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Green SCM: End to End Analysis of Post-Consumer Recycled & Recycled PET Supply Chain in Developing and Emerging Markets

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ABSTRACT

This research study is based on the end-to-end analysis for continuous sourcing of quality and quantity of rigid plastic material for Recycled P.E.T while addressing challenges and barriers in the recollection process as compared to the Virgin P.E.T for environmental sustainability. This study focuses on formalizing the sourcing strategy of Recycled P.E.T water bottles of Mehran Plastic Private Limited in the FMCG sector of Karachi due to its massive environmental degradation, the release of toxic emissions in the marine ecosystem, unfavorably affecting the human lives and development of New Plastics Economy, based on the patterns of circular economy, across the different cities of Pakistan.

The current scenario of the global and local packaging industry has been provided in the initial chapter with the systematic review of literature shedding light on plastic packaging in the circular economy, integration of reverse logistics to manage plastic waste, closing the loop of Recycled P.E.T, international standards of quality aspects of recycling P.E.T material, various recycling practices in South Asian Region (SAR) and the response of companies to the global commitment of creating waste-free economy.

In the continuance of the study, the results and discussion part focuses on the Recycled P.E.T scenario in Pakistan, mechanical recycling of P.E.T bottles, and the sourcing strategy to remanufacture the new bottles from the post-consumer water bottles in terms of sourcing channels, resource efficiency, collection hubs, costs, quantity and quality as compared to Virgin P.E.T, through reverse logistics system, for development of continuous end-to-end recycling chain of Recycled P.E.T in a sustainable manner; moving the economy towards the adoption of green supply chain management practices.

Keywords: PET (polyethylene terephthalate), SDGs (Sustainable Development Goals), PCA (principal component analysis), PPMA (Pakistan Plastic Manufacturers' Association), MFA (Material flow analysis), GHG (greenhouse gases), MSV (municipal solid waste)

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1. INTRODUCTION

Overview of Packaging Industry

The role of the plastic industry is changing worldwide and companies in Pakistan need to realize the trends and play their part in delivering more recyclable and sustainable products. The plastic industry has been under the pressure of severe criticism concerning environmental issues. The voices have been raised to minimize the use of plastic while some of the authorities lifted the complete ban against the consumption of plastic products.

While the positive applications of plastic were emerging, the world was swept away through the shocks of an inevitable pandemic. Those authorities who wanted plastic to vanish from everywhere were able to notice that it was used in medical devices, apparatus, and other applications; especially in the emergency at hospitals. Amidst the corona war, it turned out to be one of the vital products to fight against deadly attacks of the outbreak when pharmaceutical and FMCG companies functioned with greater force as compared to normal circumstances (PPMA, 2020).

During 2019-20, the plastic industry of Pakistan has been growing by 15 percent per annum. The production capacity is 624,000 metric tonnes every year. According to the statistics released by the Plastic Manufacturers' Association of Pakistan, there has been the production of 50,438 tons of municipal solid waste (MSW). Out of which, 67 percent is organic, 18 percent is plastic and 5 percent is paper.

By conducting the regional bans on plastic material, Pakistan is gradually moving towards the fulfillment of United Nations Sustainable Development Goals (SDGs). With unfaltering efforts, Hunza has been declared the first plastic-free location in the country. As per the statistics of the World Bank, the packaging and beverages industries are the major contributors of P.E.T (polyethylene terephthalate) bottles in Pakistan (Warraich, 2020).

In response to the growing concern of reducing plastic waste in the environment, Pakistan Plastic Manufacturers' Association (PPMA) has involved various ventures to develop plastic-based products that are beneficial for people and their environment despite the traumatic conditions COVID-19.

Global Packaging Industry

The packaging industry is segmented according to the type of material being used as illustrated in the diagram given below:

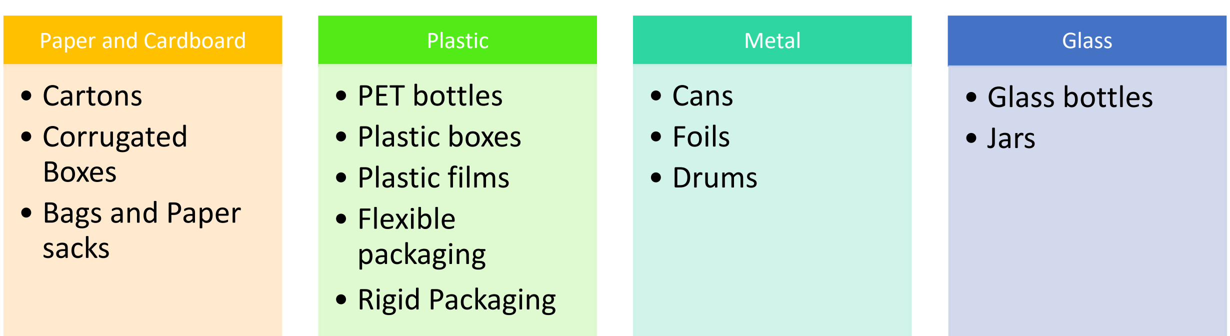

Figure 1. Segmentation of Global Plastic Industry.

The stringent protocols of a pandemic might cause hindrance in addressing the demand for plastic packaging within an overall global industry. The market share of packaging material has been demonstrated in the diagram. Massive consumer awareness of plastic waste causing immense environmental damages might place obstacles on the pathway of the packaging industry. Various regulations have been implemented such as a ban on single-use plastic bags was lifted on August 13, 2019, in Pakistan as the total sum amount of 55 billion flimsy plastic bags were disposed of within a year. Most of them were found on the roads, flying over the streets, clogging sewers and city drains, stacked in parking lots, stray cats and dogs finding their food in the plastic bags inside the piles of waste, and polluting the streams and canals of an entire nation. Fines and penalties were imposed on the single-use of plastic bags, selling them on large scale and manufacturing them in Kenya and Pakistan. Numerous warnings concerning the enforcement of the ban were given to companies involved in the production and supply of plastic bags (Constable, 2019).

Pakistan Packaging Industry

The approximate size of the packaging industry in Pakistan is USD 5.53 bn (PKR 872 bn) during 2020 as compared to USD 5 bn (PKR 789 bn) in 2019. The packaging industry has been categorized into four major areas: paper, glass, tinplate, and plastic. Amongst all of these segments, paper and plastic occupy the major share in the packaging industry while other materials such as glass and tinplate have a minimal industry size (PACRA, 2020).

Table 1. Market Segmentation of Pakistan Packaging Material.

Segment	Paper	Plastic	Tinplate	Glass
Types	Paper & Board	PET Bottles and Plastic Films	Tinplate	Glass
Demand	Used in a great variety of consumer and retail items	***PET Bottles:*** Pharmaceuticals and Beverages ***Plastic Films:*** Consumer goods including confectionary items	Ghee, Edible Oil, Paints and Canned Eatables	Mainly used for beverages and pharmaceutical products

Company Background – Mehran Plastic Industries (Pvt.) Ltd

Being one of the prominent manufacturers of rigid plastic packaging products in Pakistan, Mehran Plastic Industries (Pvt.) Ltd is SMETA Version 6.0 Certified and FSSC 22000 Version Qualified in the packaging sector. It offers a type of packaging that serves to contain, describe, display, identify, protect, promote and make the product marketable. By realizing the customer needs, appropriate packaging is being provided as a part of an indispensable part of any offer.

Mehran Plastic Industries (Pvt.) Ltd entered into the market during 1988 and established its presence through a massive production facility intending to deliver high-quality P.E.T bottle packaging to various customers. The manufacturing plant is located in the vicinity of Sindh Industrial Trading Estate (S.I.T.E) with state-of-an-art production facilities for smooth and agile operations. A skilled and competent team of professional engineers and design experts work with consistency, precision, speed, and hygiene through the latest industrial standards and modern-day technological advancements.

Over a couple of years, it has acquired an extensive range of products to provide the complete and exquisite packaging solution to customers by enhancing its printing, injection moulding, compression moulding, and blow moulding capabilities with a team of more than 100 employees over the 1.25 acres of land.

Under the supervision of experienced management, this company can define measure, analyze, design, and test the products according to industrial standards. It is highly committed to achieving excellence by delivering cost-efficient and quality products to major suppliers such as Pepsi in the beverage industry of Pakistan.

2. LITERATURE REVIEW

Plastic Packaging in Circular Economy

Plastics have gained immense attention in waste management to improve the circularity of these materials in the economy. To reduce dependency and improve the efficiency of resources, plastics are one of the focus areas for the circular economy according to the action plans of the European Union (EU). The concept of circular economy concentrates on the circulation of the wastes that are recovered, recycled, and reused. The primary objective of a circular economy is to reduce the impacts of production and consumption systems on the environment. For proper recycling, it is pertinent to separate the different polymers constituting in the streams of waste. The environmental benefit of each polymer varies, for instance, polyethylene terephthalate (P.E.T) has about half of the heating value and causes a high environmental impact during the production process as compared to other packaging polymers. The significant increase in mechanical recycling and recovery of energy through avoidance of incineration makes this plastic packaging important in the circular economy (Singh & Ordonez, 2015).

Material flow analysis (MFA) is widely used to examine the flows and inventory of materials defined in time and capacity that connects the pathways and quantify the sources of material in question. The waste streams of Austria were analyzed based on the composition of polymers and product categories that let the researchers discover that the total mass of waste plastic packaging amounted to 300,000 tonnes per year. The largest proportion of plastic waste consisted of large and small-sized films (48%) followed by small-sized hollow bodies (17%), others (13%), polyethylene terephthalate bottles (15%), large-sized hollow bodies (6%), and expanded polystyrene (1%). The results revealed that the recycling rate was (26% ± 7%) and the sorting rate was (34% ± 3%) in Austria during 2013. However, countries having a ban on landfills, such as; Switzerland, Luxembourg, Denmark, and Belgium, reported a recycling rate of approximately 95% where most of the plastic waste is incinerated. Amongst the various product types and polymers, the material flows of P.E.T have attracted strategists and environmentalists causing the growth rates to remain between 10% and 20% per year. While on the lands of Germany, the average collection rate of 48% was attained through the installation of a deposit system for P.E.T bottles during 2009. There was a marginal decline from 19% to 11% in the domestic recycling rates due to the exports of P.E.T waste in the USA. Correspondingly, the composition of the polymer dominating the waste stream was low-density polyethylene (46% ± 6%), polyethylene terephthalate (19% ± 4%), and polypropylene (14% ± 6%) in 2017. Concerning the proposed European Union (EU) target of 55% by 2025, the three product categories, including; P.E.T bottles, expanded polystyrene, and films, require additional efforts to enhance the collecting and sorting efficiencies to achieve the required target for the overall waste stream (Eygen, Laner, & Fellner, 2017).

For the evaluation of resin types forming the packaging waste, the source of particular waste must be considered. Packaging waste is usually generated while performing business operations, services, industrial activities, and household tasks. Based on the assessment on assessment, the post-consumer plastic packaging waste was around 86,000 – 117,000 tonnes in Finland during 2014. The majority of the waste was found in the mixture of polymers so new collecting and sorting facilities were launched in 2016. The waste was collected in two ways; either gathering waste by assigning regional collection points within the vicinity of stores and markets for the mixed municipal solid waste (MSW) or separately collecting the plastic packaging through households. Some municipalities were able to launch the collection trials that offered a convenient way for households to collect, sort, and discard their packaging waste at the locations near their homes. Consequently, the government provided the benchmark for the deposit system of beverage packaging to 90% causing the rise in the recycling rate of Finish waste to reach the level of 41%. The results painted that average of 60,000 – 65,000 of soft plastic packaging, whereas, 66,000 – 69,000 of hard plastic packaging were discovered in the total of 890,000 tonnes originating from mixed municipal solid waste (MSW) collected through households recycling centers. The mixed municipal solid waste (MSW) contained the moisture and scraps of food that increased the packaging weight. After considering the moisture content of 32% in soft plastic packaging and 14.5% in hard plastic packaging, the volume of waste of post-consumer plastic packaging waste aggregated to 73,000 – 104,000 tonnes. Surprisingly, the P.E.T bottles had a separate deposit system in the collection stream of post-consumer plastic packaging that worked very well as 93% of the P.E.T bottles (12,000 tonnes) sold were annually recycled (Dahlbo, Poliakova, Mylläri, Sahimaa, & Anderson, 2017).

In Europe, the study was conducted on the circularity of recycled plastic that considered quality reductions, product lifetimes, and demand growth rates. The prospective scenarios presented the key areas to enhance the circularity of P.E.T, PE, and PP flows, including; design-for-recycling initiatives, maintaining constant plastic consumption, managing plastic waste exports in the European Union, improve collection rates, and improve reprocessing and recovery of recycled plastic. Dynamic material flow analysis sufficiently captured the effects of changes in the flows and sectors in the system through the application of four indicators comprising of recycling rate (RR), circular material use rate (CMUR), closed-loop circularity rate (CLCR), and virgin material consumption (VMC).

Over 50 years, the results painted that the consumption of P.E.T, PP, and PE elevated around 400% by the European Union where Ellen MacArthur predicted an increase of 360% between 2014 and 2050. Consequently, the report of Eurostat stated that the generation of 16.3 metric tonnes of plastic waste during 2016 out of which 14.3 metric tonnes belongs to P.E.T, PP, and PE. The recycling rate (RR) turned out to be only 50% due to ineffective source separation facilities especially in fiber, automotive and packaging sectors. The substantial material losses during sorting and collection of plastic waste caused around half of the recycled plastic to originate from post-consumer recycled material and only 5% are appropriate for use in the packaging of food. From quantity and quality perspectives, the recycling of post-consumer plastic waste remains far from realizing its full potential. The largest improvements were observed in the P.E.T segment where state-of-the-art end of life (EOL) technology is available allowing the recycling of the fibers; leading towards 25%, 30%, and 35% of CLCR (closed-loop circularity rate), CMUR (circular material use rate), and RR (recycling rate) respectively. Comparatively, the CMUR remains between 20 to 30% and RR was within the range of 25 and 35%; portraying the effectiveness of collection systems to some extent (Eriksen, Pivnenko, Faraca, Boldrin, & Astrup, 2020).

To address a plastic recycling gap, the information was collected from reliable sources to examine the practice of re-using the packaging in Italy. The waste composition of packaging types involved plastic (37%), steel (24%), wood (18%), aluminum (11%), cardboard (5%), and glass (5%). A more complicated picture arises when primary, secondary and tertiary packaging are distinguished. In this case, the primary packaging seems to be considered as reusable packaging of glass and aluminum which is in direct contact with the goods. With the diverse array of applications, steel and plastic were included in both primary and secondary packaging while the rest comes under tertiary packaging. It was estimated that around 47% of identified packaging types can be re-used without any washing or repairing process while 34% require the reconditioning process. For the remaining proportion, the packaging conditions determine their usabilities such as steel barrels and wooden pallets for food products (Rigamonti, Biganzoli, & Grosso, 2019).

The amount of plastics ending up in the streams of waste is an ever-increasing issue. It is because plastics are a versatile and useful set of materials. Their applications are found to be in a wide range of products such as construction, consumer goods, automotive, and packaging. Ironically, their light weight contributes a much greater percentage of the bulk and is more visible than heavier materials in the waste stream such as metals (Goodship, 2007).

In developing countries, the rising amount of MSW (Municipal Solid Wastes) poses greater challenges concerning sustainable solutions to manage waste streams. Due to constantly changing lifestyles and rapid economic expansion, Cameroon was unable to embark on suitable waste management solutions and the negligence of governmental authorities towards its excessive environmental impact got their lands to be filled. The concept of plastic recycling requires the environmental behavior to be stirred in the routine practices of diverse communities (Oskamp, 2000).

Bringing the daily lives of households into the focus, the source separation or post-separation can be the methods to gather post-consumer plastic packaging waste (PPW) for recycling. In the process of source separation, households separate plastics from waste before it has been collected, whereas waste is separated at the treatment center after collection in the scenario of post-separation. These separation methods have a huge impact on total collection costs that influences network design and facility choices (Huysman, Schaepmeester, Ragaert, Dewulf, & Meester, 2017).

A recent study was conducted to develop a comprehensive cost model based on variable and fixed costs of containers, vehicles, and emission costs (consisting of carbon taxes). When the municipal waste collection cost model was applied in Netherlands so the collection efficiency declines in the source separation scheme than collecting plastic with other waste materials as in post-separation. Within urban municipalities, the households can place collection bags in their streets for curb side collection to reduce associated costs as compared to drop-off collection following the post-separation approach (Groot, Bing, Bos-Brouwers, & Bloemhof-Ruwaard, 2014).

The polyethylene terephthalate bottles of beverages mostly stand in sharp contrast to other packaging systems due to their high recovery rate for recycling. The life cycle assessment technique elucidates the recovery of material in terms of inventory and logistical requirements. During the collection of bottles, centralized processing often occurred near urban centers. According to the research study, the average distance from discard to recovery of the bottle was 145-175 km in the United States. The post-consumer phase required 0.45-0.66 MJ of primary energy as compared to 3.96 MJ in the pre-consumer phase. The results were robust to the sensitivity of the model in which the curb side collection turned out to have smaller parametric uncertainty and more energy-efficient than drop-off collection. The decentralized program was developed in California that had a minimal environmental impact with a large stream of post-consumer material. Building on the mature recycled PET market, the expansion of the deposit system and other applicable incentives can develop a wide range of end-user product categories (Kuczenski, 2013).

In the region of India, plastic waste has also been growing steadily where manufacturers do not want their resources to be wasted and discarded subsequently so the channels need to be formalized into the development of efficient recycling methods. The results of a recent study explored the existence of barriers in the recycling process that hindered the sustainable development of the country. The interpretive structural modeling (ISM) was used to assess the relationships between facilitators and barriers in managing the process of recycling. The findings showed that lack of awareness and absence of strong governmental policy has caused the demand for recycled products to decline. The real picture of the ground became clear when it was found that toxic gas, amount of scrap, and use of additives, acted as independent enablers to significantly influence the recycling practices. Indeed, decision-makers have to take steps for the authentic representation of the setbacks and combat these barriers proactively (Satapathy, 2017).

Integration of Reverse Logistics to Manage Plastic Waste

In the era of globalization, waste accumulation has been jeopardizing our planet from economic, environmental, and social dimensions. The fluctuations in currency rates and oil prices had fueled the intensive competition and encouraged manufacturers to explore innovative solutions for waste materials. Increased environmental awareness and stringent laws of disposal had caused returns to capture the financial as well as the non-financial value of supply chains (Paletta, Filho, Balogun, Foschi, & Bonoli, 2019).

In this regard, reverse logistics came into existence where the process of planning, implementing, and controlling the efficient flow of raw materials, inventory, finished goods, and relevant information from point of consumption to the point of origin recaptures the value of the supply chain. It aims to revolve around the backward flow of materials from the consumer to the manufacturer to maximize the expected value through proper disposal of products (Afifa, Mounir, & Habib, 2011).

Being an engineering strategy, Reverse logistics (RL) is used by diverse manufacturers to embrace environmental sustainability by recycling materials. To analyze the activities of RL performed by beverage companies, the specific type of plastic bottles in Zambia were selected due to the lack of standardized legislations and policy frameworks. Around 30% of the waste generated was collected while the rest is not recovered. The results indicated that reverse logistics is rarely practiced by beverage companies; however, they recognize its importance during the recycling process of P.E.T plastic bottles. The framework was developed known as Container Deposit and Refund Legislation (CDRL) which can lead the agency towards implementation and adoption of policy related to reverse logistics at a national level. The committee can be formed to act as a monitoring body of beverage companies comprising of representatives from a group of producers and importers, Zambia Environmental Management Agency (ZEMA), and Lusaka City Council (LCC) will be legally obliged to ensure that burden of recycling costs are shared with consumers at an extensive level (Mwanza, Mbohwa, & Telukdarie, Reverse Logistics Framework for PET bottles, 2016).

In continuation to the aforementioned study, the drivers of reverse logistics in the plastic industry were contemplated in the light of growing concerns over the development of recovery systems, resource-efficient policies, and environmental protection across several areas of Zambia. As the number of plastic products rises, the necessity to develop the mechanism of reverses logistics emerges to capture the utmost value from end-of-life products to remanufacture, recycle and reuse plastic materials. The results painted that decreasing use of raw material, decreasing waste production, and obtaining valuable spare parts are the drivers of direct gains. For the indirect gains; however, the good relation with suppliers, green image of companies, and preparation for future legislation was seemed to be the drivers to analyze the environmental concerns in terms of proposed regulations, relevant stakeholders, information systems, and customers (Mwanza, Mbohwa, & Telukdarie, Drivers of Reverse Logistics in the Plastic Industry: Producer’s Perspective, 2017).

Regarding the redesign of supply chains, the efficient product returns system was considered to address the challenges and trade-offs in reverse logistics. The problems of waste management during reprocessing of substances, materials, and products cause manufacturers to bear the massive burden of collecting and decontaminating them. Considering the Solid Waste National Policy (2010) of Brazil, there were no regulations or controls related to the viable reverse flow of products. Hence, there was an inevitable trade-off between the costs of setting up collection systems and the collection rate of P.E.T bottles from economic and financial perspectives (Gonçalves, Pereira, & Terence, 2019).

In this context, plastic packaging plays a pivotal role where 47% of the potential of recycling was observed in Italy. Ironically, the perils and pitfalls had hampered the development of efficient recycling pathways. For this study, the material recovery plants situated in Turin were selected having a collection rate of around 45% to generate quality recycled products. The four types of plastic recovering processes were highlighted; including, primary mechanical recycling (non-contaminated plastic is automatically recycled), secondary mechanical recycling (post-consumer plastic is purified and recycled), chemical recycling (plastics are turned into smaller molecules to attain the new product), and incineration (plastic is melted to produce energy). The characteristics defined in the UNI EN 13432 (2002) govern the compostability of plastics. Every recycling process has been subjected to intense criticisms due to issues of technology readiness, lack of policies regarding reverse logistics, economic feasibility, and lack of environmental awareness amongst residents of Italy. With time, the national consortium known as COREPLA took the responsibility to collect, recycle and recover gold from garbage. It was able to meet the target of around 51% in a collection of plastic packaging during 2018 (Mariotti, Ascione, Cottafava, & Cuomo, 2019).

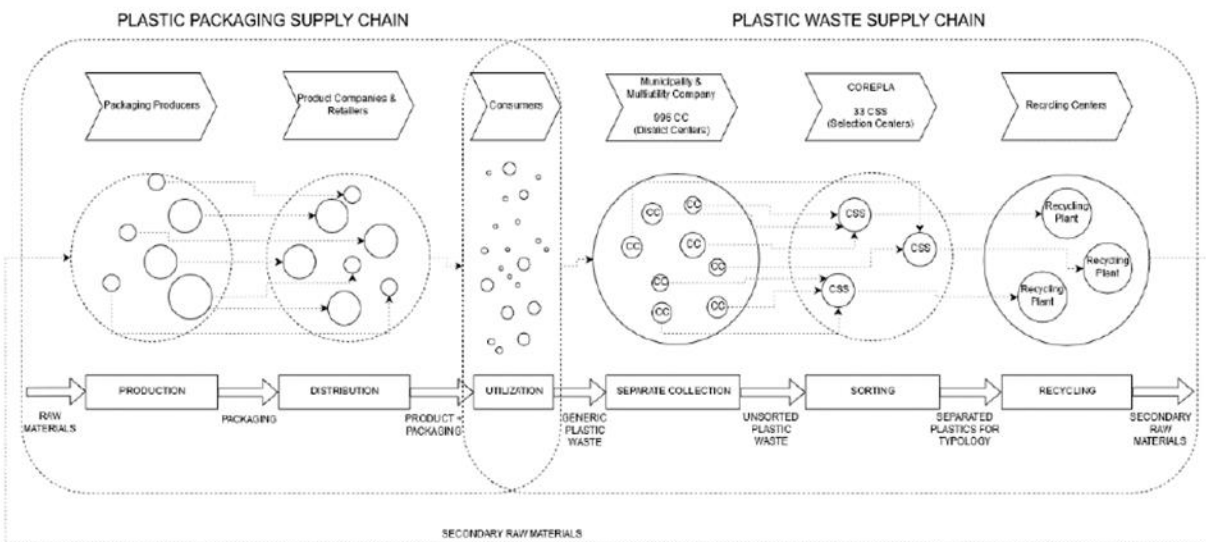

Figure 5. Plastic Packaging Supply Chain and Plastic Waste Supply Chain (Mariotti, Ascione, Cottafava, & Cuomo, 2019).

The need to minimize the "cradle to grave" environmental impacts related to the packaging design, sourcing, production, consumption, re-use, recycling, and disposal has been widely recognized amongst supply chain experts. Dobos and Richter (2004) proposed a production-recycling model where the manufacturer serves a product demand and is interested in buyback a portion of consumed products to recycle. Newly manufactured items were assumed to possess indifferent quality where they found out that quality was economical when it was accounted for a mixed policy of production and recycling (Dobos & Richter, 2006).

An extended version was developed in a recent study termed a recycling-reuse model that circulates the remanufacturing of the mixture of non-contaminated P.E.T plastic bottles and virgin P.E.T material into new plastic bottles to analyze the extent of waste reduction in landfills. In this model, a cost of filling the landfill was computed that included cost of penalty for contaminating the water, use of real-estate, harming wildlife, cost of land rehabilitation, and the other environmental costs. The findings demonstrated that the outcome of total system unit time cost (TCU) is significantly impacted by the percentage of bottles collected from the market θ. It is because of the processing time of collecting and sorting bottles (TCU_{nss}), contaminated bottle sorting (TCU_{sc}), remanufacturing bottles (TCU_{r}), and disposal of bottles in landfill (TCU_{LF}) bolstered the outcome of the total system unit time cost (TCU). These results superseded the decreasing process unit costs of virgin material regrind and mixing (TCU_{rm}) and manufacturing of new bottles (TCU_p). It was also suggested that the use of natural content, including; soy protein-starch and CGM (corn gluten meal) can be great candidates in the place of biodegradable plastic materials as they are environment-friendly and degradable substances (Matar, Jaber, & Searcy, 2014).

Recycling has been the most imperative strategy of recapturing the value of plastic waste. The performance of related activities can improve the system of reverse logistics from collection to redistribution of products. It is a strategic tool to help producers of recycled P.E.T bottles to overcome the pressures from the market, competitors, customers, and governmental legislations due to economic, environmental, and social issues. The two aspects determine the appropriateness of the reverse logistics system: proper disposal and recapturing value. Therefore, immense emphasis has been laid down on value-adding activities for a holistic framework of reverse logistics; such as recycling, reusing, remanufacturing, and refurbishing (Tesfaye & Kitaw, 2020).

Closing the Loop on Recycled P.E.T

Being the third most widely diffused polymer exploited in the packaging sector, Polyethylene terephthalate (P.E.T) enjoys a monopoly in the market of bottles for beverages. Novel advancements in the field are directing to producing P.E.T, primarily driven from non-biodegradable and fossil sources, in a more sustainable manner. The possibility of re-using the well-consolidated material can be considered by the high recyclability rate of P.E.T. The mechanical performance of P.E.T is intensely influenced by several parameters such as orientation in the manufacturing process, polymer crystalline degree, and shaping the plastic fibers. It can be enhanced by applying a stretching direction at temperatures to force the orientation of polyester's chain. There are two distinguishing regions, including; strain softening region and strain hardening region where an increase in stress is observed until a yield point is reached and settles down into the large deformations. The high strain rate enhances the hardening of P.E.T while the temperature reduces it. Once the constant version of P.E.T emerges, the environmental factors come into play, namely; thermal degradation (temperature), mechanical degradation (stress), biochemical degradation (living organisms), hydrolytic degradation (moisture), and sources of chemicals and radiation, or a combination of them. The relative loss in terms of morphologic alteration at the microscopic or macroscopic level, such as; surface roughness, color, molecular weight, cracks, and crystalline degree, and mechanical stability highlights the significant deterioration of chemical structure in the organic polymers. The biodegradable properties, however, are not present in the P.E.T to act as a catalyst in this procedure when the risk of hydrosphere accumulates (Nisticò, 2020).

Considered to be ubiquitous material in modern life, P.E.T is used in a diverse array of applications from fabrics to films. It exists as a white and opaque (semi-crystalline) thermoplastic and as a transparent (amorphous). The semi-crystalline version of P.E.T has a hardness, good strength, stiffness, and ductility, however, the amorphous P.E.T has better ductility. Both of these materials can be renewed and recycled over time for other applications. One of its most important characteristics is intrinsic viscosity (IV) measured in deciliters per gram (dl/g) and is affected by the length of its polymer chains. The higher the viscosity, the longer the polymer chains with more entanglements between them. The average polymer chain of a particular resin can be controlled at the time of polycondensation. P.E.T has grabbed an enormous market share in the beverages industry as compared to the clothing and engineering segment (Ragaert, Delva, & Geem, 2017).

Due to its good clarity without leaving any taste in water, P.E.T is embedded with such physical properties that have made it act as a great barrier against carbon dioxide and oxygen to safeguard drinking water and other substances. Indeed, the adequate gas barrier properties with ample strength, light weight, and glass-like transparency have made it a perfect agent for recyclability. Meanwhile, the mechanical recycling of P.E.T has been well-established; the new chemical recycling techniques are dependent upon depolymerization routes that transform its polymer chains into new building blocks (Lina, 2013).

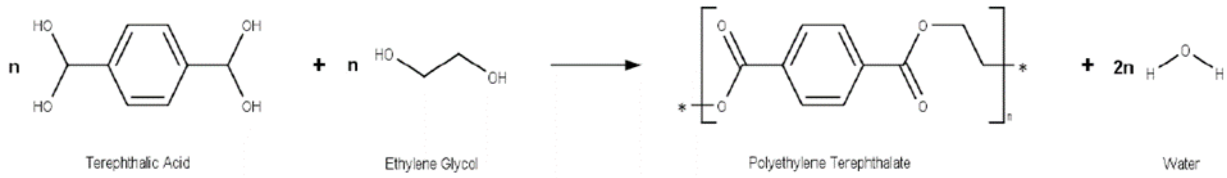

Figure 6. Depolymerization in Plastic Recycling Process (Lina, 2013).

Regarded as an excellent material for food packaging, P.E.T has physio-chemical properties such as good thermomechanical properties, highly inert material, low diffusivity, good processability, and good gas barrier properties. Moreover, it is the kind of polymer with the lowest proportion and number of additives that makes it appropriate for food contact areas. P.E.T is produced by polymerization of dimethyl terephthalate (DMT) or terephthalic acid (TPA) and ethylene glycol (EG) during a reaction of polycondensation (Chirayil, Mishra, & Thomas, 2018).

By processing the P.E.T granules (pellets), amorphous pre-forms are obtained that are stretched by a blow-molding machine to attain the perfectly oriented bottles. Each manufacturing process can generate new substances to form the part of the polymer, however; increasing the risk of unacceptable migration from P.E.T bottles into food packaging. Migration test was performed on 2 out of 20 pellet samples with three food stimulants at 60 ^{o}C for 10 days. The bottles were filled with ethanol (95%) as a fat stimulant, acetic acid (3%) as an aqueous stimulant, and pure ethanol (10%); selected according to the European Regulation 10/2011. The results confirmed the identification of seven oligomers in P.E.T pellets in migration to ethanol (95%) as a fat stimulant while none were discovered in acetic acid (3%) and pure ethanol (10%); making this material suitable for migrating to food stimulants (Ubeda, Aznar, & Nerín, 2018).

Property	Value
$[\eta]$	>0.7 dl g^{-1}
T_m	>240 °C
Water content	<0.02 wt.%
Flake size	0.4 mm < D < 8 mm
Dye content	<10 ppm
Yellowing index	<20
Metal content	<3 ppm
PVC content	<50 ppm
Polyolefin content	<10 ppm

Figure 7. Recycled P.E.T Material Properties (Awaja & Pavel, 2005).

The practice of recycling post-consumer P.E.T involves manufacturing engineering and process engineering. The driving force for recycling the P.E.T involves the environmental aspect as well as a slow decomposition rate as no organism can consume relatively large molecules of this material. Therefore, P.E.T is appropriate for the applications that have a less molecular weight (MW) such as sheets and fibers. The manufacturers of virgin P.E.T have been able to produce the co-polymer P.E.T, rather than homopolymer P.E.T; including, isophthalic acid-modified P.E.T. Usually the bottles are produced from co-polymer P.E.T because of their improved ductility, better clarity, lower crystallinity, and better process ability. The standard melting temperature (T_m) of P.E.T falls within the range of 255 and 265 ^{o}C. However, the glass transition temperature

(T_g) of virgin P.E.T is between 67 and 140 ^{o}C. It has been reported during thermal analysis in past researches that when the temperature rises, better crystal structures are formed and re-organized. Virgin P.E.T is well-known for having a slow rate of crystallization that varies between 150 and 190 ^{o}C. While focusing on the crystallization rate of P.E.T, various factors are considered, such as; degree of chain orientation, molecular weight (MW), nature of the polymerization catalyst, and presence of a nucleating agent. The granules of P.E.T can be processed in many ways depending on the requirements of the final product and involves extrusion moulding, injection moulding, and blow moulding. The past study has demonstrated that P.E.T flakes must satisfy the minimum requirements to be re-processed as tabulated below:

Recycled P.E.T undergoes several stages such as contamination for eradication of harmful acids, coloring agents, and other contaminants, namely; pesticides and detergents. There are two conventional recycling processes: chemical recycling and mechanical recycling. Chemical recycling comprises partial depolymerization into oligomers and total depolymerization into monomers through EG (glycolysis), water (hydrolysis), and methanol (methanolysis). On the other hand, mechanical recycling consists of the removal of contamination during the processes of sorting, washing, drying, and melting P.E.T flakes. The major advantage of mechanical recycling is that the process is relatively convenient, environment-friendly, and low investment is required. The mechanical, orientation, barrier, and optical properties of P.E.T bottles manufactured by the advanced technique of Injection Stretch Blow Moulding (ISBM) process depend on a wide array of factors, including; operating conditions, molecular weight, crystallinity, melt strength, and other crystallization conditions (Awaja & Pavel, 2005).

A recent study explored the thermo-mechanical recycling of post-consumed P.E.T bottles to measure the new composite performance in terms of stiffness and machinability. To measure the stiffness of bottles, compression tests were used, while machinability was evaluated by the roughness of material at different speeds, radical cutting deepness, and leads. The composition of P.E.T/HDPE material in the ratios of 80:20, 70:30, and 60:40 was selected to assess the behavior of recycled blends. The results showed that the stress reduces and stiffness increases when there is a higher molecular weight of P.E.T in the composite. The chemical properties of P.E.T make it susceptible to hydrolytic degradation where the presence of moisture affects the process of crystallization by applying the mechanism of enhanced nucleation. During the machinability test, it was analyzed that when the speed increases, the roughness value also rises; causing the discontinuous flakes to emerge. An increase in roughness value was observed in a speed of around 1.75 m/s for the composition of 70:30 and 60:40 while there was a significant decline in the 80:20 blend of P.E.T/HDPE (Avila & Duarte, 2003).

Most of the beverage containers turn into waste after their usage and cause environmental threats. The study was conducted to measure the performance capacity of the fiber in the post-consumer P.E.T bottles as compared to the polypropylene (PP) fiber for structural concrete in the volume fractions of 1.0%, 0.75%, and 0.5%. The applicable tests were performed to assess material properties, such as; restrained drying shrinkage strain, compressive strength, and elastic modulus. Flexural tests were also conducted to evaluate ductility capacity and strength of reinforced P.E.T fiber reinforced concrete in parallel with the non-reinforced concrete members. The results exhibited that comprehensive strength declined by 1-9% and 1-10% of P.E.T and PP, respectively, as fiber volume fraction increased. There was an indication of lower elastic moduli with the rising fiber content. The drying shrinkage strain was likely to be found in the material with an excessive amount of synthetic fiber volume fraction. While the fiber specimens of PP showed the decreasing strain as fiber volume fraction increased, the specimen of recycled P.E.T (0.5%) displayed the largest free drying shrinkage strain. The addition of recycled P.E.T fibers in reinforced concrete improved the crack controlling capacity where cracks occurred after 25 days at 1.0% as compared to 14 days in the non-reinforced material. The ultimate load capacity and ductility of recycled P.E.T fiber reinforced concrete material reached the maximum of 30% and

1000%, respectively while comparing with non-reinforced concrete material (Kim, Yi, Kim, Kim, & Song, 2010).

After studying the collection system of P.E.T bottles worldwide, researchers conducted the study in Beijing, China. In total, 580 respondents participated in the survey in which 119 were recyclers and 461 belonged to the diverse communities as consumers. It was estimated that around 90% of P.E.T bottles were collected by informal recyclers at collection hubs; weighing nearly 100,000 tonnes in 2012. These bottles were reprocessed with pollution control equipment by small-sized factories that offered high returns for recyclable bottles. The government had initiated the project to establish formal recycling collection system s for manufacturers, recyclers, and distributors. Formal and informal sectors had collaborated to reduce pollution, consumption, and waste streams of P.E.T bottles (Zhang & Wen, 2013).

In response to the environmental crisis, the use of recycled P.E.T has been contemplated in the production of textiles from post-consumer bottles. The difference in material properties of virgin P.E.T and recycled P.E.T were not significant as per the examination of researchers. The findings of the study showed favorable results in which recycled P.E.T had the potential to perform better as compared to virgin P.E.T. From the quality aspect, the normalized weight of recycled P.E.T can successfully eliminate the influence of chemicals as it is 5% heavier than the virgin P.E.T. There was a difference of only 0.12% where recycled P.E.T incurred a higher level of compression when it was compared with virgin P.E.T. Conversely, the key disadvantage to use recycled P.E.T is its increased rigidity (10 μN.m), around 2 units higher than virgin P.E.T, might limit its performance in the case of apparels (McCullough & Sun, 2019).

After exploring the mechanical properties of P.E.T, the presence of contaminants in beverage bottles from the several steps in the recycling loop was brought into the limelight. The measured levels of chlorine content and particle contamination were used to obtain the modeling parameters. The results revealed that the type of collection system had a great influence on the accumulation of contaminants. It was observed that the bottles collected in co-collection systems had more contaminants rather than the scenario of mono-collection systems. For this reason, the critical bottle properties, such as; migration, haziness, and paleness, often exceed the acceptable limits within co-collection systems (Brouwer, Chacon, & Velzen, 2019).

Some companies have the practice of classifying the P.E.T bottles based on physical and visual features comprising of pressure, color, and weight. There are different types of tools to identify an inconsistent set of features namely decision tress, logistic regression, and support vendor machine. A study addressed the methods of classifying the plastics into non-recycled and recycled to remanufacture the recycled bottles meeting quality standards. The performance of recycled material can also be tested through principal component analysis (PCA) and linear discriminant analysis (LDA) in scenarios of non-linear datasets (Kambam & Aarthi, 2019).

In 2013, a deposit system for plastic packaging was introduced in Germany. Since that time, the P.E.T bottles were collected through reusable packaging systems, various collection systems, depositories, and the dual system with yellow bag known as "Green Dot." The quality of recycled materials was enhanced when P.E.T flakes were examined and tested using a different channel. When plastic packaging was used for recycling, their densities were segregated in a fluid (separation medium). The water present in the separation medium is suitable for sorting the plastics with a density less than 1 g/cm^3 as compared to 1.38 g/cm^3 which is the density of P.E.T. The floating products consisted of P.E.T, PE and PP passed the float/sink test. Their extensive recycling systems produced the vast majority of P.E.T flakes which were cleaned in a labor-intensive manner to determine any minor areas of contamination. The system of "hot sorting" was initiated to recognize the contamination and other harmful particles on P.E.T flakes of 100 g were placed on a steel pan and roasted at 200 ºC in a convention oven for 30 minutes termed as oven test. Underneath a magnifying light, the roasted material is manually sorted and re-assured for impurities. Moreover, the bulk density was evaluated to test the wall thickness within 100 ml, under DIN EN ISO 60, and grain size of P.E.T bottles was found between 8 mm and 10 mm; having a favorable impact on the efficiency of the recycling process (Snell, Nassour, & Nelles, 2017).

Since the synthetic materials are unwittingly mixed with biodegradable materials, the feasibility of identifying the biopolymers in the recycling process of P.E.T was studied. The biodegradable polymers were blended with P.E.T in concentrations of 15, 10, 7.5, 5, 2.5, 0 wt%. These formulated materials were melted with a temperature profile of 270, 260, 240, 220, and 200 ^{o}C in a twin-screw extruder at a screw speed of 50 rpm from hopper to die. The mechanical characteristics of ISO-527-2 were followed as a standard and the parameter of ISO 828:2013 was used to measure the wettability in terms of water contact with a solid surface. According to the findings, the solubility of P.E.T (24.3 MP/a^2) which was highest than the other biodegradable polymers, namely; thermoplastic starch (TPS), poly (lactic acid) (PLA), and polyhydroxybutyrate (PHB) usually interfere in the mechanical characteristics of recycled P.E.T. Thus, the performance of this material is directly influenced by these contaminants either through the drastic drop in the elongation at breaks or effect on the water contact angle in the course of its degradation (Aldas, et al., 2021).

In Jordan, the study investigated the overall performance of recycled P.E.T and HDPE in terms of contaminants affecting environmental sustainability. The framework of life-cycle assessment (LCA) was used to measure the potential environmental implications of recycling these packaging materials. It comprises the variables such as solid waste, waterborne pollutants, total energy requirements, atmospheric pollutants, and other energy sources. Under the LCA standard, ISO 14040-14044:2016, the data analysis showed that incoming material from material receiving facilities (MRFs) was 83% while P.E.T reclaimed from a plastic-recycling facility (PRFs) was 17% as individual bales. These bales are broken down into flakes and sorted to mitigate the external material. The washing process of flakes excludes a variety of chemicals, such as; wetting agents, surfactants, and defoamers. It was estimated that the recycled P.E.T resin had around 80% of the incoming material where an average of 18.3% represented the inconsumable contaminants. The clean recycled material can be pelletized or it can be sold in the form of flakes. Alternatively, the incoming material of HDPE from MRFs was around 92%, and the remaining proportion from PRFs. Most of the facilities reclaimed recycled HDPE on average 94% as individual resin bales. The findings demonstrated that recycled P.E.T offered fuel energy savings of around 85% as compared to the virgin P.E.T and the net contribution of P.E.T flake in greenhouse gas emissions was 1.8 tons of carbon dioxide equals to a ton of recycled P.E.T flake. Hence, the greenhouse gas of virgin P.E.T flake was 72% more than that of the recycled P.E.T whereas the virgin HDPE pellet emitted 59% higher than that of the recycled HDPE pellet (Bataineh, 2020).

International Standards on Quality Aspects of rPET

It is the most crucial element of the recycling procedures to ensure that material used in Recycled P.E.T is available in adequate quantities to make the product viable for testing purposes. Secondly, the post-consumer P.E.T has to achieve consumer acceptance in the food packaging market. To address this expectation, certain policies are pursued in multiple countries and geographical areas. One of the remarkable examples of a similar policy is the Integrated Product Policy (IPP) of the European Union (EU) to help achieve the goals of environmental sustainability. This policy seeks to focus on the “green products” that consume resources more efficiently to minimize the environmental effect along their life cycle from raw materials extraction to end-of-life products (including recovery, reusing, and recycling). “Green companies” are considered to be in parallel with these quality directives when they enhance their collaboration with suppliers, processes, and the entire value chain to generate the environmental value of their products. European Commission presented the two harmonized methods: PEF and OEF (Perceived and Organizational Environmental Footprint) to standardize the Resource Use and Emissions Profile (RU_aEP) and organizations dealing with verified third-parties under the premise of "Building the Single Market for Green Products" since 2013. There are five blocks of Resource Use and Emissions Profile (RU_aEP): $VIRG_{IN}$ (Virgin Material Acquisition), REC_{IN} (Proportion of Recycled Material Input), REC_{OUT} (Proportion of Recycled Material Output), ER_{OUT} (Avoided Emissions from Energy Recovery Process), and $DISP_{OUT}$ (Fraction of Material Disposed Not Re-used and Recycled). After the comprehensive evaluation, the eco-label (EU-flower) is awarded to the top 20% of the best sustainable products and organizations. These guidelines are based on the Life-Cycle Assessment Standards such as BP X30-323, ISO 14044, ISO 14025, ISO 14040, GHG Protocol, PAS 2050, and ILCD Standards (European Commission , 2012).

Food Contact Regulations have been introduced in most of the regions across the world. These mechanisms vary in detail but often stand on the three primary pillars: general compositional requirements, migration tests and certain compositional requirements, and suitable manufacturing practices. General Compositional Requirements are related to the ingredients used to manufacture the product referred to as a "Positive List"; reflecting the toxicity profile of the food additive and flavorings. There is also a "Negative List" that imposes restrictions on its migration into food and comprises substances of the highest concern, such as ultraviolet inks. Migration Tests and certain compositional requirements consist of two focus areas: food migration tests that have specific migration limits according to the regulations and compositional tests to specify the restricted substances such as residues of metals, polymers, or reactive substances. Moving ahead, the suitable manufacturing practices ensures that when the material qualifies in the migration and compositional tests, the formulation of product and production parameters must be evaluated in a controlled manner and pure substances are utilized in the manufacturing process (European Food Safety Authority, 2017).

European Union has published Packaging and Packaging Waste Directive 94/62/EC on December 20, 1994, for packaging waste management with the aims to avoid any impediments during trade amongst EU countries, maintain the high degree of environmental sustainability and protection by setting the criteria for a concentration of heavy metals (such as lead, nickel, and cadmium) and promote recycling by setting the benchmarks for recovery of resources. As per these guidelines, the proportion of heavy metals shall not exceed the following limits:

1. 600 parts per million (ppm) by weight two years after the effective date
2. 250 parts per million (ppm) by weight three years after the effective date
3. 100 parts per million (ppm) by weight five years after the effective date

The Packaging and Packaging Waste Directive had a significant impact on the recycling of P.E.T as it is considered to the principal component of the packaging industry. To standardize the packaging waste management the three important aspects were brought into the limelight: introduction of metal concentrations in packaging, plastic recycling targets to be attained by 2030, and energy recovery of 50% from recycled plastic (European Environment Agency , 1994).

The Plastics Regulation (EU) 10/2011 has been the single-source reference for plastic materials and multiple products having plastic layers. It came into effect on May 1, 2011, in place of the Plastics Directive 2002/72/EC and two directives of vinyl chloride (80/766/EEC and 81/432/EEC). The regulations set by the commission members consist of:

1. Migration Limit of 10 mg/dm^2
2. European Union (Positive List) of around 900 food additives
3. Specific Migration Limits for Prescribed Substances
4. Restrictions on the use of certain groups of substances (such as heavy metals)
5. Overall migration testing protocols and certain migration testing

Concerning the plastic material in contact with food stimulants, the conditions are determined based on the contact temperature and contact time under the worst foreseeable conditions of a sample under examination. It involves whether any physical changes or any other conditions are not being taken place according to the scenarios appended below:

Contact time

Contact time in worst foreseeable use	Test time
t ≤ 5 min	5 min
5 min < t ≤ 0,5 hour	0,5 hour
0,5 hours < t ≤ 1 hour	1 hour
1 hour < t ≤ 2 hours	2 hours
2 hours < t ≤ 6 hours	6 hours
6 hours < t ≤ 24 hours	24 hours
1 day < t ≤ 3 days	3 days
3 days < t ≤ 30 days	10 days
Above 30 days	See specific conditions

Contact temperature

Conditions of contact in worst foreseeable use	Test conditions
Contact temperature	Test temperature
T ≤ 5 °C	5 °C
5 °C < T ≤ 20 °C	20 °C
20 °C < T ≤ 40 °C	40 °C
40 °C < T ≤ 70 °C	70 °C
70 °C < T ≤ 100 °C	100 °C or reflux temperature
100 °C < T ≤ 121 °C	121 °C (*)
121 °C < T ≤ 130 °C	130 °C (*)
130 °C < T ≤ 150 °C	150 °C (*)
150 °C < T < 175 °C	175 °C (*)
T > 175 °C	Adjust the temperature to the real temperature at the interface with the food (*)

(*) This temperature shall be used only for food simulants D2 and E. For applications heated under pressure migration testing under pressure at the relevant temperature may be performed. For food simulants A, B, C or D1 the test may be replaced by a test at 100 °C or at reflux temperature for duration of four times the time selected according to the conditions in Table 1.

Figure 8. Contact Time & Temperature in Recycled P.E.T Material (European Union, 2011).

To evaluate the compliance, the specific migration test values are considered to be on the real surface to volume ratio expressed in mg/kg for:

1. Containers and other similar plastic articles more than 10 liters or less than 500 grams or milliliters
2. Materials and articles with such as a form that makes it impracticable to estimate the association between plastic articles or surface area of plastic materials and food quality therewith
3. Films and sheets not in contact with food stimulants
4. Films and sheets containing more than 10 liters or less than 500 grams or milliliters

The migration value applying on the real surface to volume ratio of food (6 dm^2 per kg) shall also be expressed in mg/kg. It excludes the plastic materials used for food of young children and infants as per the Directives 2006/125/EC and 2006/141/EC (European Union, 2011).

The Recycled Plastics Regulation 282/2008 applies to all the plastic materials which are made from recycled plastic in contact with food substances or additives. It also includes the materials and articles possessing some recycled content as per the Plastics Regulation (EU) 10/2011. These guidelines exclude the following recycled plastic articles produced under Good Manufacturing Practice Regulation (EC) 2023/2006:

1. Recycled plastic articles derived from chemical depolymerization involving starting substances and monomers;
2. Recycled plastic articles in which recycled plastic material is used as a fundamental barrier as indicated in Directive 2002/72/EC
3. Recycled plastic articles produced from unused process scrap and/or production off cuts recycled within manufacturing premises or any other site according to instructions in Directive 2002/72/EC

Regarding the above instructions, Recycled P.E.T in contact with food substances should meet the requirements stated in the Migration Criteria, Compositional Requirements, GMP Regulation (EC) 2023/2006, Plastics Regulation 10/2011, and Framework Regulation (EC) 1935/2004. In mechanical recycling, the plastic waste is transformed into small pieces to remove the contaminations. The recycling process can efficiently reduce contamination to an acceptable level that mitigates the signs of potential risks to human health. The migration of contaminants should migrate below or up to the levels defined in the challenge tests in the recycling process complied with the requirements present in the Regulation (EC) No 1935/2004 Article 3. Quality assurance should validate the conditions of good practices in the recycling process. These challenge tests comprise a series of chemical compounds in terms of volatility, molecular weight, and polarity that involve "doping" the procedure that can contaminate plastic waste (European Commission , 2008).

Another imperative document presented by EFSA applicable on Recycled P.E.T was published during 2011 on the food contact substances, processing aids, enzymes, and flavorings under the title of *"Scientific Opinion on the Criteria to be used for Safety Evaluation of a Mechanical Recycling Process to produce rPET intended to be used for Manufacture of Materials and Articles in Contact with Food"* to ensure the transparency in the recycling processes of rPET and quality assurance procedure of recycled plastic articles or materials; intending to highlight several areas:

1) Overview of Recycled P.E.T bottles contamination data
2) Data related to chemical compounds in P.E.T
3) Challenge Test: Cleaning Process/Decontamination in Recycling Process
4) Migration of Potential Contaminants Criterion
5) Key Parameters regarding the Application of Evaluation Scheme

Concerning the packaging of non-food P.E.T in the plastic waste stream, the EFSA Protocols stated that the considerable proportion of the recycled plastic article must not exceed the limit of 5% to ensure the safety of humans as agreed by the Food and Drug Administration (FDA). According to the guidelines, the relevant criteria for infants using Recycled P.E.T is migration to be less than 0.1 µg/kg in food and value falling in the range of 0.15 and 0.75 µg/kg in the case of toddlers and adults (European Food Safety Authority, 2011).

To measure the recycling system of P.E.T related to the collection, sorting, and quality controls of recycled plastic materials and articles to satisfy the highest level of requirements, several standards were published covering the testing mechanism:

1) Plastics – Recycled Plastics – Sampling Procedures for testing plastics wastes and recyclers (CEN/TS 16010)
2) Plastics – Recycled Plastics: Sampling Preparation (CEN/TS 16011)
3) Plastics – Guidelines for recycling and recovery of plastic waste (ISO 15270)
4) Plastics – Recycled Plastics: Characterization of Plastics Waste (EN 15347)

5) Characterization of PET Recyclers (EN 15346)
6) Plastics – Recycled Plastics: Plastics recycling traceability and assessment of recycled content and conformity (EN 15343)

For the useful recycling process, it must have decontamination efficiency without minimizing the essential polymer-related properties (such as molecular weight and degree of crystallinity) that assist plastic to be re-made into new quality products like in bottles and films. There are general quality tests specified for the recycled plastic to be in contact with food substances in the EU regulations:

1) Melt Flow Rate (MFR): Plastics – Determination of Melt Flow Rate in (ISO 1133)
2) Distribution of Molecular Weight (MW) and its Characteristics – Determination of Molecular Weight (ISO 16014)
3) Degree of Crystallinity
4) Intrinsic Viscosity: Measurement of the Inherent Viscosity of P.E.T (ISO 1628-5)
5) Color Test (such as a, b, and L values)

For the determination of physical properties of Recycled P.E.T Materials, the samples prepared from injection moulding assess the tensile strength, softening point, impact strength, elongation, and flexural modulus. Some of the standards applicable for these fundamental properties during the recycling process are ISO 527 (tensile strength tests) and ISO 180 (impacts tests). Moreover, there are other tests for Recycled P.E.T bottles such as burst pressure test that is conducted when the equipment specifications of top-load (non-vented, vented, filled, and capped) in *"Voluntary Standard Test Methods for P.E.T Bottles"* are satisfied. The performance test methods for P.E.T bottles in hot fill, cold fill, and carbonated soft drinks applications had been prescribed so that quality test can be conveniently conducted by convertors, owners, manufacturers, and other parties to minimize the number of tests methods and one lab serves all the clients in the supply chain. It also forms the part of the ASTM F2013-10 test recommended by the American Society for Testing and Materials (International Society of Beverage Technologists, 2020).

To detect the contaminants in Recycled P.E.T, the Farunhofer Institute conducted the study funded by the European Commission under *"Programme on the Recyclability of Food Packaging Materials with Respect to Food Safety Considerations – Plastics, Polyethylene Terephthalate (P.E.T), and Paper & Board Covered by Fundamental Barriers"* on the analytical tests of packaging products where samples were heated and the retention times of substances were assessed. According to the results, the four major compounds were found in P.E.T resins and emerging from the polymer itself: AC (Acetaldehyde) for 1.8 minutes, EG (Ethylene Glycol) for 3 minutes, MD (Methyl Dioxolane) for 2.6 minutes, and Lim (limonene), used for flavoring purposes in highest concentrations, for 8.6 minutes. This research was in support of the Directive 90/128/EEC published in 2001 according to the thresholds defined by the US Food and Drug Administration (Franz, Mauer, & Welle, 2007).

Keeping the similar objective in view, another project was funded by the Food Standards Agency (FSA) under the banner of *"Develop a Post-Maker Test for Recycled Food Contact Materials"* between 2011 and 2013 to reveal the proportion of toxic contaminants migrating from recycled P.E.T into food stimulants under certain conditions. As per the research findings, five contaminants or marker compounds were determined in Recycled P.E.T known as Acetaldehyde (0.15 ug/g), Methyl Dioxolane (0.07 ug/g), Limonene (0.10 ug/g), Isopropyl Toluene (0.08 ug/g), and Monoethylene Glycol (0.70 ug/g); effectively serving as a basis for the testing Post-Consumer P.E.T flakes in compliance with European Food Safety Authority Regulations (Food Standards Agency, 2014).

Turning the Tide: Recycling Practices in South Asian Region (SAR)

Over a decade, plastic pollution has been a growing concern around the countries in, one of the most rapidly developing economic regions of the world, the South Asian Region. An estimated 80 percent of the plastic waste originates from land-based activities and the remaining 20 percent comes from marine-related activities. There are numerous contributors to these enormous consequences of plastic waste, including; insufficient and inappropriate waste management systems, storms, land-based pollution sources, open dumping areas near coastal areas, increasing dependency on single-use plastic, variation in rains, and weak collection systems of plastic waste on roads and streets. The international conventions had raised the voice to mitigate the vulnerabilities caused by plastic waste such as the Basel Convention on addressing the need for controls on Movements of Hazardous Wastes Amongst Countries and Their Methods of Disposal. Similarly, the multilateral agreement of the South Asian Association for Regional Cooperation (SAARC) had formulated the ASEAN Framework of Action on Marine Debris.

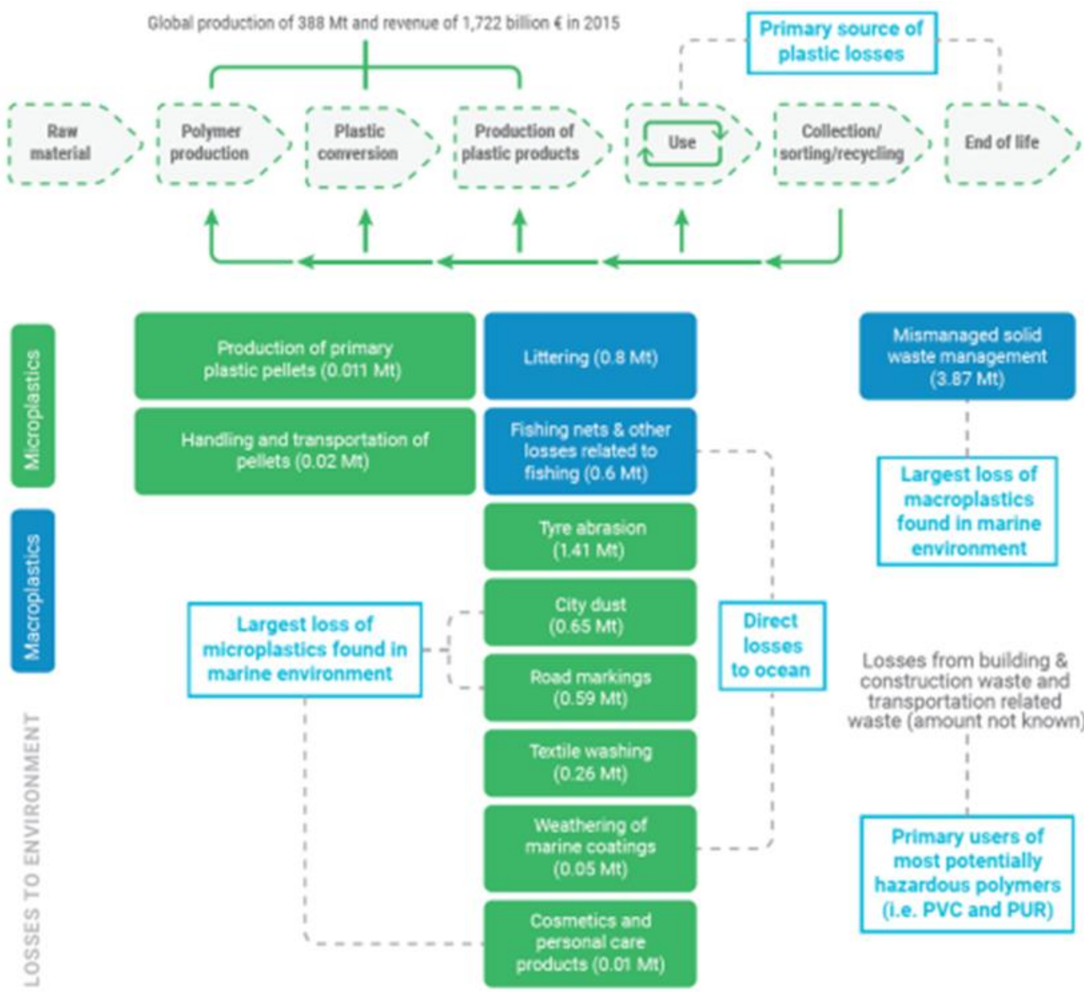

Figure 9. Plastic Loss to Oceans in the Plastic Value Chain (Kapinga & Chung, 2020).

The marine litter is everywhere and more visible than in previous years in India, Pakistan, Bangladesh, Maldives, and Sri Lanka; covering the majority of parts in the Indian Ocean as well as the Arabian Sea. This region is known for the high-density population, increased dependence on natural resources, and low-income groups that play a critical role in plastic waste distribution at the global level as illustrated in the diagram given below:

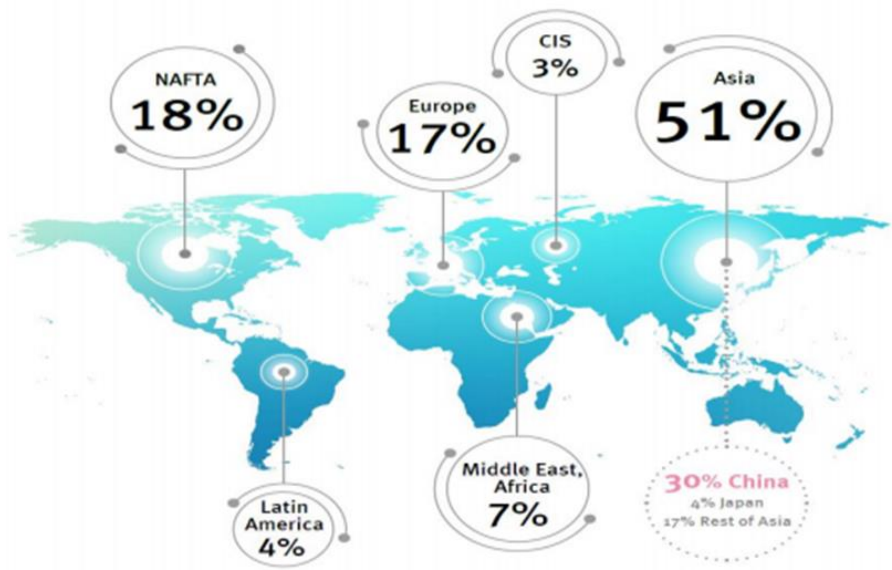

Figure 10. Global Plastic Waste Distribution (Kapinga & Chung, 2020).

During 2020, Asia generated around 51% of the overall plastic waste consisting of 30% from China, 4% from Japan, and the remaining 17% of plastic waste produced from the Rest of Asia. Based on the present conditions of human activities, plastic consumption patterns might cause plastic waste to exceed 600 million tons by the years 2025 and 2050. Assuming the constant use of plastics and forecasting the global waste management practices, 12,000 metric tonnes of plastic waste will be discarded in landfills or the environment, 12,000 metric tonnes will be incinerated and 9,000 metric tonnes will be recycled by 2050 (Kapinga & Chung, 2020).

The sudden rise in plastic consumption in the South Asian Region had pressurized the waste management systems that are relatively inefficient in eliminating leakages and handling waste as per international standards. The overall collection rate of plastic waste varies from 40% to 50% out of which around 26% to 33% belongs to rural counterparts. These estimates depict that a substantial amount of waste is not disposed of appropriately and are found to be on the roadsides for a couple of months. A large amount of waste in the South Asian Region is collected and managed by the informal sector and resell the plastic scrap at a high value such as P.E.T bottles. Such a waste disposal approach often causes chemical leakages at the dumpsite, carving its path towards the marine environment (UNESCAP, 2020).

According to a recent study, the highest mismanagement in a collection of plastic waste was observed in the countries, including; Malaysia, India, Sri Lanka, Pakistan, and Vietnam. The major areas of floating plastic over the coastal wasters hurt the living organisms to a great extent. The calculations of researchers showed 275 million metric tonnes (MT) of plastic waste entering into the oceans from the countries with coastal areas. Without the proper infrastructure for plastic waste management, the toxic debris in the marine environment would increase hundreds of times till 2025 (Jambeck, et al., 2015).

A fascinating study was conducted in India to understand the recycling potential based on the types of plastic waste generated annually. CPCB (Central Pollution Control Board) of India observed the rapid rate of industrial development had caused the plastic to constitute a considerable proportion of municipal solid waste (Centre for Science and Environment, 2017). Being the non-biodegradable material, plastic waste was burnt under improper circumstances leading towards the release of diverse hazardous air pollutants (HAPs); depending on the kind of polymers and additives used. Different kinds of plastic and their recycling potential are displayed in the table given below:

Table 2. Categories of Plastic and Their Recycling Potential in India (Centre for Science and Environment, 2017).

Type of Plastic	Code	Recyclable or Not	Type of Recycling	Few Applications
PET (Polyethylene Terephthalate)	1	YES	Converted into polymer again and used in multiple products	Water bottles, Films, Carbonated Soft Drink, Jars, and Carpets
HDPE (High-density Polyethylene)	2	YES	Converted to pellets again and new HDPE is produced	Milk pouches, Recycling bins, and caps
PVC (Polyvinyl Chloride)	3	YES	Heating is used to convert the waste into heavy metals and calcium chloride products or as a fuel for the recovery of energy	Wire Cable Insulations, Window Profile, Pipes, Lawn Chairs, and Hoses
LDPE (Low-Density Polyethylene)	4	YES	Converted to pellets again and new LDPE is produced	Plastic bags, water bottles, and other containers
PP (Polypropylene)	5	YES	Converted to pellets again and new PP is generated	Disposable cups, auto parts, and bottle caps
PS (Polystyrene)	6	NO	Not recyclable	Disposable cups, plates, foams, and trays
Others (O)	7	NO	Not Recyclable – However, different layers can be crushed and used in boards and sheets	Thermoset Plastic (Fiber Reinforced Plastic or Sheet Moulding Compound (SMC)

Pathak (2020) raised the concerns over the dark side of the unmanageable issue of India that is plastic pollution and initiated the research intending to explore the mobilization capacity of their stakeholders. Most of the crowded alleys and slum areas had become inaccessible to the waste collection trucks and the remaining waste had been dumped in the environment. When the heavy monsoon rains take place, the plastic litters are carried away by winds and waters on the roads of Mumbai. One of their clean-up efforts was to collect the entire waste from the city and dump it in the largest garbage area near the Thane creek that was pushed back into the sea again; making their attempts useless in front of the World Wide Fund for Nature (WWF). These waste management inadequacies had been a source of embarrassment for the national governments of India (Pathak, 2020).

In 2018, a review of plastic waste in India was taken place based on the guidelines in the CPCB (Central Pollution Control Board) study on the assessment of plastic waste produced in municipal solid waste (MSW). The data revealed that significant plastic was generated from HDPE and LDPE (66.91%) as compared to PET (8.66%), PVC (4.14%), PP (9.9%), PS (4.77%), and the rest of the plastic waste (6.43%). At present, the facilities of sanitary landfill sites are not available and entire plastic waste is transported to the disposal site. An incinerator plant was also established in Delhi, however, the unsatisfactory operational experience created disturbances. A sustainable step towards a healthier and hygienic environment is the need of the hour. The extended producer responsibility (EPR) of collection and segregation of plastic waste can ensure adequate recycling practices according to the governmental rules released in India (Hussain, Bhattacharya, & Ahmed, 2018).

To reduce the plastic waste in the small Beed district of India, Majalgaon, the solid waste management practices were examined from 2012 to 2017. The various kinds of plastic were produced from the waste collected daily. It was segregated into dry and wet waste. Dry waste was further sorted into non-recyclables (fiberglass and foam materials) and recyclables (paper, plastic, and metal). The results showed that paper waste (15.5%) was far more than plastic waste (7%), glass waste (4.8%), and metal waste (0.9%) in the segment of dry recyclables. On the contrary, the amount of dry non-recyclable waste constituted 48.8% than the proportion of wet waste (23%); affecting the environment in an unfavorable manner (Salunkhe, Pawar, & Gosavi, 2018).

The municipalities of various cities in India have been involved in solid waste management (SWM) and are facing a tremendous challenge. One of the studies on integrated municipal waste management in Dehradun City, Uttarakand indicated that the environmental impact of such practices led to the degradation of vegetation and the ecosystem of living organisms. The researchers observed the two scenarios: mixed municipal waste transported to solid waste processing and treatment plant where rejected waste is transferred to landfills *(Scenario 1)* and sorted municipal waste into three categories (recyclable materials, organic waste for composting and refused derived fuel (RDF)) where only waste residues end up in the landfills *(Scenario 2)*. It was concluded that the sanitary landfill had a huge environmental impact rather than the integrated system of reduced derived fuel and composting; expediting the process of energy recovery and moving towards the ideology of Zero Waste (Chauhan, Chandramauli, Vyas, & Pandey, 2018).

The selection of the most appropriate solid waste management (SWM) method has been one of the largest challenges in the urban cities of India. The success rate of municipal solid waste management requires accurate and complete information on physicochemical characteristics and production rate. Improper solid waste handling can have great environmental effects. The study proposed a method for identifying the suitable option through an applicability index consisting of Landfill (L_P), Composting (C_p), and Incineration (I_P) for each element of municipal solid waste based on its physiochemical analysis. For this index, the mean values of ash content, volatile organic carbon, moisture content, oxygen, carbon, calorific, nitrogen sulfur, bulk density, fixed carbon, and hydrogen values were used. The method adopted for the characterization of municipal solid waste has been displayed below:

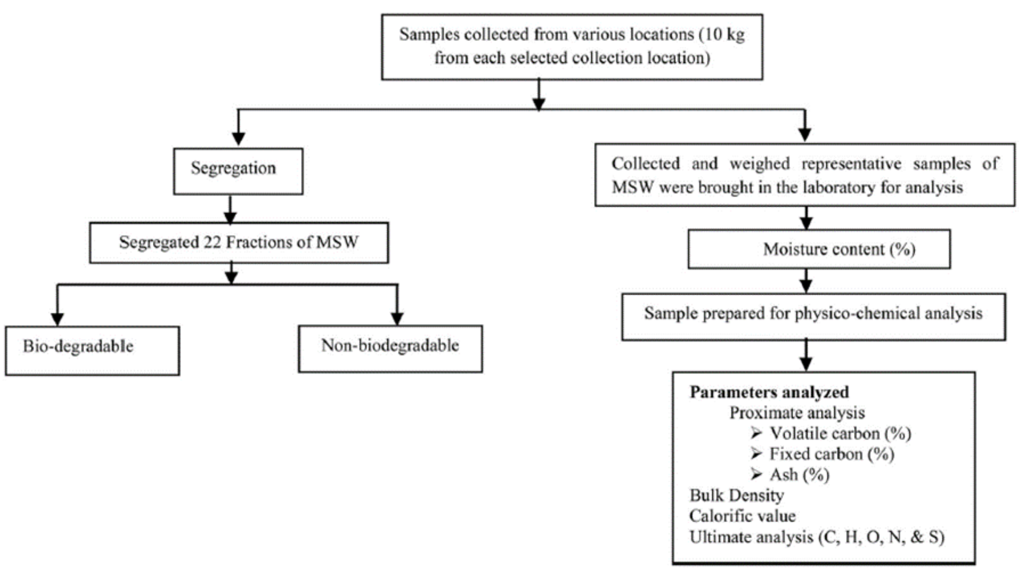

Figure 11. Characterization of Municipal Solid Waste (MSW) (Yadav & Samadder, 2018).

The research findings showed that the fraction of bio-degradable material was 66.7% in comparison to non-biodegradable material aggregating to 33.3%. Due to the variation in weather conditions and lifestyles of people, the composition of MSW differs largely from the Western countries. In this study, the food residues were found to be in a large quantity (21%), consisting of fruit and vegetable peels and other kitchen waste in the residential areas. Usually, the cardboard, textile, and PET waste were found to be in small proportions while the waste collection was being carried out. The applicability index of plastic for the suitable disposal options of composting, incineration, and landfill was 74.96, 108.27, and 42.30 respectively (Yadav & Samadder, 2018).

One of the mountainous regions of Ladakh in India was facing acute plastic pollution as the tourists transformed it into a dumpsite for many years. The study was undertaken to identify the magnitude, quantity, and composition of waste near the tourist accommodations. The results from the direct waste analysis showed that 5.11 metric tonnes of waste were produced per day during the summer season with a waste generation per capita of 1.58 kgs per room on daily basis. The average daily waste generation in the tourist season was 0.283 metric tonnes. Out of which, the estimated plastic waste was 3.10 metric tonnes (5.11%) as compared to the compostable waste of 39.69 metric tonnes (65.34%) and the remaining was non-recyclable and metallic waste constituting 29.33 metric tonnes (29.35%). An integrated waste management system that is economically and environmentally feasible needs to be adopted (Wani, Shah, Dar, & Kamraju, 2020).

Since the wide variety of plastics was generated from the waste streams in Chennai, the researchers presented the study on the mechanical recycling of P.E.T where a collection of waste was taken place in granule form. The melt flow index, bulk density, and hardness were considered for quality assurance of 200 water bottles. In the initial trial, the barrel was heated at the 260 ^{o}C (actual melting point of PET) having the screw speed of 40 Revolutions per Minute (RPM). The higher temperature often leads to the degradation in the intrinsic viscosity (IV) of P.E.T. Then the barrel was heated at 245 ^{o}C at the screw speed of 30 Revolutions per Minute (RPM). The strands of recycled P.E.T were obtained in satisfactory condition as per ASTM standards. It contained the average flow rate of 6.73 grams within 2 minutes and MFI of 33.66 grams as compared to the standard MFI of 20 grams in 10 minutes (Virgin P.E.T) and 26 grams in 10 minutes (Recycled P.E.T). Moving ahead, the bulk density of P.E.T was 0.781 g/cm^3 falling within the standard range of 0.5-1.2 g/cm^3 (Virgin P.E.T), but, more than the standard range of 0.5-0.6 g/cm^3 (Recycled P.E.T). As per the results, the hardness of samples was 77.6 less than the standard Virgin P.E.T hardness of 117 but near to the standard Recycled P.E.T hardness of 78. The outcome of this study was that the properties of Recycled P.E.T are inferior to the Virgin P.E.T after the recycling process (Krishnakumar, Ravi, & Jayakumari, 2019).

Industrialization has rapidly changed the face of India possessing a large increase in urbanization and gross domestic product (GDP). The approach towards solid waste management in India is still insufficient due to a lack of awareness and deficiencies in infrastructural amenities. A large fraction of contaminated municipal solid waste (MSW) on the outskirts of cities and districts without any preliminary waste treatments had caused groundwater pollution, the release of greenhouse gases, and the leaching of toxic chemicals. The study revealed that 80% of the waste can be recycled while the rest of the waste (20%) had entered the landfills or marine environment. A collaborative effort of integrated municipal solid waste systems and local waste management authorities can improve the potential of recycling waste through the adoption of various collection methods were proposed by the Municipal Waste Management Rules (2000), including; community bin collection, collection on regular time interval, house to house collection, and bell-ringing of a musical vehicle at the scheduled time (Nandan, Yadav, Baksi, & Bose, 2017).

Even in the recycling industry of Sri Lanka, the integrated solid waste management model identified a complex set of challenges that vary from the upstream actors in the value chain to the downstream. Being far from the glimpses of circular economy, Sri Lanka faces economic, social, and environmental problems. The multi-faceted solutions; including, private-public partnerships, law enforcement, and policy implementation, industry formalization, waste management awareness campaigns, and international collaboration with neighboring countries would prove to be fruitful for stakeholders in this market (Gunarathne, Tennakoon, & Weragoda, 2019).

Bangladesh is no exception in this regard, the current scenario of plastic waste had adversely impacted the environment, consisting the most threatening substance discovered in their waste is "microplastics". These plastic fragments less than 5 millimeters in length had damaged the natural ecosystems. Due to the non-biodegradability of plastics, the chemical reactions had placed several areas in a precarious situation; having unpleasant signs of threats to human health and the environment (Hossain, Rahman, Chowdhury, & Mohonta, 2021).

In the age of sustainable businesses, the extent of plastic consumption is a matter of great concern. The empirical evidence from the recycled plastic industry in Bangladesh highlighted the huge potential of recycling plastic as the best source of export. Based on the responses of ten officials belonging to small and medium-sized ventures, the recycling of plastic waste saved their import costs and managed to improve the overall waste management conditions. There are around 5,000 plastic industries, out of which 3,500, 1,480, and 20 are operating on small, medium, and large scales respectively. Most of the recycling centers are located in Dhaka producing 140 tonnes per day of recycled plastic. Based on the market dynamics, Bangladesh has the great potential of fostering the recycled plastic industry. On the other hand, the unsuitable waste management system, lack of standardized procedures, and infrastructure facilities might hinder the benefits of this industry to be realized according to the expectations of stakeholders (Hossain, Aditi, & S., 2020).

Being a densely populated area, Bangladesh belongs to the category of "Least Developed Country" by the United Nations. The condition of recycling in this country has been a grim reflection of the environmental hazards imposed by the plastic industry practices across the cities in Bangladesh. According to the findings, the recyclers do not produce any product from recycled plastic granules; they export them to other areas in China, Indonesia, and Malaysia. The plastic consumption rate was 5 kg per year as compared to 30 kg per year of other countries in the world. Hence, the revenue generated from the export of recycled plastic flakes was approximately $ 1500-2000 million within a year; proving the plastic recycling business to be quite rewarding (Sultana, 2019).

In the recent study, it was highlighted that 1.7 to 1.9 billion tonnes per year were generated that would reach the estimated amount of 2.2 to 2.4 billion tonnes per year by the year 2025 as shown in the diagram given below:

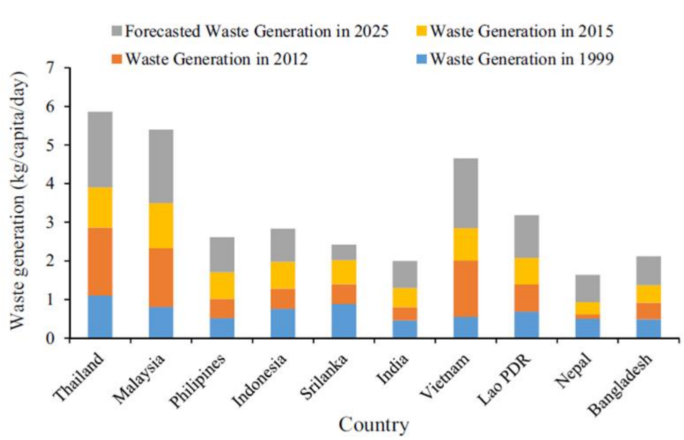

Figure 12. Waste Generation Rate for Developing Countries in Asia (Mourshed, Masud, & Rashid, 2017).

To attain the desirable plastic waste for further processing into multiple products, certain factors have to be considered such as inappropriate technology, lack of regulations and policies, and insufficient awareness of recycling plastic amongst common people; creating a challenging situation for the recyclers in Bangladesh. Unsatisfactory practices at the hands of waste collectors from the informal sector and improper plastic waste treatment activities had put the health of people and the environment at risk (Mourshed, Masud, & Rashid, 2017).

A similar study was conducted in the vicinity of Malir Cantt situated in one of the largest cities of Pakistan, Karachi. A mathematical model was applied, to measure the influence of integrated collection and disposal activities on solid waste, known as Front End Collection and Disposal of MSW. Amongst the six districts, there were around thirteen union councils who provided the data on landfills and the infrastructure of the collection system. The results showed that the cost of collection was Rs. 1,552,000 to make the entire Malir Cantt waste-free area with the help of around 34 collection vehicles. On the daily basis, Karachi generates the 12, 000 tonnes of MSW that can be used to generate 200 MW (megawatt) of electricity smoothly. The municipalities can make the procedures on the grounds of either of these two ideas as per the conditions of different cities: extended producer responsibility (EPR) or polluter pays principle (PPP) to recycle, reuse and reduce the maximum amount of resources in solid waste (Shaikh, Hussain, & Baig, 2019).

On the contrary, the solid waste generated in the city of Faisalabad ranges from 1,300 to 1,600 tonnes per day. Due to the immense spread of communicable diseases and the rapid environmental deterioration, the study was undertaken to estimate the potential impact of MSW on the surroundings. The findings showed that around 56% of waste had been collected out of which 43% is dumped openly in the landfills without any preliminary treatments or precautionary measures. The waste streams of Faisalabad can be regarded as the ultimate source of energy recovery and used in the form of fertilizers through Faisalabad Waste Management Company to mitigate social and environmental risks (Yasin, Usman, Rashid, Nasir, & Randhawa, 2017).

By shedding the light on the other side of the South Asian Region, the solid waste management system of Kabul, the capital city of Afghanistan, can be considered. Waste Management planning and scheduling was one of the greatest issues where waste collection times and location of waste bins in far-flung areas had caused the local community people to cover the distance of 250 meters on daily basis. Along with this, the worse situation of recycling facilities had caused dissatisfaction amongst plastic converters and waste management authorities. Besides the rise in illiteracy rate and inadequate recycling systems, the presence of military and terrorist groups had made the recycling process to become most challenging and time-consuming task (Azimi, Dente, & Hashimoto, 2020).

Moving ahead, the solid waste management of Nepal also requires a sustainable solution. The inefficient municipalities and frequent dumping of municipal solid waste (MSW) in the landfills had deteriorated the energy recovery rate and recycling rate. The projected average per capita of waste generation was 0.223 kg per person per day where overall waste generation was around 3,023 tonnes per day. The results of the study discovered that 60% of the waste was decomposable while 25% of waste is recyclable (metals, plastics, and paper) and the remaining was a non-recyclable waste (Maharjan & Lohani, 2019).

To minimize the presence of plastic in the environment, especially P.E.T bottles, lying around the streets and roads, the study was conducted to evaluate the recycling potential of water bottles. By considering the parameters; such as electrical conductivity (EC), heterotrophic plate count (HPC), electrical conductivity (EC), and pH value of bottled water, the samples were tested as per the guidelines released by the Department of Food Technology and Quality Control (DFTQC). The majority of P.E.T bottle samples had unacceptable pH values from 5.2 to 6.8 and the value of electrical conductivity (EC) was between 5 to 199 µS/cm. Out of 100 samples, the HPC of 48 samples was able to meet the standard value (<25 cfu/mL). The high concentration of contaminations had adversely affected the pH value of P.E.T bottles manufactured in Kathmandu Valley, Nepal. These polymers can be recycled to save the costs of raw material and reduce the levels of biological degradation in the environment (Gautum, Gyanwali, & Ussery, 2020).

Amongst the multiple countries of the South Asian Region, Bhutan is also overburdened with municipal solid waste (MSW). It has the incredible potential to generate the recycled materials from the tourists' waste on annual basis. To date, the growth prospects in the tourism sector and lifestyle changes had led to the severe condition of MSW. The composition of waste in the landfill comprised of organic waste in the highest fraction of 53% while glass, metal, HDPE, LDPE, textile, paper, and rubber were found in the proportions of 14%, 7%, 3%, 7%, 5%, 9%, and 2% respectively (Zangmo & Sharp, 2017).

Although the worldwide concern over plastic consumption had raised questions on marine plastic litter in the last ten years, the growing threat of microplastics piling up at the coastal reefs of Maldives had caused disturbances in the collection process to the great extent. The samples of sediments and seawater from around twelve locations in the Faafu Atoll were examined. Despite the scarce population and low influx of tourists, the abundance of microplastics can be depicted through 22.8 ±10.5 particles/m^3 in the sediments of the beach and 0.32 ± 0.15 particles/m^3 in the surface water (Saliu, et al., 2018).

Furthermore, the characteristics and distribution of plastic debris present in the sediments of the Gulf of Mannar were extensively examined in one of the recent studies. When testing of samples was conducted, the results showed that white-colored plastic and irregular-shaped plastic debris had worsened the environmental conditions for coastal communities. The composition of plastic debris involves a diverse variety of materials such as polypropylene, polyethylene terephthalate, nylon, and polyvinyl chloride. Tourist activities and improper fishing practices had caused the plastic waste to damage the coastal species and coral environment of the South Asian Region (Vidyasakar, et al., 2018).

Driving towards a New Plastics Economy Global Commitment

The interconnected challenges of climate change had made the companies like Coca-Cola rethink over innovative strategies proactively contributing to “World Without Waste” which includes these focus areas: design, collect, and partner. The design of carbonated soft drinks would be made from 100% recyclable material by 2025 and reuse 50% of the recycled material in their packaging by 2030 from the bottles collected through the efficient system for the plastic-free environment as indicated in the New Plastics Economy Global Commitment coined by MacArthur Foundation in collaboration with United Nations (Coca Cola, 2020).

To win the hearts of customers, the first-ever packaging of Coca Cola made from 100% Recycled P.E.T was released in North America to deliver the convenient and environment-friendly solution for greenhouse gas emissions aggregating to 10,000 metric tonnes; equivalent to the pollution generated from 2,120 cars on the roads in a year. It marks a major milestone in the large arena of the plastic industry that includes the element of encouraging consumers to adopt recycling practices in their daily lives by reading the package labels of “Recycle Me Again” awareness messages (Coca Cola, 2021).

Owing to the creation of a recycling value chain, Unilever invests around $15 million in a private equity platform known as Closed Loop Partners Leadership Fund in North America to bolster the recycling of post-consumer plastic resin and achieve reuse the 50% of the plastic material consumed in packaging products. At present, the quantity of plastic packaging was around 700, 000 metric tonnes in which 5% of recycled material content was incorporated. The goals of 2025 consists of curbing the utilization of virgin P.E.T and recycling more plastic used in bottles where at least 25% of post-consumer resin (PCR) would be consumed across all the markets in the entire world (Paben, Unilever invests in fund that acquires recycling companies, 2021).

Realizing the benefits of Global Commitment to form a New Plastics Economy by 2025, Driscoll assists to advance the pledge of generating sustainable packaging solutions. The market leader of fresh berries produced a container having 50% recycled P.E.T; driving from the used bottles. As per the commitment, the company has been actively engaged in increasing the recycled P.E.T element to ensure that their sustainable product performs efficiently in the closed-loop system (Driscoll, 2021).

One of the leading companies, Colgate-Palmolive launched the 100% Recycled P.E.T bottle for one of the dish soap brands. This dynamic change would lead to the recycling of around 5,200 tonnes of P.E.T within a year. During 2019-20, this company produced plastic packaging of 275,440 metric tonnes which contains 7% of recycled content. The objective is to reach the target of 25% PCR by 2025 (Paben, Colgate-Palmolive launches 100% PCR bottle, 2021).

To fulfill the global commitment, PepsiCo and Mondelez International also took the pledge of reducing the proportion of virgin plastic in their rigid packaging. Two major brands, Cadbury and Dairy Milk would have the reduce of virgin plastic by 25%; amounting to 10,000 tonnes of plastic by 2025. On the other hand, the target set by PepsiCo is a 35% reduction in the packaging of products such as Quaker Oats and other beverage products (Edie, 2021).

Silafrica, a prominent leader in sustainable packaging solutions, is the first company from Africa to collaborate in the development of the New Plastics Economy and establish innovative solutions for the closed-loop system. The company is currently operating at the recycling level of 1,600 tonnes per year in the segment of secondary packaging for various enterprises that would reach 5,000 tonnes per year through the inclusion of pallets and crates. The goal of this company is to produce 100% compostable, recyclable and reusable plastic packaging by 2025; having a minimum of 40% PCR in the primary, secondary and tertiary categories for home care, personal care, beverage, and other brands (Delia Associates, 2021).

With time, the sourcing of companies had shifted from the consumption of virgin materials when companies realized their responsibilities towards managing the lifecycles of their products. The expansion of scope had encouraged them to apply their learnings from the consumption patterns of previous products on the downstream stages of the value chain. One of the meaningful examples of HP Inc. signifies the iconic collaboration with waste collection communities playing a critical part in downstream processes to support the environmental sustainability and economic infrastructure of Haiti. During 2019, the investment of $2 million in the gathering of plastic in oceans and its use in laptops and computers had created more than 1,000 new jobs and expanded the recycling capacity of the region by deploying a holistic approach to address the environmental crisis (Lauren, 2021).

Being the first FMCG company to join hands with Plastic Bank, Henkel aims to prevent plastic waste through a strategy standing on the pillars of social development and environmental sustainability. The ethical recycling process would support the coastal communities to reap benefits from incredible job opportunities and earn livelihood effectively while reprocessing the waste accumulated by them in the collection centers at a diverse location; moving towards the integration of “Social Plastic” in its global supply chain (Plastic Bank, 2021).

Surprisingly, the sweets and snacks manufacturer in Chicago, Ferrara had announced to contribute to the global commitment of generating 100% recyclable packaging by increasing the use of recycled materials convenient for consumers and mitigating the unnecessary plastic in their packaging. The pledge of improving its packaging solutions would assist it to establish its footprint through increased accountability and integrity while achieving the clear target by 2025 (Ferrara, 2020).

One of the leading beverage brands in Canada, ESKA declared the complete elimination of virgin plastic from their spring water bottles. The ideology of “Recycle of Life” significantly contributes to the ecological well-being and the incessant resource flows into a circular economy. Sourced from diverse suppliers, the deployment of a natural filtration system in parallel with waste management methods would strengthen their commitment towards attaining maximum rewards from recycling practices (ESKA, 2021).

After contemplating the efforts of several companies, Ellen MacArthur Foundation under the supervision of the UN Environment Programme (UNEP) issued a progress report to share the insights on the incorporation of a recycled element in the packaging and phasing out the single-use plastic from the global economy. The experts discovered that there were major differences in the progress of the signatories; for instance, Coca-cola was achieving the target at the rate of 99% while the pilot projects in other companies such as L'Oreal, Unilever, and Natura Cosmetics reported the advancement towards global commitment at 22%, 10%, and 24% respectively. The report highlighted that bold packaging campaigns and innovative solutions would urge the consumers to take action voluntarily; buttressing the roots of the plastic circular economy (United Nations, 2020).

3. METHODOLOGY

There is a variety of research methods that gives a greater choice in several academic disciplines; including, mono method quantitative, mono method qualitative, multi-method quantitative, multi-method qualitative, mixed-method simple, and mixed-method complex. The mono method is associated with the use of a single research approach for a particular study; however, the multi-method enables a complex phenomenon that retains meaning and is holistic; being handled from all the methodological sides. On other hand, mixed-method is indicated by the use of more than one research approach such as the blend of qualitative and quantitative research methodologies (Saunders, Lewis, & Thornhill, 2015).

This study follows the mono method qualitative considering the paradigms set after a systematic review of past studies and the dimensions of the phenomenon under observation. It provides the direction to the researchers towards a single area of study without involving the use of statistical tests or numerical measurements.

Research Setting

This study was carried out in the natural or non-contrived setting as the respondents were not able to manipulate the environments for qualitative research instead of artificial or contrived setting where research is conducted in a highly controlled environment, typically for experiments. This study involves the observation of how data variables behave in the natural environment without manipulation or interference of the respondents. The naturalistic observation was the well-suited type of correlational research for this study as none of them was allowed to influence or exercise control over the data variables in any possible manner.

Research Scope

The research scope has been divided into two categories termed basic and applied research. Basic research has an aim to broaden the existing base of knowledge and is theoretical; however, certain practical problems are solved in the applied research to develop innovative techniques within a specific set of real-life circumstances (Given, 2008). Considering these types of the research scope, this study revolves around the continuous sourcing of quality and quantity of rigid plastic material for Recycled P.E.T for Mehran Plastic Industries (Pvt.) Ltd is the present condition that indicates the applied research effectively.

Sample size and Sampling Technique

The sample size was chosen by using a purposive sampling technique related to the non-probability sampling method. It seems quite reasonable as it gives chance to select a sample based on the judgment of the researcher suitable to the needs of this research with a set of certain characteristics to attain significant results based on data saturation.

Unit of Analysis

For the collection of essential and effective information, the individuals at the collection hubs and concerned personnel in the supply chain department of the company were the unit of analysis in this study.

Time Horizon

Multiple responses were gathered through interviews at the different periods instead of collecting data for a specific period so the combination of cross-sectional and time-series was followed in this study. It can be referred to as panel time horizon.

Type of Data

This study is based on the primary data collected from the concerned personnel in the company and recyclers at collection hubs by conducting interviews and observations during site visits to analyze the implications of Recycled P.E.T bottles on one of the providers of packaging solutions, Mehran Plastic Industries (Pvt.) Ltd, that can be replicated on the other manufacturing companies of P.E.T bottles in the FMCG sector. Various secondary sources have been used to gather the information such as the Pakistan Plastic Manufacturers' Association (PPMA), Pakistan Credit Rating Agency (PACRA), Pakistan Bureau of Statistics, and other associations for comparative analysis with benchmarks set by the plastic packaging industry.

Inclusion Criteria

The inclusion criteria of respondents involve the individuals working in the supply chain department as assistant managers and above from both genders along with the recyclers at the collection hubs for an in-depth view of Recycled P.E.T bottles sourcing channels.

Data Collection Instrument

Successful data collection is the main part of the research study. Data collection consists of discovering the critical information related to the subject matter. There are two types of data collection methods: primary and secondary data collection. The primary data collection involves the process of collecting raw data at the source while the collection of second-hand data or published datasets by authorities comes under the latter one (Given, 2008). This study presents the findings attained by the primary data collection to discover the subject matter and eliminate assumptions.

Data collection tools indicate the device or instrument used to gather data where the researcher must maintain the integrity and transparency of the process. These tools might vary in design, administration, and complexity (Kumar, 2014). Hence, the list of interview questions was used to impart the appropriate kind of information related to the recycling process of P.E.T bottles. It also provided the anonymity of the participants for the timely and meaningful response from concerned personnel in the supply chain department of the company.

Ethical Considerations

For clear and transparent research, ethical considerations play the most important role where respondents are informed about the purpose of the study and their rights of confidentiality have been protected. It means that research must provide benefit rather than harm to any being. It is the responsibility of researchers to show respect towards the privacy and confidentiality of respondents (Blessing & Chakrabarti, 2009).

Along with this, freedom was provided to the respondents in terms of time, extent, and circumstances so that they were able to share the information where it was deemed appropriate to them. The aims and objectives of this study were also explained and clarified to respondents by informing their roles and expectations beforehand.

This study maintains the privacy and anonymity of the responses gathered from company personnel at Mehran Plastic Industries (Pvt.) Ltd and recyclers at different collection hubs were merely used for educational purposes; without any intention to share them with an unauthorized person or utilize them for any unethical means that can place their professional, social, and political relationships at risk

4. DISCUSSION

The findings attained from the data gathered through the interviews. For the convenience of readers and reviewers, this section has been divided into various sections. The first section discusses the current recycled plastic scenario in Pakistan, whereas the second section discusses the several processes involved in the recycling process of rigid plastic in P.E.T bottles. The end-to-end analysis for continuous sourcing strategy of Recycled P.E.T in terms of sourcing channels, resource efficiency, collection hubs, costs, quantity, and quality as compared to Virgin P.E.T through reverse logistics system has been provided. Along with it, the challenges and barriers in the mechanical process of recycling P.E.T materials have been covered in the same section.

Recycled P.E.T Scenario in Pakistan

The role of the plastic industry is changing worldwide and it is necessary for the plastic industry in Pakistan to play its critical part in delivering recyclable products through environment-friendly manufacturing processes. The recent challenges need to be addressed to facilitate the appropriate disposal and collection of plastic materials.

With time, the plastic industry focusing on the circular economy rather than following the linear pattern can ensure its survival ahead. It has been widely recognized that an important role has been played by plastic to achieve a sustainable and hygienic future. Plastic material has been actively contributing to the emissions of greenhouse gases (GHG) that can be reduced by curbing the practice of single-use plastic consumption. Plastic consumption is 7 kg per person in Pakistan which is better than 90 to 100 kg per person in the countries of United States. Since plastic consumption has not reached uncontrollable levels, the plastic waste management methods can increase the use of recycled plastic without letting them move into landfills or sewerage lines.

By considering plastic waste as an essential source for recycled products, the packaging companies can maneuver the mechanism of obtaining a sustainable and green environment beneficial for future generations. Every company can set a benchmark of using the proportion of recycled content in their current packaging products portfolio as well as take the initiative of developing products from the 100% recycled plastic to realize the implications of the circular economy earlier.

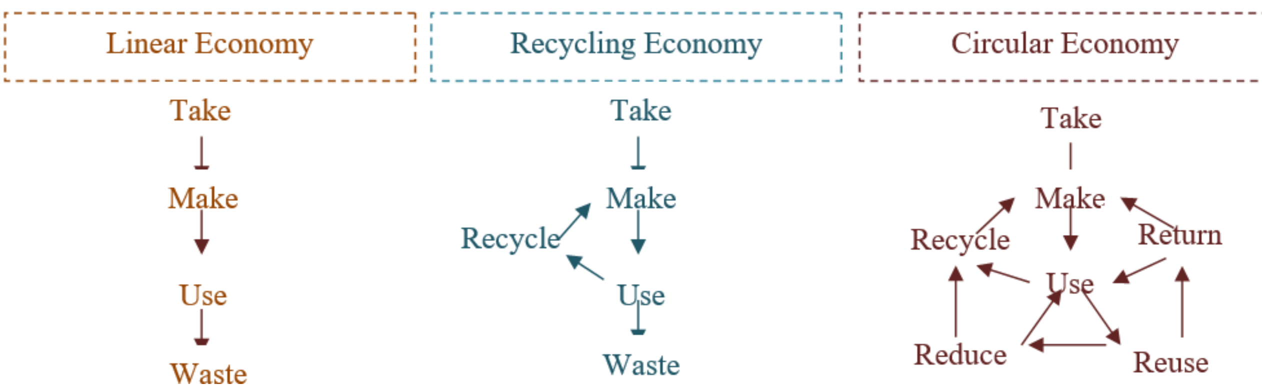

Figure 2. Difference between Linear, Recycling and Circular Economies.

In Pakistan, there were around 645 million units of P.E.T bottles consumed during 2019-20 as compared to 718 million units in the last year as exhibited in Figure 14. Due to the high levels of consumer demands, the greater concern has grown for P.E.T bottle usage immensely destructing the marine environment. The P.E.T segment seems to have the highest growth prospects due to the ease in collecting and recycling the bottles. The government bans were lifted on single-use plastic but were not stringently enforced. The suitable alternative seems to work on the circular economy through the adoption of innovative technologies and sustainable practices aligned with international standards.

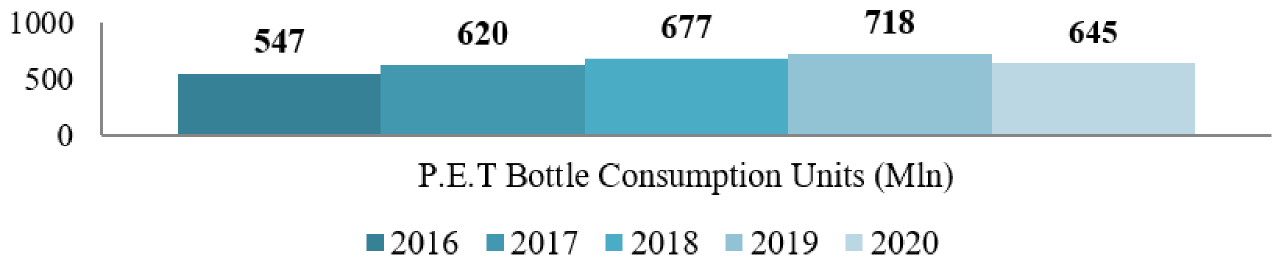

Figure 3. P.E.T Bottle Consumption Levels in Pakistan (2016-20) (PACRA, 2020).

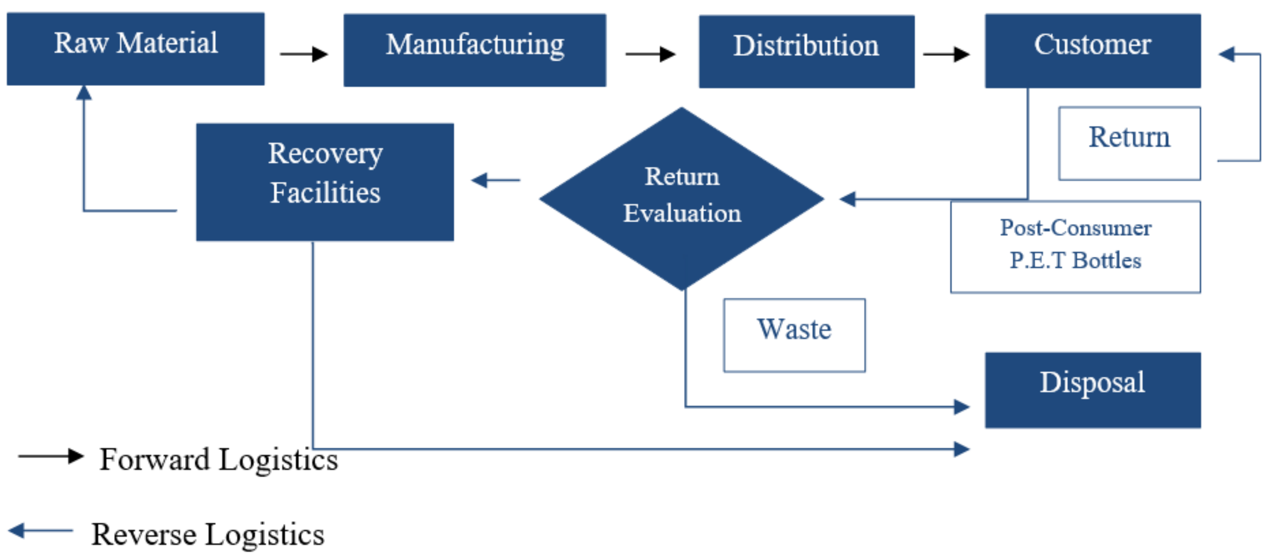

Figure 4. Forward and Reverse Logistics in Pre-Consumer & Post- Consumer P.E.T Bottles.

Role of Reverse Logistics in Recycling P.E.T Bottles

In the case of post-consumer P.E.T bottles, reverse logistics plays an imperative role by saving resources, energy recovery, and environmental degradation related to industrial activities. The complexity and quantity of solid waste are reduced to a great extent where it is considered to be a strategic tool in fostering customer relationships. It substantiates the great amount of revenue and sustainably provides a competitive advantage. Hence, the proper understanding of the reverse logistics system can help packaging companies to work with different actors executing recollection, remanufacturing, re-evaluation, and redistribution involving manufacturers, distributors, retailers, third-party service providers, and municipalities in the return activities of post-consumer P.E.T bottles. On the other hand, the reverse logistics flow needs to be managed in different ways and requires a well-established infrastructure to implement the elated activities seamlessly. The internal and external challenges can hinder the opportunities to be achieved while adopting the initiatives associated with the reverse logistics system in the recycling industry of Pakistan as exhibited in Figure 5.

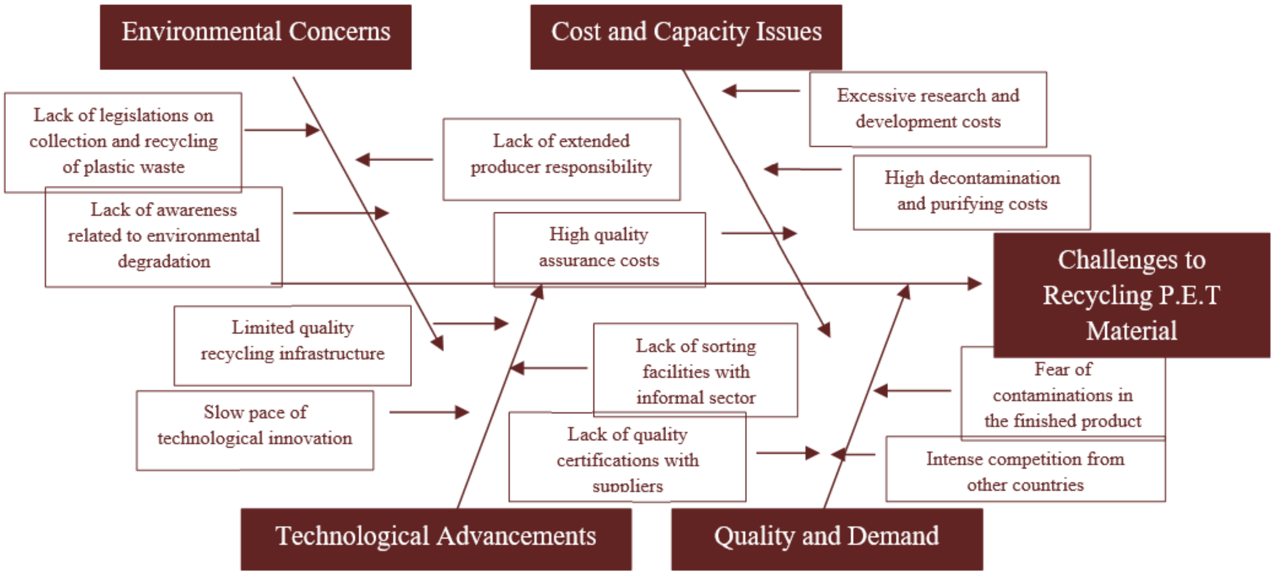

Figure 5. Challenges to Recycling P.E.T Material in Pakistan.

The economic feasibility of the packaging industry as to how to lead towards a green environment, creation of job opportunities, and generation of revenue from recycled products need to be considered. If the collection system in the local industry is brought into the limelight then it seems to be the most labor-intensive process involving waste collectors, scrap dealers, and recyclers in far-flung areas. The collection and recycling rates of P.E.T bottles can be enhanced when the informal sector handling waste management process is aware of how to sort the useful plastic materials, in what circumstances the material needs to be crushed, how to treat each plastic material separately, and how to store the compacted P.E.T bottle scrap in the clean and hygienic locations. When it comes to avail the full potential of recycled products, Pakistan lags from several dimensions such as technological limitations and legal implications of the plastic recycling industry. The low-hanging fruits can be reaped by reclaiming, processing, and recycling the plastic waste into value-added products at the local level.

Mechanical Recycling of P.E.T Bottles

Over a couple of decades, the recycling segment of P.E.T bottles has been moved from the small-scale to the vibrant revenue-generating industry area. Recycling of post-consumer bottles of carbonated soft drinks, water, or juices has been initiated in the last five years and has gradually reached the summit as the recycled material came into demand worldwide. Most importantly, the growth in the recycling industry of P.E.T bottles was triggered when producers in China bought a great amount of recycled P.E.T flakes from the far-flung areas of Khyber Pakhtun Khwa (KPK) and Balochistan. The monthly exports of 5,000 to 6,000 tons caused the industry to thrive on locally manufactured equipment. Being a labor-intensive segment, the lucrative job opportunities attracted the skilled and unskilled workforce alike. The silent contribution of this industry caused Pakistan to generate revenue and earn foreign reserves by exporting around USD 40 to 45 million on annual basis during 2019-20.

By adopting the mechanical recycling of P.E.T bottles, the rapid expansion in the range of value-added products, such as plastic sheets, bands, or thin films from the post-consumer resin, has been experienced. Unfortunately, the problematic situation of improper plastic waste management in Pakistan had led to an exponential increase in the generation of non-biodegradable plastic material; causing devastating environmental consequences. The unbridled dumping of P.E.T bottles had lead to grave health consequences to humans and animals. When these bottles have been dumped carelessly by households or consumers in shopping malls, there is a swift deterioration in their durability and strength. The proper reclaiming and recycling of the piles of P.E.T bottles need to be managed properly.

To convert the post-consumer bottles into a useful resource and reduce the consumption of virgin P.E.T resin, the conventional waste dumping system needs to be replaced with improved disposal arrangements to follow the waste hierarchy to reduce, recycle, reuse and return. Closed-loop recycling is the best process to collect the post-consumer P.E.T bottles and remanufacture them into a variety of packaging products as per their material properties and industry demands. The successful program of closed-loop recycling requires the joint efforts of converters, recyclers, and consumers to reclaim useful P.E.T bottles from the waste streams and transform them into recycled bottles.

Unlike these conventional waste dumping practices, the disposal and recycling process of P.E.T bottles consists of the four stages where different stakeholders are involved at various levels to support the recycling process:

Collecting:

This step involves the collection of recyclables in the plastic waste stream. Dustbins or waste containers have been the major sources of plastic waste that is either done by waste management authorities or waste pickers. Cost-effective collection assists the recycling of the plastic waste in a better manner. Collection of plastic waste is done from various places such as households, dustbins in public places and other locations to be deposited in the kabari market and collection hubs; such as Machar Colony, Shershah, Landhi, and Sorab Ghot in Karachi. Currently, local and municipal governments are responsible for the collection of waste from most of the areas in Pakistan. Around 60 to 70% of solid waste is collected by these authorities. The waste collection fleet consists of open waste trucks and trucks for secondary collection whereas dustbins, containers, and donkey pull-carts are used for primary collection purposes as shown in Figure 17. Some of the sweepers and sanitary workers are hired by the municipalities for the collection of solid waste on streets then gather it in informal disposal sites through waste containers. Karachi has 3 waste dumping sites while Lahore has only 2 areas for waste disposal. In other cities, there are no waste disposal sites so the waste is improperly dumped outside their vicinities.

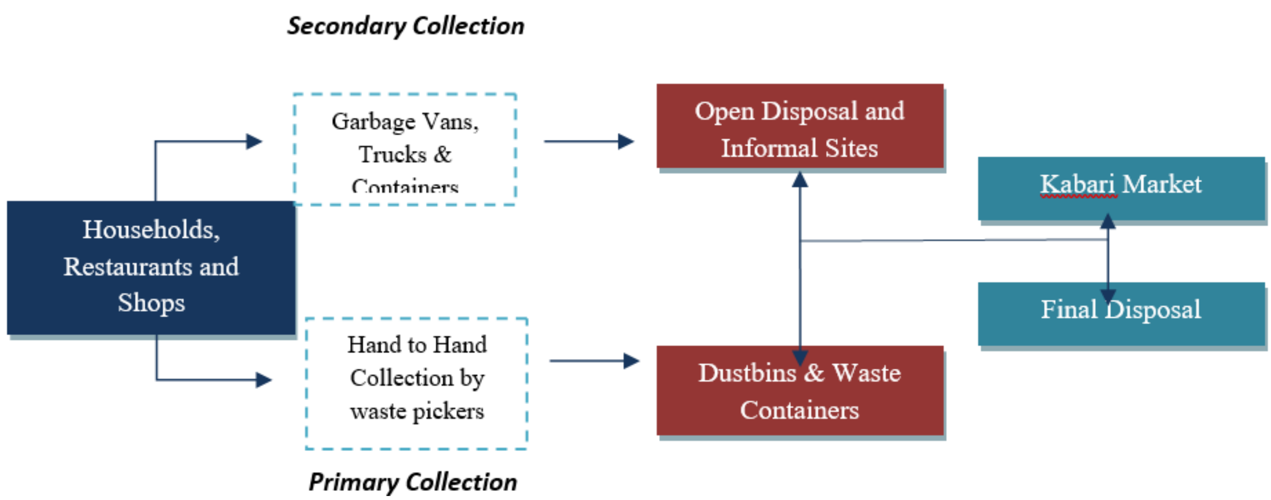

Figure 6. Conventional Plastic Waste Collection & Disposal System in Pakistan.

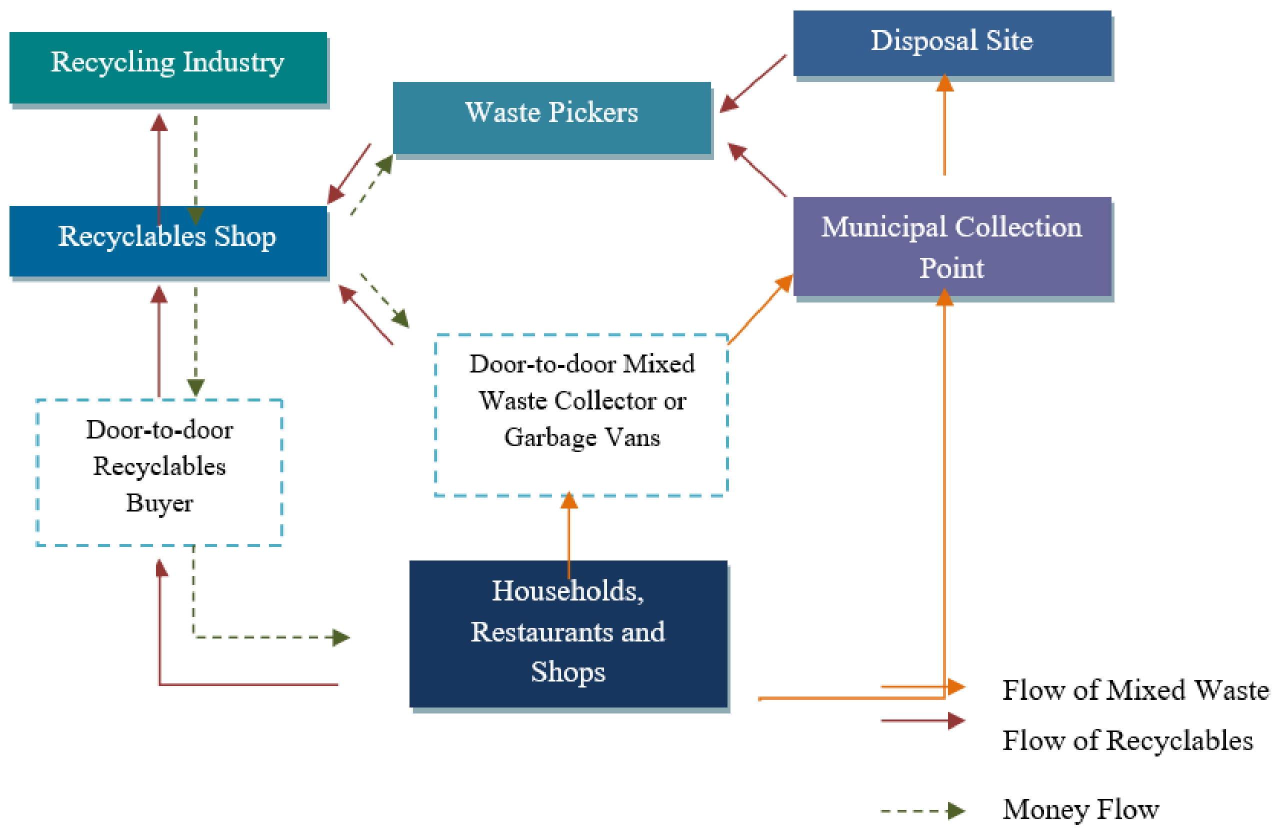

Figure 7. Overview of Recyclable Plastic Material Collection System in Pakistan.

Sorting:

The sorting of plastic bottles depends upon the demands of recyclers to whom it will be sold. It can be sorted into colors like green and white or size or types of plastic bottles in the junk. There are different types of sorting; including, sorting by selective dissolution, manual sorting, and density-based sorting methods.

Manual Sorting

In this method of sorting, the plastic materials are checked by the trained people who are aware of useful resources.

Density-based Sorting

A method to sort the plastic materials by applying density technique comprising of float sink tank. It is not an appropriate method for those materials having similar densities such as PVC and P.E.T.

Selective Dissolution Sorting

This type of sorting involves heating the mixed plastics by using solvents to attain the specific plastic material. By constantly monitoring the temperature and selecting suitable solvents, the plastics can be segregated into several categories. For mechanical recycling, this method of sorting seems to be appropriate but the acceptable quality of the product might not be obtained due to its extensive techniques. Moreover, the chemical diversity in the various plastic materials makes it complex for the people engaged in this type of sorting to identify the presence of contaminants or hazardous substances.

Figure 8. Sorting of Recyclable P.E.T Material in Karachi.

Shredding, Washing, and Drying:

In this stage, the purification process of Recycled P.E.T is carried out. Some of the post-consumer P.E.T bottles are compacted and shredded into flakes (crush material) or bales for export or remanufacturing purposes as displayed in Figure 9.

Figure 9. Virgin P.E.T Resin and Recycled P.E.T Flakes.

Washing is the most important stage to enrich the condition of post-consumer P.E.T material to produce the value-added products from decontaminated flakes in the market. There are different types of washing P.E.T material known as mechanical and manual washing as shown in Figure 21. Manual washing can be conducted by recyclers in the basins or bins through detergents to remove greasy effects from plastic material, whereas mechanical washing involves the automatic washing line linked with the motor that moves the set of paddles at normal speed.

Figure 10. Manual and Mechanical Washing Process.

In the case of Recycled P.E.T flakes, there are two types of washing known as cold wash and hot wash. The shredded material enters into the washing line and passes through the cold water to remove light contaminants. After the cold wash, the material is dried and purified further from the traces of impurities; such as dust and sand particles, in a mechanical dryer. However, the highly contaminated Recycled P.E.T material containing adhesives from labels can be given the cold wash again to satisfy international regulations of food-grade. On the other hand, these flakes can be soaked in a hot water and mixed with cleaning solutions in a continuous hot washer for Recycled P.E.T material, followed by the rinsing of material in the friction washer, to decontaminate the material intensely from the harmful substances included in the Negative List published by European Food Safety Authority (EFSA). Lastly, the mechanical dryer eliminates the moisture content up to 1% from the Recycled P.E.T flakes that become transparent in other colors such as green and blue material. The effective mechanical dryer dewaters these flakes through centrifugal force at the maximum level to bring them into the ideal condition.

Remanufacturing:

The final stage consists of reprocessing these recycled flakes into value-added products such as beverage bottles or water bottles either with 100% Recycled P.E.T material or including the element of Virgin P.E.T resin for the best outcomes. Due to the inadequate washing and drying infrastructure in Pakistan, traces of impurities or contaminants can come in contact with food stimulants. It often creates a challenging situation for manufacturers to supply the best quality of Recycled P.E.T bottles after the conversion stage so it is feasible to combine it with Virgin P.E.T resin to ensure safe and hygienic beverage products for consumers with the proportion of 75%, 50% or even 20% at the earlier stages of production levels. These plastic flakes are put into the extruder that is melted and reprocessed into a liquid form at a certain temperature. The mixture is extruded into the moulds that produce a new bottle for the use of consumers. The costs and quantity to produce the P.E.T bottles on annual basis with the varying proportions of Recycled P.E.T and Virgin P.E.T have been appended in the tables below:

Table 3. Prices of Virgin P.E.T and Recycled P.E.T per kilogram and gram.

Materials	*Price (PKR per kg)*	*Price (PKR per gm)*
Commodity Type		
Virgin P.E.T	213	0.213
Recycled P.E.T	170	0.170
Difference in Prices	**43**	**0.043**
Price Savings (%)		**20%**

Table 4. Average Price, Market Volume and Average Weight of P.E.T Water Bottles.

Product	*Value*	*Units of Measurement*
P.E.T Bottles		
Average Price per P.E.T Bottle	9	PKR
Market Volume per annum	645,000,000	units
Average Weight of P.E.T Bottles	13	grams per 500 ml bottle
Total P.E.T Consumption	**8,385,000,000**	**grams**
	8,385,000	**kilograms**

Table 6. Price Savings in Recycling Scenarios.

S.No	Recycling Scenarios		Total Price (PKR)	Price (PKR per kg)	Price Savings (PKR per kg)	Price Savings (%)
	Recycled P.E.T	Virgin P.E.T				
1	100%	0%	1,425,450,000	170	43	20%
2	80%	20%	1,497,561,000	179	34	16%
3	70%	30%	1,533,616,500	183	30	14%
4	60%	40%	1,569,672,000	187	26	12%
5	50%	50%	1,605,727,500	192	22	10%
6	40%	60%	1,641,783,000	196	17	8%
7	30%	70%	1,677,838,500	200	13	6%
8	20%	80%	1,713,894,000	204	9	4%
9	0%	100%	1,786,005,000	213	0	0%

Table 7.Total Sourcing Costs of Recycling Scenarios.

S.No	Recycling Scenarios		Total Price (PKR)	Number of 12 Ton Containers	Transportation Cost of 12 Ton Containers (PKR)	PCSIR Quality Testing Cost	Total Transport and Quality Costs	Total Sourcing Cost (PKR)
	Recycled P.E.T	Virgin P.E.T						
1	100%	0%	1,425,450,000	699	355,671	15,000	370,671	1,425,820,671
2	80%	20%	1,497,561,000	699	355,671	15,000	370,671	1,497,931,671
3	70%	30%	1,533,616,500	699	355,671	15,000	370,671	1,533,987,171
4	60%	40%	1,569,672,000	699	355,671	15,000	370,671	1,570,042,671
5	50%	50%	1,605,727,500	699	355,671	15,000	370,671	1,606,098,171
6	40%	60%	1,641,783,000	699	355,671	15,000	370,671	1,642,153,671
7	30%	70%	1,677,838,500	699	355,671	15,000	370,671	1,678,209,171
8	20%	80%	1,713,894,000	699	355,671	15,000	370,671	1,714,264,671
9	0%	100%	1,786,005,000	699	355,671	15,000	370,671	1,786,375,671

For the recycling of P.E.T, the purified and decontaminated Recycled P.E.T flakes supplied by Shazil Pakistan Private Limited at the rate of PKR 170 per kg have been considered. Recycled P.E.T Material Properties of this supplier can be checked through the details provided in Table 8. There is a noticeable difference of PKR 43 per kg between Recycled P.E.T flakes and Virgin P.E.T in Table 3. It can lead to significant savings of 20% when this recycled plastic material is being used for remanufacturing the new bottles; fulfilling the quality standards prescribed by international regulatory authorities such as FDA and EFSA Regulations (Refer to Table 6). For each recycling scenario, the price savings (PKR per kg) from PKR 43 to PKR 9 can be considered for the nine proportions of Recycled P.E.T and Virgin P.E.T in Figure 22. Indeed, the increasing trend has been observed in the total sourcing costs from PKR 1,425 million to PKR 1,786 million after including transportation costs of PKR 370,671, from Shazil Pakistan Private Limited to Mehran Plastic Industries Private Limited, and PCSIR quality testing costs of PKR 15,000 causing an additional cost of PKR 361 million (20%) to be incurred as indicated in Table 7.

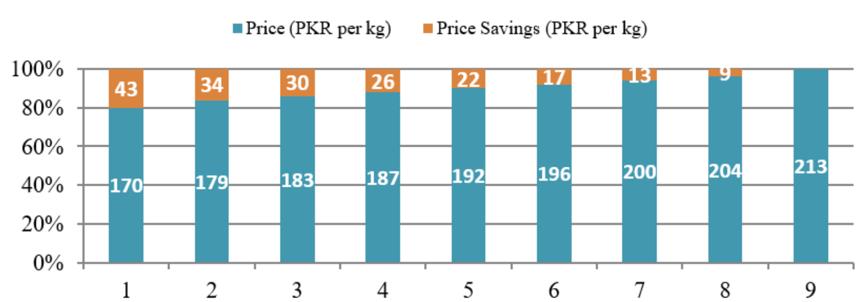

Figure 11. Unit Price and Price Savings of Recycling Scenarios.

Furthermore, the increments in prices and quantities can be analyzed at the various levels of blending Recycled P.E.T with Virgin P.E.T to produce 645 million units of P.E.T bottles on an annual basis as displayed in Table 4 and 5. There has been a gradual increase from the Recycled P.E.T price per kg towards the Virgin P.E.T price per kg as the proportion of recycled plastic material minimizes in these recycling scenarios with respect to the quantities in grams and kilograms (See Appendix for the List of Recycled P.E.T Flakes Suppliers in Pakistan and their sourcing costs).

Table 8. Recycled P.E.T Material Properties of Shazil Pakistan Pvt. Ltd.

Recycled PET Material Properties (Shazil Pakistan Pvt. Ltd)			
S.No	**Particulars**	**Unit**	**Value**
1	Intrinsic Viscosity	dl/g	0.75-0.82
2	Bulk Density	kg/cubic meter	>300
3	Crusher Screen Size	Millimeter	12
4	Flake Size Range	Millimeter	3 to 12
5	Average Flake Size	Millimeter	8 to 12
6	Moisture	Percentage (%)	<1%
7	PVC	Parts per million (PPM)	<50
8	Other Floatable Impurities	Parts per million (PPM)	<10
9	Heavy Metal	Parts per million (PPM)	<10
10	Other Color Impurities	Percentage (%)	<1%

5. RESULT

Environmental Impact of Recycled P.E.T

According to the recent study, the environmental effect of recycling resources is estimated by the proportion of greenhouse gas emissions (GHG) reduced with the plastic waste management associated with source reduction, combustion, recycling, and landfilling. Due to the several applications of plastics, the models of the Environmental Protection Agency (EPA) to calculate the greenhouse gas emissions (GHG) consist of the processes where conversion of resins takes place into plastic products. PlasticsEurope conducted the study on life-cycle inventories of some end plastic applications such as P.E.T bottles where a majority of the emissions are linked with the production of resin and generation of several plastics applications. To date, the largest application of P.E.T is the manufacturing of beverage bottles and synthetic fibers. Upon the complete substitution of Virgin P.E.T with Recycled P.E.T, the annual savings would be around 8,385 metric tons that can substantially contribute to attaining a green environment as indicated by the following environmental analogies:

- The plastic footprint of 645 million P.E.T bottles produced on annual basis is equivalent to 23,220,000 kg per year (Omni Calculator, 2021).
- 1.76 tons of carbon dioxide (CO2) is saved per ton of recycling P.E.T Material so around 14,758 tons can be saved, rather than landfilling, by recycling 8,385 metric tons of P.E.T Material (Stop Waste Calculator, 2021).
- Around 38,218 cars are taken off the road when the aforementioned quantity of P.E.T is recycled (Stop Waste Calculator, 2021).
- Every pound of recycling P.E.T material can reduce the use of energy in the production of plastic products by 84% (Brigham Young University, 2021).
- In the current scenario of recycling 8,385 metric tons of P.E.T material, the reduction in greenhouse gas emissions is around 50.83% (How 2 Recycle Calculator, 2021).

- According to PCR PET Resin Sustainability Calculator, the recycling of 645,000,000 water bottles of 500 ml having 13 grams of weight per water bottle can result in the savings in CO_2 is 11,269.5 metric tons, 2,434 cars for 1 year, 1,268,093.3 gallons of gasoline, 26,208.2 barrels of oil, supplying electricity to 1,908.2 homes for 1 year, 469,564.4 Propane Tanks for Bar-B-Que (BBQ) Grills. Furthermore, the recycling of 3,833.2 tons of waste, nurturing 187,825.8 seedlings for 10 years and growing 14,635.8 acres of forest for 1 year (PCR PET Resin Sustainability Calculator, 2021).
- One ton of recycled plastic can save 5,774 Kwh of energy, 30 cubic yards of landfill space, 16.3 barrels of oil, and 98 million Btu's of energy so around 48,414,990 Kwh of energy, 251,550 cubic yards of landfill space, 136,676 barrels of oil, and 822 billion Btu's of energy is saved by recycling 8,385 metric tons of P.E.T material (Resouce Recovery & Waste Management, 2020).
- Around 450 years are required for plastics to break down in the landfill (WWF, 2018).
- The savings for 1 kilogram of Recycled P.E.T is sufficient to give energy to a 13-watt bulb for 20 days continuously so the energy used in 8,385,000 bulbs can be saved in recycling the 8,385 metric tons of P.E.T material (Alpla, 2017).

With respect to the consumption patterns of beverages, the annual volume of P.E.T bottles is 645 million in Pakistan. By shifting towards the 100% Recycled P.E.T material of 8,385 metric tons, the massive environmental impact can be observed as demonstrated through these analogies:

Plastic Footprint
23,220,000 kg per year

CO_2 Savings
11,269.5 metric tons

Reduction in Greenhouse Gas Emissions
50.83%

Driving Cars
2,434 cars for 1 year

Gasoline
1,268,093.3 gallons

Oil
26,208.2 barrels

Supplying Electricity to Homes
1,908.2 homes for 1 year

Propane Tanks
469,564.4 tanks for BBQ Grills

Recycle Waste
3,833.2 tons

Nurturing Seedlings
187,825.8 seedlings for 10 years

Growing Acres of Forest
14,635.8 acres for 1 year

Landfill Space
251,550 cubic yards

Environmental Protection Agency (EPA) Recycled Content (ReCon) Tool was developed to measure the environmental impact of procuring or producing post-consumer recycled content with varying proportions using life-cycle perspective for waste managers, companies, and individuals to take suitable waste management decisions on a timely basis (Environmental Protection Agency, 2021). In accordance with the results of this tool, the recycling of 8,385 metric tons with 100% Post-Consumer Resin of P.E.T material will result in the greenhouse gas

Results: The table below provides emission factors and GHG emissions impacts for purchasing and manufacturing activities in the baseline and alternate recycled content scenarios. Column f provides an estimate of the impact of shifting manufacturing processes to include more recycled inputs. Negative results in this column indicate an emission savings.

Material	Surrogate Material	(a) Amount (tons)	(b) Baseline 30-Yr. Total GHG Emission Factor (MTCO2E/ton)	(c) Baseline 30-Yr. Total GHG Emissions (MTCO2E) (=a x b)	(d) Alternate 30-Yr. Total GHG Emission Factor (MTCO2E/ton)	(e) Alternate 30-Yr. Total GHG Emissions (MTCO2E) (=a x d)	(f) Differential Between Baseline and Alternate (MTCO2E) (=e - c)
	PET	8,385	0.92	7,738.48	0.92	7,738.48	0
Total			**Baseline**	**7,738.48**	**Alternate**	**7,738.48**	**0**

Notes:
· Values may not sum due to independent rounding.
· Emission factors taken from the EPA's Waste Reduction Model (WARM).
· Miscellaneous Metals: Average of aluminum and steel.
· Miscellaneous Plastics: Average of PET, HDPE, LDPE.

(GHG) emissions as given below:

Table 9. Recycled Content (ReCon) Tool – Greenhouse Gas Emissions (Environmental Protection Agency, 2021).

	MTCO2E	MTCE
The life-cycle greenhouse gas emissions for the baseline manufacturing scenario are:	**7,738.48**	**2,110.49**
The life-cycle greenhouse gas emissions for the alternate manufacturing scenario are:	**7,738.48**	**2,110.49**
The greenhouse gas benefit associated with increasing the fraction of recycled inputs is: Note: negative value indicates GHG emission reductions, i.e., benefit.	**0**	**0**
The greenhouse gas benefit in terms of passengar cars not driven for one year:	**0 cars**	

6. CONCLUSION

Focusing the gap identified in formalizing the channels of recycled P.E.T bottles while bridging the gap between recyclers and distributors, the research was conducted on searching the potential sources of Recycled P.E.T flakes from the diverse areas of Pakistan.

The souring strategy consisting of the key indicators, such as costs, quantity, quality, laboratory testing costs, and transportation costs can assist the supply chain department of Mehran Plastic Industries Private Limited to conduct the recycling activities of P.E.T water bottles through holistic and transparent reverse logistics mechanism after considering the environmental, technological, technical and economic factors.

For the successful recycling practices of P.E.T bottles, the great performance of key customers and stakeholders in the return and redistribution process can be acknowledged extensively. Effective communication amongst relevant stakeholders can strengthen the relationships with the customers and can significantly contribute to developing a sustainable recycling chain based on the patterns of a circular economy for the plastic-free economy of Pakistan.

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