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Plastics materials flow analysis for India

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Abstract

Forecasting material flows is essential for sound policy making on issues relating to waste management. This paper presents the results of the plastics materials flow analysis (MFA) for India. In the recent past, India has witnessed a substantial growth in the consumption of plastics and an increased production of plastic waste. Polyolefins account for the major share of 60% in the total plastics consumption in India. Packaging is the major plastics consuming sector, with 42% of the total consumption, followed by consumer products and the construction industry. The relationship observed between plastic consumption and the gross domestic product for several countries was used to estimate future plastics consumption (*master curve*). Elasticities of the individual material growth with respect to GDP were established for the past and for the next three decades estimated for India thereby assuming a development comparable with that of Western Europe. On this basis, the total plastics consumption is projected to grow by a factor of 6 between 2000 and 2030. The consumption of various end products is combined with their corresponding lifetimes to calculate the total waste quantities. The weighted average lifetime of plastics products was calculated as 8 years. Forty-seven percent of the total plastics waste generated is currently recycled in India; this is much higher than the share of recycling in most of the other countries. The recycling sector alone employs as many people as the plastics processing sector, which employs about eight times more people than the plastics manufacturing sector. Due to the increasing share of long-life products in the economy, and consequently in the volume of waste generated, the share of recycling will decrease to 35% over the next three

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decades. The total waste available for disposal (excluding recycling) will increase at least 10-fold up to the year 2030 from its current level of 1.3 million tonnes.

Keywords: India; Plastics; Material flow analysis (MFA); Plastics consumption; Plastics waste; Reuse; Recycling; Employment

1. Introduction

In India, plastics consumption grew exponentially in the 1990s. During the last decade, the total consumption of plastics grew twice as fast (12% p.a.) as the gross domestic product growth rate based on purchasing power parities (6% p.a.) (Fig. 1) (CPMA, 2000; ICRA, 2000; IEA, 1997). The current growth rate in Indian polymer consumption (16% p.a.) is clearly higher than that in China (10% p.a.) and many other key Asian countries (Desai et al., 1998; Industry Canada, 2002). The average Indian consumption of virgin plastics per capita reached 3.2 kg in 2000/2001[1] (5 kg if recycled material is included) from a mere 0.8 kg in 1990/1991. However, this is only one-fourth of the consumption in China (12 kg/capita, 1998) and one sixth of the world average (18 kg/capita). This consumption led to more than 5400 tonnes of plastics waste being generated per day in 2000/2001 (totalling 2 million tonnes per annum) (NPWMTF, 1997). The percentage of plastics in municipal solid waste (MSW) has also increased significantly from 0.7% in 1971 to 4% in 1995 (Bose et al., 1998). The increasing quantities of plastics waste and their effective and safe disposal has become a matter of public concern. The increasingly visible consequences of indiscriminate littering of plastic wastes (in particular plastic packaging wastes and discarded bags) has stimulated public outcry and shaped policy. Littering also results in secondary problems such as drains becoming clogged and animal health problems (both domesticated and wild). As a consequence, many big cities (e.g. Mumbai, Bangalore) and some of the states (e.g. Delhi, Maharashtra, Uttar Pradesh) have already banned the use of thin plastic bags (Chemical Weekly, 1998).[2] In this context it is essential that material flow models (incorporating factual information of the past few years and the experiences of other countries) are developed and adopted to India so as to anticipate tomorrow's problems and enable sound policy decisions to be taken in order to pre-empt these problems.

This paper presents the framework, the assumptions and the results of a material flow analysis (MFA) for plastics in India. To our knowledge, this is the first time that such an analysis has been performed for the case of India. It provides an insight into the consumption of plastics, their residence time in the economy and the patterns of waste generation. This study originated from the desire to establish the quantities of plastics waste and the amounts of recycled plastics. For this reason, the scope of the study is restricted to *plastics* applications of synthetic polymers, e.g. films, consumer products, pipes, woven sacks, etc.

[1] Statistical data in India is reported for a financial year starting on 1 April and ending on 31 March.

[2] The rule prohibits the use of the poly-bags below 25 μm from recycled plastics and 20 μm manufactured using virgin plastics.

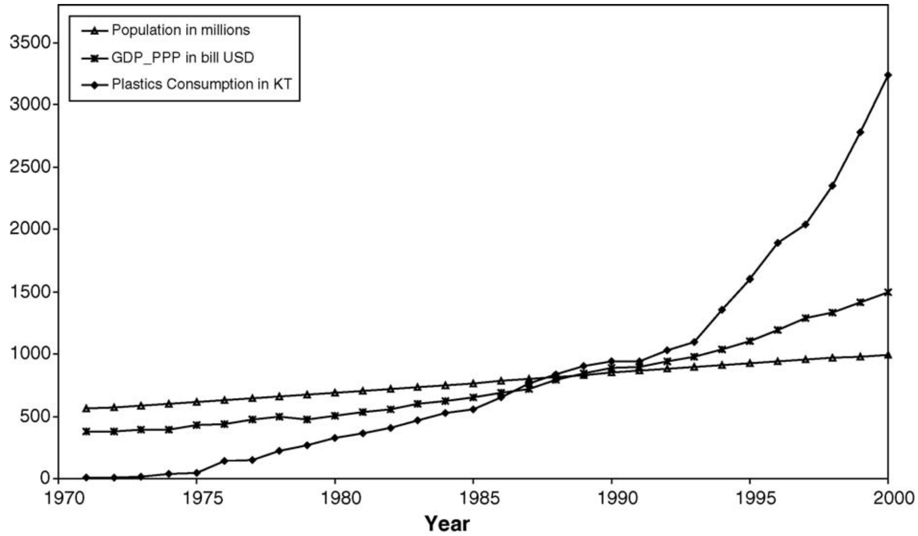

Fig. 1. Population, GDP and plastics consumption in India (CPMA, 2000; ICRA, 2000; IEA, 1997).

In contrast, synthetic fibres, elastomers and other so-called non-plastic applications (e.g. adhesives) are excluded from the study because of their different product characteristics, their limited recyclability, and also because of the different disposal methods used for waste treatment.

The study starts with an analysis of historical plastics consumption providing a solid foundation for projecting the future growth. The time period studied starts in 1960 and runs through to 2000, on the basis of which future developments are projected up to 2030. The paper also addresses the socioeconomic aspects of the polymer industry in India. Conclusions are drawn and implications for future policy making are finally discussed.

2. Plastics consumption

2.1. Current market situation

Polyethylene (PE), polypropylene (PP) and polyvinyl chloride (PVC) enjoy commanding positions in the Indian market thanks to their low cost, high durability and easy formability (Fig. 2) (CPMA, 2000). Polyolefins account for about 60% of the total plastics consumption, followed by PVC and polystyrene (PS). Together, the commodity plastics (PE, PP, PVC, and PS) accounted for 83% of the total plastics consumption in India in 2000/2001, the shares of individual polymers being comparable to those of Western Europe. Between 1990 and 2000, LLDPE was the material with the strongest growth rate of (20% p.a.), followed by PP (16% p.a.), HDPE (14% p.a.), PVC (12% p.a.), PS (10% p.a.) and LDPE (3% p.a., Fig. 3) (Chemical Weekly-Annual, 1985, 1991, 1996, 1998; CPMA, 2000; Polymer, 2002; Polymer India, 1976a,b, 1977, 1978; Polymer India-Annual, 1986).

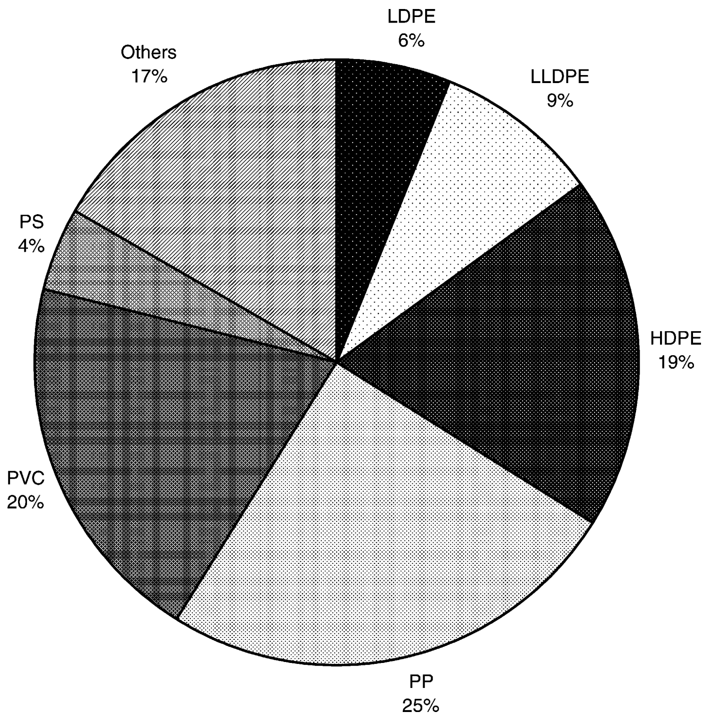

Fig. 2. Consumption pattern in India in 2000 (CPMA, 2000).

The substantial 20% growth rate for LLDPE (linear low density polyethylene) consumption can be attributed to the steadily increasing demand for LLDPE in packaging film applications plus the substitution of LDPE (low density polyethylene) in several applications. LLDPE is a form of polyethylene with relatively well-defined short chain branches as opposed to LDPE, which is a form of polyethylene with long chain branches. This difference in molecular structure permits LLDPE to be arranged into superior crystalline structures thus giving it better mechanical properties for film packaging applications, e.g. increased tensile strength, puncture and tear resistance, and elongation.

Table 1 describes the market trends according to application area for the various commodity polymers.

In India, extrusion-based methods account for 75% of the total amount of plastics processed; this is very similar to the situation in Western Europe. Products from extrusion are used in agriculture, packaging, electrical appliances and the building sector, e.g. in the form of pipes, films, wire and cable, sheets, profiles, etc. Over 27% of all extruders in the plastics processing industry are operated for the manufacture of blown films. Injection moulding is the second largest processing technique (19%) and is mainly used for the manufacture of household products, packaging, and in the electrical sector. Blow moulding and rotational moulding constitute a small share; these processes serve to manufacture products like bottles, drums, tanks, etc. (ICRA, 2000).

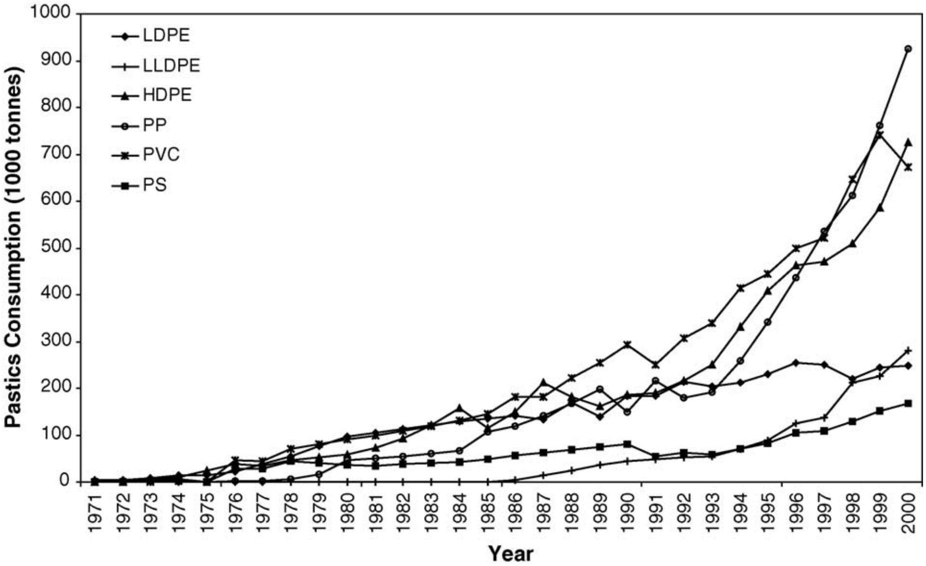

Fig. 3. Consumption of virgin plastics in India (Chemical Weekly-Annual, 1985, 1991, 1996, 1998; CPMA, 2000; Polymer, 2002; Polymer India, 1976a,b, 1977, 1978; Polymer India-Annual, 1986).

Table 1
Growth rate per annum (%) for polymer materials by application area during 1991–2000 (Chemical Weekly-Annual, 1985, 1991, 1996, 1998; CPMA, 2000; ICRA, 2000; Polymer, 2002; Polymer India, 1976a,b, 1977, 1978; Polymer India-Annual, 1986)

Application/materials	LDPE	LLDPE	HDPE	PP	PVC	PS
Films/flexible packaging	**0.4**	**30.0**	**21.3**	**14.2**	6.3	**9.2**
Wire and cable	12.9	21.5			11.8	
Extrusion coating		19.6				
Rotomoulding		32.4				
Injection moulding (including rigid packaging, novelty items, personal use items, etc.)	5.6	21.8	**14.7**	**17.3**		**17.3**
Appliances						12.6
Blow moulding			**15.4**		9.6	
Woven sacks			**8.3**	**20.4**		
Monofilaments			4.0	**21.0**		
Pipes and conduits			10.4		**12.7**	
Footwear					**10.2**	
Sheets (thick)					**15.3**	
Profile					24.1	
Hoses and tubes					10.6	
Others	−1.1	1.0	12.0	5.0	−0.8	−9.6

Note: Bold value indicates major end-use sector.

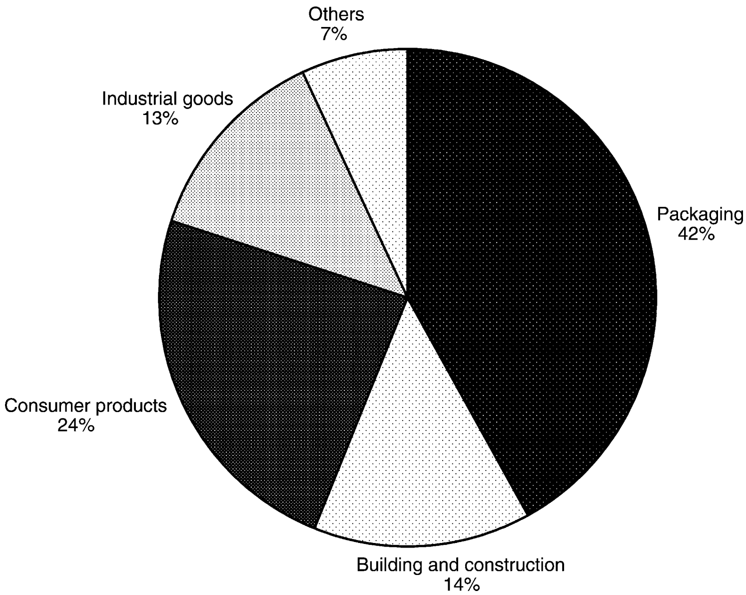

Fig. 4. Plastics use by type of application in India, 2000 (SGCCI, 2000).

Packaging is the most important application area for plastics in India and accounts for 42% of the total consumption; this is similar to the situation in Western Europe where packaging accounts for 37–40% of the total plastics consumption (APME, 2002; SGCCI, 2000; VKE, 2002a). Packaging includes non-rigid packaging e.g. films, woven sacks, etc., and rigid packaging such as bottles. Other bulk user industries are consumer and household products 24%, industrial products 14%, building and construction 13% and other miscellaneous industries 7% (Fig. 4).

2.2. Projection of the future plastics consumption

Having looked at the developments in the past the question arises how plastics consumption will develop in future. To obtain a deeper insight into the relationship between plastics consumption and a nation's wealth, the consumption of plastics per capita was plotted against the GDP in purchasing power parities per capita. If the data for various countries are combined in one graph and plotted on a logarithmic scale,[3] then a curve can be drawn as shown in Fig. 5. Countries covering the wide range of GDPs and plastics consumption levels like India, China, Turkey, Brazil, France, Germany, Canada, Japan, USA have been included in the graph. For some countries the consumption data for past 10–40 years were used, and for the remaining countries where consumption data was not readily available

[3] A logarithmic scale is applied because of the very wide breadth of the data obtained; the result of the diverse nature of the countries chosen for analysis.

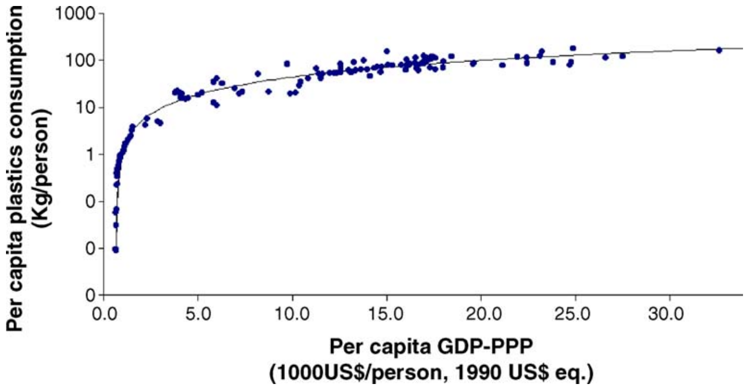

Fig. 5. Relationship between plastics consumption per capita and GDP per capita (IEA, 2000; International Energy Agency, 1996; International Status Report, 1995, 2002; PFSA, 2001; Population Division, 1996). Plastics consumption (y, kg/person, $n = 138$) with respect to the GDP in purchasing power parities (x, 1000 US$/person, 1990 US$ equivalent). Symbols represent data for Australia (1993, 1994, 2000), Austria (1993, 1994), Belgium (1993, 1994, 2000), Bolivia (2000), Brazil (2000), Canada (2000), Chile (1993,1994), China (1993), Columbia (1993, 1994, 2000), Czech Republic (1993, 1994), Finland (1993, 1994, 2000), France (1993, 1994, 2000), Germany (1993, 1994, 2000), Hungary (1993, 1994, 2000), India (1971–2000), Israel (1993, 1994, 2000), Italy (1993, 1994, 2000), Japan (1993, 1994, 2000), Malaysia (2000), Mexico (1993, 1994), New Zealand (1993, 1994), Romania (1993, 1994, 2000), Poland (1993, 1994), Slovakia (2000), Slovenia (1993, 1994, 2000), South Africa (1990–2000), South Korea (1993, 2000), Spain (1993, 1994, 2000), Switzerland (2000), Taiwan (1994), Turkey (2000), UK (1993, 1994, 2000), USA (1993, 1994, 2000) and Western Europe (1971–2000). The smooth curve represents the equation $y = 3.7(x - 0.65)^{1.114}$ (coefficient of correlation, $R^2 = 0.85$).

data of the last 5–10 years were plotted instead (Fig. 5) (IEA, 2000; International Energy Agency, 1996; International Status Report, 1995, 2002; PFSA, 2001; Population Division, 1996).

Inter-linked developments – including future economic evolution (particularly that of the plastics consuming sectors), technological progress in plastics processing, use and recycling and the substitution of other materials e.g. steel, paper, jute – will determine the actual path of future plastics consumption. Since it is outside the scope of this paper to study all these relationships, a simple approach had to be taken. Using the 'master curve' is a modest approach that takes a '*macro*' view without details and yet allows a reasonable estimate, whereas a '*micro*' view will require much more data and assumptions. It is quite remarkable that the data of 'many' countries for 'many' years fits on the same curve. While in some cases the data spans several decades (e.g. India, Western Europe), the fact that the data all fall on the one curve (primary plastics consumption per capita = (3.70) × [per capita GDP-PPP − 0.65]$^{1.114}$) with $R^2_{\text{adj}} = 0.85$ still indicates that perturbations due to local politico-economic factors or local differences in technology are not causing much of a difference to the macro quantities like total consumption per capita. Countries exporting large quantities of polymers (like South Korea) are slightly above the *master curve* whereas net importers (like China) are below (Fig. 5). However, the bandwidth is generally rather small. We are not aware of any other study that has shown such a universal trend. Other authors usually have projected plastics consumption by simple linear extrapolation of historical consumption

Table 2
Historical and projected elasticities for virgin plastics consumption and annual growth rate of GDP

Country	Year	Elasticity[a]						Growth rate (% per year)	
		LDPE	LLDPE	HDPE	PP	PVC	PS	Total consumption[b]	GDP[c]
Western Europe	1990–1994	1.3		4.6	−1.9	0.7	−0.2	2.1	0.9
	1995–1999	4.0		3.9	5.6	1.1	2.5	4.4	1.3
India	1990–1994	1.1	2.9	3.8	2.2	2.8	2.0	11.1	5.3
	1995–1999	0.1	3.8	2.5	3.5	1.3	2.1	12.2	6.5
	2001–2005	0.2	3.1	2.1	2.8	1.2	1.9	7.8	4.2
	2006–2010	0.2	2.2	1.9	2.1	0.8	1.5	5.5	3.9
	2011–2015	0.2	1.9	1.7	1.5	0.8	1.5	5.0	3.4
	2016–2020	0.2	1.7	1.5	1.2	0.8	1.5	4.1	3.7
	2021–2025	0.2	1.5	1.4	1.6	0.8	1.5	3.0	2.6
	2026–2030	0.2	1.4	1.3	1.8	0.8	1.5	3.0	2.1

[a] Elasticity is defined here as: elasticity of polymer material i = [growth rate of consumption of polymer material i (%p.a.)]/[growth rate of GDP (%p.a.)]. The elasticities were estimated based on the observed trends in the past in India and Western Europe. The elasticities are thus the result of a combined linear trend extrapolation for the two countries.
[b] Total consumption was projected using the 'master curve'.
[c] GDP projections were taken from IEA: World Energy Outlook, 2000.

or by assuming a fixed (i.e., not time-dependent) relationship between GDP and plastics consumption.

In this study, future virgin plastics consumption in India was projected by assuming that it will develop according to the *master curve*. To estimate the future plastics consumption in India in absolute terms the relationship from Fig. 5 was combined with projections for GDP and population. The 'Beyond 20/20' database of the International Energy Agency (IEA) was used for historical GDP (PPP) data (International Energy Agency, 1996). Projected data for GDP were taken from 'World Energy Outlook: 2000' by IEA (IEA, 2000), while the United Nations' 'World Population Prospects: 2050' (Population Division, 1996) was used as the source for population data.

So far, the approach chosen was to project the future consumption of plastics as a whole. As the next step we shall turn our attention to the individual types of plastics. To estimate the consumption for each polymer elasticities were generated to represent the ratio of the physical growth rate of the respective material and GDP:

$$\text{Elasticity of polymer material } i = \frac{\text{Growth rate of consumption of polymer material } i\,(\%\,\text{p.a.})}{\text{Growth rate of GDP}\,(\%\,\text{p.a.})}$$

To gauge future elasticities, the observed trends in the past in India and Western Europe were taken into consideration. The elasticities are thus the result of a combined linear trend extrapolation for the two countries. As an explanation let us consider the example of HDPE (see Table 2). Its elasticity in Western Europe was 4.6 during the period 1991–1994 and then declined to 3.9 between 1995 and 1999. For India, the elasticity was 3.8 between 1991

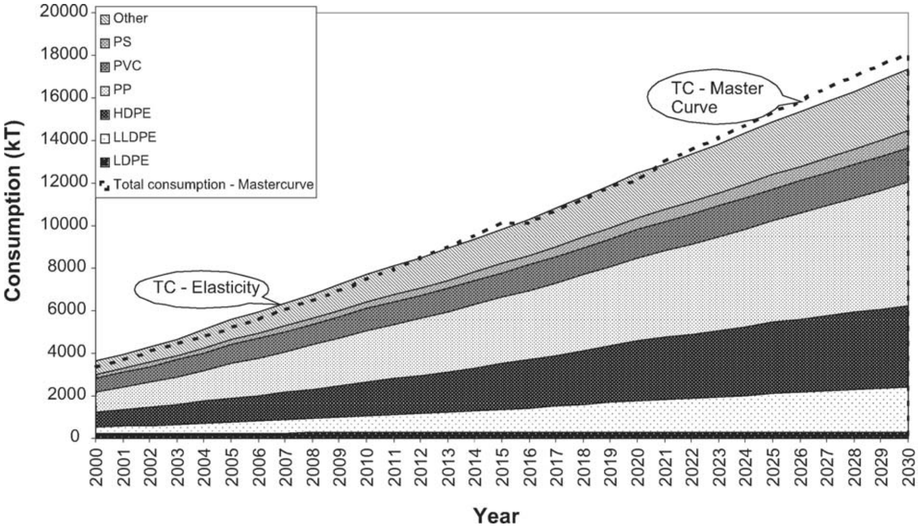

Fig. 6. Projection of individual virgin polymer material. *Note:* The dotted line in this graph indicates the total consumption of plastics calculated using the relationship between GDP and plastics consumption per capita (Fig. 5). The solid line, which envelopes the shaded area on top, represents the total of the individual projections by types of plastics (according to Table 1).

and 1995 before coming down to 2.5 over the next 5 years (2002b). Using this country comparison as the basis we estimated for India that the elasticity of HDPE would decrease further to 2.1 for 2001–2005. By analogy the elasticities have been projected for India for the other main plastics types up to 2030.

The assumed elasticities do not anticipate any step-changes in technology (possible major changes in process and product technologies), market shifts (e.g. possible commoditization of polycarbonate), discrepancies due to the politico-economic legislative frameworks (e.g. possible restrictions on PVC) or major shifts in raw materials supply due to depletion or scarcity for other reasons e.g. war.

According to the Indian Chemicals and Petrochemicals Manufacturer's Association (CPMA) the share of all the other plastics not mentioned in Table 2 (e.g. PET, ABS, phenolics, polyamides, polycarbonate, polyacetal, etc.), was about 17–19% during 1996–2000 (CPMA, 2000). This share is close to 21%, i.e. the share of the other plastics consumed worldwide in the year 2000 (APME, 2000). This share was also adopted for the projections for the future.

The total amount of plastics consumption can then be determined by adding up the projected volumes for all plastics. This should be identical to the quantities estimated by using the *master curve* (see above). However, since the elasticities for the individual plastics were projected for 5-year periods only (Table 2) the fit is not perfect. Nevertheless, the difference is quite small in the range of 5% (Fig. 6).

According to the framework explained above and the assumptions based on the situation in Western Europe, LLDPE, HDPE, PP will dominate in India too due to their versatility and cost benefits. PVC will grow very slowly because it will be replaced by PP and HDPE in many application areas. LDPE will remain constant since many of the markets will be lost to LLDPE; this means that the use of LDPE will be mainly limited to compounding (together with LLDPE for improving processing performance) and in master batches. PS will grow slowly because of its deficiencies in terms of mechanical strength (Fig. 6). The split between LLDPE and HDPE is particularly difficult to project because 70% of the total LLDPE/HDPE capacity in India is from swing plants, which are expected to play an important role also in the future. The share of LLDPE production from swing plants has increased considerably from 27% in 1990 to 34% in 1998 (ICRA, 2000). However, it is practically impossible to derive a projection for the future on this basis since the market situation at a given point of time will determine the share of these two materials.

The relationship represented by the *master curve* and those used for the individual polymers refers to the apparent consumption of virgin plastics in primary form (mostly granules). Secondary polymers produced by mechanical recycling are not taken into account. Moreover, the real demand for polymers is determined also by the trade of final products such as TVs, cars, etc. (indirect trade). For countries with a large net export of such final products the *real* consumption is smaller than the *apparent* consumption. The effect of indirect trade can be roughly estimated by combining monetary data on imports and exports and average product prices (Patel et al., 1998). Data from a global economic model and price projections would be needed to apply the methodology for the future. Since the availability and reliability of this data poses problems and since the effect of indirect trade is rather small for most countries (e.g., 3–6% of domestic consumption in Germany; Patel et al., 1998) we do not take indirect trade into account in our projections for India.

3. Plastic waste

Depending on the area of application, the service life of plastic products ranges from 1 to 35 years (Table 3). The life span of the end products shown in Table 3 also includes the reuse period. For example: the service life of the woven sacks used for packaging is less than 1 year, but these sacks are used for approximately an additional 2 years to protect goods and as roofing material in slum areas. The total service period is therefore 3 years. The weighted average service life of all plastics products in India is 8 years (Table 3); this is much less than the weighted average service life for Germany which is estimated at 14 years (Patel et al., 1998). This difference in service life reflects the fact that a particularly high share of plastics is used for short life products in India (e.g. share of plastics packaging: 42% in India versus 27% in Germany) (SGCCI, 2000; VKE, 2002c).

By combining service life and domestic consumption of virgin plastic products we can generate a first order estimate of the quantities for the post-consumer plastic waste. To arrive at a more accurate estimate, however, it is necessary to account for the use of additives, fillers – and more importantly – for plastics recycling. This will be discussed in the next section (Table 4).

Table 3
Estimated mean service lifetime of plastics products in India

End products	Service life (years)[a]
Films/flexible packaging	1
Injection-moulded goods	5–15
Wire and cable	30
Extrusion coating	1
Rotomoulded products	10
Woven sacks	3
Blow-moulding products	8
Pipes and conduits	35
Monofilaments	3
Footwear	2
Sheets (thick)	10
Profiles	30
Hoses and tubes	5
Appliances	20
Others	1–3
Mean weighted average	8

[a] The service lives reported in the table include the reuse period (wherever applicable).

Table 4
Service life of plastics products in India and Germany

Mean service life (Ts)	Share of the products with different service life (%)	
	India	Germany[a]
0 to ≤3 years	61	32
>3 to ≤10 years	23	39
>10 years	16	28

[a] See Patel et al. (1998).

4. Plastics additives and recycling

In our model, the use of additives (including fillers) and plastics recycling is taken into account by means of fractions which were estimated by type of end product (see Table 5). This chapter explains how these fractions are used, on which sources they are based, and to which results they lead.

The consumption of additives (including fillers) is not amenable from production and trade statistics and neither from associations or producers. The reason for this could be the highly competitive character of this market (which is the main cause of the unavailability of data in Europe). As an input for our material flow model for India we therefore used our own estimates for the amount of additives and fillers based on a literature review. Murphy's 'Additives for Plastics Handbook' was used as the main source (Murphy, 1996).

With regard to recycling the situation is very specific in India since the percentage of plastics recycling is much higher than that in most developed and in many developing countries (e.g. China 10%, South Africa 16%, compared to about 47% in India, see below) (IPCL, 1999). In contrast to most high-income countries where environmental legislation

Table 5
Fraction of additives and recycled materials by application area (primary recycling only)

Application	Additives and fillers (%)	pr[a] (%)	btp[b] (%)
Films	4–5	35–40	40–50
Injection moulding	6–10	20	15–25
Blow moulding	15	10	15–30
Pipes and conduits	20	20	5
Wire and cable	8–20	10	5
Woven sacks	12	25–30	30–35
Extrusion coating	7	30	0
Profiles	25	10	5
Rotomoulding	10	30	20
Monofilaments	10	25	10
Footwear	25	10	30
Sheets	15	10	30
Hoses and tubes	15	10	5
Appliances	10	5	10
Others/rest	5–15	15–25	15–25

[a] pr = fraction of recycled resin used to manufacture the product.
[b] btp = fraction of product waste converted to polymer pellets.

(e.g. for packaging waste) has usually been the driving force behind the development of the recycling industry, the recycling sector in India has developed autonomously because of the particularly low cost of labour and on account of the fairly large market for second-grade (lower-quality) products. Recycled products are available at a 20–40% lower price than the same products manufactured from virgin plastics. While the latter are preferred by the middle and upper classes, the cheaper recycled products certainly serve the markets of the low-income classes of Indian society.

In India, households segregate most of the plastic products, e.g. bottles, footwear, etc., after use and sell them to intermediate dealers. The fact that the end user is paid for the waste released (typically an equivalent of 20 Euro cents per kg) is a striking difference when compared with countries where the income level per capita is higher. Nevertheless, the same as in wealthy countries, light-weight and dirty plastics products (e.g. packaging films) are disposed of in India together with the normal household waste (without reimbursement). The major part of this waste stream is either dumped on landfill sites or remains in the environment where it is the main contributor to littering. A minor part of this light-weight and dirty plastics waste is suitable for recycling and is collected in various stages via various middlemen; it ultimately finds its way to the reprocessors (Fig. 7).

The Indian recycling industry belongs to the so-called 'informal sector' which, according to the International Labour Organisation (ILO) definition, comprises production units which typically operate at a low level of organization. Most of these recycling units have very low fixed capital (for machinery, etc.) and are generally run as small family businesses. Informal enterprises are usually not registered and thus evade rules and regulations, e.g. tax laws, minimum wage laws, accounting and workplace safety (Vishwanath, 2001). Consequently, not only child labour is come across, but dismal working conditions are also encountered (no ventilation, no protection from pathogenic waste). Moreover, it is practically impossible

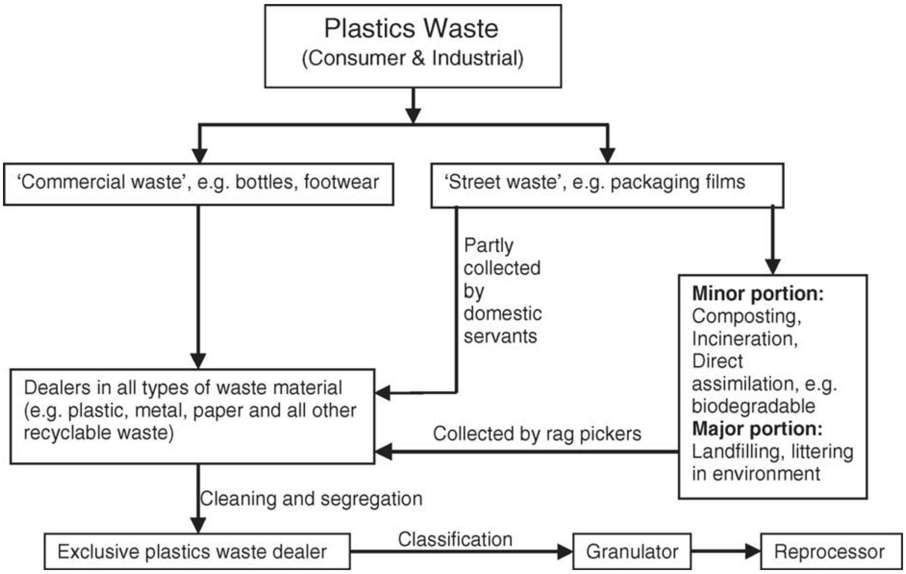

Fig. 7. Flowchart for the plastics waste.

to control the practices of post-consumer waste handling and processing; this can result in products that fail to comply with minimum safety and health requirements.

Information about the actual size of the Indian recycling sector varies greatly. According to an estimate by ICRA for 1995–1996, there were over 1800 recycling units spread across the country along with 2500 pelletisers (ICRA, 2000). In contrast, according to a study by Harriman in 1996, 20,000 micro-enterprises were engaged in the reprocessing and recovery of plastics waste in addition to 180,000 various sorting and washing units, 60% of which were unregistered (Shah and Rajaram, 1997).

Given the lack of reliable information on plastics recycling in India we generated our own estimates by using the material flow model. We estimated the quantities of recycled materials on the basis of the following two indicators:

1. Fraction pr (in %) of recycled resin used to manufacture a given plastic product.
2. Fraction btp (in %) of the waste stream of a given end product, which is converted to polymer pellets (back to polymer recycling).

Based on these indicators-pr and btp (see Table 5)—we determine the respective *absolute* quantities PR and BTP which are given in kilotonnes. It is assumed that there is no accumulation of the products recycled to resin/pellets, i.e. the net change of stocks of plastics in primary form is considered to be negligible. Therefore, for a given year, the amount of recycled resin used in products (PR in kilotonnes) equals the amount of end products converted to recyclates (BTP in kilotonnes):

$$\sum \mathrm{PR} = \sum \mathrm{BTP}\ (\text{for a given year})$$

Table 5 shows the recyclate fractions (pr and btp) we assumed. We consider these values to be somewhat on the high side, i.e. it is possible that we have overestimated the recycling flows. In some cases the recyclate fraction depends on the type of polymer which is reflected in the ranges shown in Table 5. Due to a lack of insight about the future dynamics, both pr and btp were assumed to remain constant for the total period studied. Our material flow model accounts for the period of time during which recycled materials are in use (time lag); depending on the application area this period can be quite substantial (see Table 3).

So far, we have addressed the *first cycle* of the recycling process, which we refer to as *primary* recycling. However, given the high share of primary recycling, a considerable share of the recycled products is again recycled after its service life, and this might happen even more than once. We refer to this as 'secondary recycling' (materials in the 3rd cycle) and 'tertiary recycling' (materials in the 4th cycle). Our results indicate that it is probably unnecessary to account for subsequent cycles (see below).

For films, the secondary recycling rates were assumed to equal 50% of the corresponding primary recycling rates (compare Table 5); the remaining 50% is assumed to be removed from the material cycle in the form of waste that is considered to be non-recyclable (due to deteriorated material properties and/or dirtiness). Tertiary recycling rates for films were assumed to amount to 10% of the corresponding secondary recycling rate; here, the underlying assumption is that 90% of the flow is removed from the material system. Secondary recycling rates for the end products other than the films were assumed to be 90% of the respective primary recycling rates, and tertiary recycling rates were estimated at 50% of the corresponding secondary recycling rates. The distinction is made between the secondary and tertiary recycling rates for films and for the other products because of the visible difference between film produced from recycled plastics and film produced from virgin plastics. Given the deteriorated appearance of recycled films the waste pickers receive hardly any or no reimbursement from the intermediate dealers; this makes recycled films unattractive for collection.

According to our model the total plastic waste amounted to 2380 kt in the year 2000/2001. Of this total, over 1120 kt were recycled (including primary, secondary and tertiary recycling). The share of the primary recycling was about 87% (960 kt) of the total recycling. About 150 kt of the material (13% of the total recycling) originated from secondary recycling, while tertiary recycling contributed by 10 kt (less than 1% of the total recycled material). Since this share of tertiary recycling is very small compared to the total recycling, we have not taken materials in their 5th or higher life cycle into account our model.

The total amount of recycling in the year 2000/2001 was over 26% of the virgin plastics consumption and about 47% of the total waste generated. The average recycling share of 45% in India is much higher than the share of the mechanical recycling in Western Europe in 1994 amounting to 9.4% (APME, 1996a,b). In addition, a considerable part of the plastic waste in Western Europe is incinerated with energy recovery (21% of the total waste) (APME, 2001). In contrast, mechanical recycling is the only technique used in India to process post-consumer waste; all the remaining waste is either landfilled or disposed of in an uncontrolled fashion (as litter, illicit dumping).

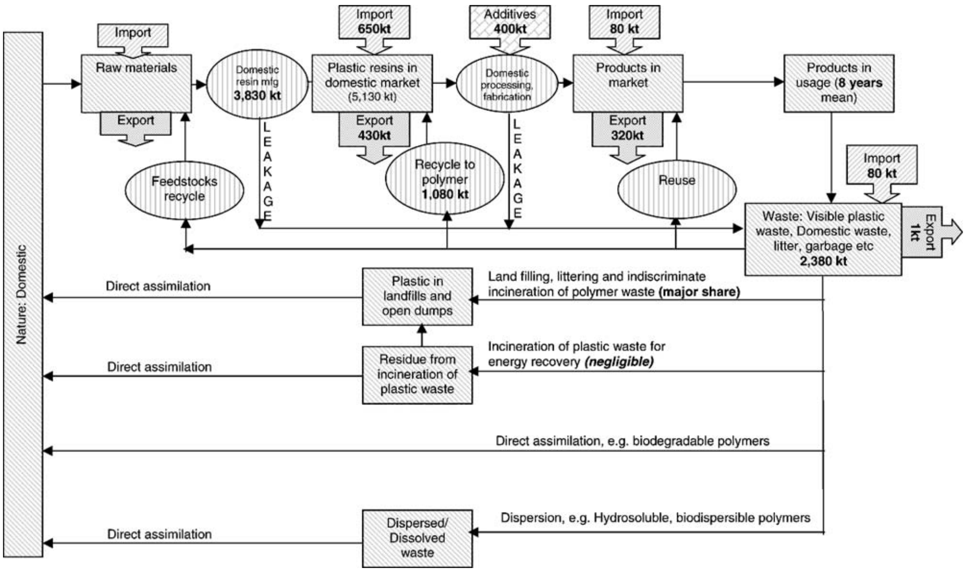

Fig. 8. The flow of plastic materials in India for 2000/2001.

5. Overview and the results of MFA

Fig. 8 presents a snapshot of the plastics material flow in India for year 2000/2001. The total plastics consumption, including recycled plastics in the year 2000/2001, was over 5130 kt; about 80% (4050 kt) being virgin plastics. About 400 kt additives and fillers were used in the plastics processing.

The Indian polymer industry is dominated by local players and shows a clear trend towards self-dependency. Over the last decade, the net imports of polymers declined from 29% in 1990/1991 to 6% in 2000/2001. The net export of plastics end products increased from 3% to 5% of the total consumption over the last 10 years.

The total amount of post-consumer plastic waste for disposal in the year 2000/2001 has been estimated at 45% of the total consumption of plastics. We also estimate that 47% of the waste was mechanically recycled (see Section 4). The remaining plastics waste is deposited in landfill sites; the main disposal option used in India.

Fig. 9 shows the results of the model projections for the future. The total virgin plastics consumption is expected to reach 20,000 kt by the year 2030 and over 18,800 kt of waste will be generated. This is 69% of the total plastics consumption (including plastics recycling). If the recycling rate remains constant, 6600 kt waste will be recycled (35% of total waste generated, including primary, secondary and tertiary recycling) and the rest will be disposed of. The total plastics consumption (including recycling) is expected to increase at an annual growth rate of about 5% between 2001 and 2030.

Over the past decade, the share of film in the total plastics consumption in India was around 20%, the same as in Western Europe. However, in India films constitute a substantial 41% of the total plastics waste, while the share in Western Europe is only 24% (APME,

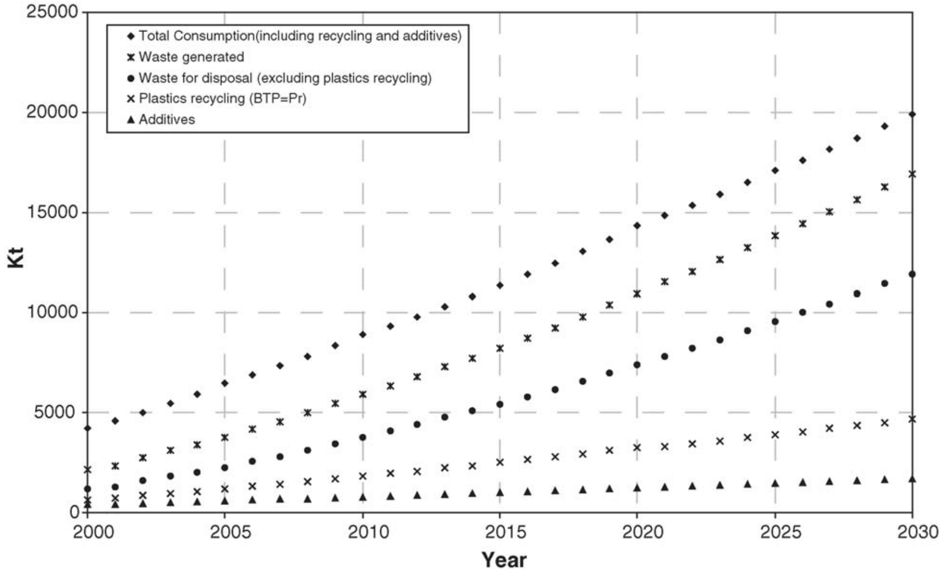

Fig. 9. Projection of total plastics consumption (including recycling and additives), waste generated, waste available for disposal, waste recycled and additives consumption.

1996a,b). This difference is due to the phenomenal growth in the consumption of plastics in India over the past decade. Consequently, more short-life than long-life products entered the waste stream. The difference in the share of the various films in the waste stream also reflects the high reuse potential of the end products in India, i.e. unlike the *'use and throw'* consumption pattern which dominates in Western Europe, in India most of the products are reused and their share in the waste stream is thus reduced.

6. Discussion of material flows

In this chapter we compare our model results with other sources. To start with, TERI (Tata Energy Research Institute) projects the virgin plastics consumption per capita in 2021 at 10–11 kg which is comparable to the 10.3 kg calculated using our model (15.6 kg if the recycled materials are also included) (Gupta et al., 1998). The Technology Information, Forecasting and Assessment Council (TIFAC), India, has forecast more than 15 million tonnes of plastic by the year 2020/2021; this is also supported by our model result of 15.3 million tonnes (TIFAC, 2001). As discussed in Section 2.2 we assumed diminishing growth rates in the consumption of plastics; for example, according to our model the total amount of plastics consumed decreases from 12% in 2000/2001 to 7% in 2007/2008; this is in line with the ICRA report (ICRA, 2000) which estimates a 20–40% reduction in the growth rate in 2007 as opposed to that in the year 2000/2001.

Several studies have also been prepared on plastics waste in India. The most renowned of these is the study drawn up by the National Plastics Waste Management Task Force formed by the Ministry of Environment and Forests (NPWMTF) in 1997 (NPWMTF, 1997). According to this task force, the plastics waste available for recycling will increase from 0.8 million tonnes in 1995/1996 to 2 million tonnes by the year 2000/2001 (see Table 6). Using our model, the recycling quantities increased from 540 kt in 1995/1996 to about 1120 kt in 2000/2001 (including primary, secondary and tertiary recycling). In other words, our model results for recycling are up to 40% lower than NPWMTF estimates. This is quite remarkable considering we believe that our assumed recycling fractions (pr, btp) is on the high side already (see Section 4). Other quantitative studies conducted on post-consumer plastics waste present contradictory results (see Table 6).

As stated earlier, we assume that secondary and tertiary recycling rates differ for films and other end products (see Section 4). Due to the lack of reliable data there is a large element of uncertainty in our assumptions. We therefore conducted a sensitivity analysis using different assumptions. In the base case, secondary and tertiary recycling rates were assumed at 50%, 10% for films and 90% and 50% for all other products, respectively. For the sensitivity analysis for secondary recycling, rates were assumed to equal 100% of the primary recycling rates, and tertiary recycling rates were taken as 50% of the secondary recycling rates. Fig. 10 shows the results for both the base case and the sensitivity analysis. By assuming higher secondary and tertiary recycling the total recycling quantities increased from 47% to 52% only for the year 2000/2001.

A sensitivity analysis was also carried out for the service life of the products. With an increase of 30% in the total service life of the product, the mean service life increases from 8 to 10 years (see Table 3). An increase in service life also results in a reduction in the total plastics waste generated by 13%, i.e. 2080 kt from 2380 kt in the base case for year 2000 (see Fig. 10).

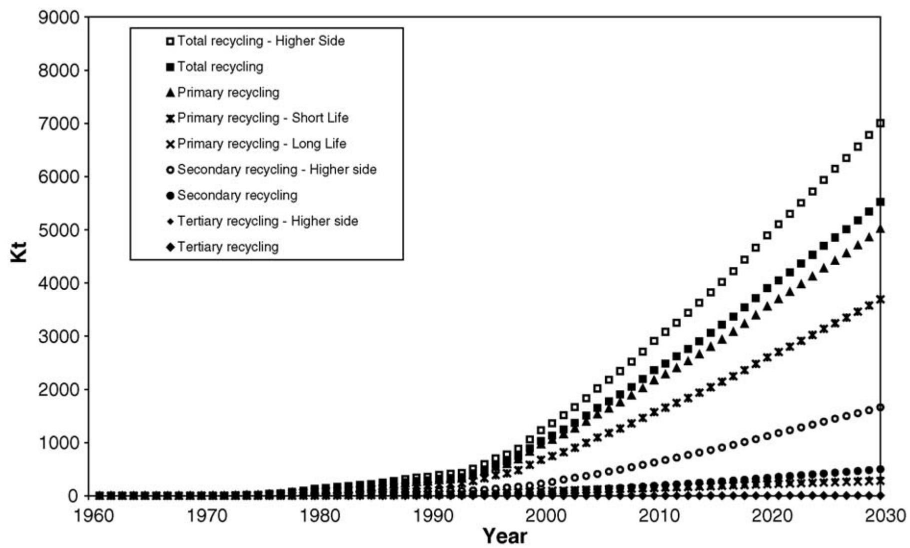

Fig. 10. Recycling scenarios. *Note:* The hollow legends in the graph represent higher secondary, tertiary and total recycling quantities.

Table 6
Post-consumer waste and recycling: comparison of our model results with other sources

Total post-consumer waste (kt)	Post-consumer recycling (kt)		Fraction recycled (includes primary, secondary and tertiary recycling) (%)	Source
	Primary recycling	Secondary/tertiary recycling		
1995/1996				
1140	460	80	47 (W), 25 (V)	This study
870	522	278	92 (W)[a]	NPWMTF (1997)
	867		35 (V)	ICRA (2000)
	848			Shah and Rajaram (1997)
	364			Modern Plastics (1995)
	750			Business World (1997)
1998/1999				
1725	690	50	43 (W), 24 (V)	This study
	1200			Banerji (2000)
2000/2001				
2380	960	120	47 (W), 26 (V)	This study
	2000[a]			NPWMTF (1997)
Mid/end 1990s according to various studies				
			40 (NA)	Shah and Rajaram (1997)
			50 (V)	Chemical Weekly (1998)
			60 (V)	NetPEM (2001), PlastIndia (2000), CSE (2000), Haque et al. (2000)
			80–93 (NA)	Shah and Rajaram (1997)

W = % recycled with respect to post-consumer waste; V = % recycled with respect to virgin plastics consumption; NA = definition not stated.

[a] 60% of the virgin plastics waste recycled along with 30% of the plastics recycled in previous year is recycled again (3rd cycle).

Imports of plastics waste are also an issue of discussion in India. Net imports of plastic waste products increased from 1% in 1990 to 3% in 2000. According to the notification laid down in 1998 by the Directorate-General of Foreign Trade (DGFT, Government of India) only companies in the export processing zone (EPZ) were exempt from the ban on importing scrap and plastics waste (DGFT, 1998). Another important guideline in that notification forbids the sale of products manufactured in the EPZ from imported scrap in India, and distinctly states that all recycled products from imported waste may only be exported (Business Line, 1998; Financial Express, 1998). The obvious drive behind this process is the enormous cost-saving potential that can be achieved from the cheap manpower available in India. The cost per hour in India – according to report issued by the PlastIndia foundation – is 35 times less than in Germany, 19 times less that in the United States and 6 times less than in Taiwan (NetPEM, 2001).

In our model we assumed an identical growth rate of materials and the respective products, i.e. that the consumption pattern remained constant over the total time period. Moreover, the recycling fractions (pr and btp) and the basic data for estimating secondary and tertiary recycling were assumed to be constant for the time period studied. However, all these relationships are likely to change as the country becomes wealthier. Detailed analyses of the future demography, income levels, income distribution, consumption patterns, and the resulting materials and product demand would be necessary to improve the model assumptions and ultimately also the results (possibly by making a distinction between various scenarios).

7. Socioeconomic aspects of the plastics industry in India

In the year 1997/1998, 60.3% of the 344.3 million workers were employed in the agricultural sector, followed by manufacturing (11.5%), trade—hotels and catering (8.6%), services (9.1%) and in the construction sector (4.8%) (Planning Commission, 2002). Polymer manufacturing, along with the processing and recycling sector, accounted for 1% of the total employment in the Indian manufacturing sector.

As shown in Table 7, the number of employees in the plastics industry differs widely depending on the various sources. The official source, the data provided by the Indian Central Statistical Organisation (CSO), may be considered the most reliable; these figures are confirmed by the data published by the Organisation of Plastics Processors in India (OPPI, India) (see Table 7). Keeping in mind the Indian productivity stipulations, the statistics from CSO are compared with the situation in the Netherlands. According to the Central Bureau of Statistics (CBS, Netherlands), there is a total of three employees per kilotonne of plastics manufactured in the Netherlands; this is about five times less than in the Indian situation: 14 employees per kilotonne of plastics manufactured according to CSO (CBS, 2002; CSO, 2002). In the processing sector, where 10 persons are employed to process 1 kt of plastics in Netherlands, 46 workers are required to perform the same operation in India (CBS, 2002; CSO, 2002). The factor of 5 difference in productivity between the Netherlands and India can be considered as a plausible estimate. On this basis it can be concluded that the Rakesh Mohan study (Government of India, see Table 7) overestimates the employment potential by far, according to which there are more than 3500 employees per kilotonne of plastics

Table 7
Employment in the Indian plastics sector according to the various sources

Year	Plastics manufacturing (NIC 2413)	End product manufacturing (NIC 252)	Plastics recycling	Source
1998/1999	31865	168661		Central Statistical Organization (Dr. Vaskar Saha, 2002) (CSO, 2002)
1993	11000000			Mr. Rakesh Mohan (GOI) (NetPEM, 2001)
1997		172320		PlastIndia (report by Tata Economic Consultancy Services, 1997) (NetPEM, 2001)
2001/2002		285000		Organisation of Plastics Processors of India (Mr. Deepak Lawale, 2002) (OPPI, 2002)
1999/2000		1300000	600000	All India Plastics Manufacturers' Association (Mehta, 2000)
1998/1999			250000	Rajagopal et al. (2002)
1998/1999			320000	ICPE (Banerji, 2000)

manufactured. (NetPEM, 2001). Also, according to a study by Rajagopal et al., some 300 workers are involved in the recycling sector per kilotonne of plastics (Rajagopal et al., 2002). This is in line with the estimate made by Banerji (2000). This is assumed to be a reliable estimate given the fact that most of the steps involved in recycling are labour intensive i.e. collecting, sorting, cleaning, etc.

8. Conclusions

In this study a clear relationship has been identified between the GDP per capita and the plastics consumption per capita for different countries. This relationship (the *master curve*, Fig. 5) was used to make projections in terms of plastics consumption in India over the next three decades. According to our projections, the consumption of plastics will increase about six-fold between 2000 and 2030. The share of polyolefins in India will remain at about 60%, a percentage comparable to that of Western Europe. In 2030, plastics waste for disposal (excluding recycled plastics) will increase 10 times compared to the situation in the year 2000/2001; this model result assumes that the plastics recycling rates will remain at the current level for the next three decades. Nevertheless, it is more likely that the recycling rates will decrease with the increasing level of wealth; in this case, plastics waste for disposal will grow by more than a factor of 10 between 2000 and 2030. Waste for disposal is increasing relatively faster than the plastics consumption because of the higher share of long-life products in waste and the lower recycling rates of these products.

In the year 2000/2001, the share of recycling accounted for 47% of the total volume of waste generated (including primary, secondary and tertiary recycling). With the current recycling rates, the percentage of recycling will decline to 35% in the year 2030. The declining share of recycling reflects the higher percentage of long-life products that accumulate in the waste; these long-life products are less suitable for recycling (see Table 5). The share of secondary and tertiary recycling is about 13% of the total volume of recycled products. According to a sensitivity analysis, secondary and tertiary recycling rates showed only a marginal increase from 47% to 52% of the total waste recycled (for the year 2000/01). The primary recycling rates shown in Table 5 are already on high side. Even with these higher recycling rates the total recycling volumes estimated by using our model remain as low as 1120 kt for year 2000/2001, compared to the projected 2000 kt of the NPWMTF. Hence we conclude that other studies tend to overestimate the recycling volumes and consequently underestimate the actual volume of waste disposed of.

Data discrepancies across the data sources were also observed for employment figures in the plastics sector (see Table 7). According to CSO, 0.2 million workers were engaged in the plastics manufacturing and processing sector (formal sectors). A factor of 5 is observed between India and the Netherlands for employees per kilotonne of plastics produced/processed in the manufacturing and processing sector. The recycling sector, which is much more labour intensive, accounts for another 0.25 million workers. More than 90% of the workers are employed in the processing and recycling sector out of the total 0.45 million employees. The recycling sector employs eight times as many people working in the plastics manufacturing sector.

Packaging will continue to be a major application area for plastics, significantly contributing to all three sections of material flow analysis viz. consumption, waste and recycling. A larger part of the packaging waste with a low mass-to-volume ratio (e.g. small packaging units for single use quantities of shampoo and toothpaste) is unsuitable for recycling and will therefore make a substantial contribution to the problem of litter. A more detailed analysis is required to calculate the exact amount of this sort of thin-film packaging waste.

Improved waste management systems and regulatory discipline are required in India because volumes of plastic waste will clearly rise in the future as the per capita consumption of plastic products increases. Plastics waste management, therefore, needs continued policy attention from both stakeholders: Government and Industry. Examples are initiatives, like the Plastics Waste Management Task Force established the Ministry of Environment and Forests in 1997, and the Indian Center for Plastics and Environment (ICPE) which was established by the Indian plastics industry in 1999.

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References

APME (Association of Plastics Manufacturers in Europe). Information System on Plastics Waste Management in Europe—European Overview 1994 Data. Brussels, Belgium: APME; 1996a.

APME (Association of Plastics Manufacturers in Europe). Plastics Packaging Consumption, Waste and Recycling 1994 Data (revised version). Brussels, Belgium: APME; 1996b.
APME (Association of Plastics Manufacturers in Europe). Plastics—An Analysis of Plastics Consumption and Recovery in Western Europe, 1998. Brussels, Belgium: APME; 2000.
APME (Association of Plastics Manufacturers in Europe). Information System on Plastics Waste Management in Europe—European Overview 1999 Data. Brussels, Belgium: APME; 2001.
APME (Association of Plastics Manufacturers in Europe). Plastics Consumption Data by Sector. Brussels, Belgium: APME (sited at http://www.apme.org/dashboard/template.asp?url=http://www.apme.org/media/public_documents/20010727_150248/euro_consumption_sector.htm&title=Consumption+data+by+sector); 2002.
Banerji S. Plastics and the environment—the Indian perspective. In: Presented at PlastIndia-2000. Indian Center for Plastics and Environment; 2000.
Bose, Vasudeva, Gupta, Sinha. India's Environment Pollution and Protection. TERI-Report No. 97ED57. Submitted to the Central Research Institute of Electric Power Industry, CRIEPI, Japan, Chapter 5, Delhi, India; 1998. p. 78–81.
Business Line. EPZs exempt from ban on plastic wastes, scrap import, India; 1998. p. 3.
Business World. Recycling goldmine (Plastics constitutes almost 4% of MSW), India; 1997. p. 88.
CBS (Centraal Bureau voor de Statistiek). Statline, The Netherlands (sited at http://statline.cbs.nl/StatWeb/start.asp?LA=nl&lp=Search/Search); 2002.
Chemical Weekly. Plastic Industry plans to promote thicker plastics bags, vol. 44, no. 15, Mumbai, India; 1998. p. 80.
Chemical Weekly-Annual, Mumbai, India; 1985. 92–101.
Chemical Weekly-Annual, Mumbai, India; 1991. p. 71–80.
Chemical Weekly-Annual, vol. I, Mumbai, India; 1996. p. 70–84.
Chemical Weekly-Annual, vol. I, Mumbai, India; 1998. p. 93–121.
CPMA (Chemical & Petrochemicals Manufacturers' Association). Chemicals and Petrochemicals, vol. II, no. 1, Delhi, India; 2000. p. 17–23.
CSE (Center for Science and Environment). Plastics Unlimited—special report. Down to Earth, vol. 9, no. 14, India; 2000. p. 20.
CSO (Central Statistical Organisation). Dr. Saha V. DG-CSO, Delhi, India, Personal communication; 2002.
Desai A, Desai J, Shrividya I, Naik K. Integrated plastic waste management: an Indian perspective. Chem Eng World 1998;33(12):129–38.
DGFT (Directorate General of Foreign Trade). Exim policy and procedures in India, Delhi, India; 1998 (as sited at http://dgftcom.nic.in/exim/2000/not/not98/not3798.htm).
Financial Express. EPZs allowed to import waste, plastic scrap, India; 1998. p. 9.
Gupta S, Mohan K, Prasad R, Gupta S, Kansal A. Solid waste management in India: options and opportunities. Resour Conserv Recycl 1998;24(2):137–54.
Haque A, Mujtaba IM, Bell JNB. A simple model for complex waste recycling scenarios in developing economies. Waste Manage 2000;20(8):625–31.
ICRA industry watch series. Indian commodity polymers industry, Delhi, India; 2000.
IEA (International Energy Agency). Energy Statistics and Balances of Non-OECD Countries (1994–1995), Paris, France; 1997.
IEA (International Energy Agency). World Energy Outlook—2000, Paris, France; 2000.
Industry Canada. Canada's Business and Consumer portal; 2002 (sited at http://strategis.ic.gc.ca/SSG/pl01306e.html).
International Energy Agency. Beyond 20/20 browser, Paris, France. Release 4.1; 1996.
International Status Report 1993–1994 (British Plastics Federation, UK), UK; 1995.
International Status Report 2000–2001 (British Plastics Federation, UK), UK; 2002.
IPCL (Indian Petrochemical Corporation Limited). Dr. Bhardwaj, I.S. Vadodara, India, Personal communication; 1999.
Mehta A (All India Plastics Manufacturer's Association). Plastics processing industry: What industry needs for growth; Popular plastics & packaging, Mumbai, India; 2000. p. 43–4.
Ministry of Environment and Forest (Government of India). National Plastics Waste Management Task Force (NPWMTF) report, Delhi, India; 1997.
Modern Plastics; 1995. p. 49.

Murphy J. Additives for plastics handbook. The Netherlands: Elsevier Science; 1996.
NetPEM (Network for Preventive Environmental Management). International Workshop on Development of Sustainable Plastic (Waste) Management Strategies for India-workshop background document-1, Nagpur, India; 2001 (sited at http://www.netpem.org/web/announcement/workshops/plastic/IndianPlasticManagementScenario.pdf).
OPPI (Organisation of Plastics Processors of India). Dr. D. Lawale, Mumbai, India, Personal communication; 2002.
Patel MK, Jochem E, Radgen P, Worrell E. Plastics streams in Germany—an analysis of production, consumption and waste generation. Resour Conserv Recycl 1998;24(3–4):191–215.
PFSA (Plastics Federation of South Africa). Personal communication with Pretorius, A., Tech Support Manager, PFSA. Cape Town, South Africa; 2001.
Planning Commission (Government of India), Quality of Life Pointers, Delhi, India (sited at http://planningcommission.nic.in/page64.htm); 2002.
PlastIndia-2000. Indian Polymer Industry, Delhi, India. p. 759–65.
Polymer Update portal (sited at http://www.polymerupdate.com/industryinfo/Cier/pl0100-polymers.htm); May 2002.
Polymer India, India; 1976a. p. 18–21.
Polymer India, India; 1976b. p. 12–5.
Polymer India, India; 1977. p. 14–5.
Polymer India, India; 1978. p. 7–13, India.
Polymer India-Annual, India; 1986. p. 24–35.
Population Division. Department of Economic and Social Affairs (United Nations). World Population Prospects—2050. New York, USA; 1996.
Rajagopal R, Tharian J, Harmati Z. Recycling in India—Environmental and Technological Imperatives, Nagpur, India (sited at http://www.netpem.org/web/announcement/workshop.htm); 2002.
SGCCI (Southern Gujarat Chamber of Commerce and Industry). The Indian Plastic Industry, compiled by the PlastIndia Foundation, India; 2000.
Shah E, Rajaram. Plastics recycling in Bangalore—India (case-study report Plastic recycling). UWEP (Urban Waste Expertise Programme), Gouda, The Netherlands; 1997.
TIFAC (Technology Information, Forecasting & Assessment Council). Vision 2020 Report. Delhi, India (sited at http://www.tifac.org.in/offer/vis/chem1.htm); 2001.
Vishwanath T. Needs and Demand in the Informal Sector and Small Enterprises for Skills and Knowledge—A Developing Country Perspective (Asian), presented at Linking Work, Skills and Knowledge: Learning for Survival and Growth, International Conference, Interlaken, Switzerland; 2001 (sited at http://www.workandskills.ch/downloads/Vishwanath_PP.pdf).
VKE (Association of the German Plastics Industry). Plastics consumption in the packaging sector of Western Europe. Frankfurt, Germany; 2002a (sited at http://www.vke.de/pdf-files/e_sonderpack.pdf).
VKE (Association of the German Plastics Industry). Plastics: business data and charts; 2002b (sited at http://www.vke.de/pdf-files/widat_engl.pdf).
VKE (Association of the German Plastics Industry). Plastics consumption Germany, Frankfurt, Germany; 2002c (sited at http://www.vke.de/pdf-files/consultic_lang.pdf).