-specific interventions.

Moreover, inconsistencies and inadequacies in regional policies often constrain progress in plastic waste management (Shin et al., 2020). While some jurisdictions have implemented stringent regulations and innovative solutions, others lag due to economic constraints and competing priorities. For example, China's 2018 ban on imported plastic waste (Brooks et al., 2018) disrupted global recycling systems, exposing the vulnerabilities of a fragmented approach to plastic waste management. These disparities highlight the pressing need for a cohesive, cradle-to-cradle, global strategy to combat plastic pollution (Alex Scott, 2021). Coordinated efforts at multiple scales could enhance resource efficiency and contribute to the development of a circular economy.

In this study we employ plastic material flow analysis (MFA) to gain detailed insights into the movement of plastics within socio-technical systems by quantifying inputs, outputs, and stocks of plastic materials. This enables to identify intervention points to enhance the efficiency and effectiveness of plastics materials management (Millette et al., 2019; Van Eygen et al., 2018).

The main research questions addressed in this study are:

1. What are the quantities of polymers and plastics circulating within the Australian economy across all stages of their life cycle, and how are these distributed across jurisdictions, sectors, and polymer types?
2. How do these quantities and patterns compare in an international context?
3. What regional differences can be observed among Australia's States and Territories?
4. What insights can be derived regarding intervention points for closing material loops and enhancing circularity?

By analysing plastic consumption, waste generation, and recycling rates, MFA helps pinpoint areas for reduction and improvement, facilitating the setting of waste reduction targets, increased recycling, and the adoption of sustainable practices. To complement the physical data, we also apply input–output (IO) method to estimate embodied plastics in plastic products and capture indirect flows across sectors. IO method is particularly valuable in addressing data gaps and revealing the connections between different economic activities, providing a more comprehensive understanding of plastic use and distribution throughout the Australian economy.

Millette et al. (2019) and Eygen et al. (2018) emphasise MFA's potential to uncover opportunities for circular plastic flows, such as utilizing plastic waste as feedstock and evaluating the environmental performance of various waste management scenarios. These findings demonstrate the role of MFA in guiding strategies to reduce plastic mismanagement, promote circularity, and support the transition to a sustainable, zero plastic waste economy.

This study provides the first comprehensive overview of plastic flows in Australia, categorised by six major polymer types and other plastics, across key lifecycle stages including production, manufacturing, consumption, and waste management. To address the limited understanding of regional variations in plastic flows, we also estimated flows across eight Australian states and territories. By identifying commonalities and divergences in plastic consumption patterns, this analysis enables stakeholders to coordinate efforts and implement more effective strategies to combat plastic pollution at a national scale.

2. Method and data

2.1. Material flow analysis

This study applied Material Flow Analysis to quantify plastic flows and stocks in Australia for the year 2021, following the mass-balance principle (Brunner and Rechberger, 2016; Fischer-Kowalski et al., 2011). The analysis disaggregates flows by polymer type, sectoral application, and region, covering Australia's six states and two territories. The MFA framework encompassed six major polymers: high-density polyethylene (HDPE), low-density polyethylene (LDPE), polyethylene terephthalate (PET), polyvinyl chloride (PVC), polypropylene (PP), and polystyrene (PS). It also included an additional category for other plastics, such as basic plastics, rubber, and plastic products. Flows were modelled across five key stages: (1) production of virgin polymers from petrochemical feedstocks (including local production and imports), (2) processing into intermediate plastic materials (including post-consumer resins), (3) manufacturing of plastic products across nine economic sectors (agriculture, mining, construction, manufacturing, utilities, retail and trade, transport, services, and government/health/education), (4) in-use stocks within the socioeconomic system, and (5) end-of-life waste management pathways. Table 1 summarises the processes and industrial sectors included across the plastics lifecycle.

Plastic waste was categorised into four treatment pathways: landfill, energy recovery, recycling, and export. Two recycling metrics were distinguished: the *local recycling rate* (the proportion of plastic waste recycled within Australia) and the *overall recycling rate* (including both domestic recycling and exports for reprocessing overseas).

The model integrated data from national production and trade statistics (UN Comtrade, 2024), sectoral consumption data, and waste management report (Farrell et al., 2022). Plastic product lifespans and sectoral allocation were informed by literature values and Australian-specific datasets. Regional flows were estimated to account for intra- and inter-state consumption and trade.

Plastics consumption and net addition to stock were calculated based on material flow relationships across the polymer life cycle, from virgin polymer production to end use and waste generation. The calculations followed the framework outlined in Equations 1 - 5.

$$\text{Virgin Polymers} = \text{Local Virgin Polymers} + \text{Imports} - \text{Expots} \tag{1}$$

$$\text{Intermediate Polymers} = \text{Virgin Polymers} + \text{Imports} - \text{Exports} + \text{Recycling} \tag{2}$$

$$\text{Plastic Products} = \text{Intermediate Polymers} + \text{Imports} - \text{Exports} \tag{3}$$

$$\text{Plastic Consumption} = \text{Plastic Products} + \text{Imports} - \text{Exports} \tag{4}$$

$$\text{Net Addition to Stock} = \text{Plastic Consumption} - \text{Plastic Waste} \tag{5}$$

Equations (1) - (4) describe the sequential flow of plastic materials through the supply chain, accounting for both domestic production and international trade at each stage. Eq. (5) represents the net addition to stock (NAS), defined as the portion of plastic materials that remain in use within the economy (e.g., in buildings, vehicles, and durable goods) after subtracting the amount of plastic waste generated. This approach enables consistent estimation of in-use plastic stocks and flows, facilitating comparison across sectors and over time.

2.2. Data collection

Plastic flows were estimated across the entire value chain, from production and imports to end-of-life management. Data sources included import and export records, domestic production figures, and preprocessor datasets (Farrell et al., 2022). Sectoral consumption was calculated using population data (ABS, 2023) and industry-specific reports for key sectors such as healthcare, textiles, and chemicals (ACTA, 2021; AIHW, 2017; APMF, 2022; Ivanović et al., 2022). This approach captures material flows from raw material inputs through to waste generation, recycling, and disposal.

State-level consumption was estimated by distributing national plastic consumption according to population shares and adjusting for regional economic activities. For example, higher PET consumption in Victoria's textile sector and significant PVC use in Western Australia's mining industry were incorporated into the model. Estimates were validated against historical trends and industry insights to ensure plausibility.

Limitations include inconsistencies in reporting methodologies across data sources and potential underrepresentation of informal plastic use and recycling activities. Besides, mismanaged plastic lost to pollution as an end-of-life destination is not included in the model, despite it being part of the overall plastic volume. Where data gaps existed, interpolation techniques were applied, introducing some uncertainty into the estimates.

Table 1
Four stages and processes of plastic flows.

Production and Manufacturing	Consumption	Waste collection	End of life
Local virgin polymer	Agriculture	Agriculture waste	Landfill
Imported virgin polymers	Mining	Mining waste	Energy recovery - incineration
Locally sourced recyclate polymers	Construction	Construction waste	Recycling
Imported recyclate polymers	Manufacturing	Manufacturing waste	Export
Imported plastic products	Utilities	Utilities waste	
	Retail & trade	Retail & trade waste	
	Transport	Transport waste	
	Services	Services waste	
	Government, health and education	Government, health and education waste	

2.3. Input-Output modelling

Input-output modelling was employed to track the transactions across various stages – virgin plastics, plastics production, intermediate polymers, plastic products, and utilization - within different regions in Australia, as well as the import and export transactions with other countries (Lenzen, 2009).

Based on the final goods demanded by consumers, the model computes the intermediate inputs required for their production, as well as the inputs needed for subsequent stages of intermediate production, iteratively. The calculations allocate the monetary demand for each input to each region-sector using transaction data recorded in the input-output tables. This monetary demand is then extended to physical demand for plastics production by incorporating a satellite account that specifies the plastic intensity of production in each region-sector.

Tracing plastic flows through an economy can be accomplished using a multi-region input-output (MRIO) database. In this study, an Australian MRIO is constructed using the Australian Industrial Ecology Virtual Laboratory (IELab) (Lenzen et al., 2017), which is a cloud-based collaborative research platform (Lenzen et al., 2014) aimed at providing input-output research infrastructure and support to streamline research workflows for a wide range of users (Wiedmann, 2017), developed with support of the Australian Bureau of Statistics (Lenzen et al., 2017). The Australian IELab is one of a number of similar laboratories (Geschke and Hadjikakou, 2017) for other countries (Indonesia, China, Taiwan, Japan and the US) (Faturay et al., 2020a, 2020b, 2017; Wakiyama et al., 2020; Wang, 2017).

Tracing physical flows uses so-called extended MRIO analysis, as pioneered by Leontief and Strout, (1963), Leontief (1970). In particular, we make use of the technique of production layer decomposition, which employs the series expansion of the Leontief inverse (Waugh, 1950).

The input-output model starts with the accounting relationship: the output of any sector-region $i = 1, \cdots, N$ is bought either as intermediate inputs for a sector-region $j = 1, \ldots, N$, or as final consumption goods for consumer-region $m = 1, \cdots, M$. In matrix form, this can be written as:

$$\mathbf{X} = \mathbf{AX} + \mathbf{y}1^M$$

Where $\mathbf{X}$ $(N\times\ 1)$ is the output vector with element x_i the output of sector-region i, $\mathbf{A}$ $(N\times N)$ the technical coefficient matrix with element a_{ij} the inputs purchased from i for each output unit of j, and $\mathbf{y}(N\times M)$ the final demand matrix with element y_{im} the final goods from i consumed by consumer-region m. $1^M = \underbrace{\{1,1,\ldots,1\}'}_{M\ \text{elements}}$ is a summation operator.

Output can be written as a function of final demand by rewriting Eq. (6) as follow:

$$X = (I - A)^{-1}\mathrm{y}1^M \equiv \mathrm{Ly}1^M \tag{6}$$

Where $\mathbf{L}(N\times N)$ the Leontief inverse matrix, with element l_{ij} the total inputs required from sector-region i to satisfy the final demand of 1 output unit of sector-region j. This incorporates both direct (inputs from i are used to make output from j) and indirect effects (inputs from i are used to make inputs from k, which are used to make output from j).

Given the output vector $\mathbf{X}$, the plastic footprint can then be computed using data on plastic intensity (plastic output per dollar of output in each region-sector). Let $\mathbf{q}$ be the plastic satellite account, where element $\mathbf{q}_j$ is the number of plastics per unit of sector j's output. Then plastic footprint is:

$$F = \mathrm{qX} = \mathrm{qLy}1^M$$

This plastic footprint can be decomposed by input-output paths based on the location of (1) the production of inputs, (2) the production of final goods, and (3) the consumers. Denote the index d for domestic (Australian) and o for overseas (imports & exports).

The matrices introduced can be partitioned into sub-matrices as follow:

$$\mathbf{q} = (\mathbf{q}_\mathrm{d} \quad \mathbf{q}_\mathrm{o}), \mathbf{L} = \begin{pmatrix} \mathbf{L}_\mathrm{dd} & \mathbf{L}_\mathrm{do} \\ \mathbf{L}_\mathrm{od} & \mathbf{L}_\mathrm{oo} \end{pmatrix}, \mathbf{y} = \begin{pmatrix} \mathbf{y}_\mathrm{dd} & \mathbf{y}_\mathrm{do} \\ \mathbf{y}_\mathrm{od} & \mathbf{y}_\mathrm{oo} \end{pmatrix}$$

Where the first index denotes the origin, and second index the destination of the flow of goods. For example, $\mathbf{L}_\mathrm{do}$ is the sub-matrix of Australian inputs going to overseas final goods production (i.e. export of intermediate inputs), while y_od is overseas final goods imported into Australia for domestic consumers (i.e. imports of final goods). The combined term, $\mathbf{L}_\mathrm{do}\mathbf{y}_\mathrm{od}$, captures the combination of paths where Australia exports inputs, and then import the final goods for domestic consumption (for example, Australian iron export → overseas cars production → imports for Australian consumers). Note that plastic intensities $\mathbf{q}_\mathrm{d}, \mathbf{q}_\mathrm{o}$ only depends on locations of production, not of use.

The plastic footprint F can then be decomposed into the sum of plastic footprint from different combinations of paths based on locations. These are[1]:

$$\mathbf{F}_\mathrm{ddd} = \mathbf{q}_\mathrm{d}\mathbf{L}_\mathrm{dd}\mathbf{y}_\mathrm{dd}1^{M_\mathrm{d}} \ - \ \text{purely domestic paths}$$

$$\mathbf{F}_\mathrm{odd} = \mathbf{q}_\mathrm{o}\mathbf{L}_\mathrm{od}\mathbf{y}_\mathrm{dd}1^{M_\mathrm{d}} - \text{intermediate import paths}$$

$$\mathbf{F}_\mathrm{ood} = \mathbf{q}_\mathrm{o}\mathbf{L}_\mathrm{oo}\mathbf{y}_\mathrm{od}1^{M_\mathrm{d}} - \text{final import paths}$$

$$\mathbf{F}_\mathrm{dod} = \mathbf{q}_\mathrm{d}\mathbf{L}_\mathrm{do}\mathbf{y}_\mathrm{od}1^{M_\mathrm{d}} \ - \text{intermediate feedback loops}$$

$$\mathbf{F}_\mathrm{ddo} = \mathbf{q}_\mathrm{d}\mathbf{L}_\mathrm{dd}\mathbf{y}_\mathrm{do}1^{M_\mathrm{o}} - \text{final exports}$$

$$\mathbf{F}_\mathrm{odo} = \mathbf{q}_\mathrm{o}\mathbf{L}_\mathrm{od}\mathbf{y}_\mathrm{do}1^{M_\mathrm{o}} \ - \text{foreign feedback loops}$$

$$\mathbf{F}_\mathrm{doo} = \mathbf{q}_\mathrm{d}\mathbf{L}_\mathrm{do}\mathbf{y}_\mathrm{oo}1^{M_\mathrm{o}} - \text{intermediate exports}$$

$$\mathbf{F}_\mathrm{ooo} = \mathbf{q}_\mathrm{o}\mathbf{L}_\mathrm{oo}\mathbf{y}_\mathrm{oo}1^{M_\mathrm{o}} - \text{purely foreign paths}$$

These combinations can be used to create Sankey diagrams such as Fig. 1.

The plastic footprint can also be decomposed into paths by the number of intermediate supply-chain transactions, using the series expansion of the Leontief inverse $L = \sum_n^\infty A^n$:

$$\mathbf{F} = \boldsymbol{q}\left(\sum_{n=0}^{\infty}\boldsymbol{A}^n\right)\mathbf{y}\mathbf{1}^{\boldsymbol{M}} = \sum_{ijm} q_i\left(\delta_{ij} + A_{ij} + \sum_k A_{ik}A_{kj} + \ldots\right)y_{jm}$$

$$= \sum_{im}\underbrace{q_i\delta_{ij}y_{jm}}_{direct} + \sum_{ijm}\underbrace{q_iA_{ij}y_{jm}}_{1^{st}-order} + \sum_{ijkm}\underbrace{q_iA_{ik}A_{kj}y_{jm}}_{2^{nd}-order} + \cdots$$

where δ_{ij} is the Kronecker symbol ($\delta_{ij} = 1$ if $i = j$ and $\delta_{ij} = 0$ if $i \neq j$). Each term $q_iA_{ik}A_{kj}y_j$ is called a *Structural Path*. The number of A_{ij} terms determine the *order* of the path; for example, $q_iA_{ik}A_{kj}y_j$ is a path of 2nd order. Paths of 2nd order involve two intermediate supply-chain transactions, for example plastics manufacturing $\overbrace{>}^{1}$ plastic products $\overbrace{>}^{2}$ truck manufacturing.

3. Results

Total virgin polymer consumption, including domestic production and imports, amounted to 1280 thousand metric tons (kt). Of this, only 23 % was produced domestically, while the remaining 77 % was imported. Polyethylene (PE), comprising HDPE and LDPE, was the most widely consumed virgin polymer, accounting for 45 % of total consumption, followed by PVC (19 %), PP (14 %), and other plastics (11 %).

[1] $\mathbf{1}^{\boldsymbol{M}_\mathrm{d}}, \mathbf{1}^{\boldsymbol{M}_\mathrm{o}}$ are summation operators of lengths equal to the number of domestic and overseas region-consumers, respectively

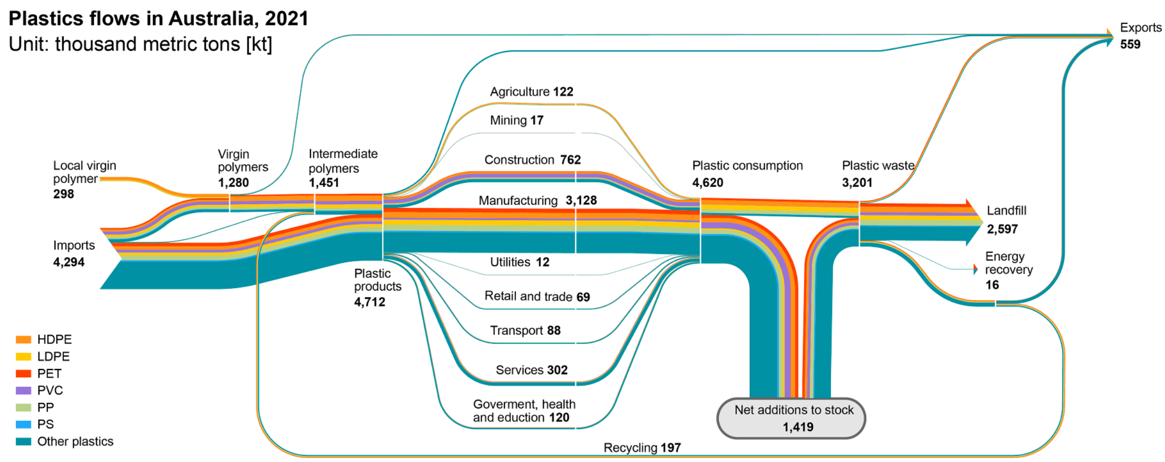

Fig. 1. Plastic flows, stocks, and waste generation in Australia in 2020–21 in thousand metric tons. The data used to generate this figure are available in the tabs labelled Figure_1, and Table_S2 of the supplementary materials.

The manufacturing and construction sectors[2] were the largest consumers of plastics, accounting for 3128 kt and 762 kt, respectively. The total plastic consumption across all sectors was 4620 kt, calculated as production plus imports minus exports.

Plastic products, categorised by type, are divided between waste and stock. As shown in the 2020–21 Sankey diagram, the net addition to stock, calculated as total plastic consumption minus total plastic waste for the same year, was approximately 1419 kt. Packaging, with a typical lifespan of less than one year, is the only category assumed to become plastic waste within the same year. According to the Australian Packaging Covenant Organisation (APCO), packaging accounted for 1188 kt, representing 38 % of plastics used in manufacturing. Of the total plastic consumed, 26 % became waste in 2020–21, while the remaining waste originated from products consumed in previous years.

A total of 3201 kt of plastic waste was generated in Australia during the reporting period. The top five contributors to plastic waste materials were other plastics (including basic plastics, other polymers, plastic products and rubber) comprising 40 % of the total, followed by HDPE (15 %), PP (14 %) LDPE (11 %), and PET (10 %).

Plastic waste treatment in Australia in classified in Australia into four main pathways: landfill (81 %), energy recovery (1 %), overall recycling (13 %) and direct plastics waste export (5 %). Of the total waste recycled, 6 % was reused domestically, while the remaining 7 % was reprocessed and exported overseas.

The selection of plastic types for specific applications is primarily determined by their physical properties and cost-effectiveness. Fig. 2 compares the primary uses of different plastics across major sectors in Australia. The data indicate that the manufacturing sector is the dominant consumer of plastics, accounting for 68 % of total usage, followed by the construction sector, which contributes 16 % (see the tab labelled Figure_2 in the supplementary materials for detailed data).

Plastics such as PET, LDPE/HDPE, and PP are widely used in the manufacturing sector, particularly for container production. HDPE, valued for its excellent corrosion resistance, is used extensively in both packaging applications (e.g., bottle caps) and construction (e.g., water piping). Unlike packaging materials, which typically become waste within one-year, plastic components used in construction often remain in service for extended periods due to their long lifespans. PVC and other plastic types are particularly important in the construction sector because of their durability and structural performance.

Furthermore, Fig. 2 disaggregates the "other plastics" category from Fig. 1 into three subcategories: basic plastics, other polymer and plastic products, and rubber products. This classification provides greater resolution for how different plastic materials are distributed and utilised across sectors.

Examining plastic material flows across Australia's states and territories is essential for understanding regional variations in plastic production, consumption, and waste management. Regional analysis helps identify distinct patterns in plastic usage, recycling rates, and waste management practices, providing valuable insights to inform targeted and effective interventions.

Fig. 3 A-H illustrate plastic material flows across six states and two territories in Australia. Notably, the highest per-capita plastic consumption was observed in Victoria (VIC) and South Australia (SA), at 186 kg per capita, while residents of the Australian Capital Territory (ACT) record the lowest consumption, at 163 kg per capita, which is 12 % lower than the highest levels. Variations in plastic consumption within the manufacturing sector followed a similar trend: the ACT reported the lowest usage, 17 % below SA, which had the highest manufacturing sector consumption.

Australia's average domestic (local) recycling rate was 6 %, while the overall recycling rate, including reprocessing for export, reached 13 %. Regional differences, however, were substantial. South Australia (SA) reported a local recycling rate of 9 % and an overall recycling rate of 22 %. In contrast, the Australian Capital Territory (ACT) exhibited minimal local recycling capacity (0.1 %) and an overall recycling rate of only 5 %.

Of the total 445 kt of recycled plastic waste, 197 kt (46 %) was reprocessed and reused domestically within the states and territories where it was collected. An additional 29 kt was transferred to other states, primarily Victoria (VIC) and New South Wales (NSW), for reprocessing due to limited local facilities (Farrell et al., 2022). The remaining 231 kt (54 %) was reprocessed and subsequently exported overseas. Furthermore, 160 kt of plastic waste was exported directly without prior processing.

Malaysia was the primary destination for Australian scrap plastics, receiving 32 % of exports, followed by the United Arab Emirates and Indonesia, each accounting for 12 % (Farrell et al., 2022).

Fig. 4 presents a heatmap depicting plastic consumption across sectors in different states and territories, based on Input-Output analysis. The dark blue cells along the diagonal of the square heatmap indicate that most of the plastic consumption occurs within the same state, reflecting strong intra-state flows and limited inter-state trade.

For instance, in New South Wales (NSW), only 23 % of plastic products manufactured are distributed to other states, while 60 % are consumed within the state's own manufacturing sector. Similar patterns are observed in other highly populated states, such as Victoria (VIC), Queensland (QLD), and South Australia (SA), underscoring the predominance of localised plastic use and supply chains.

[2] To view the list of subsectors in each sector, refer to the tab labelled Table_S1 of the supplementary materials.

Fig. 2. Distributions of plastics into end-use sectors in Australia in 2020–21. The horizontal axis lists the sectors; the vertical axis lists the nine categories of plastics. The area of each bubble represents the percentage of the relevant sector consumption of each specific plastic. All bubbles with the same colour along the horizontal axis aggregate to 100 %. The percentage atop each vertical bubble line represents the proportion of all plastics utilized in that end-use sector. The data used to generate this figure are available in the tabs labelled Figure_2 of the supplementary materials.

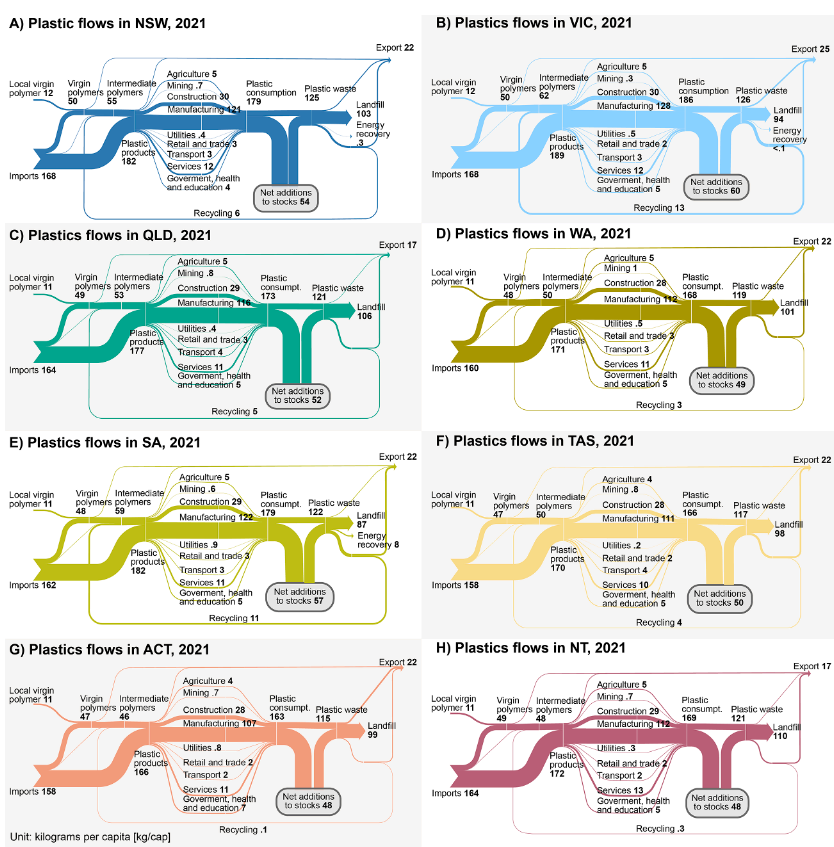

Fig. 3. Plastic flows in different states and territories in Australia in 2020–21 in kilogram per capita. The data used to generate this figure are available in the tabs labelled Figure_3A, Figure_3B, Figure_3C, Figure_3D, Figure_3E, Figure_3F, Figure_3G, and Figure_3H of the supplementary materials.

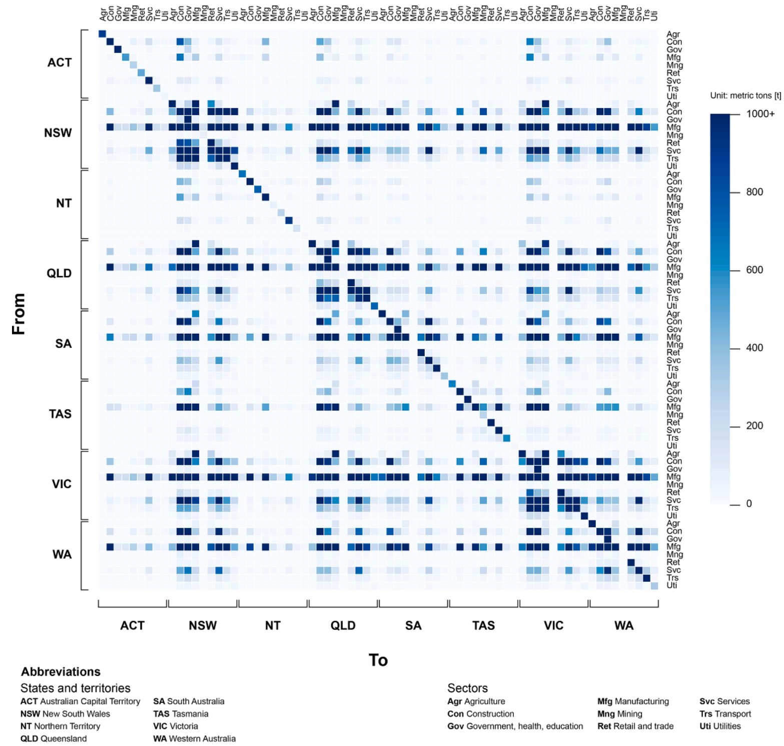

Fig. 4. Plastic Consumption Heatmap Input-Output Analysis in Australia 2020–21 in metric tons. The data used to generate this figure are available in the tab labelled Figure_4 of the supplementary materials.

4. Discussion

This study provides the first comprehensive material flow analysis of plastics in Australia, disaggregated by polymer type, sectoral application, and regional variation. By tracing flows across production, consumption, and waste management, the analysis offers critical insights into systemic inefficiencies and opportunities for advancing a circular economy for plastics.

4.1. Key findings in the context of global plastic flows

Our results reveal that Australia's plastic consumption and waste generation patterns mirror global trends of increasing plastic use and low recycling rates. Similar to international findings (OECD, 2022; Ritchie et al., 2023), polyethylene (HDPE and LDPE) dominates material flows, driven by its extensive use in packaging and manufacturing. However, Australia's domestic recycling rate remains low (13 %) relative to regions such as the European Union (32.5 %) (Chawla et al., 2022) and South Korea (Jang et al., 2020), highlighting gaps in infrastructure and policy frameworks.

The predominance of intra-state plastic flows, with limited interstate trade, indicates a high degree of localisation in Australia's plastic value chains. This localisation presents both challenges and opportunities: while it limits economies of scale in recycling, it also enables tailored regional strategies for plastic waste management.

4.2. Regional disparities and infrastructure gaps

Significant regional disparities in recycling capacity were observed, with South Australia achieving an overall recycling rate of 22 %, compared to 5 % in the Australian Capital Territory. These differences reflect both historical investments in waste infrastructure and policy leadership, such as South Australia's early adoption of container deposit schemes. The ACT's negligible local recycling capacity underscores the vulnerability of smaller jurisdictions reliant on interstate or overseas processing.

Moreover, 54 % of Australia's recycled plastic waste is exported for reprocessing, exposing the system to global market disruptions, as illustrated by China's National Sword policy (Brooks et al., 2018). Building domestic capacity for high-quality recycling and markets for recyclates is thus essential to reduce reliance on international waste trade and to achieve circular economy goals.

4.3. Policy and market interventions to close the loop

Transitioning to a circular economy for plastics requires interventions across the entire value chain. Extended Producer Responsibility (EPR) schemes, as implemented in South Korea and parts of Europe, have demonstrated success in incentivising eco-design and improving collection rates (Jang et al., 2020; Velenturf and Purnell, 2021). In Australia, scaling up EPR programs, coupled with mandates for minimum recycled content in products, could stimulate domestic demand for recyclates and improve material circularity.

Targeted interventions by polymer type are also critical. While PET and HDPE exhibit higher recycling rates due to established collection systems and markets, polymers such as PVC and polystyrene remain under-recycled, requiring innovation in processing technologies and material substitution strategies. Designing plastic products for minimal material use, durability, and ease of repair can significantly reduce the need for replacement and overall plastic consumption. Additionally, designing for modularity and reuse, such as refillable packaging or multi-use containers, can shift consumption patterns away from single-use plastics (Pomponi et al., 2022). Bioplastics, derived from renewable sources, can lower reliance on fossil fuel-based plastics and reduce greenhouse gas emissions across the product life cycle. When compostable or biodegradable under real-world conditions, certain bioplastics may also help reduce long-term plastic pollution, especially in applications where retrieval is difficult (Jin et al., 2023).

The MFA results reveal critical inefficiencies in collection, recycling, and market development that hinder circularity. Priority intervention points include (i) improving source separation and collection systems to reduce contamination and increase recovery of high-value polymers such as PET and HDPE; (ii) expanding regional reprocessing capacity, particularly in low-performing jurisdictions such as the ACT, to address infrastructure disparities; and (iii) stimulating domestic demand for recyclates through recycled-content mandates and procurement incentives. To effectively “close the loop,” a combination of robust EPR schemes, design-for-recycling initiatives, and investment in advanced recycling and bioplastic technologies is required. These strategies, aligned with proven international models, provide a clear pathway for strengthening Australia’s transition toward a circular plastics economy.

4.4. Limitations and future research

This study provides an essential baseline for understanding plastic flows in Australia, yet several limitations merit attention. Data gaps on the lifespan of plastics in different applications introduce uncertainties in stock and waste flow estimations. Future research should incorporate dynamic stock modelling to account for time lags between consumption and waste generation (Van Eygen et al., 2018). To address the limitation of the IO modelling, Fry and Schandl (2024) discussed the benefit of using physical flows rather than monetary transactions in footprint analyses. Moreover, assessing the environmental and socio-economic impacts of alternative waste management scenarios through life cycle assessment could complement the MFA framework and guide evidence-based policy development.

4.5. Toward a circular economy for plastics in australia

Achieving a circular economy for plastics in Australia will require coordinated in alignment with and considering prioritisation of the waste hierarchy. Strengthening regional recycling infrastructure, fostering domestic markets for secondary plastics, and designing out problematic materials are pivotal steps. As global negotiations for the UN Plastics Treaty progress (Dreyer et al., 2024), aligning national strategies with emerging international frameworks will be critical to addressing plastic pollution comprehensively.

Overall, this study highlights the value of integrating material flow analysis (MFA) into policy design and strategic planning. MFA offers a robust evidence base for identifying systemic inefficiencies, quantifying material dependencies, and evaluating the effectiveness of circular economy interventions. By bridging scientific analysis with economic and social dimensions, policymakers can more effectively align environmental objectives with industry capabilities and community expectations.

Future research should incorporate dynamic modelling approaches to assess the long-term impacts of policy scenarios, including shifts in consumer behaviour, technological innovation, and international trade dynamics. Such insights will be critical for designing adaptive, resilient strategies to advance a sustainable, circular economy for plastics.

5. Conclusion

Despite the significant consumption of plastics across key sectors, particularly manufacturing and construction, only a small portion of the resulting waste is recovered or reprocessed locally. The majority is landfilled, and regional disparities in recycling infrastructure further limit the effectiveness of national resource recovery efforts.

Addressing these challenges requires targeted, evidence-based interventions across the plastics value chain to advance circularity. MFA results highlight priority areas for action across production, consumption, and waste management. Strengthening local recycling infrastructure across all states and territories is critical, particularly in regions such as the ACT, and should be supported through policy instruments such as investment grants, procurement mandates, and recycled-content requirements. Policy and market instruments can establish robust domestic demand for recycled plastics through procurement mandates, recycled-content standards, and targeted incentives, stimulating investment in local reprocessing capacity. Improving product design to enhance recyclability, durability, and modularity will be pivotal, alongside phasing out problematic polymers and implementing upstream interventions such as banning or redesigning single-use plastics.

Improving product design to enhance recyclability and durability will also be pivotal, alongside phasing out problematic polymers. There is growing justification for taking stronger measures to reduce plastic waste at the source, such as banning or designing out single-use plastics and non-recyclable packaging. These upstream interventions are essential to reduce the flow of low-value, high-impact plastic materials that burden the waste management system and pollute the environment.

Harmonising data collection, reporting, and policy frameworks at the national level will support consistent monitoring, coordination, and evaluation of progress. Regional collaboration and adoption of best practices from higher-performing states, as well as international examples of successful EPR and recycling programs, can accelerate policy and industry innovation.

Achieving these transitions will require sustained government investment in infrastructure, research, and policy development. Industry stakeholders can leverage MFA insights to redesign products and supply chains, integrate recycled content, and participate in EPR programs, translating evidence into measurable circular outcomes. Public engagement and education remain essential to drive changes in consumption behaviour and increase participation in recycling programs. By implementing these measures, supported by scientific evidence from comprehensive material flow accounts, Australia can reduce its reliance on virgin materials, divert plastic waste from landfill, and take decisive steps toward a circular economy that conserves resources, protects the environment and supports sustainable economic growth.

CRediT authorship contribution statement

Nargessadat Emami: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Quoc Anh Nguyen:** Writing – original draft, Methodology, Formal analysis, Data curation. **Alessio Miatto:** Writing – review & editing, Visualization, Methodology, Investigation. **Jacob Fry:** Writing – review & editing, Methodology. **Mohammad Sadegh Taskhiri:** Writing – review & editing, Validation, Investigation, Data curation. **Mengyu Li:** Writing – original draft, Methodology, Formal analysis, Data curation. **Manfred Lenzen:** Writing – review & editing, Writing – original draft, Validation, Methodology, Data curation. **Deborah Lau:** Writing – review & editing, Validation, Project administration, Funding acquisition, Conceptualization. **Heinz Schandl:** Writing – review & editing, Writing – original draft, Validation, Supervision, Project administration, Methodology, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.resconrec.2025.108718.

Data availability

Data are provided in the supplementary materials and will be available online

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