Plastics in Circular Economy: A Sustainable Progression

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Abstract Extensive usage of plastics causes environmental deterioration, global warming and health imperilments, costing the economy around $139 billion annually. Conversely, from childcare products to coffins manufactured with plastics, they have become an integral part of our life. At this situation, banning the use of plastics is not sustainable. Therefore, it is necessary to espouse circular economy (CE) in plastic sector. Meaning, preventing waste by manufacturing products that are efficiently reusable, recyclable or recoverable and gradually replacing non-degradable with degradable plastics. This chapter focuses on the concept of CE in plastic industries, recycling and recovering methods of plastics, government frameworks and challenges faced for implementation of circularity. From the case studies reported in this work, though there are successful execution of circularity in few scenarios, it can be noted that the implementation of CE is still at infant stages, as large proportion of companies have yet not committed 100% circularity until 2025. This work also identifies that more advancements in research and technologies, more tax benefits and funding allocation, need for collaborative business models, boosting and advertising the demand for recovered products and increased awareness on social responsibility of consumers and manufacturers are still necessary for achieving efficient circularity of plastics.

Keywords Plastics circularity · Key indicators for CE · Plastics recycling techniques · Challenges

Learning Objectives

- Understanding the concept of plastic circularity.
- Necessity to adopt plastic CE.
- Understanding the key challenges and indicators involved in CE implementation.
- Case studies, where plastic circularity is implemented.
- Knowing the status of global initiatives and legal frameworks.

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1 Introduction

In recent years, a number of products are being manufactured using plastics, mainly due to it's low cost, less weightness and ease of processing. It is estimated that 359 million metric tonnes of plastics were produced in 2018 alone to meet the global demands [1]. In 2019, the value of global market for plastics is approximately $568.7 billion with an average increasing rate of 3.5% until 2027 [2]. The consumption of plastics per person per year ranges from 9 to 108 kg. Figure 1 shows the per capita consumption of plastics across various countries in 2015. Polyolefin (PO) makes up the biggest share thereof, with low-density polyethylene (LDPE) being the most prominent, followed by polypropylene (PP), high-density polyethylene (HDPE) and polyethylene terephthalate (PET). Smaller shares are contributed by polyvinyl chloride (PVC), polystyrene (PS), polyamide (PA) and other plastics. Figures 2 and 3 show the consumption of general plastics and usage of these common plastics in different sectors. Most of the common plastics used in the industry are non-biodegradable. With its extreme durability, the life span of plastics and polymers

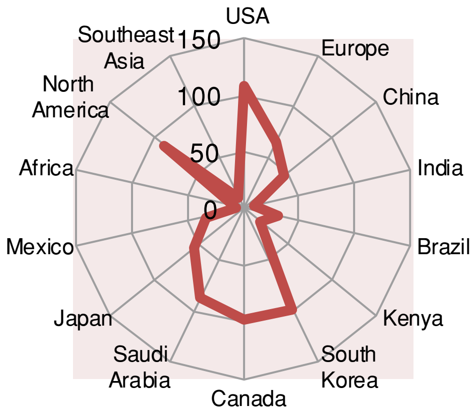

Fig. 1 Per capita consumption of plastics (kg/person) [4–7]

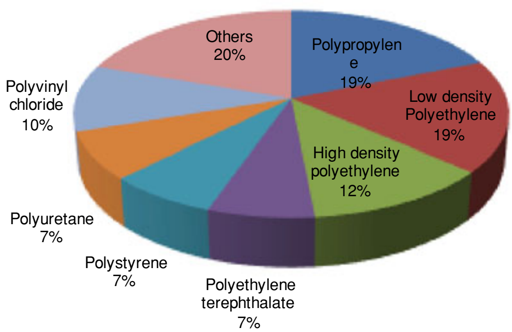

Fig. 2 Global consumption of common plastics [8]

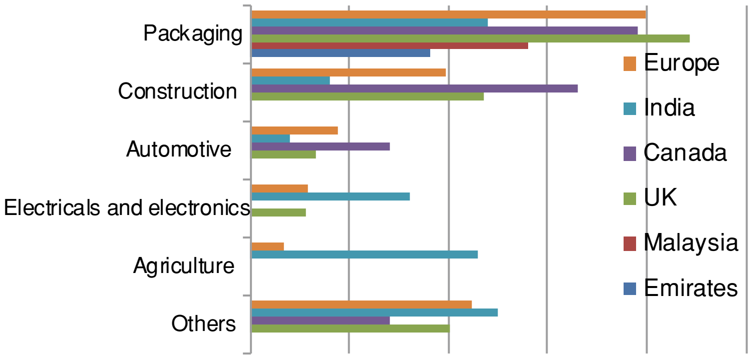

Fig. 3 Consumption of plastics by sector (%) [9–13]

is around some centuries. With increase in global usage of plastics, they often end up in landfills after their consumption. The usage of plastics has become one of the most pressing issues for the globe, as they are the leading source of global warming, reduction in groundwater due to clogging of river/canal streams and health hazards. Management of plastic waste (as they reach their end of life) has turned out to be so omnipresent that it has triggered the efforts to frame a worldwide treaty under the witness of United Nations. To tackle the issues, the stakeholders are also marching towards the adoption of circularity of the plastics. Circularity is adopted through developing and pursuing a concept of 'circular economy'. Circular economy is briefly defined by European parliament as 'a model based inter alia on sharing, leasing, reusing, repairing, refurbishing and recycling, where products and the materials they contain are highly valued, and where waste is reduced to a minimum' [3].

2 Circular Economy of Plastics

In recent trends, all the stake holders are moving towards more sustainable approach of circular economy from linear economy, where the products are used and disposed. 'Circular economy aims to keep resources in use for as long as possible, to extract the maximum value from them while in use, and to recover and regenerate products and materials at the end of their service life. It offers an opportunity to minimize the negative impacts of plastics while maximizing the benefits from plastics and their products, and providing environmental, economic and societal benefits'. The concept of progression from linear economy to circular economy is represented in Fig. 4.

In short, three important principles to manage the circularity of plastics or circular economy, in general, are as follows:

- Preserve and enhance the natural capacity by controlling finite stocks and balancing the flow of renewable resources.

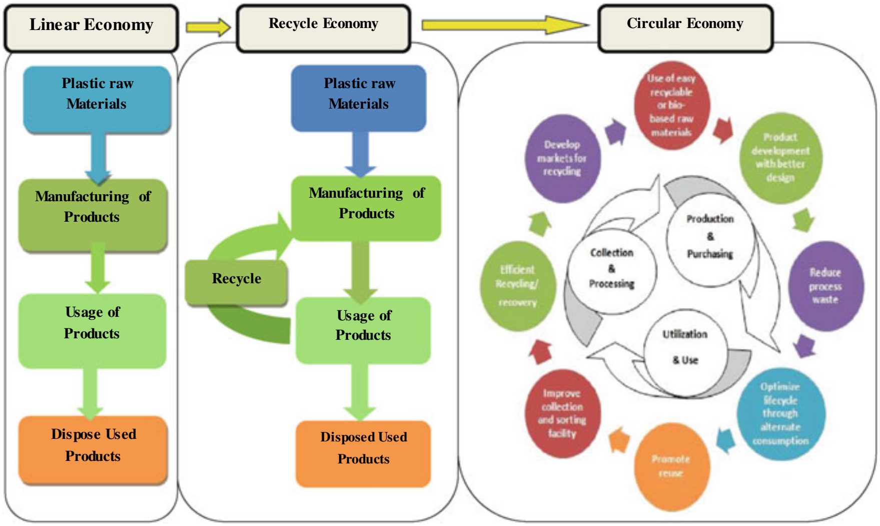

Fig. 4 Progression of polymer usage from linear model to circular model

- Optimizing the raw materials and yield through product circularity and using the materials with high value at all times.
- Make the system more effective by removing the negative externalities.

3 Recycling Rates, Policies and Initiatives for Circularity of Plastics Undertaken in Various Countries

Recyclability and reusing are parts of initiatives taken for promotion of circularity of plastics. In early days, many countries were exporting the plastic wastes to other countries, which were equipped with state-of-the-art recycling technologies. Until recently, China was the leading country to import the plastic wastes from various countries. For instance, Australia alone exported around 1.25 million tonnes of plastic wastes during a period of 2016–2017.

In early 2018, China began enforcing its National Sword policy, where stringent rules and regulations were imposed on the quality of plastic wastes to be imported. Further, in recent years, China minimized the import plastic wastes from major countries. Since the ban imposed by China, many countries started recycling of plastics within its territory. However, the recycling rates are still quite lower. Figure 5 shows the recycling rates of plastic wastes across various countries in 2018. India, South Korea, Japan and China are the leading countries in recycling of plastic waste.

From Fig. 5, it can be noted that the recycling rates of countries such as Singapore, USA, Brazil, etc. are still only at very low rate of 4–20%. To fight against the waste management, several governments and organizations are taking leaping steps towards

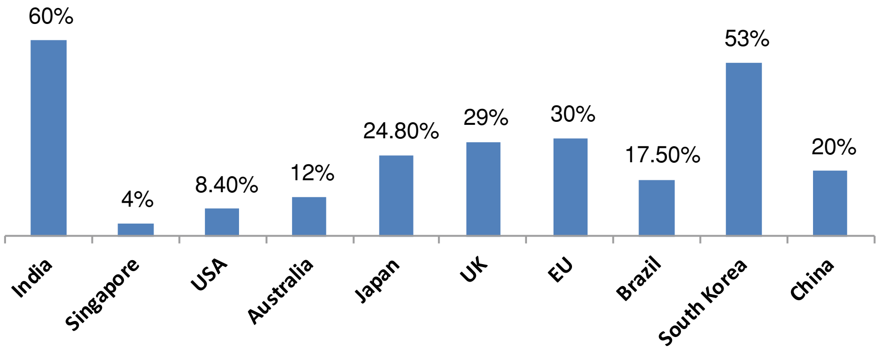

Fig. 5 Recycling rates of plastic waste of different countries [12–19]

the adoption of circularity of materials. Taking the lead, China adopted the Circular Economy Promotion law in 2009. In the following years, several detailed action plans (such as State Council 2013) have briefed the clear strategies and legal frameworks for the successful execution of CE in China [20].

Down the timeline, in 2012, Germany enforced Circular Economy Act also called as 'kreislaufwirtschaftgesetzKrWG' or German Circular Economy Law. Further, in December 2015, European Union came forward in adoption of CE. The 'Circular Economy Package' of European Union emphasizes on the new path of closed-loop cycle for production, usage and recycling of plastics. The framework also serves as a reference point for drafting of circularity principles for the countries, which focused on CE in later years. With respect to strategies for plastics in focus, the framework came into force from 2018. Later, Netherlands, in September 2016, passed on new legislation called 'A Circular Economy in the Netherlands by 2050'. Apart from this, several other programmes and initiatives such as Green Growth, From Waste to Resource (VANG) and the Bio-based Economy are also encouraged to embrace circularity of plastics. Later, the government of Spain elaborated a new initiative in 2017 for reduction of landfills and to promote CE. It is stated that around 300 signatories and stakeholders have indulged in the new pact of Government of Spain. The Government of India has recently drafted a National Resource Efficiency Policy in 2019, aiding the country to move towards the circular economy and approach zero landfill strategy.

Apart from government institutes, several non-governmental entities have come forward with a mission to progress towards circularity of plastics. For instance, American Chemistry Council's (ACC) Plastics Division has released a new obligation for its members. The new proposal has set a target to recycle and recover the plastics used in packaging sector, completely by 2040. In addition, the plastic pellet stewardship is to be encouraged by 2022. Further, in 2018, around 200 leading companies and business organizations, 16 governments of various countries, 26 financial institutes and 50 academic and research institutes have collaborated in a program called 'New

Plastics Economy Global Commitment' to make the virtual vision of CE into reality. The Ellen MacArthur Foundation heads this new initiative in collaboration with UN Environment [21].

4 Challenges Faced in Embracing Circularity of Plastics

In the holistic progression from open-loop/linear usage of plastics to implementation of close-loop/circularity of plastics, all the participants from industrialists to consumers need to face a significant challenge. Several strategies are reviewed and available for implementation of circular economy, especially in packaging industries. Researchers and analysts have constructed a database of the key factors and challenges that are to be considered in successful operation for adoption of CE [22], which is briefly summarized in Fig. 6. A number of important challenges are discussed as follows.

4.1 Finding Value

The recycled plastics are sometimes expensive than the virgin plastic raw materials. Though recycled plastics are up expensive, the quality is often questionable. Therefore, there is a need to find the addition of value to the recycled plastic materials.

4.2 Redesigning

Many goods are manufactured such that plastic content is made complicated to recycle. Many products such as bottles, packaging covers etc., in order to meet the market needs, are often produced with other additives and materials such as glues and bonds. However, these lead to difficulty in dissembling the products into waste separates. Therefore, a sustainable approach must be adopted to design the products with focus of easy recycling. In addition, new eco-based materials should be designed which not only offers recyclability but also are eco-friendly. For instance, polyethylene furanoate (PEF), a new bio-based plastic, is being developed, which serves as an alternate to existing PET bottles. In 2016, AVANTIUM, BASF with partnership of other leading companies such as Coca-Cola Company, Danone and ALPLA came forward to start a joint venture called 'Synvia'. They established a manufacturing unit in Belgium for the production of these bio-based materials which also offer opportunities to be recycled [24].

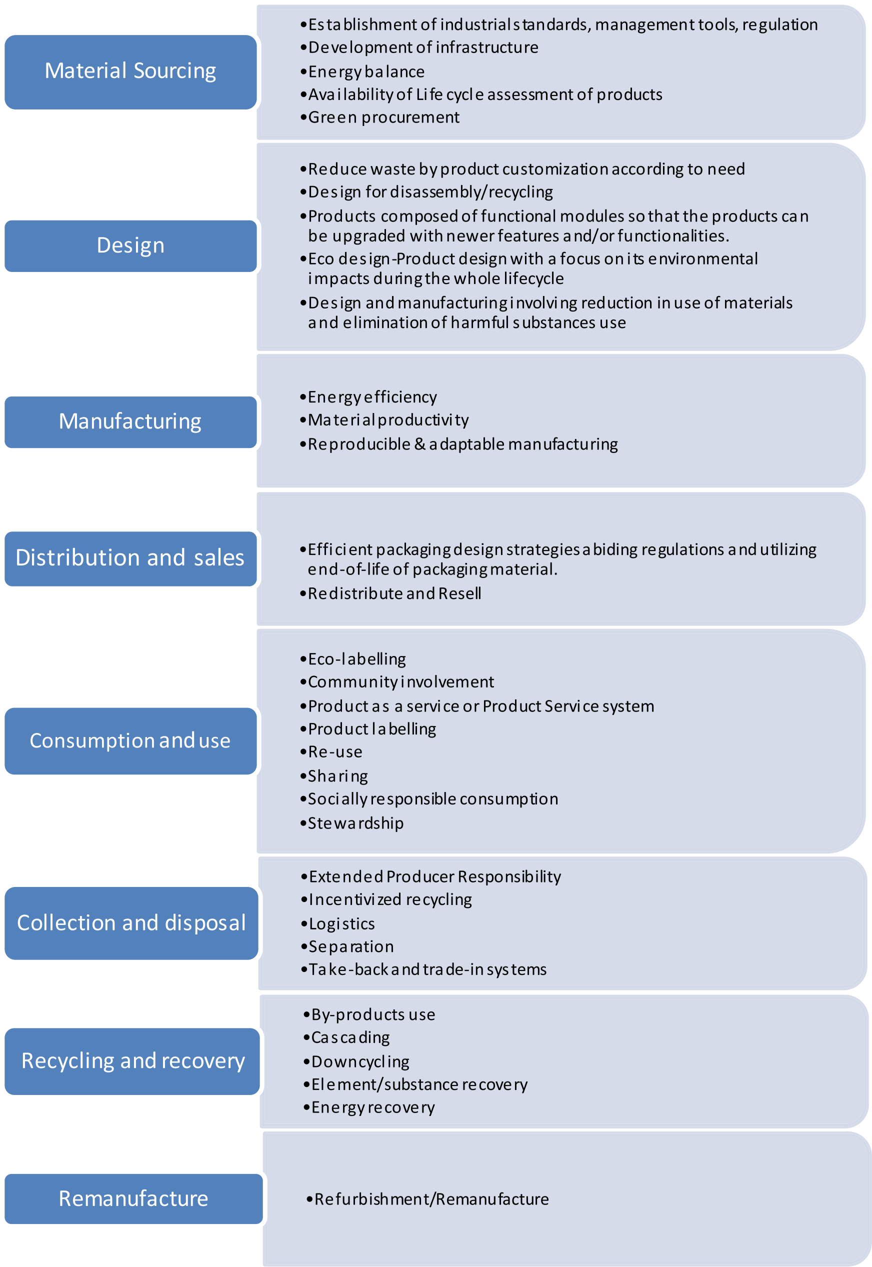

Fig. 6 Challenges and key indicators in implementation of circular economy [23]

4.3 Increasing Availability

Finding an alternate sustainable material is a key aspect in implementation of CE. Further, it is also equally important to make sure that new raw materials need to possess a stable supply, for uninterrupted manufacturing process.

4.4 Respecting Manufacturing Processes

Redesigning and usage of new alternate materials may affect the existing manufacturing process. Therefore, it is also necessary to find efficient approaches that do not interfere with the existing production processes and cost.

4.5 Sorting

Since different plastic goods have variable attributes such as shape, design, structure, different chemical properties and colour, it becomes very difficult for the recycling units to sort and categorize them to retrieve a good yield of recycled plastics. Manual sorting, induction sorting, eddy current sorting, sink float separation, tribo-electric separation and speed accelerators are some of the state-of-the-art sorting technologies used in current recycling facilities. X-ray, infrared and laser-induced breakdown spectroscopy are some of the technologies used for quality control of the sorting process.

4.6 Recycling

Recycling is one of the important aspects in CE to curb the leakage of plastics from the loop. The plastics are generally recycled either by mechanical or chemical recycling. A brief note on the types of plastic recycling is explained in the following sections.

4.6.1 Mechanical Recycling

Using mechanical recycling, the plastic wastes are processed into secondary/recycled raw materials without altering the chemical structures of the polymer. Mechanical recycling is more suitable and limited to thermoplastic polymers. It is often not suitable for thermoset polymers mainly due their cross-linked structures. The steps involved in mechanical recycling include collection, sorting, chipping, washing and pelletizating. The main challenge faced in mechanical recycling is that the plastic wastes need to be sorted, as they are susceptible to contamination. Another drawback is that the heat occurred during the process tends to soften the polymer or even cause degradation resulting in poor properties of the recycled yield.

4.6.2 Chemical Recycling

Chemical recycling (also called as feedstock recycling) is used for converting the larger polymeric chains into smaller units that can be further used into a variety of valuable resources. For instance, the plastic wastes are converted into gases, fuels and other chemicals through a number of processes such as pyrolysis, gasification and hydrogenation. On other hand, chemical depolymerization or chemolysis technology is used to convert the plastic wastes into monomers, oligomers and higher hydrocarbons that can be used to reproduce plastics that has been recycled or can be used for producing new plastic materials. The processing conditions, advantages and challenges of the process and examples of plastic treated and their yield are summarized in Table 1.

4.7 Collaboration

The adoption of circularity of plastics is a tedious progression, which is often not possible by a single stakeholder. It is necessary that all the stakeholders involved in the product and supply chain must corporate and collaborate for a smooth progression from linear to circular economy.

5 Case Studies of Circularity of Plastics

With the above-mentioned challenges, there are many designers, economists, activists, industrialists and manufacturers coming up with novel solutions to design the circularity of consumer used plastic products. Many smarter solutions for recycling, redesigning and minimal disposal of plastic wastes are being implemented in the day-to-day life. Figure 7 summarizes the consumption of some of established consumer brands, packaging companies, retail and hospitality companies. In addition, the organization's commitment to recycle and use the post-consumer recycled plastics by 2025 are listed in Fig. 7. A few examples of plastic waste circularity with respect to both upcycling and downcycling are briefed.

Table 1 Summary of chemical recycling methods [25–28]

Recycling method	Process Description	Processing conditions	Advantages	Challenges and drawbacks	Polymer Type	Products
Chemolysis/Chemical depolymerization	Depolymerization of plastic wastes with various chemical reagents to produce monomers	Temperature: 25–280 °C Pressure: 1–40 atm	Generates recycled monomers of plastics with no significant compromise on the quality	• Limited to recycling of condensation polymers and not suitable for additional polymers such as PP, PE and so on • Needs larger volume to be cost efficient	PET	• Terepthalic acid (TPA), bis(hydroxyethy1) terephthalate (BHET), Dimethyl terephthalate (DMT) (monomers for PET) • Polyols (monomers for PE, PU and epoxy)
					PA, PC	Caprolactam, hexamethylene diamine and adipic acid (monomers for PA and PC)
					PU	• Polyols and isocyanate (monomers for PU) • Urea

(continued)

Table 1 (continued)

Recycling method	Process Description	Processing conditions	Advantages	Challenges and drawbacks	Polymer Type	Products
Gasification	Partial oxidation process (using air, steam orsub-stoichiometric oxygen) for conversion of plastic wastes into gases.	Temperature: 1200–1500 °C Pressure: 10–50 atm	• Polymer separation into different categories is not necessary • Can also be gasified with non-plastic contaminants in the waste	• Release of toxic gases such as NOx, H2S and Carbonyl sulfide • Still lacks technological advancements and research for gasification of mixed plastic waste	All plastics	• Syngas (A flammable gas consisting mainly of CO, H_2, with smaller amounts of CH_4, CO_2, H_2O and some inert gases) can be used as fuel or for production of methanol and paraffinic hydrocarbons
Pyrolysis	Degradation of polymeric chains in presence of inert atmosphere	Temperature: 500–800 °C	• Simple technology • Relatively no significant release of toxic gases • Can be used to produce electricity and heat	• Complex chemistry involved depending upon nature of plastics • Requires high volumes to be cost effective • Less easiness for PVC processing	PE, PP, PS	• Gases such as butene and propylene • Hydrocarbon liquids ranging from C_5–C_{16}
					HDPE, LDPE	Gases such as isobutane, isobutene, propylene, propane and isopentane
					PET	Benzoic acid, benzene and terephthalic acid
					PVC	HCl, benzene, toluene, and naphthalene
Hydrogenation	Plastics degraded using hydrogen in presence of heat	Temperature: 100–300 °C Pressure: 50–100 atm	Fuels obtained can be used directly without further vigorous treatments	• High cost, due to usage of hydrogen • Operated under high pressure	All plastics	Hydrochloric acid, halogenated solid residue and gas

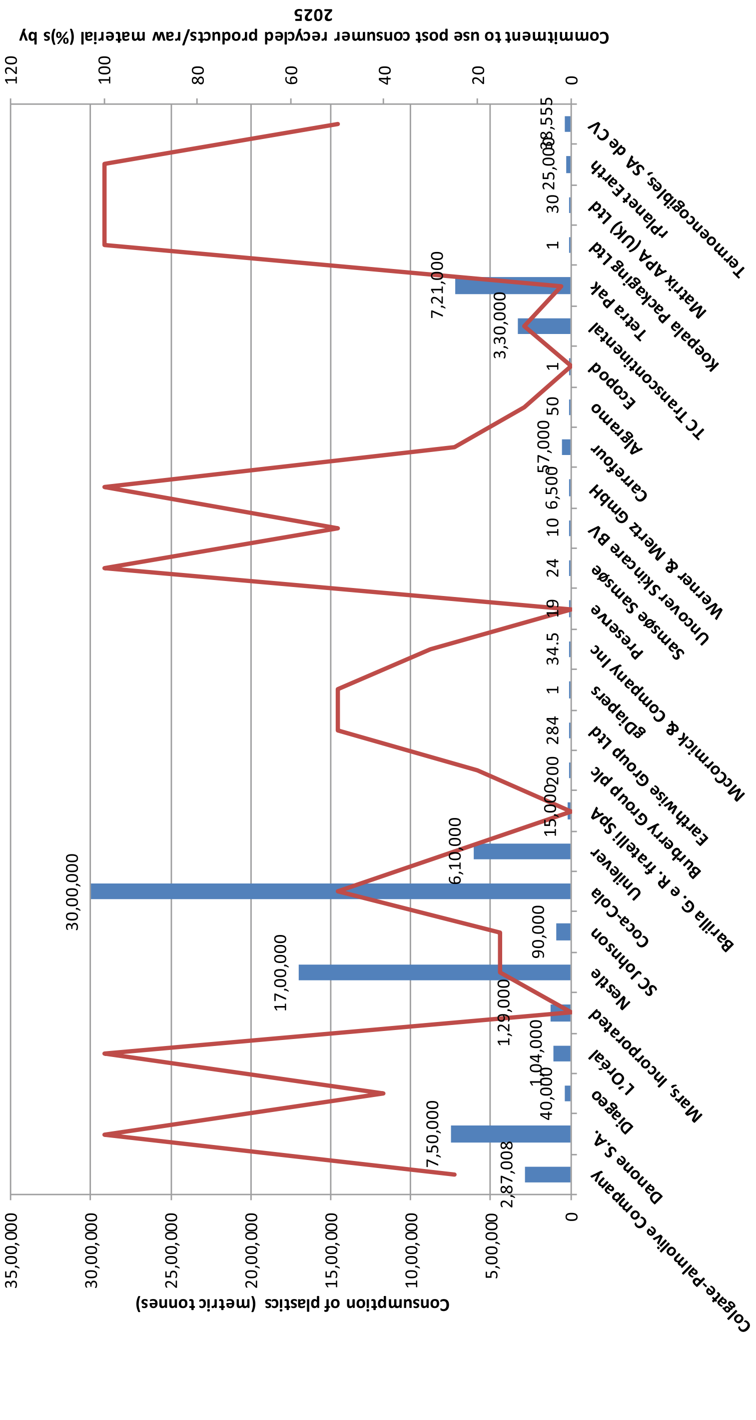

Fig. 7 Consumption of plastics by companies and their commitment to circularity of plastics (*Data Source* New Plastics Economy Global Commitment Report—2019)

5.1 Plastic Wastes in Construction and Maintenance of Roads

As an initiative to adopt CE, a new trend towards using the recycled plastics in laying roads and pavements has been tested and implemented across various countries. In general, the collected plastic wastes are first segregated into thermoplastic and thermosetting plastics. Mostly, thermoplastics are preferred because for this concept, as the softening point of thermoplastics is in acceptance level with the processing temperatures of bitumen and tar (155–165 °C). Further, plastic waste is melted and mixed with bitumen in a prescribed ratio (from 5 to 20%) based on the quality of tar or asphalt. Normally, blending takes place when temperature reaches 45.5 °C [29]. The mixture is then heated to higher temperatures of 155 °C, for enhancing better bonding between the bitumen and plastics. These heated mixtures are used for laying roads.

Other benefits of plastic roads include [30–32] the following:

- Approximately, cost of laying up roads reduces up to Rs. 45,000 per kilometre.
- The strength of the roads is almost doubled with respect to conventional roads.
- Since seepage during rainwater stagnation is reduced, the problems of frequent potholes occurrence are most likely reduced.
- The problem of bleeding that occurs in hot weather is also reduced.
- The use of plastic roads does not need any additional or specialized machineries and technologies. Hence, no significant change in the operation cost.
- Reduces the usage of initial raw materials such as bituminous, tar or asphalt leading to reduction of procurement cost.

India is one of the pioneer countries to have laid roads made up of plastic waste. It all started in 2015, when the government of India made it compulsory for all the road builders to implement the plastic wastes in roads. So far, the country has around 1 lakh kilometres of road laid using plastic across 11 states [33]. Further, the roads are being laid in UK, Canada, Australia, New Zealand and gulf nations using the patented product MR6, which consists of pellets manufactured with the blends of plastics and 20% bitumen. These patented plastic waste/bitumen blends are supplied by a road product specialists, Macrebura. These specialized products were also used as pot hole fillers during the repairing and maintenance of roads [34].

Apart from construction of roads and repairing potholes, the plastic wastes are also being used in manufacturing tools for reducing the cracks and buckling of the roads. For instance, in Texas (USA), the frequency of occurrence of cracks and buckling is higher due the nature of the soil, which often contacts or expands at different climatic conditions. To combat the issue, Dr. Sahadat Hossain, University of Texas at Arlington has projected a new technology of using ‘pins’ manufactured using plastic wastes, drilled into the roads. These pins keep the materials in contact and reduce the occurrence of cracks and the buckling. Approximately, 500 used plastic bottles are used in producing one such pin [35].

Key points: (1) Plastic roads not only offer an alternate for reducing the plastic wastes to landfill, but also the value of the plastic waste is upcycled as plastics in form of roads stay longer in the circular loop. (2) Use of plastic waste reduces the cost of roads thus adding potential contribution to the circular economy. (3) Plastic in roads increases the lifespan of the roads.

5.2 Circularity of Plastic Bottles and Liners

Procter & Gamble (P&G) collaborates with Purecycle™ to reuse the PET bottles. A recycling plant has been set up in Ohio, USA to have a commercial capacity to recycle 105 million pounds of PET and PP bottles with operation resuming in 2020. They use a patented depolymerization technology, which is less energy consuming to make the recycled materials economically viable [36]. P&G has also collaborated with other recycling specialists such as TerraCycle and SUEZ to make use of ocean/beach recycled plastics in manufacturing of shampoo bottles. The companies have committed to use up to 25% of beach plastics in manufacturing of shampoo bottles [37].

Coca-Cola European Partners (CCEP) along with Avery Dennison, Viridor and PET UK have collaborated with a mission to recycle the PET bottle liners rather than incinerating. In 2016, they upcycled 70 tonnes of PET bottle liners. The liners were shredded mechanically and reused into PET staple fibres and strappings. Also, thermo-foam sheets are produced from these plastic wastes which will be used in the production of trays [38].

Key points: (1) Collaboration between the manufacturers and plastic recycling experts is more efficient for adopting circularity. (2) New product design and materials must be implemented in order to avoid contamination caused by labelling, glues and so for easy processing during recycling.

5.3 Circularity of Plastics Used in Absorbent Hygiene Products

Single use disposable absorbent hygiene products such as nappies, diapers and sanitary napkins are often manufactured using absorbent pads covered with plastics such as polypropylene and polyethylene. Polyester fleeces are also used in manufacturing of the cloth diapers. It is estimated that around 300,000 tonnes of used diapers end up in Netherlands and 900,000 tonnes in Italy. Around 5% of landfills in U.S.A consists of absorbent hygiene products (AHP) [39]. Most commonly, these wastes are sterilized and incinerated for energy recovery. However, recently many novel ideas have been developed to recycle and reuse the plastics recovered from such wastes. P&G in Russia has started an initiative to use the recycled plastics from such product in cement applications. Further, the company has also collaborated with Angelini Group and Fater Spa to develop more circularity options. The plastics recovered from these wastes is proposed to be recycled into various applications such as bedding pads for pets, automotive, bottle caps and plastic park benches [40].

Key points: (1) Separate collection of these AHP wastes, separate sterilization process and quality control are serious challenges involved in developing circularity ideas for such wastes. (2) New disposal system and specialized collection must be implemented.

6 Conclusion

With respect to the increasing pressure of plastic waste management, there is an urgent need for the implementation of plastics circular economy. To help all the stakeholders move towards execution of CE, several government and non-governmental agencies have put forward new legislations and framework. Nevertheless, it is to be noted that, not all the leading industrialists, companies and even some smaller countries have yet committed for endorsement of complete circularity of plastics. These could be mainly because of the challenges such as

(a) lack of more evidence on the merits and demerits of recycled plastics,
(b) lack of more specialized waste collection and processing infrastructure, low progress in setting eco-design requirements,
(c) lack of advanced technologies, high cost of recycled plastics in comparison to virgin plastics and uncertainty in addition of value to recycled plastics.

In spite of these challenges, a few case studies have shown that circularity of plastics is possible. However, the implementation has not reached its maturity. From the market study, it can be noticed that all the entities are focusing on dealing with the challenges mentioned. However, the effect of absolute transformation is time-consuming and needs to be assessed regularly down the time. Focusing more and addressing the following priorities can make a significant progression from linear economy to circular economy of plastics easier:

(a) accessing ways to provide better transportation/collection/sorting of plastics,
(b) expanding the eco-design rules,
(c) facilitating and boosting the demand for circular products,
(d) providing funds for research advancements and
(e) use of new materials and providing more tax benefits.

From the case studies, it can also be seen that encouraging and developing more effective business models for collaboration between the companies, experts and speciality commodity manufacturers will also help the progression to be better and faster. Moreover, the concept of plastic circularity should not be burdened on the shoulders of established companies and government alone, but should be cultivated as a social responsibility from the grass root levels of every entity.

Questions

(Q1) What is the feasibility of chemical recycling methods for recycling plastic waste?
(Q2) Is plastic waste recycling energy efficient when compared to incineration?
(Q3) Is chemical recycling better than mechanical recycling?
(Q4) Can 100% circularity of plastics be achieved by enforcing government legislations?

Answers

(A1) With chemical recycling methods, the long polymer chains of the plastics into small units when subjected to high temperatures and with presence of solvents or catalysts. Chemical recycling in most cases is used for converting plastic wastes into fuels and energy. Except for chemolysis technique of PS and PET where the raw materials can be produced through repolymerization of monomers produced through chemical recycling. In general, the operational costs are higher. However, successful development of these technologies can help the plastic slowly decouple from petroleum dependence and self-potentially close the circular loop.
(A2) Plastic waste is commonly incinerated to tackle the problem of plastic waste management. However, new technologies are being developed to recover the raw materials through various recycling methods. On the other hand, it is speculated the recycling methodologies are very energy consuming making the process not sustainable. But in reality, for incineration the heating value for plastics is ~36,000 kJ kg^{-1}, whereas mechanical recycling conserves ~60,000–90,000 kJ kg^{-1}. Therefore, recycling plastic waste is more energy efficient than incineration.
(A3) Though both methods have its own pros and cons, the waste recycled using chemical methods can recover raw materials repeatedly for a number a times. In chemical recycling methods, the plastics are broken down into their molecular level and repolymerized from the monomers yielded from the process. The loss of integrity of the properties of plastics is lesser when compared to mechanical recycling. As in mechanical recycling, the heat and shredding of plastics causes an impact on the properties of the materials recovered.
(A4) Several governments have enforced the frameworks for implementation of circular economy of plastics. Nevertheless, these legislations more often provide a detailed framework and monitoring process for encouraging the

plastic sector to progress towards CE. They have also provided tax benefits and funding opportunities for development of technologies and materials for improving plastic circularity. However, they do not impose fines or any other legal punishments for not adopting 100% circularity of plastics. From market study, it can be seen that not all the companies and brands have committed to 100% plastics circularity for a period until 2025. Hence, these rules and legislations cannot help achieve complete circularity of plastics but they encourage and push the economy to progress towards circularity.

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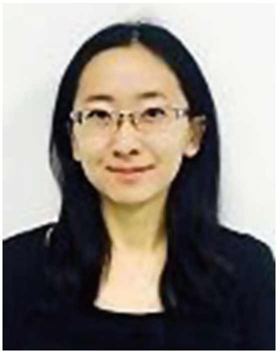
Dr. Anand Bellam Balaji received his Ph.D. degree in Chemical Engineering from University of Nottingham, Malaysia in 2019. Currently, he pursues as Postdoctoral research fellow in New materials Institute, University of Nottingham Ningbo campus (UNNC). He currently works on development of green, sustainable and flame retardant composites for aerospace, automobile and high-speed train applications. He works actively along with his team, whose current interests' focuses on developing and application of composite materials with sustainability and recyclability as one of the key aspect. His other area of research includes thermoplastic polymer applications for biomedical applications, radiation processing of polymers and nano-composites.



Dr. Xiaoling Liu graduated from University of Nottingham, UK and joined Ningbo campus (UNNC) in 2015. Within only a little over 2 years, Dr. Liu has built up a research platform from scratch to train undergraduate students, Ph.D.s and support industry with 2 key labs, collaborating a joint lab with AVIC Composite group, China. Her research focuses on developing polymer composites with interests towards biomedical, fire retardant, conductive, green and thermoplastic composites. Until today, she has been successful in securing various grants (apprx. RMB 25M) from multiple sources including international companies and prestigious state-level SoEs. It is noteworthy that in recent years, she has also extended her interests in research and development of sustainable materials, recyclability and adopting principles of circular economy to keep the carbon fibres and polymer composites at their highest utility and value at all times. Below are few notable undergoing projects to generate solutions, develop competence and technology through cross-disciplinary cooperation for value creation, sustainability, recyclability and resource management in the field of composites.

- ACC TECH and UNNC Joint Laboratory in "Sustainable Composite Materials", Industry project; 2017–2022
- "Composite recycling and reuse"—Collaboration project; 2017–2021
- "Eco-friendly, high performance and multi-functional green building composites and its application technology" —Commonwealth project; 2019–2022
- "Development of Property-Improvement of High Temperature Cure, Full Green composites"—Airbus (Beijing) Engineering technology centre co. ltd; 2019

- Zhejiang Innovation Team—“Multi-functional green composite for the next generation aerospace application”; 2018–2021

With her keen interest, proactive nature and hard work, she has played an important part in taking UNNC composites technology from start-up status to national recognition within China’s fast-moving composites industry.