Supplementary information for

Complexities of the global plastics supply chain revealed in a trade-linked material flow analysis

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22 Supplementary Pages

12 Supplementary Figures

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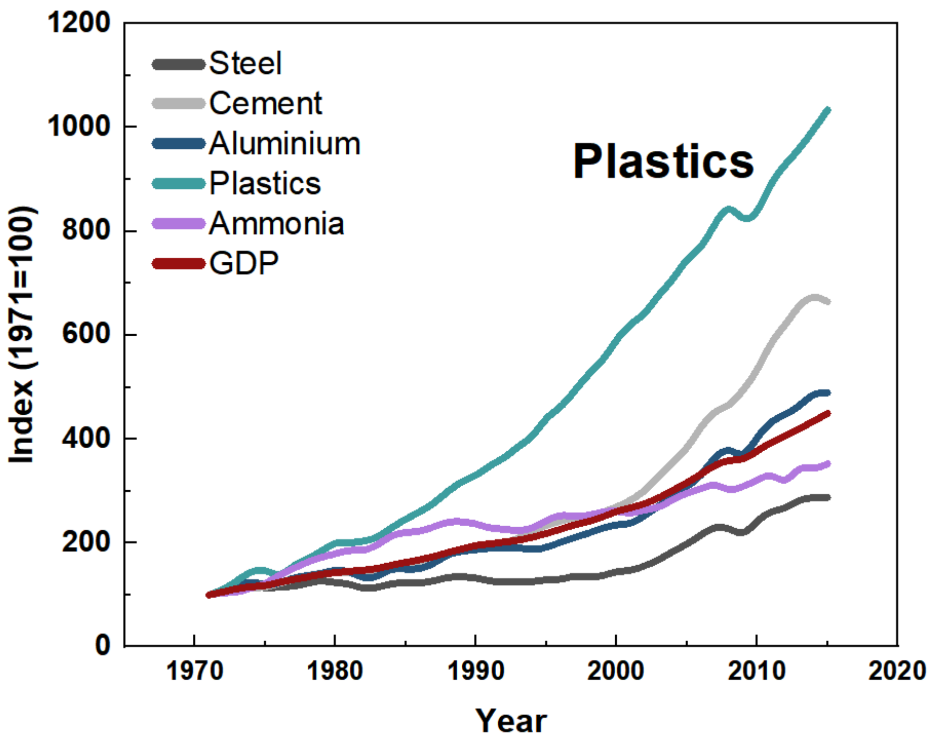
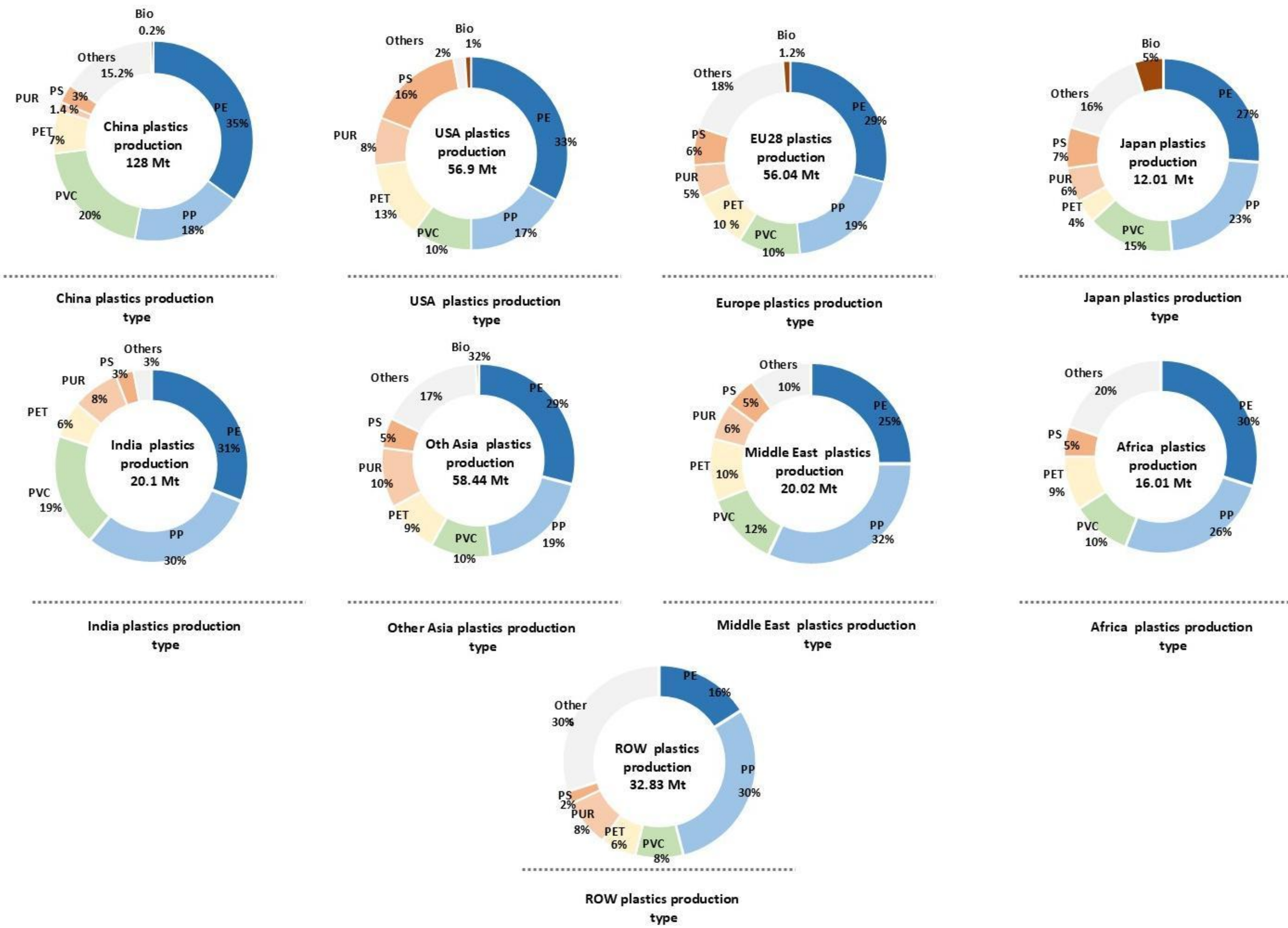
5 Supplementary Notes

Supplementary Figure 1 Comparison of the production growth of selected bulk materials.

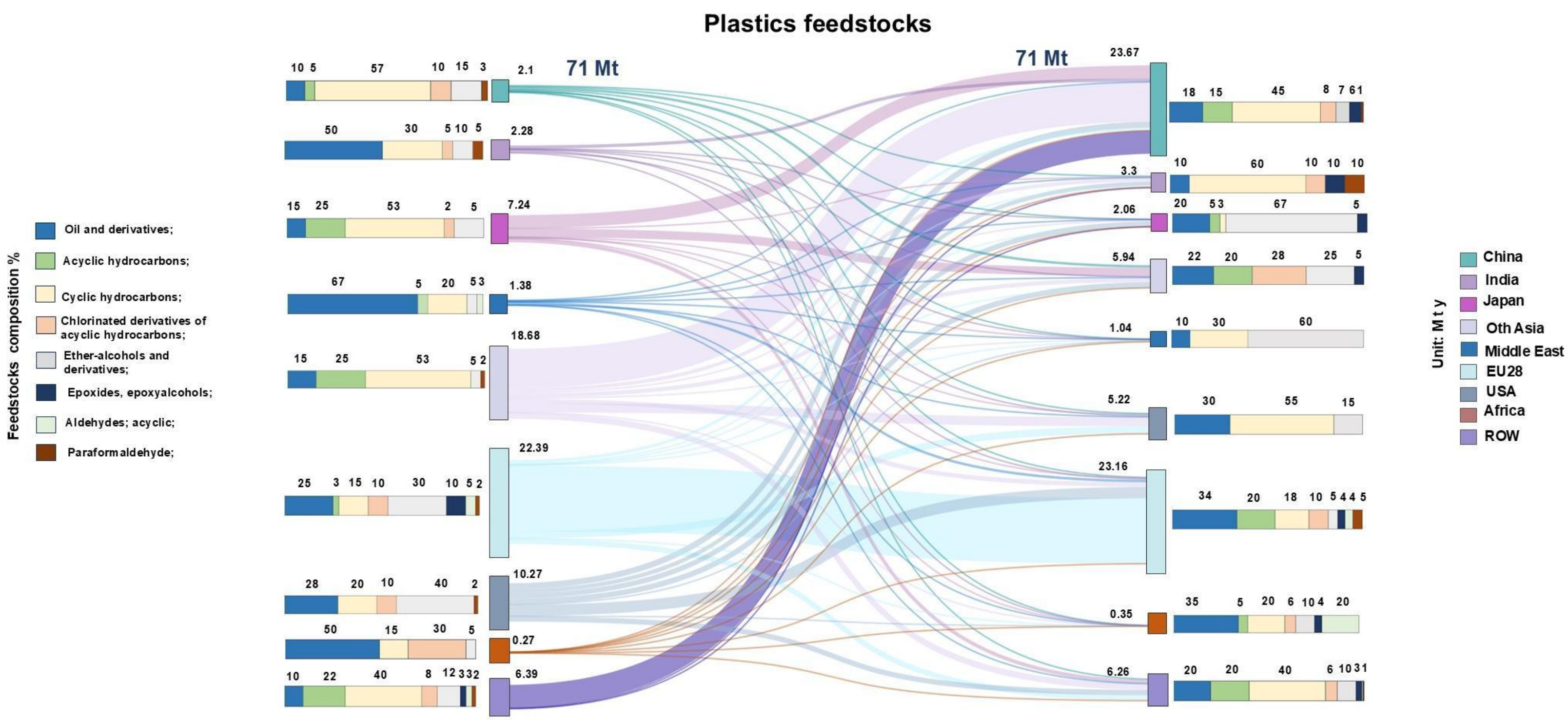
Source: IEA [1]



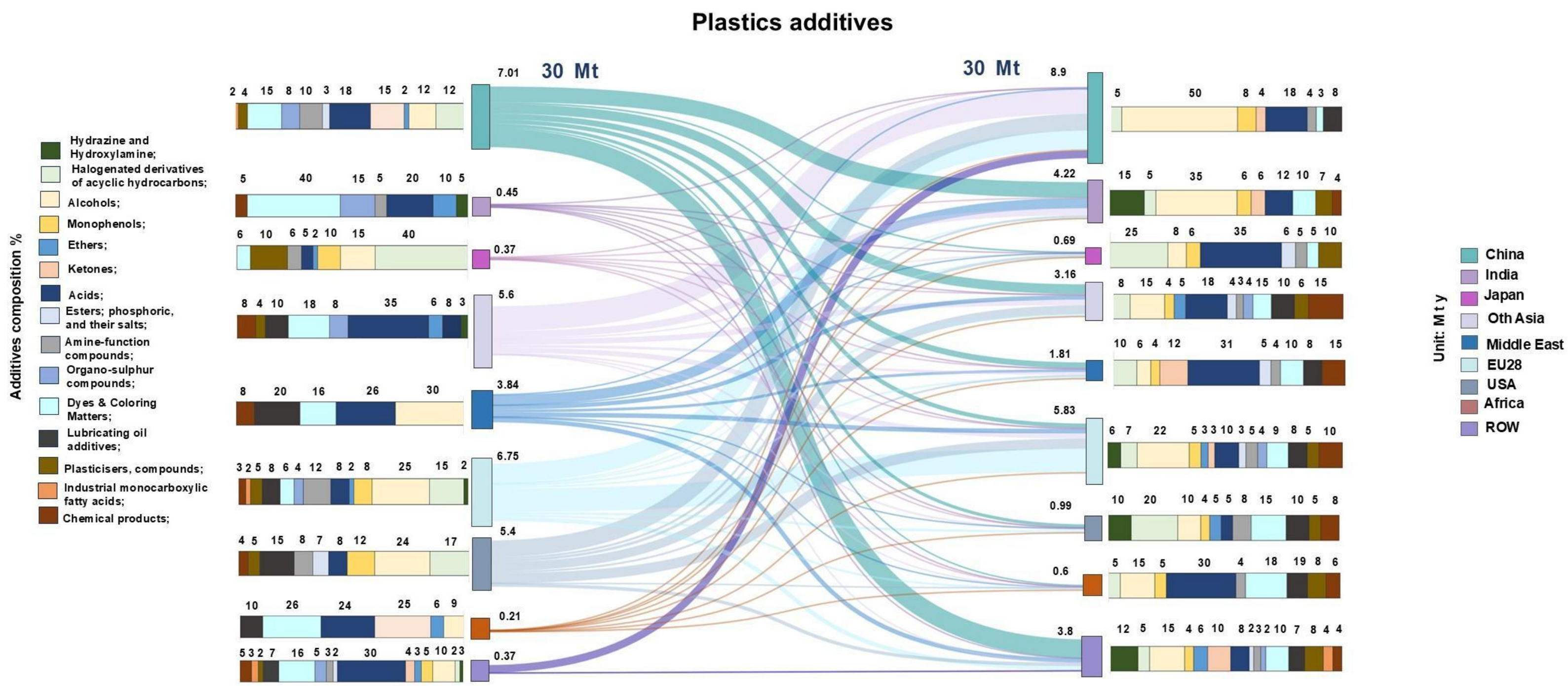
Supplementary Figure 2 Regional plastic production with a breakdown per polymer type. Plastics production values are expressed in Mt/y and plastics type distribution in %. For more details about the regional divisions and countries classification see **Supplementary Table 10.**



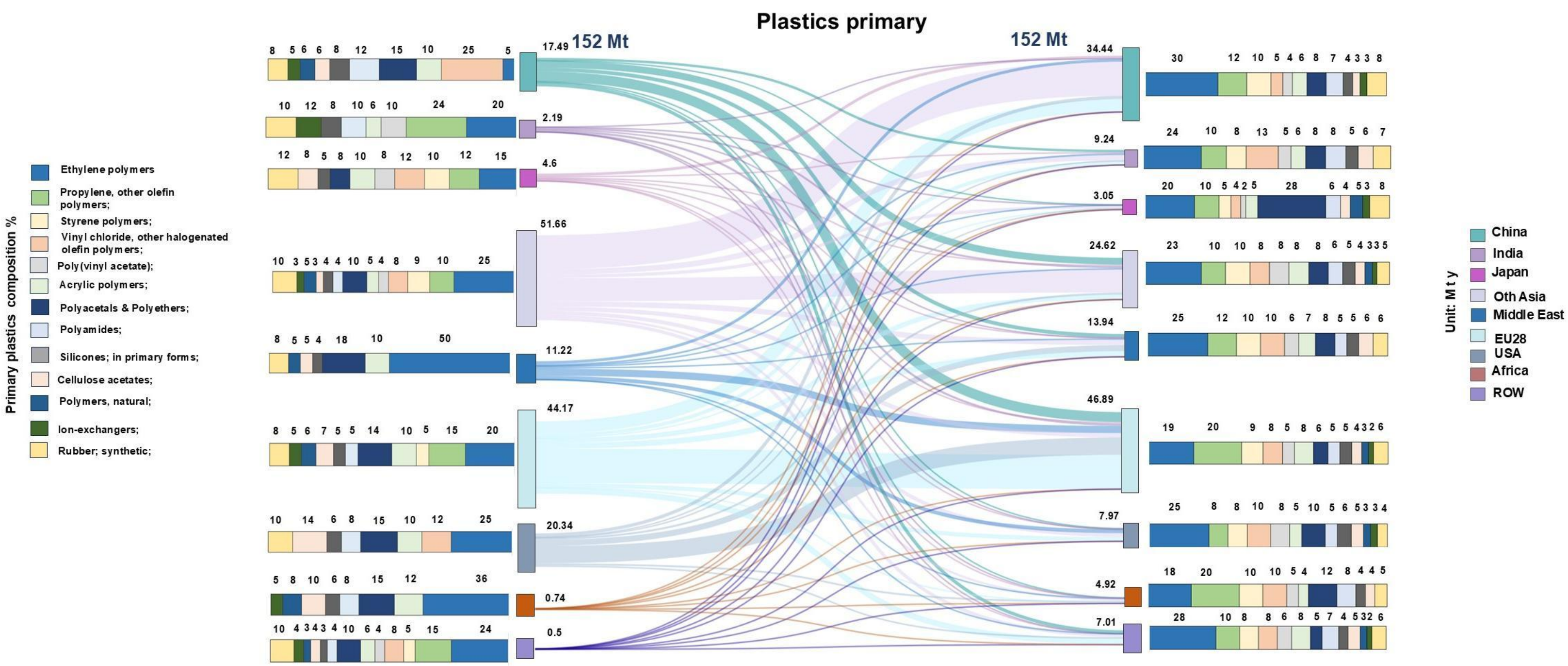
Supplementary Figure 3 Global plastics feedstock trade with feedstock import and export component per region. The trade flows are expressed in Mt/y, and the feedstocks component in %. The feedstocks components are based on the UN Comtrade HS codes for plastics feedstocks and have been selected based on their significance in the global feedstocks trade for plastics production (≥ 0.1 Mt).



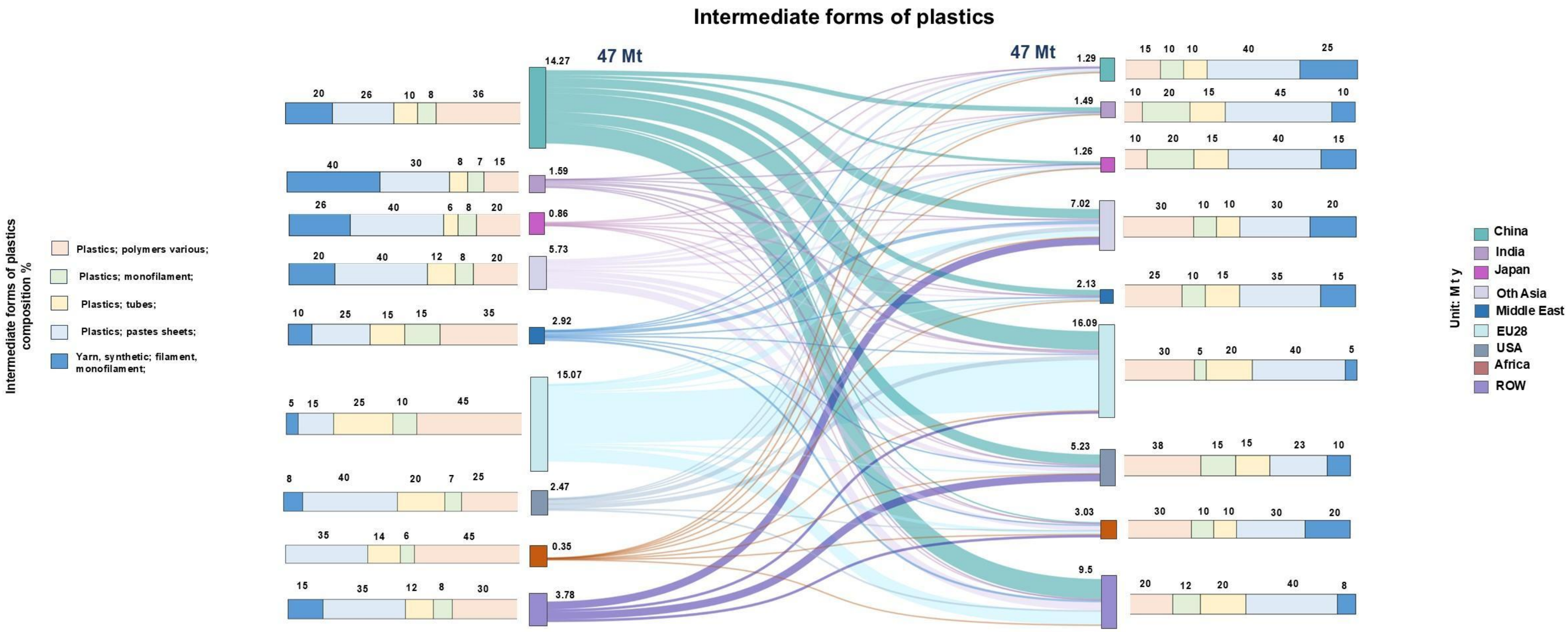
Supplementary Figure 4 Global plastics additives trade with import and export components per region. The trade flows are expressed in Mt/y, and the components in %. The plastics additives trade components are based on the UN Comtrade HS codes and they have been selected based on their significance in the global plastics additives trade (≥ 0.1 Mt).



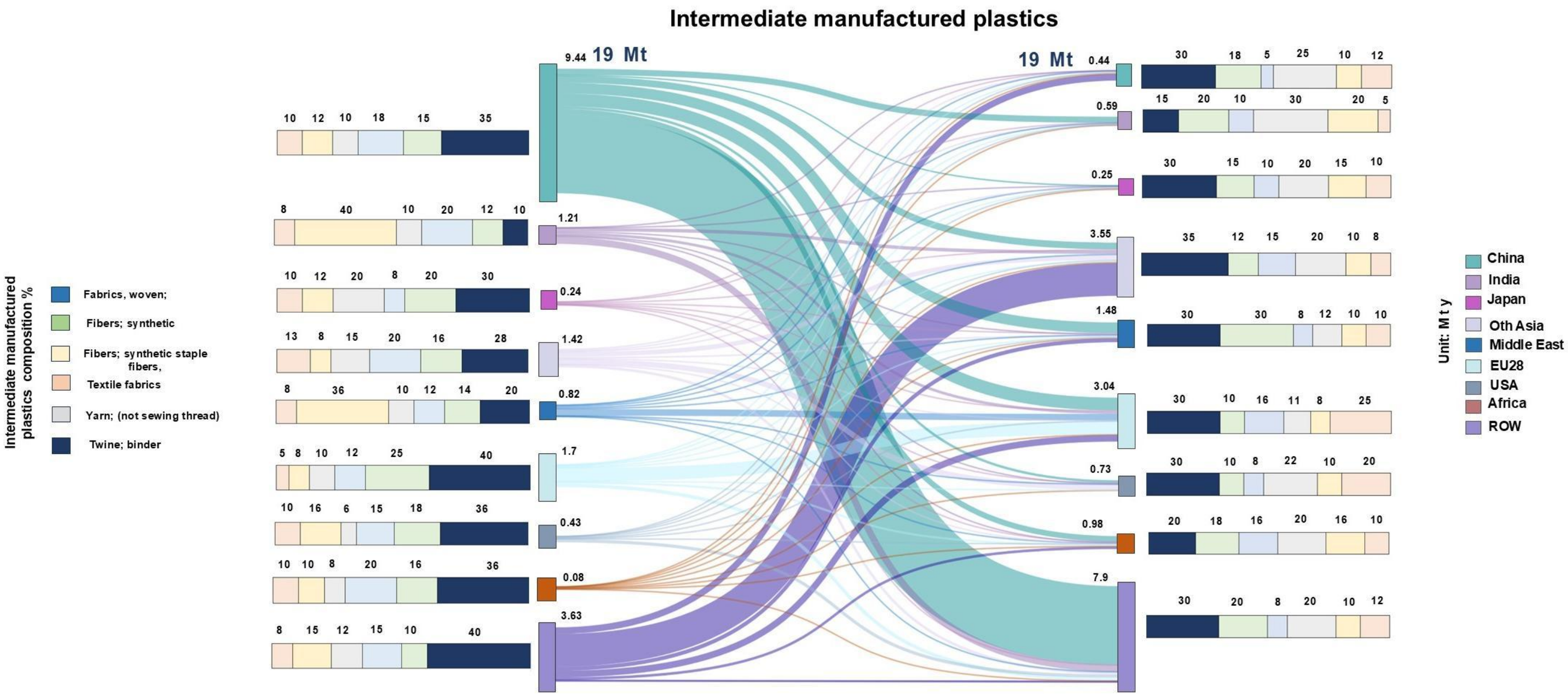
Supplementary Figure 5 Global primary plastics trade with import and export components per region. The trade flows are expressed in Mt/y, and the components in %. The primary plastics components are based on the UN Comtrade HS codes for plastics feedstocks and have been selected based on their significance in the global primary plastics (≥ 0.1 Mt).



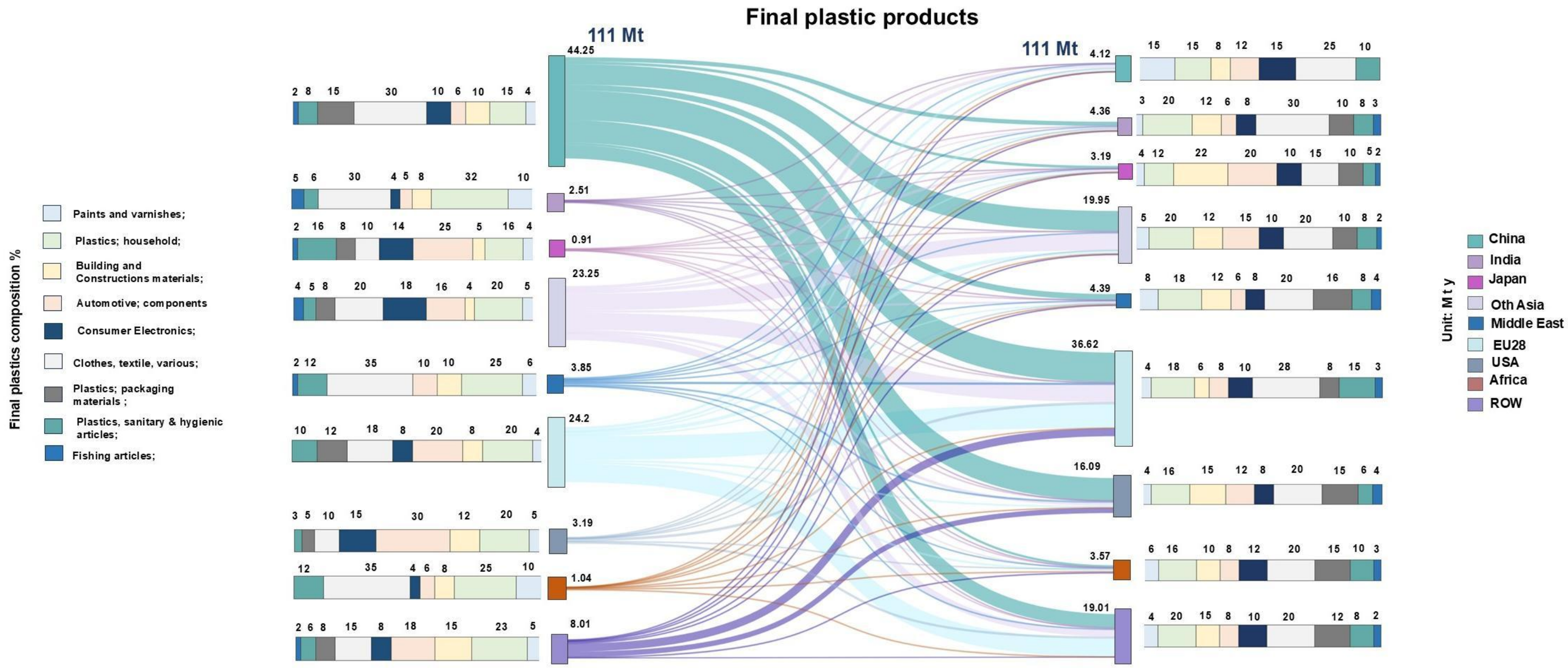
Supplementary Figure 6 Global intermediate forms of plastics trade with import and export components per region. The trade flows are expressed in Mt/y, and the components in %. The intermediate forms of plastics trade components are based on the UN Comtrade HS codes and they have been grouped as follow: plastics polymers, various; plastics, monofilament; plastics, tubes; plastics, plates sheets; yarn, synthetic filament, monofilament.



Supplementary Figure 7 Global intermediate manufactured plastics trade with import and export components per region. The trade flows are expressed in Mt/y, and the components in %. The intermediate manufactured plastics are based on the UN Comtrade HS codes and they have been grouped as follow: fabrics, woven; fibers, synthetic; fibers, synthetic staples fibers; textile fabrics; yarn, not sewing; twine, binder.



Supplementary Figure 8 Global final plastics products trade with import and export components per region. The trade flows are expressed in Mt/y, and the components in %. The final plastics products trade components are based on the UN Comtrade HS codes and they have been grouped based on their product type categories and application sector



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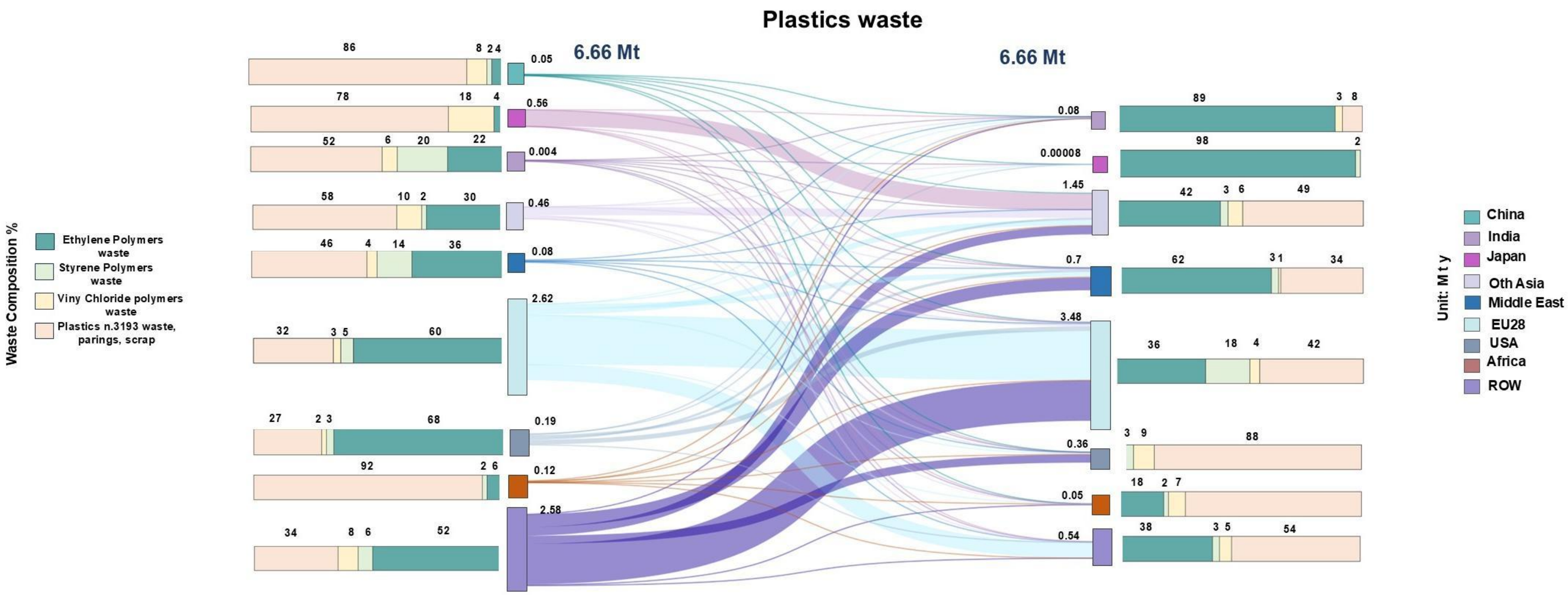
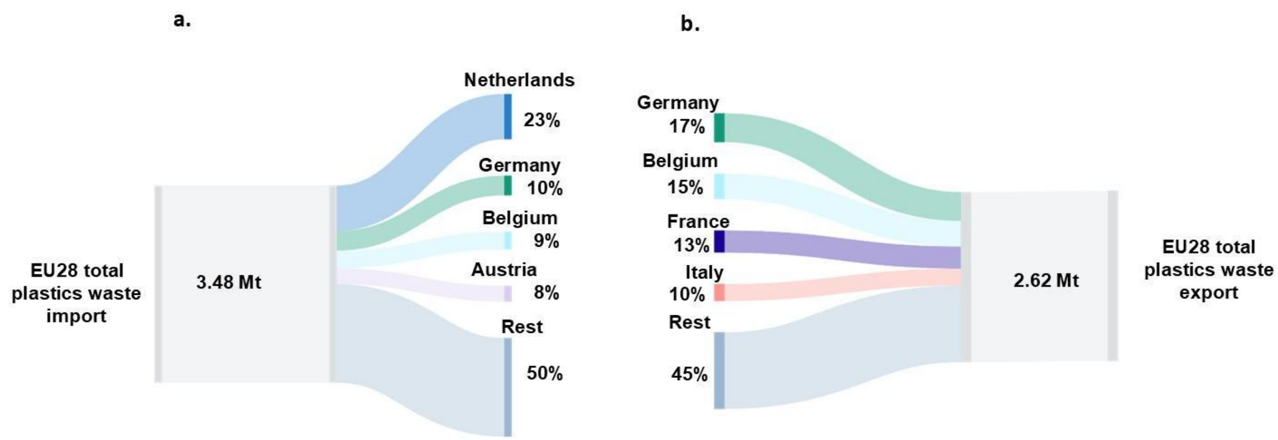
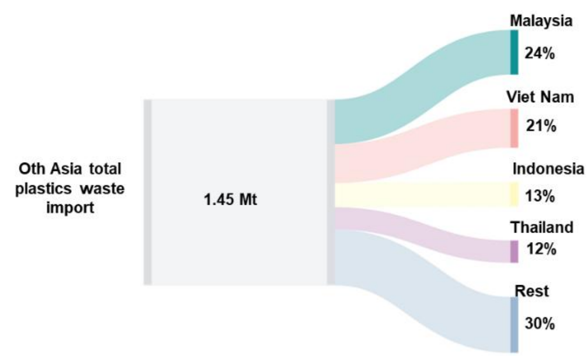
Supplementary Figure 9 Global plastics waste trade with import and export components per region. The trade flows are expressed in Mt/y, and the components in %. The global plastics waste trade components are based on the UN Comtrade HS codes.



Supplementary Figure 10 EU28 total plastic waste import and export, breakdown per country. **a.** EU28 largest plastic waste import countries. **b.** EU28 largest plastic waste export countries. Rest refers to the rest of European countries. Color and width of flows correspond to the countries and mass of plastic waste, respectively. All units in Mt/y (2022), and rate in %.



Supplementary Figure 11 Oth Asia total plastic waste import with breakdown per country. The largest plastic waste importers are represented in this figure. Rest refers to the rest of Oth Asian countries. Color and width of flows correspond to the countries and mass of plastic waste, respectively. All units in Mt/y (2022), and rate in %.



Supplementary Table 1 Global production and consumption of plastics in 2022

Region	Plastic production				Plastic consumption		
	Share of global production	Production per country/region [Mt/Y]	Per capita plastic consumption [kg/cap]	Reference	Population World Bank,2022	Total consumption [Mt]	Share of global consumption
EU28	14%	56.04	85.6	Calculated by authors	747,636,000.00	64.00	16%
USA	14%	56.84	216.02	Calculated by authors	333,287,557.00	72.00	18%
China	32%	128.09	56.01	Calculated by authors	1,425,887,337.00	80.00	20%
Japan	3%	12.01	129.08	Calculated by authors	123,951,692.00	16.00	4%
India	5%	20.01	15.52	Calculated by authors	1,417,173,173.00	22.00	5.5%
Oth Asia	15%	58.44	23.83	Calculated by authors	2,014,000,000.00	48.00	12%
Middle East	5%	20.02	62.22	Calculated by authors	450,000,000.00	28.00	7%
Africa	4%	16.01	13.35	Calculated by authors	1,497,580,300.00	20.00	5%
Rest of the world	8%	32.83	28.79	Calculated by authors	1,736,669,681.7	50.00	12.5%
World		**400 Mt**				400 Mt	

Supplementary Table 2 Plastics categories and product composition

Category	Plastic products composition
Packaging	Plastic bottles, food containers, shrink wrap, plastic bags, blister packs, clamshell packaging
Building and Construction	PVC pipes, insulation materials, window frames, siding, electrical cable insulation
Automotive	Dashboard components, interior panels, bumpers, fuel system components, seat covers
Electrical and Electronics	Computer casings, phone cases, electrical wiring insulation, electronic device components
Household and Textile	Plastic furniture, kitchen utensils, synthetic fibers for clothing, plastic hangers
Agriculture	Greenhouse films, irrigation pipes, plant pots, agricultural nets
Others	Medical devices (e.g., stents, syringes), sports equipment, plastics toys, office supplies, personal care products

Supplementary Table 3 Global polymer production and share

Global Plastic Type	Amount [Mt]	Share [%]	Reference
PE	105.27	26.3	
PP	75.65	18.9	
PVC	50.83	12.7	
PET	24.81	6.2	
PUR	21.21	5.3	[2,3]
PS	20.81	5.2	
Others	63.01	15.9	
Recycled	28.42	7.1	
Bio	2.00	0.5	

Supplementary Table 4 Global amount and share of plastics application per sector

Application	Amount [Mt]	Share [%]
Packaging	176.13	44
Building and Construction	72.05	18
Automotive	32.02	8
Electrical and Electronics	28.02	7
Household and Textile	28.02	7
Agriculture and Farming	16.01	4
Other	48.03	12

The amount and share of the global plastics application per sector is calculates by the authors based on the global plastics mass accounting

Supplementary Table 5 Distribution of polymers use rate per sector

%	PE	PP	PVC	PET	PUR	PS	Oth	Reference
Packaging	50.44	29.51	3.02	9.47	1.22	1.28	5.47	[3–7]

Building & Construction	8.22	2.21	56.65	1.15	1.34	1.41	29.99
Automotive	8.72	26.93	6.23	3.53	5.66	0.05	50.44
Electrical & Electronics	1.42	17.84	2.49	3.56	1.07	33.75	39.97
Household & Textile	20.90	28.29	0.0	43.62	0.0	0.0	7.13
Agricultural & Farming	70.00	5.00	25.0	0.0	0.0	0.0	0
Other	83.74	1.87	14.88	0.0	0.0	0.0	0.0

The distribution of polymer use rate per sector (%) is based on literature and the mass balance of the study. Plastic type rate might vary significantly from region to region; therefore, we estimated the average based on exiting studies. [8–10]

Supplementary Table 6 Life-time of plastic containing products

Sector	Lifetime (Y)	Standard deviation	Reference
Packaging	0.5	0.1	[3,6]
Building & Construction	35	7	
Automotive	13	3	
Electrical & Electronics	8	2	
Household & Textile	5	1.5	
Agricultural & Farming	2	0.5	
Other	5	1.5	

Supplementary Table 7 Global waste management ratios and corresponding sources

End-use sectors	Mismanagement	Landfill	Incineration	Recycling	Reference
Packaging	≈ 0.13	≈0.45	≈0.16	≈0.25	[3,11]
Building & Construction	0.00	≈0.60	0.00	≈0.40	
Automotive	0.00	≈0.60	0.00	≈0.40	
Electrical & Electronics	≈0.08	≈0.032	0.00	≈0.60	
Household & Textile	≈0.12	≈0.40	≈0.17	≈0.11	
Agricultural & Farming	≈0.01	≈0.49	≈0.04	≈0.45	
Other	≈0.11	≈0.44	≈0.18	≈0.26	

The global waste management ratio is calculated as a function of plastics use (in volumes), following Geyer [3] based on lifespan distributions of the sectors listed above. The global waste management end-of-life fates are based on the OECD 2022[11].

Supplementary Table 8 Regional waste management ratio and corresponding sources

Region/ country	Mismanagement	Landfill	Incineration	Recycling	Reference
China	≈0.02	≈0.14	≈0.60	≈0.23	[6,12–15]
USA	≈0.04	≈0.76	≈0.12	≈0.05	[16,17]
EU28	≈0.03	≈0.29	≈0.38	≈0.14	[2,4,8,18–21]
Japan*	0.00	≈0.14	≈0.70	≈0.14	[22,23]
India**	≈0.43	≈0.37	≈0.05	≈0.15	[24–26]
Oth Asia	≈0.22	≈0.40	≈0.20	≈0.12	[11,27,28]
Middle East	≈0.22	≈0.40	≈0.20	≈0.08	[11,27,29]
Africa***	≈0.20	≈0.40	≈0.25	≈0.07	[11,13,27]
ROW	≈0.20	≈0.50	≈0.20	≈0.09	Authors calculation

*The total incineration ratio of Japan is estimated around 0.7. Among this rate incineration with energy retrieval is around 0.6 and 0.1 with non-energy retrieval

**India and African countries are reported to have informal recycling practices.

The regional waste management end-of-life fates data sources are based on national and regional statistics, OECD database [11] and studies conducted for the above selected regions.

Supplementary Note 1. Feedstock energy source and feedstock resources for the global plastics production

The global mapping of plastics along the supply chain from its virgin production to waste management requires the analysis of the feedstock for the virgin plastic production. For this purpose, we analyze the fossil resources used as feedstocks and fuel for the global plastic production. Moreover, the regional flows of plastic feedstocks resource production are mapped and accounted at a regional level.

Data of feedstock plastic production for 2022 are retrieved from IEA 2022 outlook [30]. The feedstock energy source for the production of plastics is calculated in accordance with the estimations of Hamman[31]. We used as a key factor polyethylene plastic (PE), the largest plastic produced at a global level with a share of more than 26%. The net heat of the combustion for polyethylene is estimated to be about 4.5 x 107 J/kg following the calorimetry experiments conducted by Walters et al.[32]. For the upper-value estimate of plastics production in 2022, PE［Lower Heat Value (LHV)*mass quantity］is divided by a factor of 0.26, since about 26 % of plastics (by weight) was made of PE plastic globally. For the lower-value of fossil-fuel diverted to plastics production is calculated by multiplying the upper estimate by a factor of 0.5, as around 50% of all plastic production by weight is represented by PE, polypropylene (PP) and polystyrene (PS) [33]. These three types of plastics share two common features: they are pure hydrocarbon polymers and share a similar heat of combustion values[32].

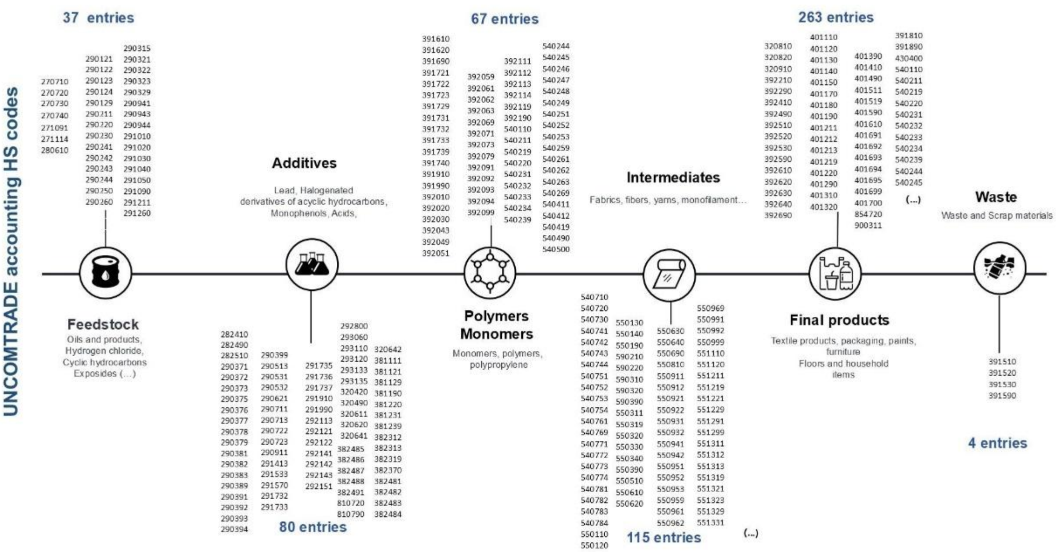
Supplementary Note 2. HS codes used for data extraction from UN Comtrade

Understanding the complex dynamics of global plastic trade necessitates a comprehensive approach that captures the full spectrum of plastic materials, products, and waste. This study leverages Harmonized System (HS) codes from the UN comtrade database to perform a detailed analysis of the global trade flows of plastics. We have totally collected 566 HS codes (37 HS codes for plastics feedstocks, 80 for plastics additives, 67 for primary plastics in polymers and monomers forms, 115 for intermediate plastics, 263 for final plastics, and 4 for plastics waste).

The selection criterion was based on the polymer composition and the monomeric units comprising the polymer chains. The selection process ensures that the chosen HS codes accurately reflect the categories of plastic materials and products pertinent to the analysis. By prioritizing specificity, we considered HS codes that provide detailed insights along the whole supply chain, thereby enabling precise tracking of material flows. Consistency in code selection aligns with the study's scope, maintaining data integrity and reliability. Furthermore, the principle of coverage ensures comprehensive inclusion of all relevant plastic categories, capturing the entirety of material flows. These principles collectively facilitate a robust, standardized, and comparative analysis across the temporal and geographical scope of our study, underpinning the validity and utility of the research findings. For instance, for feedstocks, we selected HS codes such as 2710 (petroleum oils and oils obtained from bituminous minerals) to capture the primary raw materials. Plastics additives, essential for enhancing plastic properties, were represented by HS codes like 2903 (halogenated derivatives of acyclic hydrocarbons), 3811 (lubricating oil additives), 3812 (plasticizers) and so on. In our analysis, we have selected 80 HS codes for plastic additives based on their trade significance as documented in UN Comtrade's global and regional data collection. This selection criterion ensures that our analysis focuses on the most traded and economically significant additives, providing a representative overview of their impact on global and regional plastics flows. Although there are thousands of additives utilized in the plastics industry, our aim is to capture those that are most relevant from a trade perspective. This focus is essential for the objectives of our material flow analysis, as it enables us to better understand and quantify the dynamics of plastic additives within international trade networks and their broader implications for global plastics management.

The primary plastics, crucial for initial manufacturing processes, were included within HS codes 3901-4002, covering polymers of ethylene, propylene, styrene, and other vital polymers. Manufactured plastics and final products, which signify the intermediate and end-uses of plastics, were categorized under HS codes 3920-6305 encompassing plastic plates, sheets, films, containers, and other consumer and industrial products. Lastly, the end-of-life stage, representing plastics waste, was captured using HS code 3915. This comprehensive selection of HS codes ensured that our analysis represented the entire lifecycle and trade flows of plastics—from crude oil feedstocks through to final products and waste management—providing deep insights into the global material flows and stocks of plastics. The full list of the HS codes along the lifecycle of plastics is provided in the excel data file of the SI. An illustration of the selected HS codes is illustrated in the figure below.

Supplementary Figure 12 An illustration of the HS codes selected for the global plastics trade analysis



Supplementary Note 3. Sensitivity Analysis

We conducted a thorough sensitivity analysis to evaluate the robustness and reliability of our findings. The methodology involved systematically varying key parameters within plausible ranges to assess their impact on the outcomes of the global trade-linked MFA model. Central parameters included global and regional plastics production rates, consumption rates, waste generation metrics, and plastics product lifespans. For global and regional plastics production, we applied variations of ±10% and ±20% to observe the model's response. Similarly, regional production data were adjusted within these ranges to investigate localized impacts. Consumption rates, which reflect regional socio-economic behavior, were varied from their base values by ±5% and ±10%. Plastic waste generation rates were altered by ±5 kg and ±10 kg per capita. We also performed a sensitivity analysis on the plastic content of various plastic products, drawing on a comprehensive review of literature values. This involved varying the plastic content by ±2% when uncertainties were considered low (e.g., based on well-documented data) and by ±10% when uncertainties were high (e.g., extrapolation of missing data). Standard deviation was applied to plastic-containing products (see **Supplementary Table 6**) to measure the dispersion of data points around the mean value, providing insights into the stability and consistency of the findings.

Regarding trade quantification based on UN Comtrade data, uncertainties were assessed by comparing reported import and export figures between trading partners. Discrepancies often arise due to differences in reporting practices, timing, and classification systems. We calculated the absolute differences between matched import and export records and expressed them as a percentage of the total trade volume to quantify the level of uncertainty (**see Supplementary Table 9**). The percentage uncertainty is calculated as the absolute difference divided by the total trade volume (import + export) for each pair, multiplied by 100. This analysis helps identify potential data inconsistencies and provides a basis for adjusting trade estimates to align with the most reliable information available. The uncertainty analysis in the estimation of the global plastic trade along the supply chain is illustrated through error bars in **Figure 3h**, which visually represents the range of possible values for each trade flow, accounting for the identified uncertainties. This comprehensive approach to sensitivity and uncertainty analysis ensures that our findings are robust and reliable, considering the inherent complexities and variabilities in global plastics data.

Supplementary Table 9 Assessment of uncertainties in trade quantification based on UNComtrade data

Trading Partners	Reported Import Volume (tons)	Reported Export Volume (tons)	Absolute Difference (tons)	Percentage Uncertainty
Country A - Country B	10,000	9,700	300	1.52%
Country C - Country D	8,000	8,700	700	4.19%
Country E - Country F	12,000	12,200	200	0.82%
Country G - Country H	15,000	15,400	400	1.31%
Country I - Country J	6,000	6,100	100	0.82%

Supplementary Note 4. Classification of countries

In our study, when referring to developed countries or high-income countries, we refer to those nations classified by the World Bank as having a high Gross National Income (GNI) per capita. According to the World Bank, high-income economies are defined as countries with a GNI per capita of $14,005 or more, calculated using the Atlas method[34]. These countries are characterized by advanced industrial and service sectors, well-developed infrastructure, and high standards of living. They also typically have strong political institutions, stable governance, and advanced technological capabilities, which contribute to their overall economic development and sustainability. **Supplementary Table 10** provides the detailed classification of countries and regions considered in the study.

Supplementary Table 10 Classification of regions and countries

Countries and Regions	Description
China	China Mainland (China Hong Kong, China Taiwan and China Macau are grouped in Oth Asia)
the USA	the USA
India	India
Japan	Japan
Europe (EU28)	Austria, Belgium, Bulgaria, Cyprus, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, the United Kingdom
Middle East	Bahrain, Cyprus, Egypt, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Palestine,

	Qatar, Saudi Arabia, Syria, Türkiye, the United Arab Emirates, and Yemen
Africa	Algeria, Angola, Benin, Botswana, Burkina Faso, Burundi, Cabo Verde, Cameroon, Central African Republic (CAR), Chad, Comoros, Congo (Democratic Republic), Congo (Republic), Cote d'Ivoire, Djibouti, Equatorial Guinea, Eritrea, Eswatini, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Libya, Madagascar, Malawi, Mali, Mauritania, Mauritius, Morocco, Mozambique, Namibia, Niger, Nigeria, Rwanda, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, South Sudan, Sudan, Tanzania, Togo, Tunisia, Uganda, Zambia, Zimbabwe
Oth Asia (Other Asia)	Afghanistan, Tajikistan, Uzbekistan, Kazakhstan, Turkmenistan, Kyrgyzstan, China Hong Kong, China Taiwan, China Macau, Mongolia, North Korea, South Korea, Japan, Sri Lanka, Bangladesh, Pakistan, Bhutan, Nepal, and the Maldives
ROW (Rest of the World)	The remaining countries of the world

Supplementary Note 5. Plastics terminologies definitions

(i) **Plastics Mismanagement:** Plastic mismanagement refers to the inadequate disposal and management of plastic waste, which can lead to environmental contamination and ecological imbalance. This includes waste that is inappropriately disposed of, such as in open dumps or unspecified landfills, or waste that is unaccounted for.

(ii) **Plastic Loss**: Plastic loss is the amount plastics that is lost along the life cycle of plastics. This loss can occur during the manufacturing stage where inefficiencies in chemical processes lead to material loss and unusable resin due to quality or contamination issues. In manufacturing, material is lost through processing inefficiencies, such as trimming and cutting, as well as degradation. Further losses occur during waste management disposal due to inadequate waste collection and sorting which results in leaking into the environment.

(iii) **Plastics Emissions**: Plastics emissions encompass the environmental impacts associated with the entire lifecycle of plastics, including carbon emissions from production, use, and disposal, the release of plastics waste in the ecosystem

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