India – Australia Industry and Research Collaboration for Reducing Plastic Waste

A material flow analysis of polymers and plastics in India

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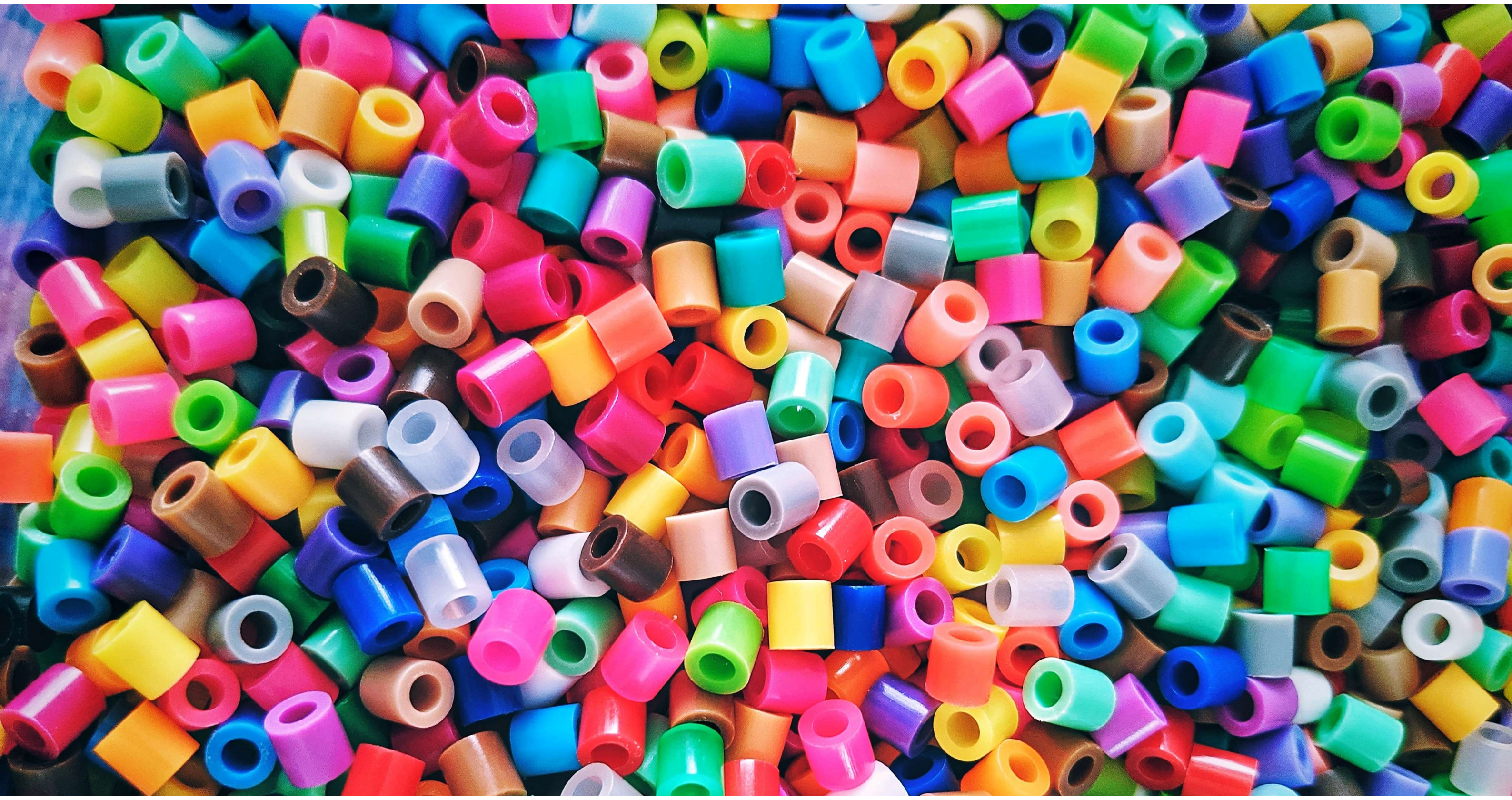

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The India – Australia Industry and Research Collaboration for Reducing Plastic Waste is a three-year collaboration with partners in both India – the Council of Scientific and Industrial Research (CSIR), Development Alternatives and The Energy and Resources Institute (TERI) – and Australia – the University of New South Wales (UNSW), the University of Technology Sydney (UTS) and CSIRO. Through key activities, this collaboration works closely with industry, government and community stakeholders to evaluate the economic and policy implications of transitioning to a circular economy for plastics.

Project co-ordinating organisation

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The Challenge

Over 300 million tonnes of plastic waste are created globally each year yet only nine per cent of this plastic waste is recycled. Plastic waste also leaks into the environment and creates large problems for terrestrial and marine ecosystems and species as well as a loss of material value.

Both India and Australia are committed to take action to reduce plastic waste by driving innovation and enabling new technologies and business models to achieve this. By doing so, both countries can reduce the environmental and health impacts of plastic waste and enable new growth industries and employment in a zero-plastic waste economy.

The *India – Australia Industry and Research Collaboration for Reducing Plastic Waste* is a three-year collaboration with partners in both India - the Council of Scientific and Industrial Research (CSIR), Development Alternatives and The Energy and Resources Institute (TERI) – and Australia - the University of New South Wales (UNSW), the University of Technology Sydney (UTS) and CSIRO. Through key activities, this collaboration works closely with industry, government and community stakeholders to evaluate the economic and policy implications of transitioning to a circular economy for plastics.

The three-year research program will result in:

- a comprehensive knowledgebase of plastics material flows from import and domestic production, to use, disposal, recycling and reuse;
- a full supply chain analysis of plastics use in key sectors including packaging, agriculture, construction, automotive, electronics and household appliances sectors identifying supply chain participants and physical and monetary interactions;
- a roadmap identifying the main technical innovations, both at community and large industrial scale, that will help to innovate across the plastics supply chain reducing end-of -life plastics waste and enabling design for circularity;
- a set of principles and strategies including institutional and economic factors, new business models and markets that facilitate the transition to a circular plastics economy;
- a series of demonstration projects located in different parts of India including in urban and rural locations and both small and community scale and large industrial scale applications of circular economy;
- a continuous process of evaluation and learning that will build a knowledgebase that can be scaled up to the whole economy for all types of materials to foster circular interactions; and
- a platform for research and industry collaboration between India and Australia beyond the initial three-year research program.

This report focuses on the development of metrics and datasets that assess the magnitude of the plastics waste problem in India and how quickly it is growing.

Glossary

ACRONYM	NAME
ACN	Acrylonitrile (monomer produced from propylene and ammonia)
CAGR	Compound annual growth rate
CPCB	Central Pollution Control Board
CSIR	Council of Scientific and Industrial Research
CSIRO	Commonwealth Scientific and Industrial Research Organisation
EEE	Electrical and Electronic Equipment
GDP	Gross domestic product
GHG	Greenhouse gas
MFA	Material Flow Analysis
MoEFCC	Ministry of Environment, Forests and Climate Change
MPW	Mixed Plastic Waste
MSW	Municipal Solid Waste
Mt	Megatonnes = 10^6 tonnes = 10^9 kilograms
PCR	Post-consumer recyclates
SWM	Solid waste management
ULB	Urban Local Bodies
UN	United Nations
WITS	World Integrated Trade Solutions
Thermoplastics	
ABS	Acrylonitrile-butadiene-styrene (see ACN)
BOPET	Biaxially-oriented polyethylene terephthalate
EVA	Ethylene-vinyl acetate
EPS	Extended Polystyrene
HDPE	High Density Polyethylene
LDPE	Low Density Polyethylene
PC	Polycarbonate
PE	Polyethylene
PET	Polyethylene terephthalate
PMMA	Polymethyl Methacrylate (perspex)
PP	Polypropylene
PS	Polystyrene
PVC	Polyvinyl chloride
Thermosets	
PU	Polyurethane
PR	Polyester resin (fibreglass)
	Duroplast
	Vulcanised rubber

Executive Summary

India's compound annual growth in apparent consumption of major commodity plastics has been nearly 7% for a decade. However, a complete material flow analysis (MFA) of Indian plastics has not been conducted since Mutha et al. (2006) compiled data from the year 2000. We present a 20-year update, including the current features of plastic production and end use by polymers and in sectors; a complete account of national plastics material flows; and an analysis of key drivers of change into the medium-term future.

In an ideal situation, there would be data on three flows: plastic consumed and disposed of by sectors (including households) within a reporting year; plastic retained in long-lived products in the same sectors; and plastic waste from end-of-life of products made in earlier years.

There are significant and inherent data gaps, notably around the collection and treatment of post-consumption flows and their ultimate fate. Acknowledging these uncertainties, we have developed a self-consistent MFA model, representing available data on national flows for 2018–19, estimating data where primary sources were unavailable.

The MFA depends on assumptions and modelling to span the direct data gaps regarding plastic production, consumption and waste flows. These include the proportion of production going into long-lived (>1 year) stocks; the fate of waste flows from long-lived stocks; and the connection between recycled or reutilised flows and their return point into the Indian economy.

To estimate flows from end-of-life for different use sectors we have used expert judgement on the proportion of long-lived products that come out of service, assuming that 10 to 25% of long-lived products enter the waste stream in a given year of consumption/use.

The proportion of e-waste plastic recycling and reutilisation are both assumed to be 10%, and likewise, household plastic waste is assumed to be reutilised or mismanaged in the ratio 50/50. These remain our best judgements and there are some data from state and city level information that can inform the boundaries of possible recovered flows, though sometimes urban or regional reporting is incomplete.

Although we have estimated the flows to recycling and reutilisation, we do not attempt to quantify recycled flows back into production. Except for the flow of recycled PET back for use as fibre, there is a complete absence of data on existing flows of recyclates back into the production system.

This is a major data gap for future work and one that we expect links to flows of low-value secondary plastic products that cater to the demand of the poorer sections of Indian society. These products will likely have a high percentage of recycled inputs as mechanical recycling of plastic waste into new moulded products often happens in the informal sector.

Leakages of plastic waste into the environment, and their connection to mismanaged plastic waste, are likely to remain data-scarce topics and may only be understood from the MFA balance, when all other flows are reasonably accounted for.

Total domestic production of plastic amounted to 14.24 Mt for the year 2018–19, while the trade in plastic polymers is relatively significant: 46.5% of total domestic production is either imported or exported. However, India remains a net importer, with a negative balance of 1.3 Mt. For the consumption of plastic and plastic-containing products by sector, flexible packaging accounts for 42%, followed by rigid packaging (17%), and buildings and construction (14%).

Additions to stock were concentrated in buildings and construction, agriculture, household and automotive sectors (totalling 4.72 Mt). Approximately 9.73 Mt of plastic waste was generated in 2018–19, a majority of which was packaging products (6.24 Mt of flexible packaging and 2.44 Mt of rigid packaging). Based on collected inputs from industry experts, and considering the composition of plastic types used in different sectors, we estimated the distribution of waste occurs between recycling (61%), reutilising (12%) and mismanagement (27%).

Future consumption was projected based on demand elasticities until 2035, which show that demand is likely to remain strong, driven by consumption in major sectors including construction, electronics and packaging, among others. Per capita plastic consumption is predicted to grow substantially from a historical 8 kg per person in 2010 to around 29 kg per person by 2035. At this rate, total plastic consumption in India will grow from 9.9Mt in 2010 to 44.8 Mt by 2035.

There is a growing agreement among stakeholders that future demand will be significantly shaped by the changes in the policy environment as envisioned under the draft Plastic Waste Management (Amendment) Rules, 2021, and stricter enforcement of extended producer responsibility.

1 Introduction

India's economic growth has been accompanied by increased production and consumption of plastic products. Plastic has emerged as a primary material used in packaging and finds application across almost many end-use sectors: building and construction, household/consumer products, automotive, electrical and electronics, agriculture, medical products and in industrial machinery.

In 2018–19, India consumed 16.9 million tonnes (Mt) of thermoplastics and 1.57 Mt of thermosets (Plastindia Foundation, 2019). The major commodity polymers consumed in 2018–19 are shown in Table 1.

All polymers listed in Table 1 belong to the family of thermoplastics and are technically recyclable. However, these polymers are often used in products with multi-layered combinations of different polymers or multi-layered combinations of polymers with materials such as aluminium or paper. Recycling the thermoplastic polymers from these products thus becomes a challenge, and only around 60% of waste plastics are actually recycled, mostly in the form of PET bottles, HDPE bottles and containers, and PVC pipes (Kapur-Bakshi et al., 2021). Thermoset polymers constituted 8% of the total polymer consumption in India in 2018–19 and technically cannot be remoulded or recycled.

Table 1 Proportion of major commodity polymers in consumption of plastics in India 2018–19. Does not show Paste PVC, CPVC, engineered plastics or EVA that are normally included within the thermoplastics category

POLYMER	% OF THERMOPLASTICS	% OF TOTAL CONSUMPTION	MASS FLOW (MT)
Polypropylene (PP)	30%	28%	5.08
Polyethylene (PE)[1]	31%	29%	5.30
Polyvinylchloride (PVC)	19%	17%	3.19
Polyethylene Terephthalate (PET)	6%	5%	0.97
Biaxially-oriented polyethylene terephthalate (BOPET)	4%	4%	0.67
Polystyrene and Expanded Polystyrene (PS+EPS)	3%	2%	0.38

Source: Based on (Plastindia Foundation, 2019)

The recycled material is mostly used in the informal sector to manufacture low quality products to meet the demand of the large low-income groups. Some part of the recyclates is also exported to other countries and a small percentage (about 5%) is looped back to the formal manufacturing sector (this can be considered to substitute for virgin plastics in a circularity context).

The consequences of increases in Indian plastic production and consumption are an increase in plastic waste, which contributes to the problem of waste management in the country. India does have one of the highest recycling rates, however most plastics recycling takes place in the informal

[1] PE, used in three forms: High Density PE (HDPE), Low Density PE (LDPE) and Linear Low Density PE (LLDPE).

sector and often involves downcycling to produce low quality recyclates. There is also a substantial quantity of non-recovered or mismanaged waste plastic.

The informal sector consists of waste collectors, rag pickers, small and large scrap dealers, and *kabadiwalas* (scrap collectors). The processing of waste also happens mostly in informal units. Recycling of plastic waste is largely a mechanical process, leading to generation of post-consumer recyclates (PCR) or downcycled secondary raw materials.

In addition to recycling, plastic waste is reutilised for energy recovery as refuse-derived fuel, plastic to oil, combustion into thermal energy or for power generation (which can be operated by the private sector or local governments). Other forms of reutilisation include repurposing into lumber or tiles, use in road construction, or upcycling into sophisticated products. The plastic waste that does not get recycled or reutilised is considered to be mismanaged and is seen as litter, dumped at garbage vulnerable points (GVPs), thrown away in drains, water bodies, and dumped at landfills (mostly 'unscientific' landfills in India).

This presents both a socio-environmental challenge and, simultaneously, it suggests there are large flows of material that are not being recovered. This creates business opportunities not just for collection and recovery of waste, but also those related to recycling and reutilisation. This can help reduce leakages of waste into the environment and the associated economic costs of managing the mismanaged (including leaked) waste.

This report aims to develop a quantitative understanding of the size and nature of major commodity plastic production, consumption, and waste flows in India, in order to gauge the magnitude of the challenges and opportunities of a circular economy for plastic. Part of this assessment is the volume of material (Mt/year), but we also seek to understand the role of long-lived plastic products and the flow of plastics at end of life (EoL).

The scope of this work looks at major commodity plastic polymers: PP, HDPE, LDPE (including LLDPE), PVC, PET and PS. We also look at information on plastic application areas and end-use sectors, as commonly classified by Indian reporting entities and key industry bodies (CPCB, 2015; Plastindia Foundation, 2019). The base year is 2018–19 as the Indian financial year, and often the reporting year, goes from 1 April to 31 March in successive years. This may also be referred to as '2019' where other data is available by calendar year. In all cases where data is used from other reporting periods as a proxy or estimate for 2018–19, we acknowledge that difference.

An earlier study for India, by Mutha et al. (2006), developed a material flow framework to investigate the stocks and flows of plastic in India. That investigation was based on data for the year 2000. To our knowledge there has been no comprehensive material flow analysis (MFA) of commodity plastics in the intervening 20 years. The framework of Mutha et al. (2006) was directed to informing plastic waste management planning and there have been several structural economic changes since that time, and a more recent strategic emphasis on the circular economy. Plastics waste management is part of the aim here, though we seek to emulate the broader framework of plastics material flow accounting by Hsu et al. (2021) – see Figure 1.

We obtain datasets and develop metrics related to these flows of plastics, and some measure of how quickly these flows are changing. Through this, we aim to gain an understanding of: the main supply chains for the major commodity polymers commonly used; the associated waste flow and end state destinations; and the subsequent leakages to the environment.

Based on our survey of contemporary academic literature, government and industry reports, we use the MFA model to both represent the system, and aid in the estimation of data where no primary source exists.

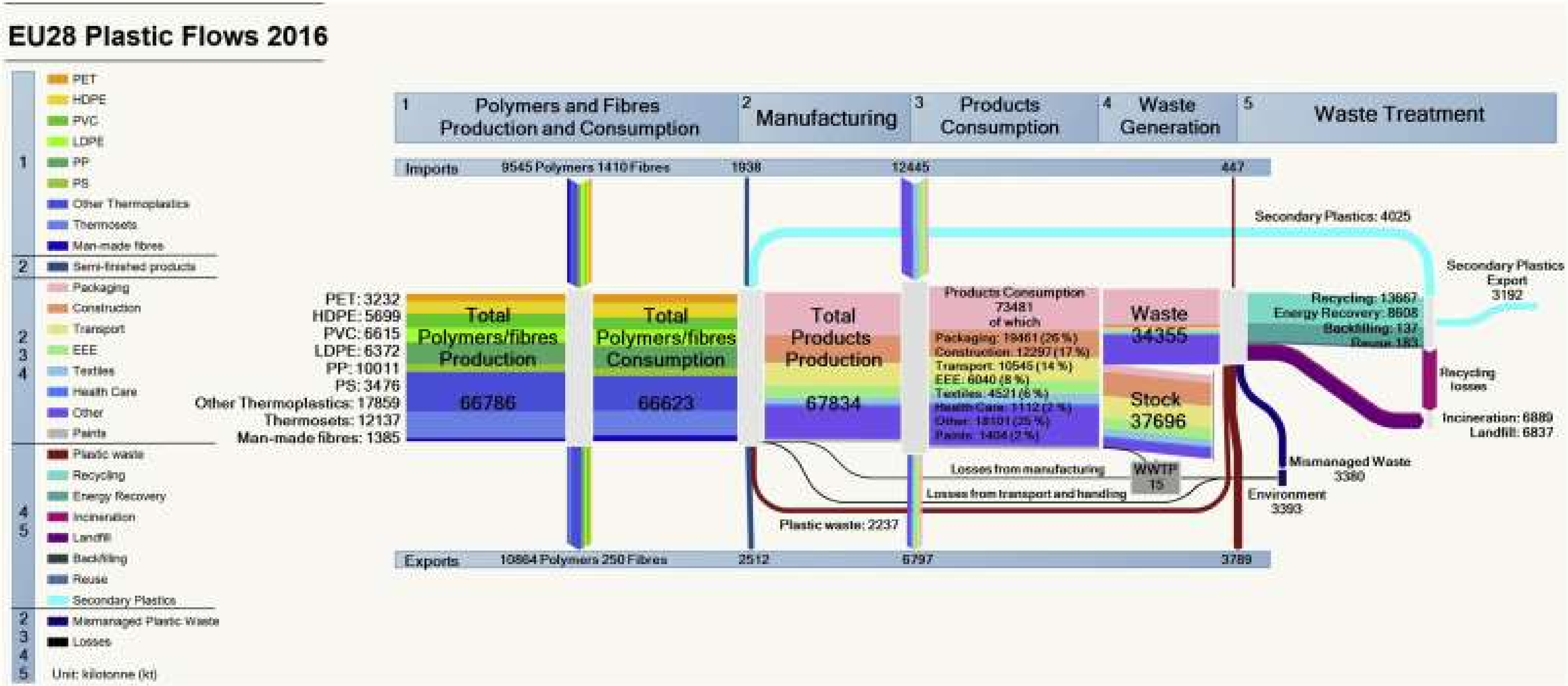

Figure 1 Framework of plastics material flow accounting in the EU28 showing breakdown by polymers, products and ultimate destinations to stock or waste flows. From (Hsu et al., 2021)

2 The Current State

2.1 Domestic Production

Polymer and feedstock suppliers consist of a few large manufacturers such as Reliance, Haldia Chemicals, Indian Oil Corporation (IOC), Bharat Petroleum, and Gail India. Downstream plastic processing operations are fragmented, consisting mainly of micro, small and medium enterprises (MSME) (HBL, 2020). Demand for polymer plastics is driven by the packaging, automotive, agriculture and textile industries. As of 2018–19, the total estimated market size of the Indian plastics industry was approximately $US73 billion (IBEF, 2021). Based on apparent consumption (see later section: Plastic consumption across sectors), and reported imports and exports, domestic production was estimated to be 11.6 Mt in 2018–19.

2.2 Trade

Plastics represent the 6th largest imported product and rank among the top 15 export commodities in India (World Integrated Trade Solutions (WITS), 2018). Some of the polymers (PP, PS/EPS) are available domestically for use by the manufacturing/processing industry but for PVC India is heavily dependent on imports to meet demand. Feedstock monomers, Polyacetals, other polyethers, and epoxide resins, polycarbonate, alkyd resins, polyallyl esters and other polyesters are also imported in primary forms. Table 2 and Table 3 below present the trends in monetary and mass terms for plastic polymers (and plastic product and waste scrap) imports and exports of India.

India also imports and exports plastics in product form. These include sheets, film, foil and strips of plastics, non-cellular and not reinforced, laminated, supported or similar products combined with other materials. Until 2019, plastic waste, parings and scrap were also imported. The total imports of plastic products (and virgin polymers) by India during the period 2015–2019 saw a steady increase, as can be seen from Table 2.

According to the World Bank's World Integrated Trade Solution (WITS) statistics, in 2018, the top partner countries from which India imported plastics in terms of the trade value were: China, Republic of Korea, Singapore and USA. The total value of imports of plastic and rubber was around $US23 billion (WITS, 2018).

In 2019, India was the 17th largest plastic exporter in the world, exporting $US3.61 billion of plastic products, including processed plastic such as plastic sheet, film, plates, and packaging materials (United Nations, 2019). In 2018, the major importers of Indian plastic or rubber export products were the United States, China, United Arab Emirates, Italy and Germany. The total value of exports of plastic and rubber was around $US11 billion.

Table 2 Plastic imports to India during 2015–19

YEAR	NET VALUE (MT) OF PLASTIC RAW MATERIAL IMPORTED	TRADE VALUE (USD BILLION) OF PLASTIC RAW MATERIAL IMPORTED	NET VALUE (Mt) OF PLASTIC PRODUCTS IMPORTED	TRADE VALUE (USD BILLION) OF PLASTIC PRODUCTS IMPORTED
2015	5.8	8.75	0.87	2.59
2016	6.34	8.66	0.89	2.72
2017	5.9	9.04	0.94	3.02
2018	7.14	11.47	1.16	3.71
2019	7.64	10.84	1.22	3.78

Source: Based on (United Nations, 2019)

Table 3 Plastic exports from India during 2015–19

YEAR	NET VALUE (MT) OF PLASTIC RAW MATERIAL EXPORTED	TRADE VALUE (USD BILLION) OF PLASTIC RAW MATERIAL EXPORTED	NET VALUE (Mt) OF PLASTIC PRODUCTS EXPORTED	TRADE VALUE (USD BILLION) OF PLASTIC PRODUCTS EXPORTED
2015	1.83	2.35	1.05	2.65
2016	2.12	2.4	1.13	2.8
2017	1.18	2.94	1.26	2.97
2018	3.32	4.51	1.28	3.35
2019	3.14	3.73	1.32	3.61

Source: Based on (United Nations, 2019)

2.3 Polymer Applications

Various polymers undergo different engineering processes to be used in manufacturing products across sectors. Major processes include extrusion, injection moulding, blow moulding and rota moulding. For example, products from extrusion in the form of pipes, films, wire and cable, sheets, profiles, etc. are used in almost all sectors. Applications such as injection moulding find use in high precision engineering components to disposable consumer goods largely used in households, packaging, electrical and electronics, and the automotive sector. Rota moulding is a process used for producing hollow plastic products in the form of bottles, drums, tanks that again find multiple uses across sectors.

2.4 Plastic consumption across sectors

Plastics have emerged as convenient materials for application across wide range of sectors. They are light, durable easy to mould, and economical while offering desired strength. India has witnessed phenomenal growth in the consumption of plastics in the past few decades. Between 2011 and 2019, apparent consumption (Imports + Domestic Production – Exports) of major commodity plastics increased from 9.41 Mt to 15.99 Mt with an estimated compound annual growth rate (CAGR) of 6.9%. The year-wise consumption of these polymers is presented in Figure 2.

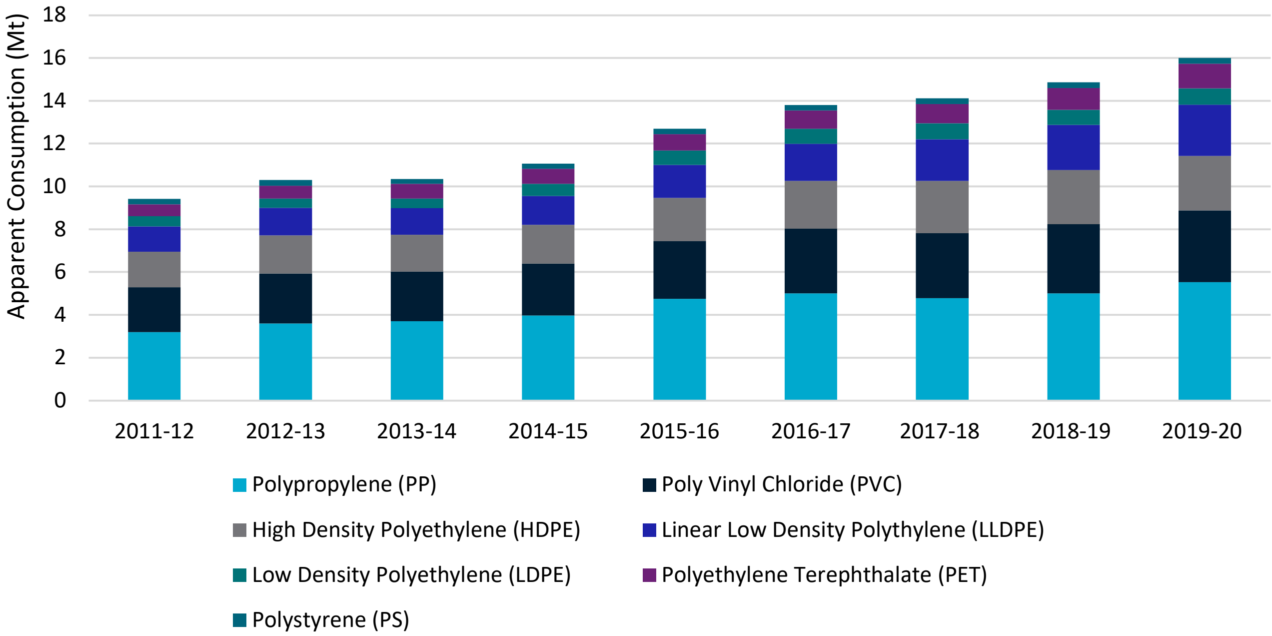

Figure 2 Trends in apparent consumption of polymer in India by type

The share of polymers consumed in different end-use sector products suggests that the packaging sector dominates plastic consumption (59% including flexible and rigid packaging), followed by building and construction (13%) and agriculture (9%) (Plastindia Foundation, 2019) – refer to Table 4. Some sectors witnessed substantial increases in their shares between 2013 and 2019. The largest increase, from 48% to 59%, occurred in the packaging sector. The share in the automotive sector rose from 3% to 7% while there was a marginal rise of 1% in the building and construction sector (Plastindia Foundation, 2019).

The subsequent sections present an overview of major polymers consumed across various end-use sectors and their contribution to the total plastic waste generated, with 2018–19 as a reference year for the analysis. This is used in developing the MFA presented in a later section.

Table 4 Share of plastic consumption in major end-use sectors

SECTORS	SHARE IN 2013–14	SHARE IN 2019
Flexible Packaging	35%	42%
Rigid Packaging	13%	17%
Household**	10%	7%
Building & Construction***	12%	13%
Agriculture	9%	9%
Electrical and Electronics	14%	2%
Automotive	3%	7%
Others****	4%	3%

Source: (Plastindia Foundation, 2019)

* Consumption of major polymers: PE/PP/PVC/PET+BOPET/PS.

** This includes FMCGs such as toiletries and cosmetics, furniture, toys, luggage, homewares and other lifestyle related products.

*** Building and Construction would include water pipes, water tanks, roof shelters, sheets, etc.

**** This includes sports and leisure, medical, dental care, and industrial machinery as a heterogeneous category.

2.4.1 Packaging (Rigid and Flexible)

Packaging is broadly categorised into rigid packaging and flexible packaging. Flexible packaging, which is the newer form of packaging, has the largest share among the key end uses. The common types of flexible packaging are stand-up pouches, milk pouches and bags, laminated tubes, and squeezable bottles. It is anticipated that there will be strong growth in the future due to the numerous advantages of flexible packaging, such as light weight and small size that results in convenience in handling and disposal, price advantage in transportation, and energy savings, which has traditionally been limited by rigid packaging.

2.4.2 Building and Construction

The construction sector is one of the world’s largest consumers of polymers and polymer composites. The various polymers used in the construction sector include polypropylene (PP), polyvinyl chloride (PVC), high density polyethylene (HDPE), linear low-density polyethylene (LLDP), Polyethylene (PE), Polyurethane (PU) and others. The most commonly used polymer in the construction sector is PVC and the various applications of these different polymers are illustrated in the table below.

Table 5 Application of polymers in the Building and Construction sector in India

KEY POLYMERS	CLADDING PANELS	CABLES	PIPES AND GUTTERS	DOOR AND WINDOWS	SHUTTERING	WALL LININGS	FLOOR COVERINGS	CELLING PANEL	ROOF COVERING	SINK, BASIN, BATH AND SHOWER	INSULATION MATERIAL
PP		■	■			■					
PVC	■	■	■	■		■					■
HDPE		■	■		■		■	■			
PS						■					■
PE		■	■		■				■		
PU											■
Others*						■				■	

Source: Authors' Compilation.

* Polymethyl Methacrylate (PMMA), Polyester Resin (PR), Phenolic Resin (PR), Organic Silicon

2.4.3 Agriculture

Plastic products and packaging are also used extensively in agricultural applications. Plastic films, mulch fields, drip irrigation and sprinklers for irrigation, pond liners to conserve water during monsoons, firm nets or plastics through a frame for greenhouses, maple tubing nursery containers, as well as containers used for pesticides and dairy sanitisers are some of the plastic products used in the agricultural sector. In addition, polyethylene films are widely used to extend and increase yields, expand growing seasons, reduce the usage of pesticides and herbicides, and help conserve water. Plastics which are most widely used in agriculture, water management and related applications are PE, (LLDPE, LDPE and HDPE), PP and PVC.

Table 6 Application of polymers in Agriculture or 'Plasticulture' sector in India.

KEY POLYMERS	DRIP IRRIGATION		SPRINKLER IRRIGATION		GREEN HOUSE	LOW TUNNEL	MULCHING
PVC	Main/sub main lines	Control Valves	Main/sub main lines	Control valves	Main/sub main lines	-	-
LDPE	-	-	Connecting line	-	UV films	UV films	-
LLDPE	Laterals/ emitting pipes	Micro tubes			UV films	-	UV films
HDPE	Screen filter	Disc filter	Main/sub main lines	Nozzles	Main/sub main lines	Hoops	-
PP	Drippers/ emitters	fittings	Fittings	Nozzles	Ropes	Ropes	Non-Woven

Source: (FICCI, 2014)

2.4.4 Automotive

Nearly 7% of the total plastic consumption in India reported in 2019 was in the automotive sector, compared to 3% reported in 2013–14. The Indian automobile sector has undergone rapid transition in recent years with an objective to achieve better fuel economy standards and reduced tailpipe emissions. Making vehicles lighter without compromising on desired strength has led to increased use of various polymers, polymer blends, and composites in innovative ways across various automotive components. Engineered plastics such including Acrylonitrile butadiene styrene (ABS), Polypropylene (PP), Polyethylene (PE), etc. are durable, provide desired strength, and reduce frequent wear and tear. On average, the proportion of plastics in an automobile may range from 7% to 12% of the kerb weight, although this may increase to almost 15% in electric vehicles. Key plastics used include PP, HDPE, ABS and PC. These constitute nearly 40% of total plastics consumed. Use of selected plastics across key automotive components is presented in Table 7.

Table 7 Application of selected plastics in major automotive components

KEY POLYMERS	DASH BOARD	FUEL SYSTEMS	BODY (INCL PANELS)	UNDER-BONNET COMPON-ENTS	INTERIOR	ELECTRIC-AL COMPON-ENTS	EXTERIOR TRIM	LIGHTING	UPHOLS-TERY	LIQUID RESERV-OIRS
Polypropylene (PP)	■	■	■	■	■	■	■		■	■
Polyvinyl Chloride (PVC)					■				■	
Polystyrene (PS)				■						
Expandable Polystyrene (EPS)				■						
PE (including HDPE)		■				■			■	■
ABS (Acrylonitrile Butadiene Styrene)	■				■		■	■		
Polybutylene terephthalate (PBT)		■			■	■	■	■		
Polycarbonate (PC)	■							■		
Others	■	■	■	■	■	■	■	■	■	■
% total weight of vehicle	0.7%	0.6%	0.6%	0.9%	2.0%	0.7%	0.4%	0.5%	0.8%	0.1%

Sources: (Satpathy et al., 2016) (Dattopadhye, 2016)

PP is estimated to have the largest share at 44%, followed by PVC (6.2%), PE (2.0%), etc. If we consider total reported plastic consumption in the country, the estimated plastic going into the automotive sector was 1.07 Mt for the year 2019.

2.4.5 Electrical and Electronic Equipment (EEE)

Plastics have been increasingly used in the EEE sector on the account of their unique combination of properties. In addition to their outstanding insulating properties, plastics can also conduct electricity under modified conditions, which leads to designers choosing them for a diverse range of EEE. The major polymers used in EEE are PP, PC, ABS, and EPS, while PVC, PE, PET and some engineered polymers comprise small shares of the overall consumption.

The significant fall in consumption of polymers in the electrical and electronic sector between 2013–14 and 2019 could be partly due to changing accounting practices for packaging of plastics in the EEE sector (into packaging as end use) and partly due to emphasis in the EEE sector on aspects or circularity such as reuse, remanufacture, and repair.

2.4.6 Household sector

This sector refers to the consumption of plastics for non-packaging use in the form of consumer products including Fast Moving Consumer Goods (FMCGs) such as toiletries and cosmetics, kitchenware, furniture, toys, luggage, homewares and other lifestyle related products. There are a variety of polymers used in this sector. For example, HDPE is used in storage containers for food and other products such as toys, LDPE is used for plastic bags and cling film, PVC is used for upholstery coverings, PP for food storage containers, PET for plastic bottles and tarpaulins and PS is used for disposable cutlery.

2.5 Waste generation and management

In India, waste generation significantly increased between 2001 and 2011 by over 200% and is projected to reach 436 Mt by FY 2050. In the year 2015, Indian cities generated 62 Mt of Municipal Solid Waste (MSW) or 450 g/capita/day, of which 82% (50 Mt) was collected, and the remaining 18% (12 Mt) became litter. Out of the collected waste only 28% (14 Mt) was treated and the remaining 72% (36 Mt) was openly dumped (Sharma and Jain, 2019). The main sources of post-consumer waste plastics are municipal solid waste (MSW), construction and demolition waste (CDW), waste from electric and electronic equipment (WEEE), and end-of-life vehicles (ELV).

2.6 Recycling – formal and informal

There are four main phases of plastics recycling based on the degree of technological input, material separation, recovery and reuse potential:

Primary recycling: This refers to the processing of waste or scrap into a product. Primary recycling involves the downstream recovery of relatively uncontaminated waste plastic materials. This is the most common form of recycled materials sent back to manufacturers.

Secondary recycling: This refers to the transformation of waste or scrap into new uses with different characteristics from the base plastic materials. Secondary recycling is suitable for use in manufacturing processes that accept higher contamination levels.

Tertiary recycling: This involves the recovery of basic chemicals and fuels from plastic waste and scrap; processes like pyrolysis and hydrolysis are suitable for tertiary recycling. This is often seen for co-mingled plastic wastes in organic municipal waste streams.

Quaternary recycling: This is a last mile recovery from plastic waste in the form of energy or fuel through incineration. The use of plastic waste as alternative fuels in cement co-processing is a prime example.

The recycling industry in India comprises many small processors, and is fragmented and highly unorganised, with large participation from informal waste collectors and recyclers. Estimates suggest over 3500 organised and 4000 unorganised plastic recycling units in India (FICCI, 2016).

Mechanical recycling is the most preferred method applied by the informal sector, which provides livelihoods to over 1.5 million waste pickers that work under inadequate health and safety conditions (Plastindia Foundation, 2019). The informal sector performs mechanical recycling (mainly downcycling) of plastic waste into flakes, pellets and granules, which is used to produce predominantly non-food-grade plastic items of low quality. Notably, there is an intricate relationship between formal solid waste management (SWM) and informal plastic recycling; they co-exist in the same area and the recycled pellets are sold in a common market (Mahesh et al. 2011).

The relatively high levels of overall recycling rates in India can mainly be attributed to the country’s widespread network of informal workers – mainly women – who forage streets and dumpsites for valuable plastics. However, according to industry experts, only 5% of these recycled materials are channelled back into the formal economy to replace demand for virgin raw materials. The remaining 95% of recyclates are downcycled into low-grade materials, which quickly add to the country’s growing amounts of mismanaged plastic waste.

The volume of plastic recycling in India in 2016, was reported to be around 3.6 Mt, providing direct and indirect employment to almost 1.6 million people annually (FICCI, 2016). Some of the issues ailing India’s recycling industry include weak critical infrastructure, systems and financial support for material segregation, data reporting and product disassembly by waste collectors and recyclers. Manual processes for cleaning and material segregation by unorganised recyclers emit effluents, dust and debris in natural systems, in addition to value losses along the waste value chain.

3 Material Flow Account

3.1 Scope

This plastics material flow analysis (MFA) for the Indian economy has been prepared for the year 2018–19, the latest year for which key data across the plastics value chain is available. The scope is limited to only the dominant thermoplastics (PE in its key forms of LDPE, LLDPE, HDPE, PP, PS (including EPS), PVC, PET including BOPET). Polymers for synthetic fibres are not included. Additives used in plastic production which are embedded in the plastic material flow are not considered in this study. Geyer et al. (2017) estimate that approximately 7% of plastic products may be additives. However due to the lack of data and their relatively small share in the overall weight of plastics, these are excluded. Discussion about additives in plastics can be found in Hahladakis et al. (2018).

Polymer production processes include use of virgin raw material and imported resins. Yet, the starting point of the system boundary for the material flow in this paper is the production of polymers (resins from the petrochemical industry). The initial extraction of primary materials (fossil fuels) and manufacturing of monomers lie outside the defined system boundaries of this MFA.

Though this MFA is based on a single year of plastics (polymer) production (2018–19), it includes an estimation of waste generated from consumption of plastics in previous years by integrating lifetimes of prior years' plastic products and estimating end-of-life flows.

The waste generation does not cover post-industrial plastic waste. This is based on the assumption that these materials (such as cut outs, trimmed out portions) are generally clean and in high demand and therefore have high recycling rates, often within the same manufacturing facility, or may be able to undergo industrial symbiosis.

The flows are subject to using available data and will also use some informed assumptions and proxy estimates which have been vetted by key sector experts. Also, given that there have been inconsistencies found in data from different sources, it was not always possible to maintain the system boundaries and application of material balance at all stages.

3.2 Methods

Following the principle of mass conservation, MFA is one of the most broadly applied approaches to measure flows and stocks of materials within a specified spatial and temporal boundary (Brunner and Rechberger, 2016). The results can be useful for decision makers, since the mass-balance approach can identify ways to improve raw materials' efficiency, contribute to saving natural resources, minimise environmental impacts, and consequently help to accomplish sustainable development goals (Gao et al., 2020).

3.3 Data

Data on imports, domestic production and exports of polymer resins are obtained from country reports published by CPMA in the APIC series of conferences (CPMA, 2020).

Plastic products manufacture is based on domestic production, and imports of resins and finished plastic products. The plastic products consumed consist of durable goods or long-life products, and non-durable goods or short-life products. The former is not consumed in one use and yields utility over time. For example, products from the household end-use sector – furniture, houseware, footwear, toys, etc. – or from the building and construction end-use sector, products such as construction tools and equipment, products from the electrical and electronic sector, auto sector and agriculture (such as agricultural equipment, tools).

The longer-term uses are accumulated in the system boundary of the plastic material flow data as stock in use. Stocks in use are important to account for as they become part of future waste and thus in a current year's waste, some part of the stock that was in use in previous years (based on the average lifetime), will come out as waste.

Short-life products or non-durable goods are either consumed immediately in one use or have a lifespan of less than a year, such as disposable cutlery, packaging, and selected medical devices (such as syringes, gloves and masks). Additions to stock in use are very small for packaging sector products, whereas they are very high in the case of construction and automotive sector products.

Within each end-use sector, there are a variety of polymers used to make the different products, including combinations of polymers at times to make a product. The data for the polymer level consumption disaggregation within end-use sectors came from different sources (refer to Table 8), including value judgements by key sectoral experts.

In terms of the relative consumption share of the dominant polymers in selected end-use sectors, please refer to Table 8.

Table 8 Distribution of major commodity polymers to end-use sectors in 2018–19

END-USE SECTORS KEY POLYMERS	FLEXIBLE PACKAGING	RIGID PACKAGING	HOUSEHOLD	BUILDING & CONSTRUCTION	ELECTRICAL & ELECTRONICS	AGRICULTURE	AUTOMOTIVE
PE	38%	11%	25%	22.8%	19.18%	73%	16%
PP	33%	13%	25%	9.4%	53.42%	16%	63%
PVC	9%		12.5%	65.8%	17.81%	8%	16%
PS			12.5%	2.2%	5.48%	3%	5%
PET+BOPET	20%	76%	25%		4.11%		

Sources: For Flexible and Rigid Packaging based on (Alam, 2021); for Household, estimates indicated by industry experts; for Building and Construction, Electrical and Electronics, based on (Plastindia Foundation, 2019); for Automotive, based on (Khemkpmaa, 2019).

Plastic packaging is dominated by polyolefins (PE and PP) and is predominantly single use. All but 5% of it is assumed to be disposed of in the same year. Given its short use life and its ubiquitous presence, the sector generates significant amounts of waste and also presents significant opportunities to improve the circularity of the plastics economy.

The large market for household products, including items like kitchenware, toys, personal care items, footwear, luggage, etc. is made up of different polymers and items have an average lifetime of three years. In the building and construction sector, the plastic composition is unclear, though PE and PP are considered to be the key polymers used, followed by PVC, which is used in the form of pipes, tubes, window frames, etc. PVC, if mixed with the MSW stream, can introduce lot of challenges as a contaminant in the mechanical recycling processes which are mostly used.

Besides resin level imports, imports in the plastics industry also include imports of intermediate plastic products such as sheets, films, plates and caps which are then used to make final products by brand manufacturers. Similarly, plastic imports also occur in the form of finished final products (related to different end uses such as footwear, furniture, electronics, toys and automobiles). A major data gap here is the lack of information on the resin composition of these imported goods. Exports include raw materials and plastic products (which can be final or intermediate as the data using the HS code does not give a disaggregation).

3.4 Estimating End of Life Flows

Given the mean product lifetimes for the different sectors, it may still be reasonable to assume that for long-life plastic products (mean average life greater than a year), a certain percentage of plastic products in the respective sectors end up as waste in the year of consumption, due to multiple reasons including poor quality, natural damage, redundancy, etc. Though short-lifetime plastic products (mean average life of up to a year) end up in the waste stream within a year assuming normal or average rates of physical usage, a small percentage of these products can also be assumed not to end up as waste in the year of consumption. Based on consultation with key experts, it is assumed that 5% of short-lifetime plastic products, mainly packaging, do not end up as waste in the year of consumption.

For long lifetime plastic products, the mean lifetime varies from three years for consumer and institutional products to as high as 35 years for building and construction products. Here it is assumed that 10–25% of long lifetime products (depending on the product and sector) come out as waste in the year of consumption/use – refer to Table 9.

The long lifetime plastic products or durable products belong mostly to the non-packaging sectors – household, electrical and electronics, automotive, buildings and construction. However, it is important to note that these non-packaging sectors also show significant variation in the lifetimes of products. For example, these sectors also include products with very short lives (1 day) such as for disposable service-ware and garbage bags.

Some packaging can have a surprisingly long lifetime. For example, Mutha et al. (2006) estimated the total service period of woven sacks to be three years, though the service life of woven sacks used for packaging was less than one year. The authors attribute this to the fact that these sacks are used for approximately an additional two years to protect goods and as roofing materials in slum areas.

To estimate plastic waste, we combined the service lifetime distribution parameters in Table 9, and the total annual consumption of all plastics in India, to generate a first order estimate of the quantities of post-consumer plastic waste related to consumption in the year. This analysis makes the simplifying assumption that distribution of plastics across market sectors is constant and equal to the share of plastic consumption in end-use sectors presented in an earlier section for the year 2013–14. While this assumption is a limitation – the distribution of plastic usage across market sectors very likely has shifted – it is necessary in order to make use of existing data.

Table 9 Summary of product lifetime (log-normal) distribution parameters

MARKET SECTOR	LIFETIME (YEARS)			
	MIN	**MAX**	**MEAN**	**STANDARD DEVIATION**
Transport	1	20	13	3
Packaging	0	1	0.5	0.1
Construction/Building	10	60	35	7
Electrical and Electronic Applications	1	10	8	2
Consumer and Institutional	1	10	3	1
Industrial Machinery	5	30	20	3
Others	1	10	5	1.5

Source: Geyer et al. (2017).

It is equally important to acknowledge that a small share of plastic will also end up in the plastic waste stream based on replacement of components and parts in products that may still be in use. Such replacement may arise from damages, defects, and sudden changes in consumer preferences. Some of these components and parts may be reused in the same form, depending on their conditions and the maturity of the after-sales market in India. For example, in the automobile sector, plastic waste generation may arise from discarded components that are damaged or from replacement due to changing consumer preferences, where the plastics from these components cannot be reused or refurbished.

While the estimation of sectoral consumption of plastics and the share of polymers is based on analysis of secondary data, contribution to the plastic waste stream from discarded components and parts from in-service products across various sectors is drawn heavily from insights and inputs received from stakeholders concerned. Industry experts were consulted about the possible fates of plastic waste from sectors. Following this we use our best judgement to estimate the probable percentage of annual consumption directed toward recycling, reutilisation (often via energy generation from incineration), or mismanagement.

3.5 Recycling, incineration, and mismanagement

Plastic waste flows, including end states from different end-use sectors, are analysed to be able to feed into the overall material flow of plastics. Plastic waste from the building and construction sector and that from the automotive sector are treated separately as these are not captured in the MSW stream.

3.5.1 Packaging Sector

The most widely used polymers are thermoplastics, which by their characteristics have high recyclability. However, apart from PET and HDPE used for rigid packaging products, the current recycling rate is low. This is mainly attributed to design aspects, which include the use of multi-polymers or multi-materials (polymers combined with aluminium or paper), use of colours and additives, use of difficult to remove labels, the small and lightweight nature of many FMCG products, contamination during use (with food, dust) and collection (lack of segregation or incomplete separation from other materials). The PET waste in packaging makes up around 10%; around 85–90% of PET is recycled in the country, with the largest proportion (almost 90%) being used in Recycled PET (rPET) for making polyester fibre (Bhandare and Sundaresan, 2015; Mohanty, 2018). A small share of rPET is also used for manufacturing straps, monofilaments, sheets, etc. While Indian regulations do not allow rPET to be used in the production of bottles, it does take place at smaller scale in the informal sector and among niche manufacturers (PET Packaging Association for Clean Environment (PEACE), 2019). The remaining PET waste (around 10%) is assumed to be reutilised for road construction.

For non-PET polymers in packaging, the average recycling rate is much lower, at around 50%. Within the non-PET category of plastic waste, HDPE and PVC have relatively higher recycling rates compared to LDPE or LLDPE. HDPE found in milk bottles and FMCG products (such as shampoo bottles, toilet cleaners), LDPE-based single polymer products (e.g., milk pouches, squeezable bottles) is also recycled. The remaining non-PET waste (50%) is mostly mismanaged, and a small percentage of around 10% is currently reutilised.

It is important to note here that packaging waste in the current year consists of 95% of the packaging sector consumption in the current year and 5% of the previous year's packaging consumption (since the average life of packaging is less than a year, but some packaging materials go into stock in use for some time).

3.5.2 Building and Construction Sector

For plastic waste from the building and construction sector, the relative share is mostly reported along with other non-bulky materials such as wood, metal and bitumen. Bulky materials are found to occupy over 90% of the waste and the remaining 10% comprises wood, metal, bitumen, plastics, etc (MoHUA & NITI Aayog, 2019). Plastics used in construction have a long lifespan of 30 to 35 years (approximately). Hence, in a time period of increasing consumption, the generation of plastic waste is low in a given year compared to plastics consumption in that same year. However, in the current year there will be plastic construction and demolition (C&D) waste generated linked to plastic consumption in the building and construction (B&C) sector 30 years back (again, an assumption here is made that 10% of the consumption of plastics becomes waste in the year of consumption and the remainder after its average life is completed) and the waste linked to consumption of plastics in the B&C sector in the current year.

According to MoHUA & NITI Aayog, (2019), plastic comprises 3% of the C&D waste generated. The main applications generating waste in the C&D sector are fitted furniture, floor and wall coverings (PVC), pipes and ducts, insulation materials (PU) and profiles (PET, PVC, PP). According to global estimates, PVC constitutes the major proportion of the C&D waste from the building sector and has a very high recycling rate globally and in India. PVC and PP have high recycling rates of more than 50–60%. Similarly, energy recovery from incineration and landfill varies across different polymers; the estimates of polymer-specific waste, waste recycled and incinerated from the building and construction sector for Europe are given in Table 10 below. Due to the lack of any other data, for the time being we are also using percentage shares across end states for different polymers for C&D waste in India.

Table 10 End of life status and management of key polymers

POLYMER	RECYCLING	ENERGY RECOVERY (PART OF REUTILISATION)	LANDFILL (PART OF MISMANAGED)
PE-LD	27.0%	51.0%	22.0%
PE-HD	24.0%	49.0%	27.0%
PP	23.0%	50.0%	27.0%
PS	7.0%	64.0%	29.0%
PVC	34.0%	41.0%	25.0%
Other	8.0%	65.0%	27.5%

Source: Stakeholder inputs

While thermoplastics (PE, PP, PVC) can be recycled, recycling involves high costs. The lack of adequate markets, high recycling costs and lower quality recyclates are the major commercialisation barriers in recycling composite materials. PVC-U, sourced mostly from window and door fabricators, is being recycled into wiring accessories and cable management systems, including skirting and trunking (Roychowdhury et al., 2020).

3.5.3 Automotive sector

Plastics and process polymers constitute 7–10% by weight of end-of-life (ELV) vehicles (Ram et al., 2015). At the ELV stage, most metallic parts of ELVs are recycled while components made of plastic (or non-metals) are shredded and disposed of in landfills. Given that more and more vehicles are using composite materials, the percentage of materials sent to landfills is increasing. The thermoplastic content of the shredder residue is processed for the production of secondary products. In terms of end states of the different polymer waste types from the sector, for PP, 15% is recycled, 25% is reutilised (incinerated for energy recovery), and 60% is mismanaged (mostly landfilled); for PVC, 45% is recycled, 25% is reutilised and 30% is mismanaged (mostly landfilled). For PE, 25% is recycled, 65% is mismanaged and 10% is reutilised. For PS, only around 10% is recycled, 20% is reutilised and the remaining 70% is mismanaged. For this sector, the waste in the current year consists of waste (80%) from consumption in the sector 13 years back (since the average vehicle lifetime is 12 years) and 20% of the waste comes from the sector’s consumption in the current year.

3.5.4 Household sector

Given that there is a mix of polymers used and this waste comes out as part of MSW, the average recycling rate is about 60% for non-PET polymers (higher than that for non-PET in the packaging sector as this waste is less contaminated and there is a relatively higher share of rigid plastics). Many children’s toys, park benches, plant pots, and pipes are also made from HDPE and these can be easily recycled. Further, recycled HDPE is used in making different products such as pens and bottles. For PET waste in the household sector, 90% recycling is assumed. The remaining household waste is assumed to be reutilised or mismanaged (in a 50/50 proportion). With an average life of three years, the current year's waste consists of waste from consumption in the sector three years back and then from consumption in the current year. For consumption in the previous year, since 25% of the waste came out in the year of consumption, in the current year, 75% of the three years back consumption of plastics will come out and 25% of the current year's consumption.

3.5.5 Electrical and Electronic Equipment (EEE) Sector

E-waste plastics are one of the fastest-growing waste streams globally. The end-of-life handling of e-waste in India is mostly done through informal channels which correspond to 95% of the total e-waste generated. Poor choices made around disposal mean that large quantities end up being incinerated and only small quantities can be recovered due to poor extraction techniques. Recycling plastics is difficult because e-waste consists of more than 15 different polymers and contains brominated flame retardants (BFRs) including PBBs/PBDEs (Taurino et al., 2010).

E-waste in India contains around 20% plastic (Sahajwalla and Gaikwad, 2018). In the case of waste mobile phones, plastics account for about 25 to 55% by mass content of each unit and represent the heaviest part in comparison to other parts of waste devices (Nnorom and Osibanjo, 2009; Tan et al., 2017). According to the joint study by ASSOCHAM-NEC, out of the total e-waste produced in 2016, only 20% (8.9 Mt) was documented to be collected properly and recycled, while there is no record of the remaining e-waste (Mohanty, 2018; Sahajwalla and Gaikwad, 2018). Plastic retrieved from electronic waste is recycled to make insulators, trays, and fencing posts.

If we take the example of mobile phones, incineration and mechanical recycling are the most common methods for their plastic waste treatment (Singh et al., 2020). Mechanical recycling provides the separation of various types of plastics that can be used for closed-loop recycling systems, while incineration is the method used to generate energy from waste plastics by burning (Chandrasekaran and Sharma, 2019; Mendes Campolina et al., 2017).

We assume here that the plastics in e-waste have an average recycling rate of 10% and reutilisation rate (mostly energy recovery through incineration) of 10% and that the rest of the plastic waste in e-waste is landfilled. Some estimates point towards as little as 2% being recycled through formal channels in India (Karo Sambhav, 2016). It is important to note here that most e-waste generated in the current year will be EEE consumption from eight years back, given that the average lifetime of the sector is eight years. About 15% of the current year's EEE consumption is assumed to come out as waste in the current year.

Novel recovery and conversion methods from e-waste plastics to value-added products are being successfully developed (Lahiry, 2019) and could improve recycling rates in future. A demonstration plant at the Central Institute of Plastics Engineering & Technology (CIPET), Bhubaneswar, can convert plastics from e-waste to virgin master batches for use in value-added products. The process is capable of converting about 76% of waste plastic into master batches.

3.5.6 Agriculture Sector

There is no data available on the end states of Indian agri-plastic waste, except the information provided in the PlastIndia (2019) report, where it is mentioned that agri-plastic waste, if collected, can be recycled. However, evidence from other countries suggests that at the end of their useful life plastic wastes are often burned in open fields, abandoned in the fields or along watercourses, buried in the soil, or disposed of in landfills (Vox et al., 2016). To give an example, polyethylene films used in coverings are low density by design, and any waste from this process is rarely accepted by recycling facilities and often ends up in landfills and oceans.

In contrast to waste generated from the automotive sector or building and construction, agri-plastic waste is collected along with solid waste. So, one way to calculate the waste flow in the agriculture sector for plastics is to assume an average recycling rate of about 60% for agri-plastics and that the remainder is reutilised or mismanaged. Agri-plastics consumed are not short-life plastics and their lives range from one to five years, implying an average lifespan of three years. So, in the agri-plastic waste generated in the current year, waste related to the consumption of agri-plastics three years back will also be a part, and given that some percentage (around 15%) of agri-plastic consumption comes out as waste (for example, mulching films) in the year of consumption (due to unforeseen reasons, poor handling, damage), the agri-plastic waste generation in any year will consist of 85% of the agri-plastic consumption three years back and 15% of the agri-plastic consumption in the particular year of study.

3.6 Results

The results from the MFA of plastic for the year 2018–19 are summarised in Figure 3. The total domestic production amounted to 14.24 Mt. The plastic includes PE, PP, PVC, PET, BoPET and PS. The most consumed plastic polymer is PE, closely followed by PP and PVC. The trade in plastic polymers is relatively significant (46.5% of total domestic production is either imports or exports), with a negative trade balance of 1.29 Mt (3.96 Mt imported and 2.67 Mt exported).

Total mass of plastic in plastic-containing products assembled and distributed into different applications was 15.53 Mt (total apparent consumption). Figure 3 illustrates the consumption of plastic and plastic-containing products by sector. Flexible packaging accounts for 42%, followed by rigid packaging (17%), and buildings and construction (14%).

Plastic products will be distributed between waste and stock depending on the sector and lifetime of product. A total of 9.73 Mt of plastic waste was generated in 2018–19, a majority of which was packaging products (6.24 Mt of flexible packaging and 2.44 Mt of rigid packaging). On the other hand, additions to stock were much higher in buildings and construction, agriculture, household and automotive sectors (totalling 4.72 Mt). Accumulation of stocks is important to account for as they will become future waste. Considering the composition of plastic types used in different sectors, we estimated the distribution of waste between recycling (61%), reutilising (12%) and mismanagement (27%).

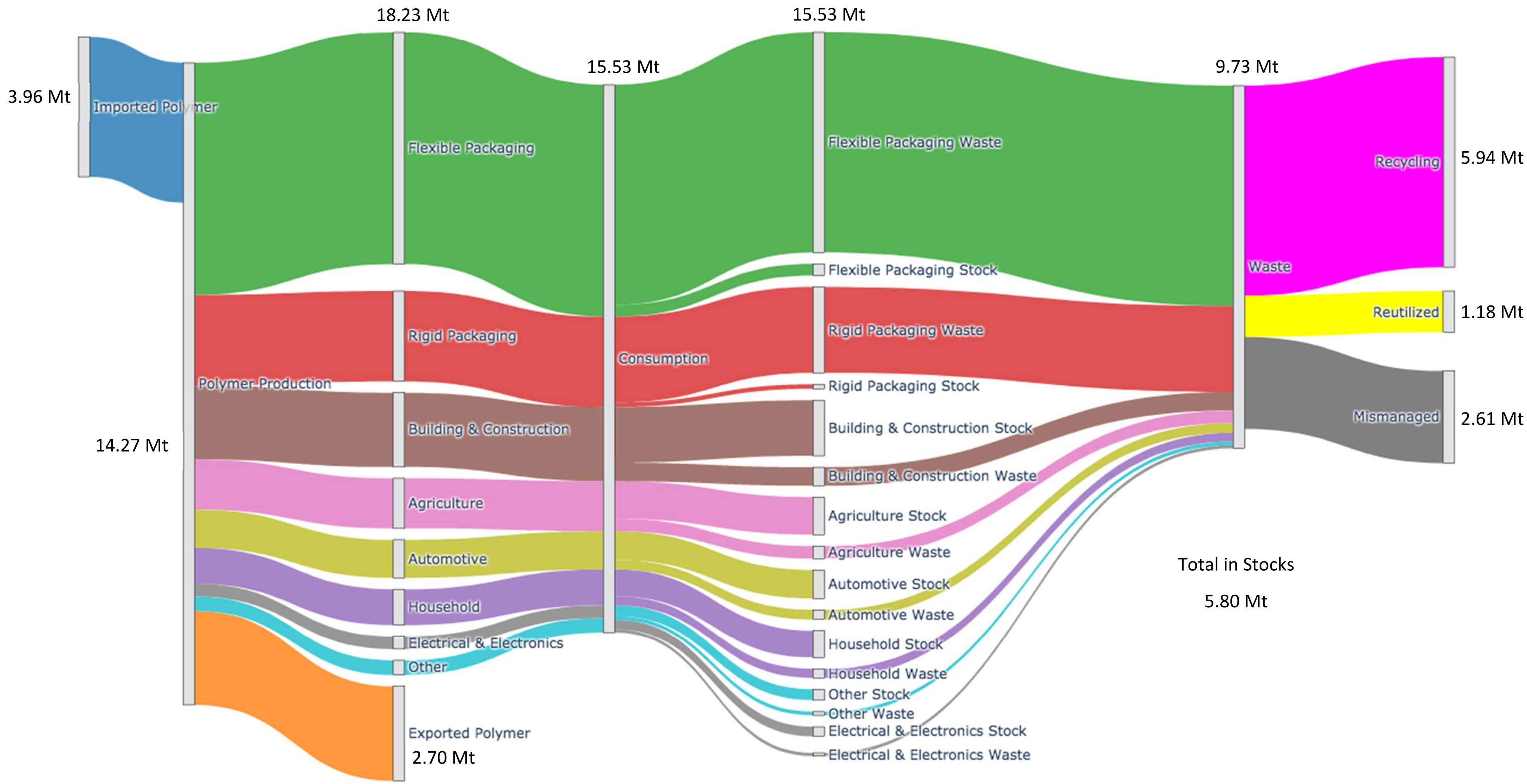

Figure 3 Summary of total plastic material flows in India for 2018–19

3.7 Gaps and data challenges

There are a few key points in the MFA that depend on assumptions and modelling to span gaps in the set of direct data sources. These include the proportion of production going into long-lived (>1 year) stocks; the fate of waste flows from long-lived stocks; and the connection between recycled or reutilised flows and their return point into the Indian economy.

We have modelled the proportion of production going into long-lived stocks through identifying sectors with long-lived products, and separating the total production of plastics into stocks of those products, e.g. automobiles, houses and electrical goods. Some 5% of both rigid and flexible packaging is assumed to remain in circulation for >1 year, but otherwise this group of plastic products enters the waste stream in the same year they were produced. In an ideal situation, there would be data on three flows: plastic consumed and disposed of by sectors within a reporting year; plastic retained in long-lived products in the same sectors; and plastic waste from end-of-life of products made in earlier years.

To estimate flows from end-of-life for different use sectors we have used expert judgement on the proportion of long-lived products that come out of service, assuming that 10 to 25% of long-lived products enter the waste stream in a given year of consumption/use. Ideally, a stock population model would provide key secondary data. For example, to have a census of automobiles, or database on building completions, or information on units of electrical goods purchased in a year. Such ancillary information would not give us direct data, but we could more precisely estimate the quantity and age of products in circulation and apply what *is* known about their respective plastic material intensities.

The proportion of e-waste plastic recycling and reutilisation are both assumed to be 10%, and likewise, household plastic waste is assumed to be reutilised or mismanaged in the ratio 50/50. These remain our best judgements and there are some data from state and city level information (CPCB, 2019a) that can inform the boundaries of possible recovered flows, though sometimes reporting is incomplete.

Although we have estimated the flows to recycling and reutilisation, we do not attempt to quantify or direct recycled inputs to production. Except for the flow of recycled PET back for use as fibre, there is a complete absence of data on existing flows of recyclates back into the production system.

This is a major data gap and one that we expect links to flows of low-value secondary plastic products that cater to the demand of the poorer sections of Indian society. These products will likely have a high percentage of recycled inputs, given that processing through mechanical recycling of plastic waste into new moulded products often happens in the informal sector.

Leakages of plastic waste into the environment, and their connection to mismanaged plastic waste, are likely to remain data-scarce topics and may only be understood from the MFA balance, when all other flows are reasonably accounted for.

4 The Future

India’s rising trend in plastic use has been dominated by growth in consumption of four key commodity polymers: Polyethylene (PE), Polypropylene (PP), Polyvinyl Chloride (PVC) and Polystyrene (PS). The growth drivers have been low consumption per capita; growth in end-use sectors; and product innovation and diversification. Although the share of PET in total consumption is relatively low compared to other polymers, demand grew by 7.6% in the past 8 years. PET resin demand is projected to grow at nearly 7% per annum between 2022 and 2030.

A review of recent assessments and stakeholder feedback reveals that the industry is likely to see a surge in demand in the post-pandemic era. Post COVID-19, with rising demand for plastics particularly in the healthcare sector, future demand will remain strong. There has also been an increase in utilisation capacity by major India polymer manufacturers including Reliance Industries Limited (RIL), ONGC Petro additions Limited (OPaL) and Indian Oil Corporation Ltd. The government, having realised the need for an integrated supply chain, is currently working on establishing Plastic Parks. At present, six Plastic Parks across the country have been approved and are expected to provide an ecosystem to synergise production capacities with modernised infrastructure.

PP is the most consumed polymer in India with a share of more than 40%. In the past five years, strong growth of nearly 8% has been reported and it is expected to maintain a healthy growth rate in the coming years. Its consumption will be driven by strong growth in the packaging, automotive and electronics sectors.

Durability and affordability have pushed demand for HDPE in India. The surge in demand for personal care, pharma products, consumer durables, and electrical and electronics products will drive demand for HDPE in the future. Consumption of HDPE grew annually at 6% over the last 7 years and is estimated to grow by more than 7% per annum in the next decade.

Growth in PVC will be driven by consumption primarily in the building and construction sector. Pipe grade PVC accounts for over 40% of the overall demand for PVC, for use in water distribution and sewerage networks.

However, that growth has been tepid over the past few years. Imports of polymers have been weak. Since the middle of 2019, the prices of key polymers including PE and PP, which form the bulk of India’s polymer consumption basket, have fallen amidst growing inventories and economic slowdown. Growth in demand for polymers in India fell to 5.3% in the 2018–19 fiscal year against 10.6% reported the year before.

An exercise has been undertaken to estimate the future demand for various polymers in India, as presented in the section below.

4.1 Assessing elasticity and future demand of polymers in India

4.1.1 Polymer consumption elasticities

Polymer consumption is sensitive to income changes. Depending on the convenience, affordability and availability of substitutes, elasticities of key polymers will vary. Similar trends have been observed for plastics consumption in India. Figure 4 presents polymer consumption and GDP per capita over time represented in the primary and secondary Y-axes. It is evident that GDP has been growing steadily over time while there have been considerable variations in polymer consumption.

Polymers such as HDPE, LLDPE, PVC, and PP have demonstrated an upward trend while the consumption of other polymers witnessed moderate growth over time. However, variations in demand have been observed for polymers including LLDPE, HDPE and PP. Such fluctuations in demand can be attributed to economic performance of the consuming sectors including product prices, production capacity utilisation, and availability of feedstock. As evident from the above figure the high consuming polymers witnessed a marginal dip in 2011 and 2013. Between 2011 and 2013, the construction sector witnessed economic slowdown affected, thereby reducing cement consumption and production. Demand for PP raffia for cement packaging reduced. It also took a toll on the consumption of PVC, a major material that goes into construction. Other end-use sectors, including the automotive sector, were affected considerably. There was a 20 to 40% decline in production as major vehicle manufacturers including Toyota, Honda and Suzuki were disrupted following the 2011 earthquake and tsunami in Japan.

Consumer spending was affected in 2013, when the inflation rate reached more than 9% followed by high interest rates. This reduced the real purchasing power of households which had direct consequences on the consumption of major polymers. This period also witnessed one of the poorest performances of India’s manufacturing industry, which grew at less than 1% after experiencing robust growth since the beginning of the millennium.

The relationship of polymer (and total) consumption and income has also been captured using a scatter plot, as presented in Figure 4. India’s GDP (in current billion US $) is presented on the X-axis and consumption of polymers is plotted on the Y-axis. It can be inferred that with increasing gross income, consumption of polymers has also increased. There have been cyclical fluctuations, which are attributed to certain factors, as explained above. However, over a long period of time, there seems to be a stable and highly correlated relationship that can be established for most polymers. The best fit of consumption of polymers and gross income has been achieved using a power function (antilog) with consumption being explained by gross income with an estimated correlation co-efficient of 0.897.

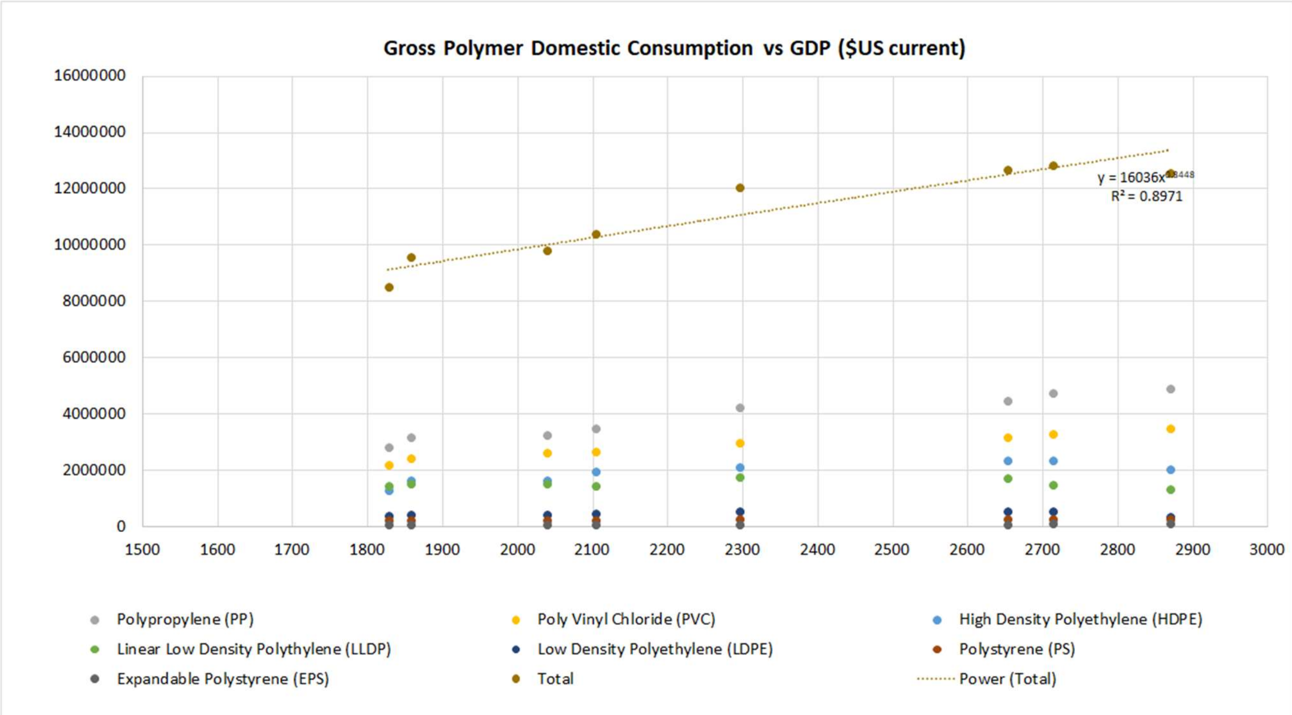

Figure 4 Mapping of polymer consumption against various levels of gross domestic product (Current billion US $)

The above analysis supports the use of an income–consumption elasticity approach in estimating future demand for polymers. The income–consumption relationship was established based on a bivariate regression equation using GDP per capita and plastic consumption as the key variables. The time period considered for the analysis is between 2010 and 2017. The regression estimates have been used to arrive at the future consumption of various polymers in India. The relationship between plastic consumption by polymer and GDP per capita are assumed to be constant, i.e. they are not time dependent.

4.1.2 Projected demand for polymers

With an estimated annual consumption of more than 16 Mt, India is the third largest consumer of polymers, after China and the US. In a post-COVID-19 world, demand is expected to pick up, driven by consumption in major sectors including construction, electronics and packaging, among others. An attempt has been made to estimate the future demand of major polymers in India for the next 15 years (i.e. untill 2035). The estimation is based on the demand elasticities calculated using data from previous years, as presented in the previous section. Figure 5 presents a forecast up to 2035 of projected future plastic consumption by polymer type, assuming a constant growth rate of plastic consumption by polymer, relative to GDP per capita during 2008–2017. This represents a compound annual growth of nearly 6%. While consumption of HDPE is estimated to grow at 6.5%, PS may record an average annual growth rate of nearly 2%.

Per capita plastic consumption is predicted to grow from 8 kg per person (as observed in 2010) to around 29 kg per person by 2035. At this rate, total plastic consumption in India will grow from 9.9Mt in 2010 to 44.8 Mt by 2035. This is a predicted growth of 255% over 25 years.

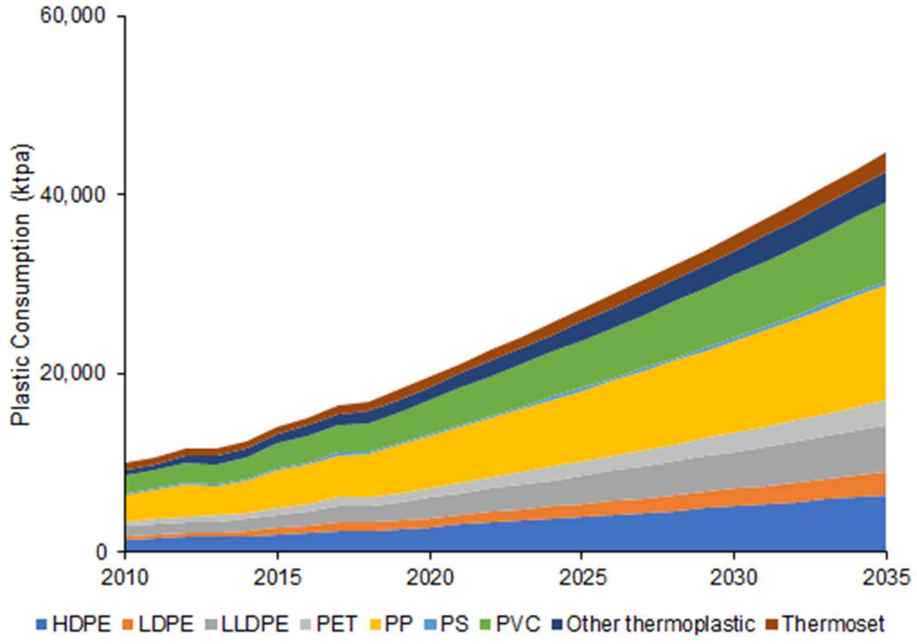

Figure 5 Predicted plastic consumption by polymer type

4.2 Recent developments shaping future polymer demand

There is growing consensus among stakeholders that future demand for polymers will be significantly influenced by economic, regulatory, and consumer choices, some of which are described briefly.

4.2.1 Influence of draft Plastic Waste Management Rules, 2021 on polymer consumption

While plastics are affordable and convenient, leading to their application across all sectors in the economy and making them indispensable in our daily lives, there are however reasons to worry because of their growing threats to ecology. Such threats largely arise due to irresponsible attitudes while disposing of end-of-life plastics. Unlike the natural ecological mechanism where everything gets consumed in nature, plastic can remain in the environment for centuries. The situation is further complicated by inadequate capacity in the system for managing them, leading to water and soil pollution. According to estimates by CPCB, (2020), India on average generates nearly 26,000 tonnes of plastics wasted per day. A significant share of these plastics are mismanaged and there has been serious thinking, particularly among policy makers, to ensure that these products are produced, consumed and disposed of more responsibly.

The draft Plastic Waste Management Rules, 2021, of the Ministry of Environment Forest and Climate Change (MoEFCC, 2021), propose to eliminate single-use plastics by 2022. The rules are proposed to be implemented in three phases, starting from 30 September 2021 with carry bags. In 2022 six major categories of plastics will be eliminated and by the middle of 2022, this ban will include almost all major items that are intended for single-use purposes. These include products such as disposable cups and glasses, cutlery items, straws, trays, packing and/or wrapping, films, cigarette packets, and PVC banners, to name a few. Thermoset plastic and thermoplastic will also fall within the ambit of these rules. Since many of these products are produced from PE, the demand for PE is likely to be affected by the enforcement of bans on single-use plastics in India. Demand for thermoset plastic and thermoplastic will also be affected.

Several state governments have also imposed partial or complete bans on the use of plastic carry bags/single-use plastic items through separate notifications. If the policies come into existence with stricter implementation, it is reasonable to assume that plastic use may reduce in the near future. Since most of these products fall under the packaging and household sectors, current patterns of polymer use in these sectors may be affected.

4.2.2 Stricter enforcement of 'Extended Producer Responsibility' as mandated under the Plastic Waste Management Rules, 2016

The introduction of extended producer responsibility by the environmental ministry under the Plastic Waste Management Rules of 2016 put the onus on manufacturers, including plastic producers, importers and brand owners, for the treatment, recycling, reuse or disposal of plastic products. Based on extensive feedback from stakeholders, MoEFCC also produced a guideline document for the implementation of Extended Producer Responsibility.

This is expected to create impetus for increased recovery and recycling of plastics. Good end-of-life management practices will lead to less plastic leakage and more polymers getting recycled in the economy. However, more research is required about hotspot sectors, their ability to replace virgin plastics with desirable properties, and more importantly, consumers' acceptance of the use of recycled plastics.

4.2.3 Changing consumer perceptions and attitudes towards plastic consumption

Although overall consumer awareness about the detrimental impacts of improper plastic disposal to the environment is still limited, there is however improved understanding reported among consumers in selected regions and this is expected to grow over time. In a recent global survey by Accenture, (2019) nearly 83% of respondents reported that it is important companies design products that are meant to be reused or recycled. In addition, more than 50% of consumers expressed a willingness to pay more for sustainable products designed to be reused or recycled. A study by Capgemini Research Institute, (2020) post COVID-19 in India revealed that the sustainability agenda is significantly influencing consumer purchasing choices. Social responsibility, inclusiveness, or environmental impact are major purchase considerations for nearly 80% of consumers. Further, COVID-19 has increased consumer awareness and more than two thirds of consumers reported that they will be more cautious about the scarcity of natural resources due to the COVID-19 crisis.

4.2.4 Emergence of environmentally friendly substitutes to plastics

Rising environmental concerns and consumer awareness will also lead to demand for substitutes including alternative and bio-based packaging solutions. Bio-plastics may or may not be biodegradable but their fundamental properties are quite close to synthetic polymers. These biodegradable polymers can be used in various sectors including agriculture, automotive, packaging, etc. and growing availability of feedstock at competitive prices and conducive regulations can help in their faster adoption. However, the development of these substitutes is at a nascent stage, and large-scale production and economics will determine their future penetration and replacement of fossil fuel-based plastics used in the economy.

5 Conclusion

This working paper has attempted to strengthen quantitative understanding of the size and nature of key plastics production, consumption, and waste flows in India, while gauging the extent of the challenges and opportunities towards promoting a circular economy for plastics in India.

India has witnessed a strong growth of 7% in consumption of major polymers like PP, HDPE, LDPE (including LLDPE), PVC, PET and PS over the last decade. In 2018–19, India's total plastic consumption stood at 16.94 Mt. Three quarters of this share is attributed to only three polymers, i.e. PP, PE, and PVC. Major plastic consuming sectors include packaging, building and construction, household/consumer products, automotive, electrical and electronics, and agriculture. The packaging sector dominates plastic consumption, with a share of 59%, followed by building and construction (13%) and agriculture (9%).

Growing domestic production capacity has made India a major exporter of polymers. However, imports continue to dominate over exports. Net imports increased from 4.93 Mt to 6.42 Mt between 2015 and 2019. Trade in plastic polymers is relatively significant (46.5% of total domestic production is either imported or exported). However, India remains a net importer, with a negative balance of 1.3 Mt. The packaging sector depends heavily on PE and PET-BOPET. PP and PVC are major polymers used in the construction and electrical and electronics sectors, while the agriculture and automotive sectors use PP and PE, respectively.

A detailed material flow analysis has been undertaken to capture the flow of polymers from production to their use across various sectors and end-of-life management for the reference year 2018–19. Based on their characteristics, application and use, these polymers have been further categorised into short-lived and long-lived plastics. Short-lived plastics mostly reach the end-of-life stage within a year of production while long-life products remain in the consumption stage for more than a year. Using data based on literature and inputs from sectoral experts, it was estimated that 9.73 Mt of plastic waste generated in the reference year, the majority of arose from packaging applications (6.24 Mt of flexible packaging and 2.44 Mt of rigid packaging). A smaller quantity (4.72 Mt, mostly long-lived products) became additions to stock. Nearly 61% of plastic waste was recycled, while 12% was reutilised and the remaining 27% was found to be mismanaged.

There are significant data gaps in the set of direct data sources regarding estimation of waste flows from long-lived products as plastic stocks; the fate of waste flows from long-lived stocks; and the connection between recycled or reutilised flows and their exact return point into the Indian economy. Industry experts were consulted about the possible fates of plastic waste from sectors and this information was used with judgement to estimate the probable percentage of annual consumption directed toward recycling, reutilisation (often incineration), or mismanagement. Further consultation is needed to refine these estimates and improve the rigour of the quantitative outputs here.

Consumption was also projected to 2035 based on demand elasticities which reveal that demand is likely to remain strong, driven by consumption in major sectors including construction, electronics and packaging, among others. Consumption is estimated to increase from 19.6 Mt in 2020 to 44.8 Mt by 2035.

However, there is growing consensus among stakeholders that future demand will be significantly influenced by the changing policy environment as envisioned under the draft Plastic Waste Management (Amendment) Rules, 2021, and stricter enforcement of extended producer responsibility. The environmental challenges arising from mismanagement of plastics are also leading to increased consumer awareness, which will considerably influence future consumption preferences, including switching to more socially- and environmentally- favourable alternatives.

From the above analysis, it can be inferred that the polymer sector is undergoing demand, supply and regulatory transformations. While the projections presented above are largely based on consumption responses to past changes in national income, future use and the extent of decoupling of virgin plastics will be highly influenced by demand and supply side factors. There is a need to undertake deeper scientific assessments to discover how such changes will affect the future consumption and production of plastics in India.

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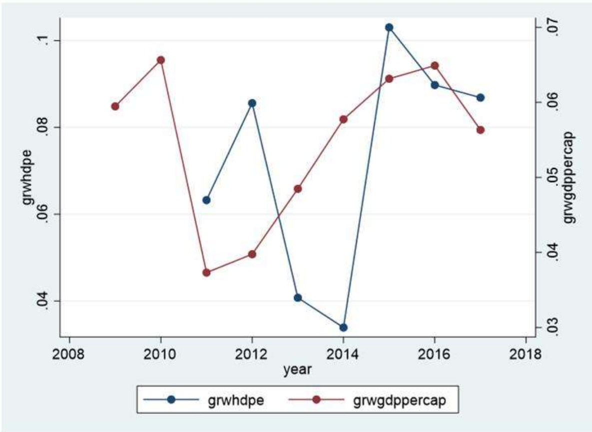
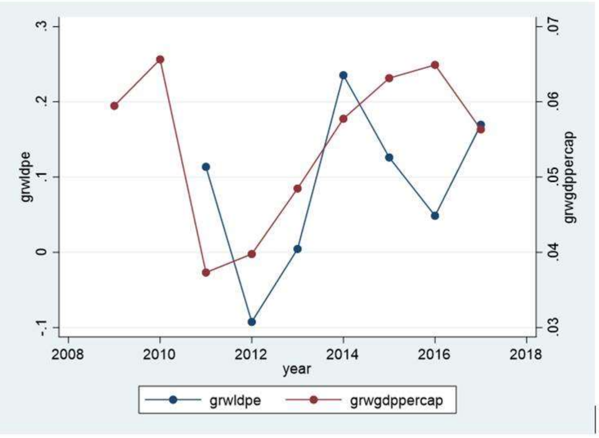
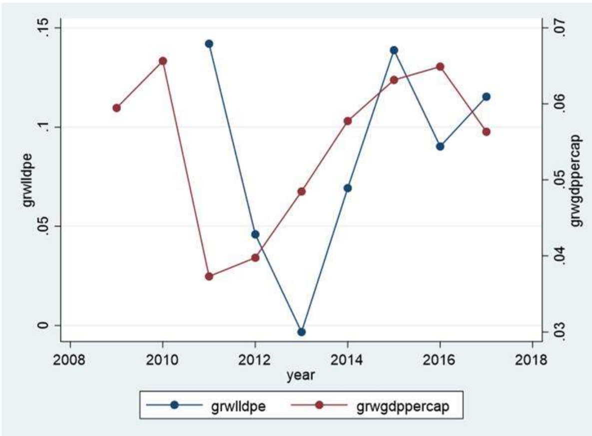
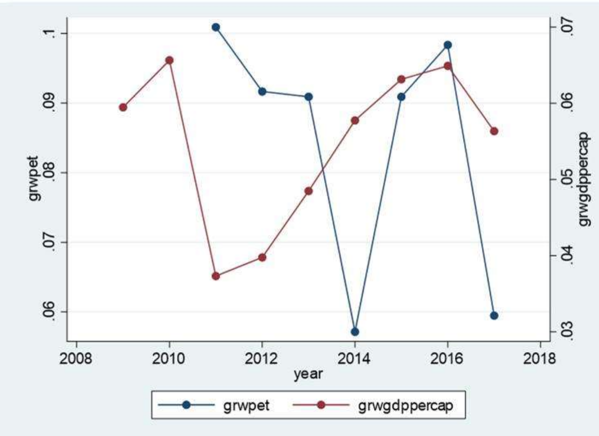
Appendix A

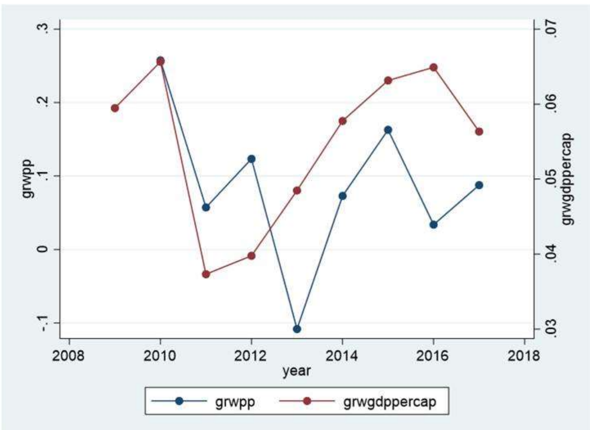
The next set of 10 graphs are a plot of the *growth rate per annum* of polymers versus the *growth rate per annum* of GDP per capita – one polymer per graph. The growth rate of LDPD (see grwldpe) seems to follow the growth pattern of GDP per capita very closely. The lag in the growth pattern of polymers as compared to GDP is interesting.

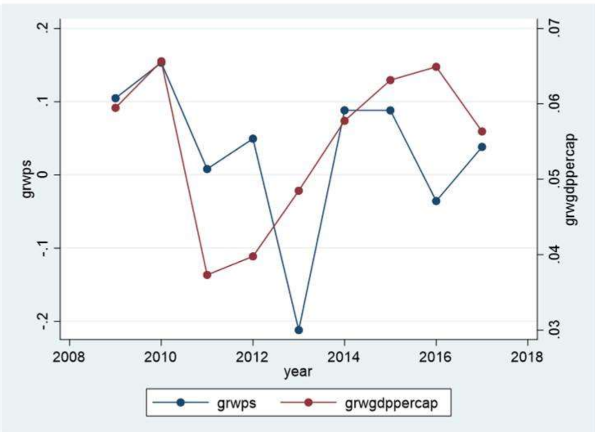


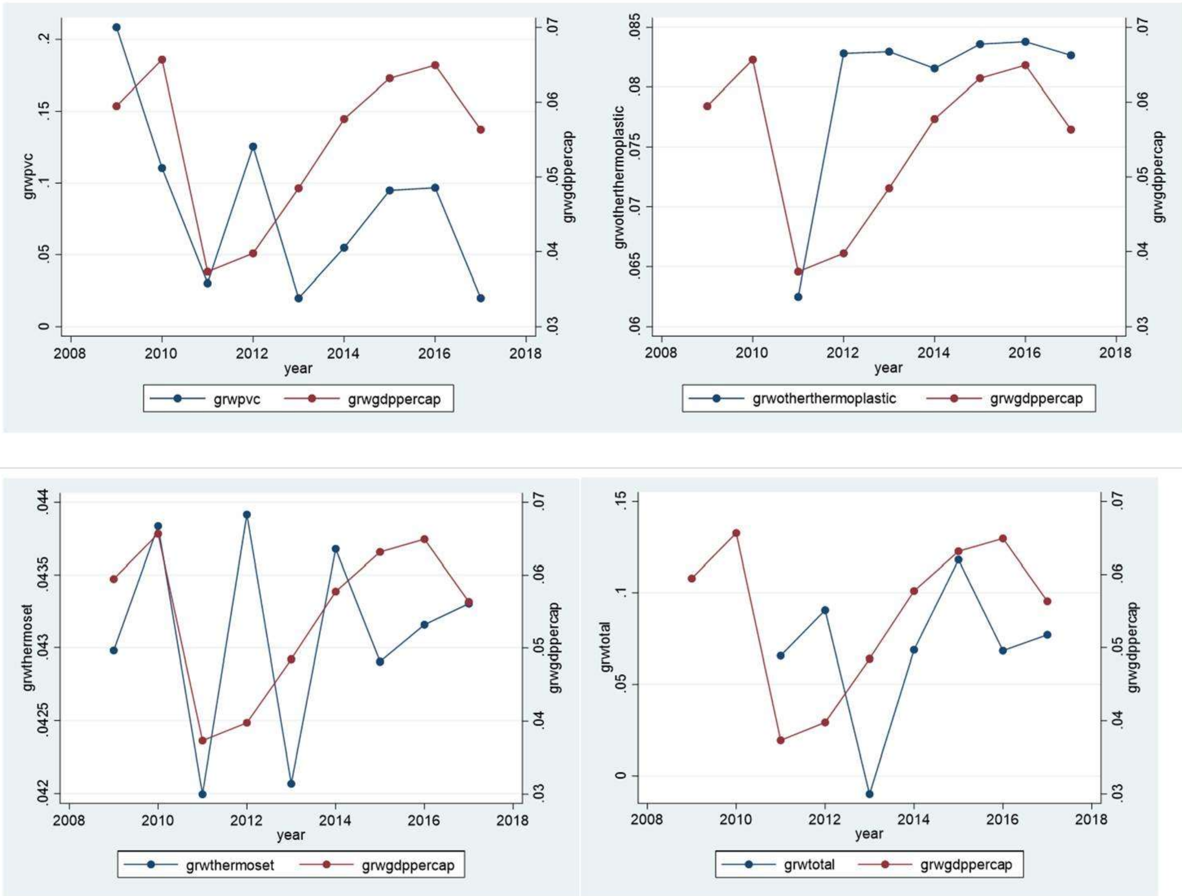












Appendix Figure A.1 Comparative trend analysis of GDP per capita and consumption of selected polymers in India

Appendix Table A.1 Plastic waste generation in different states in India

STATE/UT	ESTIMATE PLASTIC WASTE GENERATION (TPA)
Andaman & Nicobar Islands	1850
Andhra Pradesh	66314
Arunachal Pradesh	3787.37
Assam	32277.87
Bihar	68903.328
Chandigarh	11715.4
Chhattisgarh	6000
Daman & Diu, Dadra Nagar Haveli	1947.7
Delhi	224810
Goa	32580.52
Gujarat	356873
Haryana	68735.26
Himachal Pradesh	3672
Jammu & Kashmir	34367.37
Jharkhand	51454.53
Karnataka	272776
Kerala	133316
Lakshadweep	148
Madhya Pradesh	72327.39
Maharashtra	409630
Manipur	12453.8
Meghalaya	1263
Mizoram	13.306
Nagaland	268.18
Odisha	90138.98
Punjab	119414.64
Puducherry	8433
Rajasthan	104704.383
Sikkim	5.66
Tamil Nadu	401091
Telangana	183014.65
Tripura	26.2
Uttarakhand	31093
Uttar Pradesh	254401.8
West Bengal	300236.12

Source: (CPCB, 2019b).

Appendix Table A.2 Historical and projected elasticities for plastics consumption by polymer material and annual growth rate of GDP for India

YEAR	ELASTICITIES									GROWTH RATE (% PER YEAR)	
	HDPE	LDPE	LLDPE	PET	PP	PS	PVC	OTP	THER	TOTAL	GDP
2008/09	-	-	-	-	-	-	-	-	-	-	-
2009/10	-	1.76	3.51	0.72	-	-	-	-	-	-	0.06
2010/11	-	3.92	2.33	1.68	0.67	-	-	-	-	-	0.07
2011/12	1.70	3.05	3.81	2.70	1.53	0.21	0.81	1.67	1.13	0.07	0.04
2012/13	2.15	-2.33	1.16	2.31	3.10	1.24	3.16	2.08	1.10	0.09	0.04
2013/14	0.84	0.09	-0.07	1.88	-2.23	-4.37	0.41	1.71	0.87	-0.01	0.05
2014/15	0.59	4.08	1.20	0.99	1.26	1.53	0.95	1.41	0.76	0.07	0.06
2015/16	1.63	2.00	2.20	1.44	2.58	1.40	1.50	1.32	0.68	0.12	0.06
2016/17	1.38	0.75	1.39	1.52	0.52	-0.55	1.49	1.29	0.66	0.07	0.06
2017/18	1.54	3.01	2.05	1.06	1.56	0.68	0.36	1.47	0.77	0.08	0.06
2018/19	0.39	-1.30	-0.60	2.28	1.43	1.77	3.59	1.49	2.53	0.02	0.02
2019/20	1.23	1.53	1.33	1.37	1.26	0.48	1.27	1.35	0.72	0.08	0.06
2020/21	1.21	1.49	1.31	1.33	1.23	0.51	1.25	1.32	0.70	0.08	0.06
2021/22	1.20	1.44	1.28	1.30	1.22	0.58	1.23	1.29	0.74	0.07	0.06
2022/23	1.18	1.40	1.27	1.29	1.20	0.53	1.21	1.27	0.77	0.07	0.06
2023/24	1.17	1.37	1.24	1.26	1.19	0.54	1.20	1.25	0.82	0.06	0.05
2024/25	1.16	1.36	1.23	1.26	1.18	0.61	1.19	1.24	0.85	0.06	0.05
2025/26	1.15	1.33	1.22	1.23	1.17	0.55	1.18	1.22	0.88	0.06	0.05
2026/27	1.14	1.31	1.20	1.21	1.16	0.61	1.17	1.21	0.90	0.06	0.05
2027/28	1.13	1.29	1.19	1.21	1.15	0.61	1.16	1.20	0.94	0.05	0.05
2028/29	1.13	1.27	1.18	1.19	1.14	0.61	1.15	1.19	0.95	0.05	0.05
2029/30	1.12	1.25	1.18	1.19	1.14	0.67	1.14	1.18	0.99	0.05	0.04
2030/31	1.12	1.24	1.17	1.18	1.13	0.60	1.14	1.16	0.99	0.05	0.04
2031/32	1.11	1.23	1.15	1.17	1.12	0.66	1.13	1.16	1.03	0.05	0.04
2032/33	1.11	1.22	1.15	1.16	1.12	0.66	1.13	1.16	1.04	0.05	0.04
2033/34	1.10	1.20	1.14	1.15	1.11	0.71	1.12	1.14	1.07	0.05	0.04
2034/35	1.10	1.20	1.14	1.14	1.11	0.65	1.11	1.14	1.08	0.04	0.04

Source: Author's calculation

OTP = Other thermoplastic, THER = Thermoset

A.1 Issues of Waste Management and Plastics in India

In its 2018 discussion paper, India's Ministry of Environment, Forests and Climate Change (MoEFCC) identified India's plastic waste challenges and opportunities for better collection, segregation and recycling, as alternatives to replace low-value plastic materials and products (Bhattacharya et al., 2018).

Under the SWM rules, 2016, respective Urban Local Bodies (ULBs) are responsible for waste generated in their city including storage, collection, transportation, processing/treatment, and scientific disposal of the waste. However, most ULBs find it difficult to manage the volume of waste generated because of inefficient collection and transportation systems, inadequate processing/treatment facilities, lack of technical expertise, inadequate financial resources, and lack of options in scientific disposal methods, negatively impacting the environment and public health. Some of the major challenges faced by the ULBs are discussed below.

A.1.1 Limited collection efficiency

The waste collection efficiency of Indian metropolitan cities ranges between 70 and 95%, whereas in smaller cities it is lower than 54% (Sharma and Jain, 2019). The Ministry of Environment states that, currently, only 50 to 80% of generated waste is collected, and only about 40% is segregated (MoEFCC, 2016). Among large cities, Ahmedabad stands at 95% door-to-door collection, followed by Mumbai and Chennai at 80%, and Delhi being the lowest at 39%. In medium sized cities, Bhopal stands at 100% door-to-door collection followed by Chandigarh, Mysore, and Indore at 95%, 95%, and 90% respectively and Ludhiana being lowest at 25%. Small cities like Alappuzha, Tirunelveli and Suryapet have 100% door-to-door waste collection (Patel, 2019).

Waste collection in Indian ULBs is driven by the informal sector, which carries out collection for small financial incentives. This often leads to unscientific disposal of waste, such as open dumping and burning, resulting in air pollution and increased likelihood of disease (Dhindaw and Kumar, 2019).

A.1.2 Lack of segregation

Segregation at source is an important factor in efficient and sustainable waste management which is rarely practised in Indian cities. Only five states in the country practise efficient source segregation. The state of Tamil Nadu has succeeded in achieving 100% segregation in 20 of its 50 smaller ULBs and 80–90% segregation in the remaining ULBs (Singh, 2020). According to the 2020 *Swachhata Sandesh Newsletter* by the MoHUA, 63,204 wards (74.82%) had achieved 100% waste segregation at the household level as of January 2020.

Under the SWM rules, 2016, waste generators are mandated to use colour coded bins for separating waste streams into biodegradables, non-biodegradables, and hazardous waste. Waste generators are also required to pay user charges for collection services provided, though the fee determination mechanism is not clear. However, the rules do not have provision to incentivise or impose penalties to encourage segregation at source at the micro level. Segregating waste at source helps in value recovery from waste and hence only inert waste ends up in landfills.

A.1.3 Disposal and land availability

Landfilling is the most common practice for waste disposal in low- and middle-income countries as it is the most economical method and does not require skilled labour for operation (Sharma and Jain, 2019). However, this requires huge amounts of land to sustainably manage waste in sanitary landfills. India is one of the countries with a high percentage of open and illegal waste dumping at 72%, along with Algeria, Pakistan, and Thailand at 96, 90, and 54%, respectively. According to the

Ministry of Finance, if India does not manage its municipal solid waste efficiently, the country would require a land area of more than 1,400 km^2 by the end of 2047 for solid waste disposal, which is equivalent to the area of Hyderabad, Mumbai and Chennai combined (Annepu, 2012).

A.1.4 Waste to fuel

Some of the current downstream solutions for plastic waste management include the recovery of secondary raw materials like HDPE and PET through scientific recycling; waste to fuel, which is currently being piloted in India; cement co-processing; and road mix with bitumen. Waste to fuel is problematic due to technical, financial and structural inefficiencies in India's waste system. Source segregation, although encouraged through mammoth initiatives like Swachh Bharat (Clean India), has gathered momentum only in select cities and urban local bodies. Mixed waste streams pose immense challenges for the technical feasibility of waste to fuel infrastructure in India. Secondly, the high energy consumption of waste to fuel technologies renders them environmentally inefficient, especially in countries like India, which lack scalable output due to the high concentration of organic waste.

Though waste to energy (WTE) has huge opportunities it is not well established in the country. Out of the 11 WTE plants in India only six are operational (CPCB, 2016). Other technological options include anaerobic digestion, composting, gasification and bio-methanation.

A.1.5 Financial constraints

As a result of deficient budget allocation, less than a quarter of collected waste is treated and processed, with the rest ending up in landfills (MoEFCC, 2016). In FY 2015, only 28% of collected solid waste was treated and the remaining 72% was openly dumped. ULBs spend 60–70% of total SWM expenditure on collection, 20%–30% on transport, and less than 5% on the final treatment of waste, showing the minimal attention given to the scientific disposal of solid waste (Sharma and Jain, 2019).

Appendix Table A.3, below, shows a glimpse of the waste management infrastructure in India.

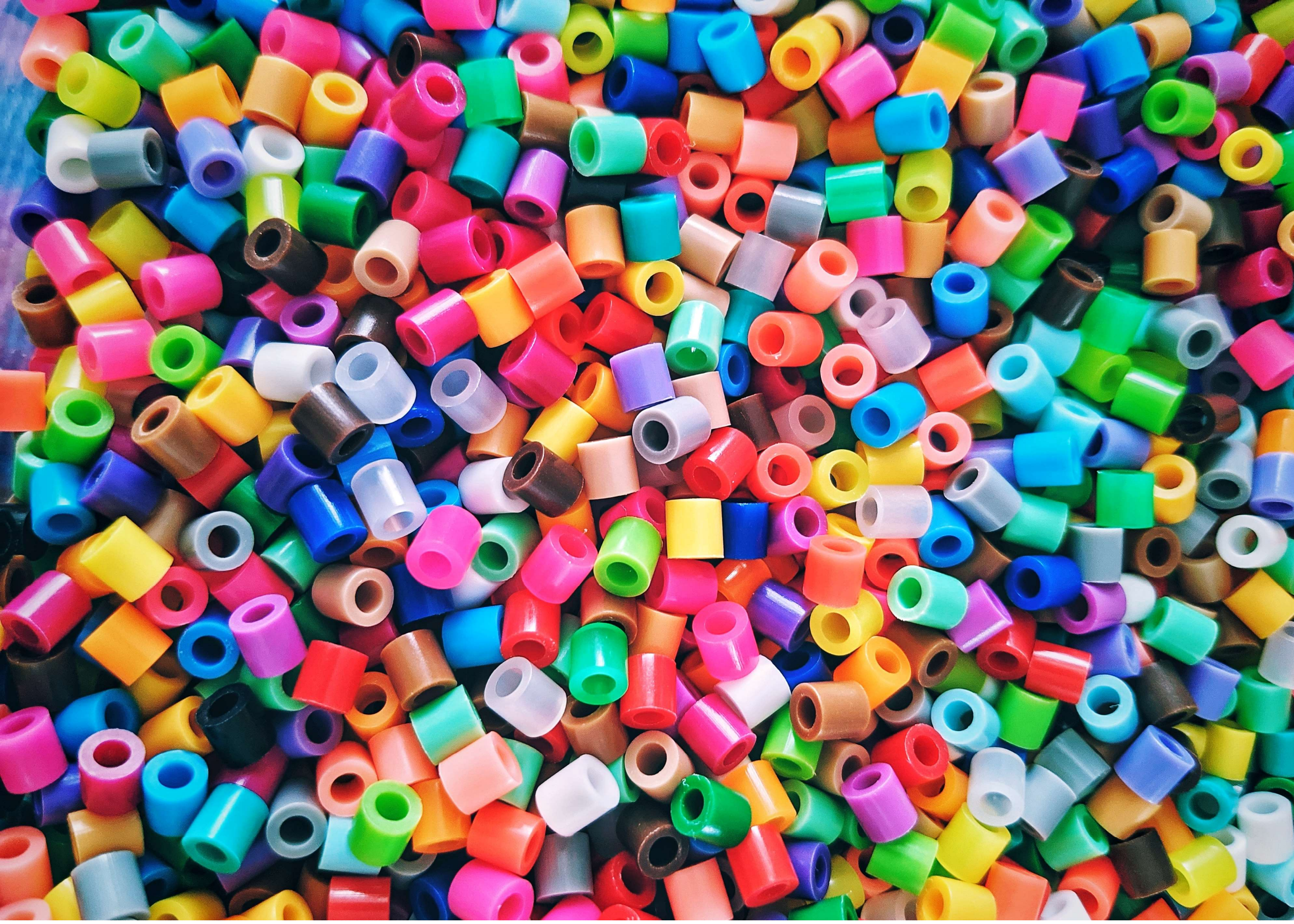
Appendix Table A.3 Solid waste infrastructure facilities in India

INFRASTRUCTURE FACILITIES	NO. OF UNITS
Door-door collection	18 states
Source segregation	5 states
Sanitary landfill	95
New sites identified for landfills	1285 (242 ULBs)
Composting/vermicomposting facility	553
ULBs with composting/vermicomposting facility	173
Operating pipe composting facilities	7000
RDF facilities	12
Small biogas plants	645 (600 in the state of Kerala)
WTE plants	6 operational (11 in total)
Waste generated	143,449 t/day
Waste collected	117,644 t/day (82%)
Waste treated	32,871 t/day (28%)

Source: (CPCB, 2016)

A.1.6 Role of informal sector in plastic waste management

Plastic waste collection in the country is primarily driven by the informal sector. The informal sector can be described as a small-scale, labour-intensive, unregulated entity that makes use of crude technology to revive the value of waste streams (Petra Schneider et al., 2017). Under the new rules, municipalities are directed to include informal waste pickers in their waste management processes. However, there is no provision to provide incentives to the informal sector, nor do they recognise the economic value of informal waste recycling work (Singh, 2020). The formalisation of the informal sector in SWM through various institutions like Resident Welfare Associations (RWAs), Community-Based Organisations (CBOs), non-government organisations (NGOs), self-help groups (SHGs), and the private sector will contribute to the reduction of overall MSWM costs, provide support to the local recycling industry, and create new job opportunities (CPHEEO, 2016).



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